grütter consulting

Benchmark Report on Commercial Electric Vehicles

Client	AFD
Version	02
Date	15/01/2021
Author	Jürg Grütter
Revision	Verena Arauz, Daniel Wunderlin
Contact	Rte. des Esserts 92, 1854 Leysin, Switzerland jgruetter@transport-ghg.com, www.transport-ghg.com

Contents

Abbreviations

AC	Air Conditioning
BaaS	Battery-as-a-Service
BEB	Battery Electric Bus
BEV	Battery Electric Vehicle
BRT	Bus Rapid Transit
CAPEX	Capital Expenditures
CNG	Compress Natural Gas
EIRR	Economic Internal Rate of Return
EV	Electric Vehicle
FAME	Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles
FIRR	Financial Internal rate of Return
FTA	Federal Transit Administration
GEF	Global Environment Facility
GHG	Greenhouse Gases
HEV	Hybrid Electric Vehicle
HVAC	Heating, Ventilation and Air Conditioning
JV	Joint Venture
LCV	Light Commercial Vehicles
LEFVs	Light Electric Freight Vehicles
LFP	Lithium-Iron Phosphate
LMD	Last Mile Delivery Services
LMO	Lithium Manganese Oxide
LPG	Liquefied Petroleum Gas
LTO	Lithium-Titanite Oxide
MC	Motorcycle
MDO	Empresa Masiva de Occidente
NMC	Lithium Nickel Manganese Cobalt Oxide
OPEX	Operational Expenditures
PHEV	Plug-In Hybrid Electric Vehicle
PPP	Public Private Partnership
SOC	State of Charge
SOH	State of Health
SME	Small and Medium Enterprise
TA	Technical Assistance
TCO	Total Cost of Ownership
TfL	Transport for London
TM	TransMilenio
ULEZ	Ultra Low Emission Zone
VAT	Value Added Tax
WACC	Weighted Average Capital Cost

Summary

Disclaimer: *All sources are included in the main text and not the summary. The main text also includes further details for all of the paragraphs.*

E-Mobility General

1. The sales of full electric and plug-in hybrid cars have soared over the last five years. By 2019 there were about 4.8 million full electric and 2.4 million plug-in hybrid cars on the worlds' roads. Whilst 4.8 million units is a large number the global electric car stock currently corresponds to just 1% of the total number of passenger cars sold . The share of newly registered electric cars is growing strongly in many countries and have reached over 60% in Norway in 3rd quarter 2020 – however this still only represents 9% of the vehicle stock (due to vehicle replacement rates), showing clearly that large-scale impacts will take a lot of time and that early action to increase the share of newly registered EVs is critical.

2. Electrification is happening in all vehicle segments including also vessels. However, long-range vehicles such as coach buses, long-haul trucks or long-haul vessels, are only at the start of electrification. Hydrogen technology might be, at least initially, a more appropriate technology solution for these vehicle segments. EVs are the most competitive and also have the largest environmental impact in urban areas.

3. More than 860,000 publicly accessible chargers are operating worldwide as of 2019 of which around 30% are fast chargers. No fixed relation between number and type of charger's and electric car uptake is given i.e. country circumstances are critical when developing a charging system strategy. Public charging systems are subsidized in all countries by governments.

4. Policies to support e-mobility have been introduced around the world to motivate people to purchase electric vehicles. High purchase price, limited driving range and limited public charging infrastructure consistently appear in all surveys as top 3 barriers for people to purchase EVs. The experience of Norway in policies to foster Eelectric passenger cars can be summarized in "cheap to buy", "cheap to use" and "easy charging access".

5. The motivating forces to foster e-mobility are basically around reducing the GHG emissions of the transport sector whilst reducing local air pollution. Even if a life-cycle approach is made commercial EVs will reduce GHG emissions in nearly all countries except those with extremely high carbon grid factors going beyond 1.3 $kgCO_2/kWh$. Additional reasons why EVs are fostered include reduced dependency on fossil fuels which need to be imported by many countries resulting on exposure to external price shocks. EVs also use around 3x less energy than fossil vehicles thus increasing the efficiency of usage of energy resources. Another positive feature is the reduced noise, important for example for urban buses and trucks. Some countries also foster EVs due to industrial policies thereby strengthening the domestic industry and maintaining or creating new jobs.

E-Buses

6. Hybrid and plug-in hybrid buses were an intermediate technology as long as battery electric buses were not yet technologically ripe. Hybrid buses can recover their incremental investment but only have a limited environmental impact. They still remain a largely fossil technology and continue having environmental impacts which are only slightly less than a fossil bus. Plug-in hybrid buses have never really been popular outside China and within China only due to subsidy policies which made them

cheaper than hybrid units. Their limited re-charging make their environmental impact the same or only marginally better than hybrid buses whilst having a sur-cost of 40% compared to diesel buses. They thus neither make financial nor environmental sense.

7. Clearly hybrid or plug-in hybrid buses are no longer the option of choice for urban bus operators. China as well as most European countries no longer subsidize such units. The largest fleet of hybrid buses in Europe, London, started in 2012 with 300 hybrid buses. Originally plans were to fully hybridize the fleet. This plan was dropped in favour of switching towards electric buses. The fast development of the e-bus technology has clearly made hybrid and plug-in hybrid urban bus technology obsolete. Fostering of such buses is therefore not recommended except for special circumstances like limited and unreliable electricity supply.

8. E-bus systems are available today for all urban bus sizes and sizes from minibus to bi-articulate units running on high frequency BRT routes. Technical know-how on appropriate system design is however often locally limited resulting in a large number of e-bus systems being designed for overnight charged buses which are best known and which are being promoted most actively by some market players. Such systems might however not be the technically, operationally and financially optimal option. A know-how and information gap is thus visible.

9. Large-scale (not pilot buses) deployment of e-buses is still limited to few countries but picking up very rapidly. Whilst China still dominates in numbers of buses deployed, European cities are increasingly electrifying their fleets and in Latin America Chile and Colombia have started operations of large fleets.

10. E-bus deployment requires a system design optimizing bus types and chargers. Investments need to be made in buses, charging equipment, grid connections and bus depot upgrades. E-bus systems potentially require also an additional number of buses as well as additional land e.g. for chargers on or close to routes or at bus depots. E-bus assessments often lack such important components.

11. E-bus business models include the more traditional (bulk) purchase of buses through municipalities (with operations through private concessionaries or with municipal operator) and leasing models as deployed also in other vehicle segments. Leasing can be limited to the bus or include also charging infrastructure, energy supply systems and bus depots. Leasing fees are also limited to the bus or include maintenance and in some cases also energy. Leasing systems are interesting for e-bus deployment due to their high upfront capital requirement thus putting stress on the finance of bus operators. It can also serve as risk mitigation instrument. Many countries have separated ownership and operation of buses with bus purchase either made by the municipality (and thus also allowing for bulk purchase) or by 3rd parties.

12. Different types of companies have entered e-bus leasing systems. Traditional leasing companies offer e-buses in some cases whilst electric utilities have also entered in various countries the field to increase demand for their core services. Electric utilities will however only be involved initially to kick-start the market as vehicle leasing is not related to their core business. The experience e.g. in Chile shows that they are replaced at a later stage with investment funds and traditional finance institutions. Leasing will only take off if e-buses can be run profitable and if guarantees are offered to enable long-term leasing agreements commensurate with the lifespan of e-buses (often going beyond concession agreement periods) and to cover the risks of payment defaults related also to the limited information available on the re-sale value of e-buses.

13. A challenge for finance models is that e-bus systems not only involve buses but also significant investments in charging infrastructure, grid and depot upgrades. Latter are partially sunk investments.

Buses, chargers and routes are also not necessarily interchangeable i.e. an overnight charged bus has range limitations and cannot be used on all routes and its batteries cannot be fast-charged. This results in potential problems of concession contracts not being in-line with vehicle life-spans. It also points to specific problems associated with separation of asset ownership and operations. Asset ownership in the ideal case includes for e-bus systems not only buses but also charging infrastructure, grid connection and bus depot.

14. TCO calculations vary widely between countries and e-bus systems and depend on a myriad of assumptions. The TCO argument for e-buses is built on forecasts savings with medium to long-term payback periods, whilst transit authorities and transport operators have immediate needs, limited capital and budgets. Whilst TCO is a criteria, it is only one of multiple factors to be considered when purchasing buses.

15. Countries with large e-bus fleets have supplied significant upfront subsidies to cover 80-100% of the incremental CAPEX of e-buses and in most cases also finance at least partially charging infrastructure and other e-bus system components, independent of TCO calculations. Total system costs of e-buses involve a CAPEX which is 2.5-3 times higher than of fossil buses. Operational expenditures are lower but linked to uncertainty and risk and only result in more profitable operations in the medium or long-turn. The additional risk of purchasing e-buses is not retributed currently in most countries with a commensurate profitability. The benefits of e-buses are basically of global and local public nature whilst the risks and potential losses remain with the fleet owner or operator. Incentive schemes to reduce upfront risks and investments are a necessary condition to kick-start e-bus fleet deployment beyond pilot buses. Without investment subsidies e-bus deployment on a mass scale will take at least another 5-10 years until e-bus costs are comparable to those of fossil units and performance risks are not perceived by operators to be anymore substantial.

16. The experience of incentive programs of many cities is that these schemes can be scaled back after deployment of initial large fleets. This together with the global price decrease of e-buses and charging infrastructure give a clear indication that initial investment subsidies are required but will only be needed of temporary nature.

Taxis

17. Mileage and utilization rate of taxis is often very high. Frequently more than 1 drive share the cab which can be in operations for 24/7. Slow-charging at home is thus in most cases not a feasible option. High-range electric vehicles will require home-charging of 8 or more hours, even if installing a Type 2 charger at home. This means that electric taxis not only require a large battery set to enable a long range, but also need to have fast-chargeable batteries (capable of receiving at minimum 100 kW i.e. a C-rate in general >1.5) and they require a network of fast chargers. As electric taxis cover many miles, they need to be able to charge quickly and frequently. Promoting only taxis without a fast-charging network is a recipe for failure in most cities.

18. Plug-in hybrid vehicles have small battery sets with a typical real-world electric driving range of less than 50km and batteries not capable of receiving a high-powered charge. Therefore, with taxi distances driven per day of 200-300km the electric drive share will be on average only 10% and might even be less if taxis are used constantly. The same phenomena has been observed with private or commercial plug-in vehicles as well as with buses where the overwhelming fleet of plug-in buses in China is never charged but only used as hybrids (ADB, 2018). PHEVs with a large battery set and capable of driving nearly 100km electric (like the Black Cab PHEV) have a price tag comparable to full electric vehicles with the disadvantage of still having a very limited electric range plus much higher

maintenance costs. To use PHEVs as taxis is therefore financially, technically and environmentally not recommended.

19. China has deployed large fleets of electric taxis. These were and continue to be massively subsidized. An interesting component is that chargers are shared with bus operators (same ownership structure in many cities).

20. Uber as well as Grab are looking at methods to electrify the fleets of vehicles running under their umbrella by offering incentives to drivers and by charging an additional fee on trips to subsidize the purchase of EVs, whilst also making sales deals with large electric vehicle manufacturers. This business model seems to work well e.g. in London where restrictions on usage of high-emission vehicles in urban zones are prevalent. Also the share of vehicle costs in total operational costs of taxis in such cities is much lower than in developing countries i.e. the subsidies would need to be larger in developing countries whilst the surcharge fee which can be charged is lower. The application of this business model to developing countries has thus its limitations.

21. The importance of subsidies for electric taxis is shown in an exemplary manner by the experience in Shenzhen which has China's largest electric taxi fleet (100% of the 22,000 taxis are electric). The government launched the electric taxi project in 2010, but progress has been slow because of concerns about the availability of charging stations and the duration of charging and safety. 2015 then the subsidy was increased to 31,000 USD per electric taxi[1] which made electric taxis lower cost than fossil units. The incremental cost has dropped in the meanwhile to around 10,000 USD which has also resulted in reduced subsidies given to taxis.

22. The availability and proximity of public fast charging stations for taxi drivers is core. Centralized charging services like operated in Shenzhen have their drawbacks in potentially high dead-kilometres. It is not unsurprising that a survey done by newspaper Southern Metropolis Daily in 2018 showed that 80% of Shenzhen's cab drivers were unsatisfied with the supply and allocation of charging stations in the city[2]. The same claim is given for example by taxi drivers in Washington, DC, which state that the Nissan Leafs in the fleet take too long to charge and sometimes require going well out of the way to find a publicly accessible charger. The city offered a series of grants to offset the cost of purchasing electric vehicles, but drivers said they ended up losing income because of the charging difficulties[3].

23. Incentive policies apart from subsidies are an important driving force. These include privileged ranks at popular waiting sites e.g. train stations or airports, usage of bus lanes, access to taxi licenses, limitation of city centre access for fossil taxis, usage of electric taxis on all days whilst fossil units have usage restrictions etc. Getting priority at a taxi rank can for example be more valuable than a subsidy scheme as it results in more clients and a reduced waiting time.

24. The conclusion is that electrifying taxis requires a systematic and combined approach of incentives of financial and other nature with the establishment of a well-planned fast-charging infrastructure with priority for taxis and good coordination and information of taxi owners to inform them of important aspects of e-taxis (the focus is in general only on range whilst the charging rate of batteries can be more important than the range). Without public finance a fast charging network in the density required cannot be established.

[1] Shenzhen offers new incentives to boost switch to electric taxis | South China Morning Post (scmp.com)
[2] First buses, now Shenzhen has turned its taxis electric in green push | TechCrunch
[3] Shenzhen, China touts nearly all-electric taxi fleet | Smart Cities Dive

Urban Cargo Vehicles

25. Urban cargo transport, especially last-mile delivery services are growing very quickly. Although the number of vehicles as share of total vehicles remains small their impact on GHG emission and local pollutants is significant and could be the major transport emission source in cities within a decade.

26. Urban freight is composed of micro vehicles to medium sized trucks. Common features are relatively short daily distances combined with urban usage which in principle are positive starting points for usage of electric vehicles.

27. The majority of logistics operators are not fleet owners. Small vehicles (motorcycles and partially LCVs) are basically owned by drivers whilst larger units (LCVs and most trucks) are owned by fleet management companies. Whilst logistics firms might be interested in EVs they are reluctant to change their business model or to oblige transport providers to realize the transport service with electric units.

28. To reach individual vehicle owners a link must be established with financial institutions which provide loans and leasing of vehicles. Battery swapping systems for micro vehicles can also be an important anchor point as they can provide a solution to the range problem, the charging time and the initial CAPEX. Drivers can thus earn additional income from day one by using electric micro vehicles. However such systems need to be established at scale from the start to be attractive and will require kick-off funding.

29. LCVs and small trucks in most cases still have slightly higher TCOs than fossil units. Their incremental CAPEX as well as the lack of public fast chargers are main barriers towards massive deployment. Business models working through large scale fleet managers and finance institutions collaborating with fleet managers are potential entry points. A coordination with logistics companies for charging points as well as the establishment of a net of public fast-charging points is important.

30. Countries with a significant number of electric urban cargo vehicles have provided regulatory incentives and/or subsidies. Electric 2-wheelers in China have profited from the ban of fossil motorcycles in all major cities, whilst the widespread usage of LCVs e.g. in Shenzhen has profited from subsidies covering incremental costs. Also in various European countries subsidies representing 80-100% of incremental investment costs of electric LCVs are handed out to companies which purchase such units. At the same time public charging infrastructure – also subsidized – is established to resolve the barrier of lack of charging sites and therefore range issues.

1. Objectives and Layout

The objective of the benchmark report is to identify policies, business models and critical success factors for promoting EV deployment of commercial vehicles. The approach focuses on critical technology features, profitability and barriers to deployment of EVs, business models, and support instruments used by different countries. Commercial vehicles covered by this report are urban buses, taxis, urban cargo vehicles, and commercial electric vessels. The focus is on commercial vehicles as these offer a high mileage with high energy usage and resulting high emission levels. Focusing EV support policies on commercial vehicles will result in a large impact.

2. EV Overview

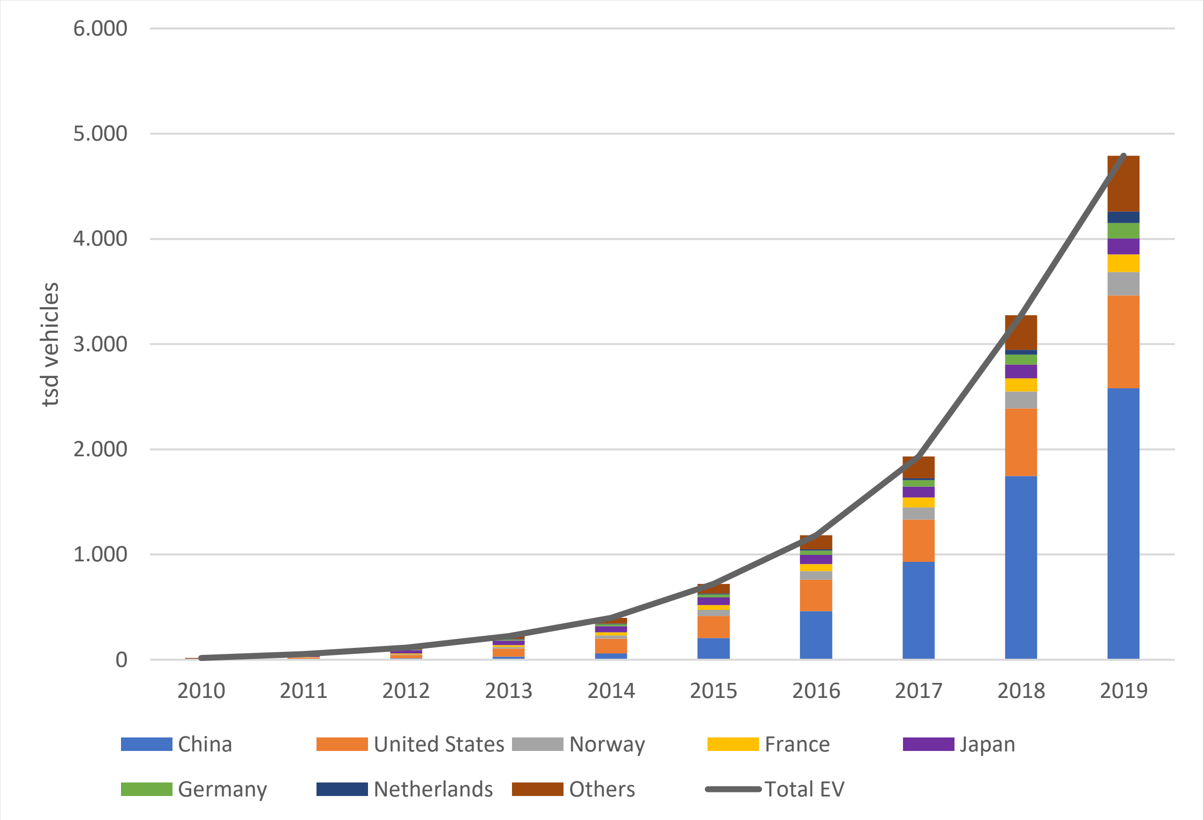
2.1. Vehicles

A short overview of Electric Vehicles deployment in the different sectors, policies and main barriers in general is given, prior to focusing on the EV vehicle categories targeted.

Passenger Cars

The sales of full electric and plug-in hybrid cars have soared over the last five years. By 2019 there were about 4.8 million full electric and 2.4 million plug-in hybrid cars on the worlds' roads (IEA, 2020). 8 countries (in decreasing EV stock numbers PR China, USA, Norway, France, Japan, Germany, Netherlands and the UK) have more than 90% of all electric cars in operation worldwide.

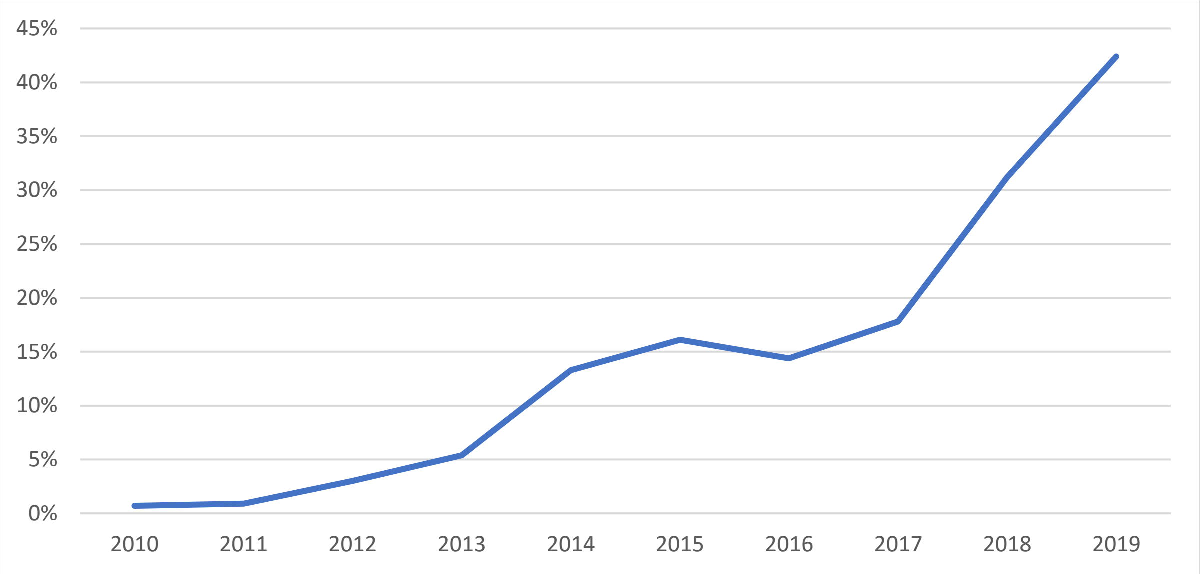
Figure 1: Battery Electric Passenger Car Stock, 2010-1019



Source: (IEA, 2020); separately listed are countries with >100,000 EVs registered by 2019

Whilst 4.8 million units is a large number the global electric car stock currently corresponds to just 1% of the total number of passenger cars sold . The share of newly registered electric cars is growing strongly in many countries and have reached over 60% in Norway in 3rd quarter 2020[4].

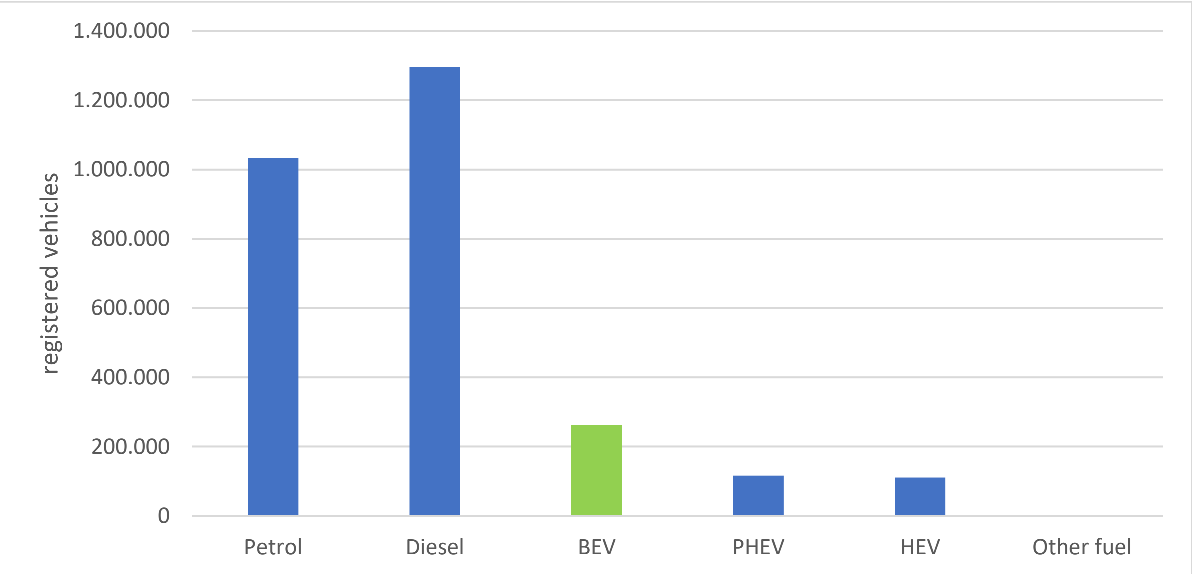
Figure 2: Share of BEVs of New Registered Vehicles



Source: (IEA, 2020)

However, EVs as percentage of total car stock rises much slower due to vehicle replacement rates. The figure below shows that pure EVs even in Norway represent as of end 2019 only 9% of the vehicle fleet. This shows clearly that achieving significant environmental impacts, which are dependent on the car stock and not new registration numbers, will take time. It also shows the importance of acting early to achieve a high penetration rate of new registered vehicles to enable an impact in the medium term.

Figure 3: Registered Passenger Cars in Norway 2019



Source: Statistics Norway, 2020; BEV = Battery Electric Vehicle; PHEV = Plug-in Hybrid Electric Vehicle; HEV = Hybrid Electric Vehicle; Other fuels incl. CNG, LPG

[4] [Electric cars reached over 60% market share in Norway - electrive.com]

More than 860,000 publicly accessible chargers are operating worldwide of which around 30% are fast chargers. The relation between numbers of electric cars and available public chargers varies widely as can be seen in the following table. Norway, the country with the largest share of electric cars, has only 1 charger per 24 electric cars but a very high share of fast chargers. China, with a comparable share of fast chargers has however only 5 electric cars per charger. Obviously no fixed relation between number and type of charger's and electric car uptake is given i.e. country circumstances are critical when developing a charging system strategy.

Table 1: Chargers per Electric Car

Country	EVs per all chargers	EVs per fast charger	share of fast chargers
Canada	9	81	11%
China	5	12	42%
France	6	82	7%
Germany	4	51	8%
Japan	5	19	26%
Korea	9	31	29%
Netherlands	2	130	2%
Norway	24	56	42%
UK	4	21	17%
USA	11	67	17%
Median	5	54	17%

Source: compiled by Grutter Consulting based on (IEA, 2020) data including countries with more than 50,000 registered electric cars

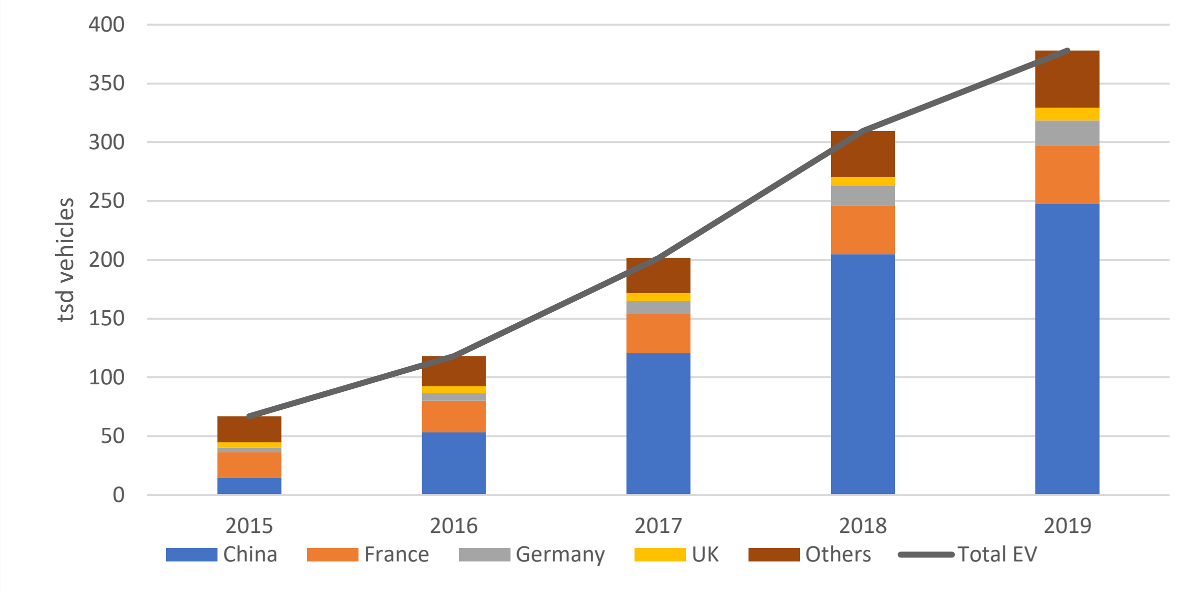
Electric 2 and 3-Wheelers

China dominates the electric 2-wheeler market in terms of annual sales (estimated at 36 million units in 2019) and a fleet close to 300 million units (IEA, 2020). Regulations not allowing fossil motorcycles to ply the streets of most cities and modest prices have led to these large numbers. In many countries electric 2 and 3-wheelers are not registered, so official data is difficult to obtain. However, large fleets of such vehicles have been reported in Bangladesh (especially 3-wheelers), India, Nepal and Vietnam. Two- and 3-wheelers are also quite straightforward to decarbonise due to low weight, short range and the high efficiency of electric motors.

Electric Light Commercial Vehicles and Trucks

Electric Light Commercial Vehicles (LCVs) are getting close to being commercial and have risen in vehicle sales strongly in the last few years reaching some 400,000 units by 2019 (including plug-in hybrid vehicles) (IEA, 2020).

Figure 4: Electric (battery electric and plug-in hybrid) LCV Stock, 2010-1019



Source: (IEA, 2020); separately listed are countries with >10,000 electric LCVs registered by 2019; LCV = Light Commercial Vehicle

Last-mile delivery services in many cities of the world are growing at high annual 2-digit numbers. Urban freight is thus quickly becoming one of the major if not the major source of transport-related air pollution and Greenhouse Gas emissions in cities. For more information see chapter 5

Electric Buses

More than 500,000 battery electric buses (BEBs) operate worldwide in 2019 of which 98% operate in China (IEA, 2020). E-buses in China represent around 1/5th of the total bus fleet with many cities going for 100% electric bus fleets within the next few years, a target already met by Shenzhen in 2018 with more than 16,000 e-buses operating in the city. For more information see chapter 3.

Electric Vessels

The global electric vessel market size is projected to triple from the current USD 5.2 billion (2019) to > 15 billion by 2030[5]. Norway is a world leader on electric mobility and also plays a leading role in electric vessels[6]. The Norwegian Parliament passed 2015 a regulation requiring low-and zero emission solutions for all cruise ships and ferries in the Norwegian world heritage fjords as soon as technically possible and no later than 2026. This will make the fjords the world's first zero emission zone at sea. It has also led to an electric revolution in the Norwegian fjords, as more than 60 electrical ferries will be seaborne within the next few years[7].

Amsterdam decreed in 2013 that all recreational boats in the city centre should be emission free by 2025 and in the entire city by 2030 in order to reduce pollution and Greenhouse Gas (GHG) emissions[8].

---

[5] https://www.marketsandmarkets.com/Market-Reports/electric-ships-market-167955093.html?gclid=EAIaIQobChMI7YXo75PR6QIVh8wYCh04DgEUEAAYASAAEgJaWvD_BwE

[6] Norway is the world's seventh largest shipping nation measured by number of vessels, and the ninth largest measured in terms of gross registered tonnage. Norway was also the fifth largest shipping nation measured by fleet value in 2017

[7] https://maritimecleantech.no/2018/05/03/norwegian-parliament-adopts-zero-emission-regulations-fjords/

[8] http://verenigdderederijenamsterdam.nl/wp-content/uploads/2014/09/Nota-Varen-in-Amsterdam.pdf; https://www.reuters.com/article/us-climate-change-netherlands/amsterdams-boats-go-electric-ahead-of-2025-diesel-ban-idUSKBN20Q1W7

The transition among commercial vessels is well underway, with 75% of the 550 on the city's water qualifying as emissions free[9]. The city is also working with contractors to have 100 boat charging stations installed by the end of 2021, as well as a floating charging station expected to help with grid balancing[10].

Another example for electric vessels is Bangkok where Energy Absolute, together with partners, is planning to deploy 42 electric high-speed vessels for 200-250 passengers cruising at 16 knots on the canals of Bangkok, Thailand. The trip distance is 30 km with fast charging being done with four 300 kW chargers at each end for 15 minutes during boarding and de-boarding of passengers. The vessels battery capacity is 800 kWh and the engine rated power is 2x90 kW. Bangkok has already 8 smaller electric vessels running on secondary canals. These are 12 m boats for 30-40 passengers running on a 5 km route[11].

Electric propulsion is used for different sizes of vessels and with different charging technologies (slow overnight charging or fast charging; battery technologies for slow and fast charging are different). The major advantage of full electric vessels are there very low noise and zero local emissions. GHG emissions depend on the power generation source, but even with the relatively high carbon grid factor e.g. of China electric vessels still reduce GHG emissions compared to diesel units. The major limitations are power and range, and limited shore-side electric facilities making charging complicated. Cost-effective applications are primarily in small to medium sized vessels, at slow speed, e.g. for tourism and for environmentally sensitive areas. The common denominator for successful battery use is that the vessels operate close to shore.

2.2. Policies and Regulations

Policies to support e-mobility have been introduced around the world to motivate people to purchase electric vehicles. Multiple surveys of persons have been made to assess their attitudes towards electric passenger cars. Major barriers are always the high purchase cost of EVs, their limited range and related the lack of charging infrastructure (see the following figure).

Figure 5: Major Perceived Disadvantages of Electric Passenger Cars

Source: Compiled by Grutter Consulting based on (Lebeu K., 2013), (Dow J., 2019), (Boradbent G.H., 2019), (Gaton B., 2019), (McKinsey, 2016), (Hertzke P., 2016), (UK DOT, 2016), (UBS Evidence Lab, 2017); similar results were confirmed in a survey realized by ADB in Kyrgyz Republic (Grutter Consulting, 2020)

[9] https://gcaptain.com/amsterdams-boats-go-electric-ahead-of-2025-diesel-ban/
[10] https://plugboats.com/amsterdam-floating-battery-terminal-electric-boats/
[11] All data based on Grutter Consulting (implementing agency of ADB pilot project on E-Vessels)

High purchase price, limited driving range and limited public charging infrastructure consistently appear in all surveys as top 3 reasons. Other important reasons mentioned by consumers are long charging times, the inability of charging at home, lack of reliability of EVs, limited electric vehicle models/types and lack of information. The following table shows policy options available for tackling directly the barriers mentioned by citizens towards purchasing an electric car.

Table 2: Barriers and Possible Policies to Remove Barriers

Barrier	Potential Policies
High purchase cost	EV subsidy, reduce tax rates on EVs, foster leasing/rent systems for EVs
Limited range	Information policy to reduce range anxiety; support to establish dense network of high-powered fast-charging network which reduces the potential problem of a short range
Limited public charging infrastructure	Subsidize establishment of a charging infrastructure; provide incentives for private operators of chargers; create a clear legal framework for the operation of chargers; no power/demand charge at least initially for public chargers; low electricity price for companies with public chargers (thereby making the business model to establish public chargers attractive); prioritize investments on grid networks to enable public fast-chargers
Long charging times	Provide incentives for fast and ultra-fast chargers; no power/demand charge at least initially for fast chargers; prioritize investments on grid networks to enable ultra-fast public chargers
Lack of reliability of EVs	Publish results on EV testing; Inform the public on possible issues with used EVs; require a state-of-health (SOH) report and require a minimum SOH level for the import of used EVs to ensure a sufficient remaining battery lifespan
Limited electric vehicle models	Inform the public about available EVs worldwide as often local vehicle dealers do not want to import EVs due to lower profit margins on EVs and less after-sales services (spare parts and maintenance)
Lack of information	Information campaign on benefits of EVs

The following table shows policies adopted by countries which have been leading the EV revolution being PR China with the highest absolute number of vehicles and the three countries with the highest share of EVs (Norway, Netherlands and Iceland).

Table 3: Policies of Countries with high Impact on EV Sales

Country	Major Policies to Promote Electric Passenger Cars
PR China	Central and local government incentives exist. Upfront cash subsidies for cars; subsidies for charging infrastructure; waiving of vehicle tax. Non-financial incentives basically from cities e.g. a preferential treatment of EVs when travel restrictions apply or no or less restriction on issuing license plates for EVs whilst for a fossil car a bidding process is applied or a lottery system with an extremely low chance of being awarded a license plate.
Norway	Official target is to only sell EVs by 2025; registration tax incl. VAT (25%) exemption also on leased vehicles; Monetary incentives amount to on average USD 25,000 per EV (Lorentzen E., 2017); no annual road tax; local incentives such as waivers on toll roads or ferries, free parking, use of bus lanes etc.[12]
Netherlands	zero tax on EV car acquisition and annual car registration fee; Drivers of leased electric and hybrid cars are exempted from taxation on private use of lease car (20% of value of new car for fossil units); subsidy of public charger installations; official target is that no new fossil cars are sold after 2030.
Iceland	Exemption from import excise duties for EVs (fossil cars up to 65%); VAT exemption for EVs; Grants for public fast-charging stations; Reykjavik offers free public charging as well as free

[12] With increasing share of EVs various incentives for EVs are being phased out

	parking for EVs; Low electricity price combined with high fossil fuel prices create a positive environment; Iceland is also one of the most urbanized countries in the world with a maximum of 500 km to cross the country East to West making range anxiety less of an issue

Sources: (Fox-Penner P., 2019); https://www.acea.be/uploads/publications/Electric_vehicles-Tax_benefits_incentives_in_the_EU-2019.pdf; https://www.government.nl/topics/environment/policy-on-eco-friendly-transport-fuels; https://theicct.org/blog/staff/iceland-ev-market-201807

The experience of Norway in policies to foster EVs can be summarized in “cheap to buy”, “cheap to use” and “easy charging access” (Lorentzen E., 2017).

2.3. Motivating Forces for E-Mobility

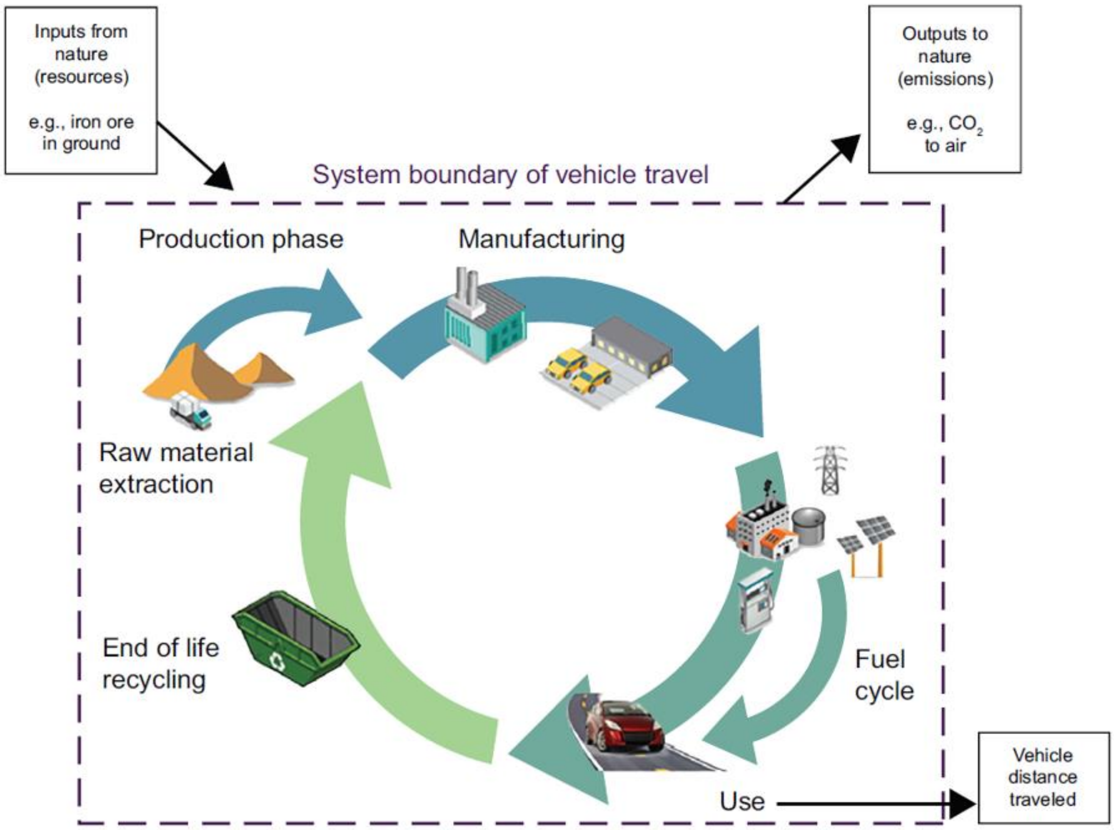
The major motivating forces for government to promote e-mobility are:

- Improving air quality: many cities worldwide suffer under serious air pollution problems with the resultant health problems, degradation of quality of life and attractiveness of the city, loss of productivity and economic costs. EVs have zero combustion emissions. They still have, equal to their fossil counterparts, non-combustions emissions resulting from tire and brake pad abrasion as well as from re-suspension of particles. Nevertheless, EVs will still result in a significant impact on improving air quality in cities.
- Reducing the carbon footprint of transport: EVs reduce, even in electric grids largely dominated by fossil fuels, GHG emissions. The transport sector has a growing share of GHG emissions and electric vehicles present an option to tackle this problem. Even under a cradle to grave perspective EVs have lower overall GHG emissions than fossil units in the overwhelming majority of countries. Intelligent charging technologies can also avoid charging EVs during peak production periods and can for example take up wind or hydropower produced also at night.
- Less noise: this is a strong argument especially for electric motorcycles and for electric urban delivery vehicles which could then also operate during the night without disturbing the sleep of residents. This again can increase the productivity of urban freight companies as they can operate outside normal business hours and use their assets better.
- Reduced energy usage: EVs are far more energy efficient using around 3x less energy than their fossil counterparts. This allows countries to reduce their energy bills.
- Less dependency on fossil fuel imports and external price shocks: Fossil fuel prices are extremely volatile. This creates constantly changing fossil fuel prices and changing transport tariffs or subsidy levels. Many countries have a large national potential to increase renewable energy generation whilst having to import fossil fuels. Electrifying the transport sector reduced the political and economic dependency on volatile and politically sensitive fossil fuel markets and reduce the drain of foreign exchange.
- Industrial policy: countries which are vehicle or component manufacturers will have to adjust to the new vehicle technology which will phase out fossil vehicles. Creating a domestic market for EVs and favourable conditions for EV and battery manufacturers can strengthen the domestic industry and maintain or create new jobs.

2.4. GHG Impacts of EVs

The GHG impact of EVs can be separated in 3 levels: (i) combustion emissions which are 0 for EVs (ii) well-to-wheel emissions which include emissions produced for electricity generation plus transmission and distribution losses, and (iii) life-cycle emissions or cradle-to-grave which include vehicle manufacturing and disposal emissions (see also following figure).

Figure 6: Life-Cycle Emissions of Vehicle

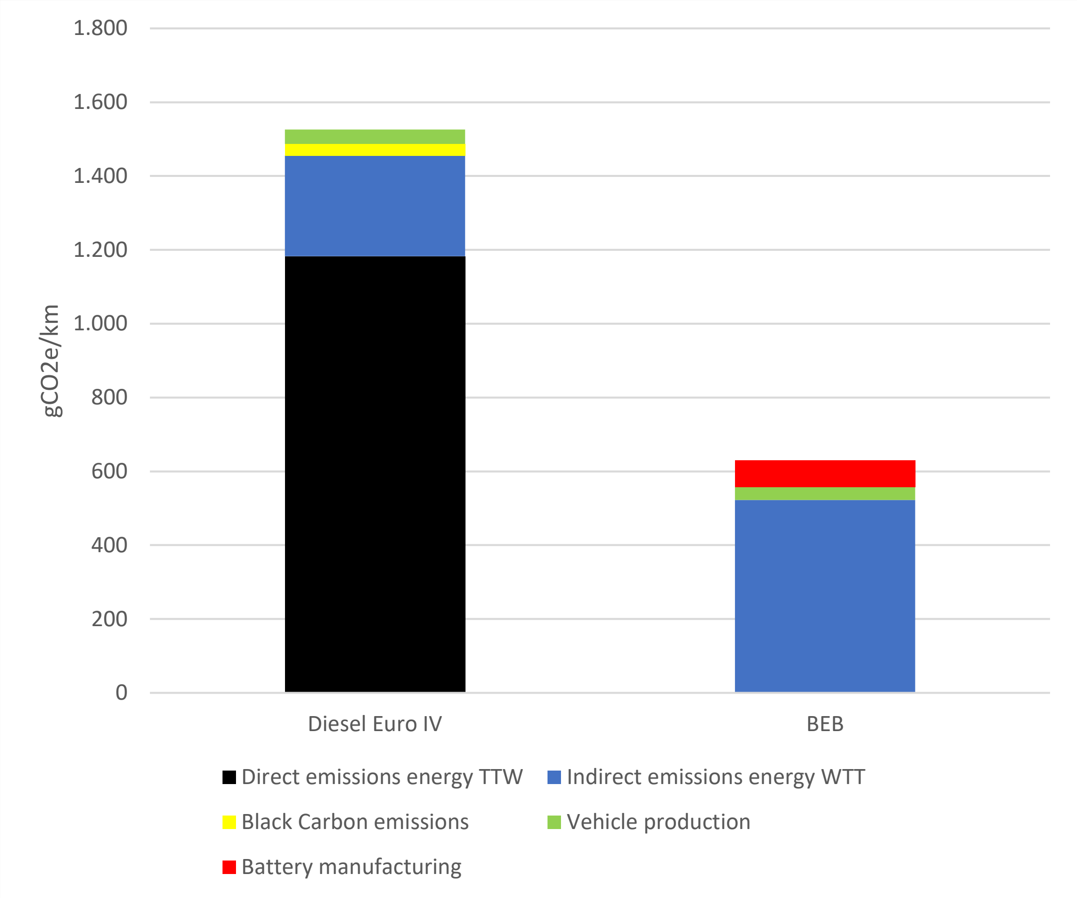


Source: (MIT, 2019)

To determine emission reductions of EVs assumptions need to be taken on various parameters such as energy usage, lifetime mileage, battery size and which comparison fossil vehicle to chose. The following graphs show for the commercial vehicle sectors targeted comparative GHG emission reductions based on a life-cycle approach.

Standard Urban Bus

Figure 7: Life-Cycle GHG Emissions Urban Bus with World Average Carbon Intensity of Grid



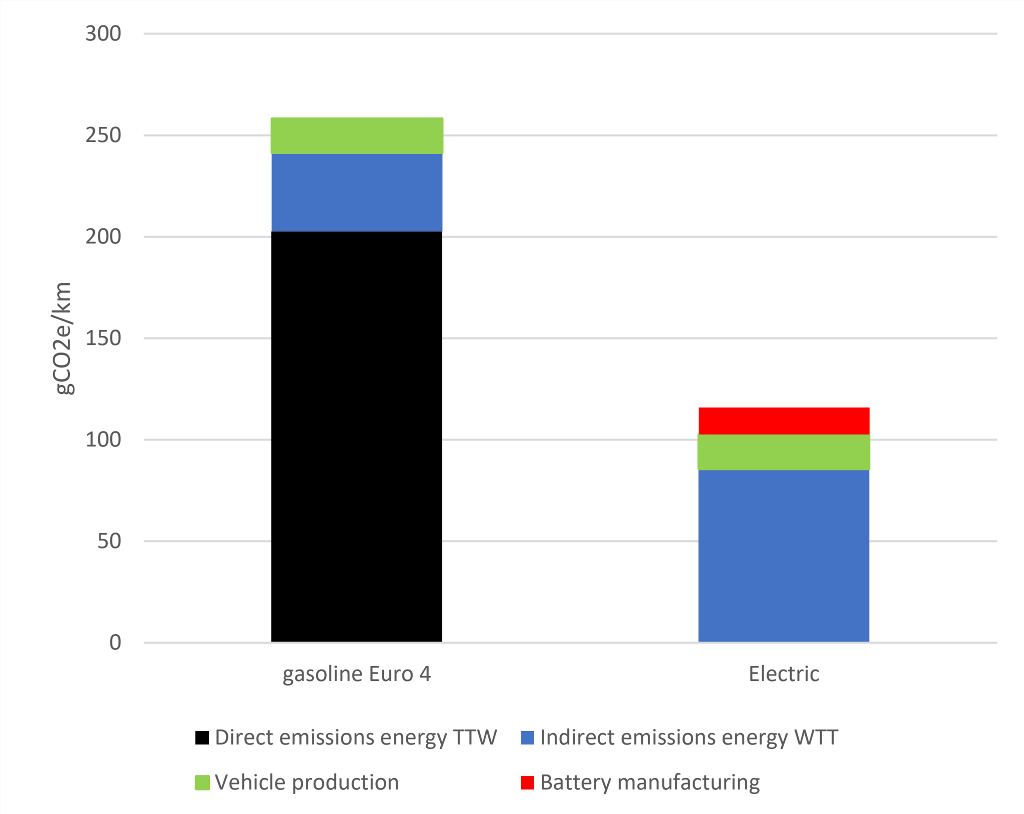
Note: WTT includes also Black Carbon emissions; 12m standard urban bus
Source: Grutter Consulting; major assumptions: 16 years usage bus and 8 years battery; 60,000 km per annum; diesel bus 44 l/100 km; BEB with battery size of 315 kWh and 1.1kWh/km; average carbon intensity world: 0.475 $kgCO_{2e}$/kWh for 2019 (IEA); Sources include mobitool, ICCT, EEA, IEA

E-buses result in 60% GHG reduction life-cycle relative to a diesel bus. The break-even point where an e-bus would have the same emissions as a diesel bus is at a carbon intensity of electricity of 1.29 $kgCO_2$/kWh. Virtually no country is at these levels today (even countries such as Australia, India, China or South Africa well known for having a coal dominated power sector do not surpass 1 $kgCO_2$/kWh)[13]. A standard electric bus also uses only 25% of the energy (in MJ) of a diesel bus and 18% of energy compared to a CNG bus[14].

[13] Compare your country by OECD
[14] Based on Tier 3 consumption values for diesel Euro IV urban bus at 17km/h, 50% occupation rate, 0% gradient and CNG EEV bus at same conditions; BEB with 1.1 kWh/km

Taxi

Figure 8: Life-Cycle GHG Emissions Taxi with World Average Carbon Intensity of Grid



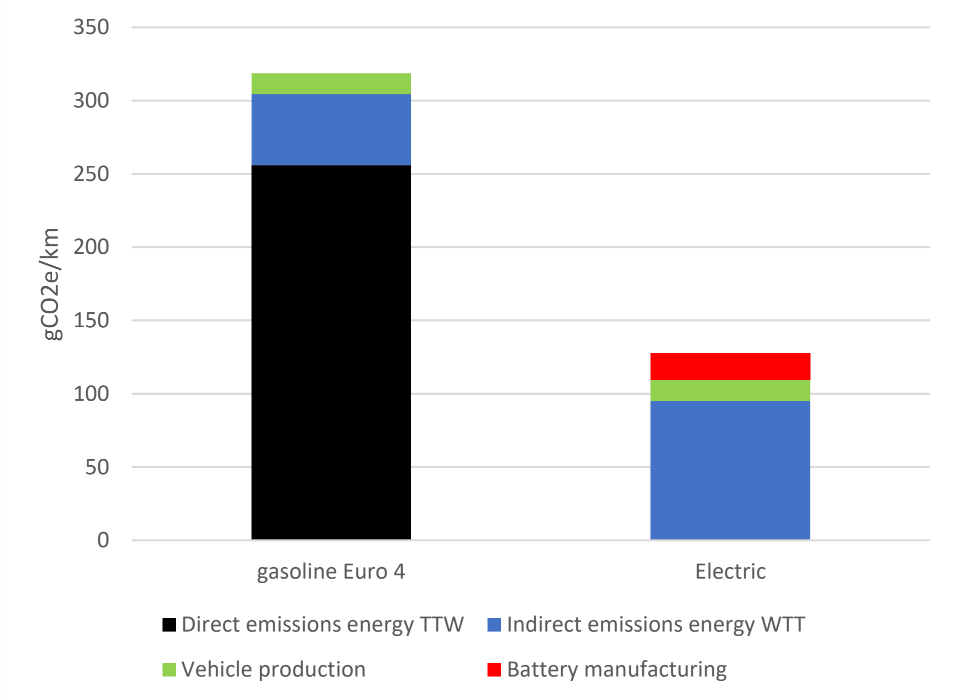
Note: WTT includes also Black Carbon emissions;
Source: Grutter Consulting; major assumptions: 10 years usage taxi and 10 years battery; 50,000km per annum; gasoline taxi 8.9 l/100km; e-taxi with battery size of 60 kWh and 0.18 kWh/km; average carbon intensity world: 0.475 $kgCO_{2e}$/kWh for 2019 (IEA); Sources include mobitool, ICCT, EEA, IEA

E-taxis result in 55% GHG reduction life-cycle relative to a gasoline unit. The break-even point where an e-taxi would have the same emissions as a fossil unit is at a carbon intensity of electricity of 1.27 $kgCO_2$/kWh. Virtually no country is at these levels today (even countries such as Australia, India, China or South Africa well known for having a coal dominated power sector do not surpass 1 $kgCO_2$/kWh)[15]. An electric taxi will also use on average only 22% of the energy (in MJ) of a gasoline or 27% of a comparable diesel unit.

[15] Compare your country by OECD

LCV

Figure 9: Life-Cycle GHG Emissions LCV with World Average Carbon Intensity of Grid



Note: WTT includes also Black Carbon emissions;
Source: Grutter Consulting; major assumptions: 20 years usage LCV and 10 years battery; 30,000km per annum; gasoline LCV 9 l/100km; e-LCV with battery size of 50 kWh and 0.20 kWh/km; average carbon intensity world: 0.475 $kgCO_{2e}$/kWh for 2019 (IEA); Sources include mobitool, ICCT, EEA, IEA

Electric LCVs result in 60% GHG reduction life-cycle relative to a gasoline unit. The break-even point where an electric would have the same emissions as a fossil one is at a carbon intensity of electricity of 1.43 $kgCO_2$/kWh. There is probably no country is at these levels today. An electric LCV will also use on average only 23% of the energy (in MJ) of a gasoline or 21% of a comparable diesel unit.

3. E-Buses

3.1. E-Bus Deployment

More than 500,000 battery electric buses (BEBs) operate worldwide in 2019 of which 98% operate in China (IEA, 2020). E-buses in China represent around 1/5th of the total bus fleet with many cities going for 100% electric bus fleets within the next few years, a target already met by Shenzhen in 2018 with more than 16,000 e-buses operating in the city.

Outside China far less BEBs are operating - however, this is changing rapidly with many cities gearing up for electric buses. India, as example initiated the Faster Adoption and Manufacturing of (Hybrid and) Electric Vehicles (FAME) program to stimulate the demand and the supply side of e-buses. The government has sanctioned 5,600 electric buses in 64 cities under the second phase of FAME India scheme[16] - with Fame I 600 e-buses where supported which are operational as of 2020. Latin America had end 2020 some 1,100 electric buses operating (plus 900 trolleybuses)[17] of which the largest fleets

[16] 400 intercity units and the rest urban buses; https://india.uitp.org/fame-ii-allocates-5595-electric-buses-64-cities-thrust-public-transport, 80% are 9m buses
[17] E-BUS RADAR

in Santiago de Chile of around 800 e-buses and Bogota with 130 units. Next to Chile countries with 20 or more BEBs are Argentina (20 units, 18 of which in Mendoza), Barbados (33 units), Brazil (46 units), Colombia (200 units of which 70 in Medellin and 130 in Bogota), Ecuador (20 units in Guayaquil), and Uruguay (33 units). Moscow, Russia operates as of September 2020 450 electric buses[18] and only wants to purchase e-buses from 2021. In Europe BEBs are since 2017 the largest segment of alternative fuel buses having passed the previously dominant Compress Natural Gas (CNG) buses. More than 2,500 BEBs are operating as of 2020 in Europe next to electric trolleybuses. Annual registration of new BEBs has jumped from 35 units in 2015 to more than 1,700 units in 2019 - in 2019 however Europe also still purchased nearly 37,000 diesel buses i.e. the market share of e-buses of newly registered units is less than 5% as of 2019[19]. In Western Europe the largest number of BEBs are operated in the Netherlands, followed by France, Germany and the UK[20].

China also dominates the BEB manufacturing market with Yutong (market leader with around 20%), BYD[21], Zhongtong and Jinlong having a combined market share of 50% (BNEF, 2018). However, outside China other bus makers have geared up e-bus production e.g. in Europe VDL, Volvo, Solaris, Irizar (which inaugurated recently Europe's first plant dedicated to e-mobility), Iveco, MAN, Mercedes, Optare, and Scania; in Indian manufacturers such as TATA or Ashok Leyland (jointly with Optare UK); in Russia Kamaz and GAZ; in Turkey Bozankaya, in Belarus Belkommunmash and in the US manufacturers include New Flyer and Proterra. In Western Europe plus Poland the top -selling BEB brands in 2019 were VDL (23% of market share), followed by BYD (14%), Solaris (9%), Volvo (8%), Irizar (8%), Mercedes (8%), Yutong (6%) and Ebusco (6%)[22]. The Middle East & Africa are also getting poised for electric bus assembly or manufacturing: In 2018, Kiira Motors partnered with China's CHTC Motor Co, a subsidiary of state-owned Sinomach Automobile Co. Engineers to manufacture e-buses. In May 2019, Foton Motor signed an agreement with Egypt's Military Production Ministry to manufacture more than 2,000 electric buses in the country over the next four years and in November 2019, Egypt's Arab Organisation for Industrialisation started its first smart electric bus in the country with the help of Shanghai Wanxiang Group, China. In Mexico Zhongtong made a Joint Venture with a national company to produce CNG and e-buses in January 2020[23]. Volvo also plans to manufacture e-buses in Mexico[24]. It is clear from above that many suppliers are entering the electric bus market which means electrification of buses is becoming main stream and multiple suppliers are today available.

3.2. Hybrid and Plug-in Hybrid Electric Buses

Hybrid Buses

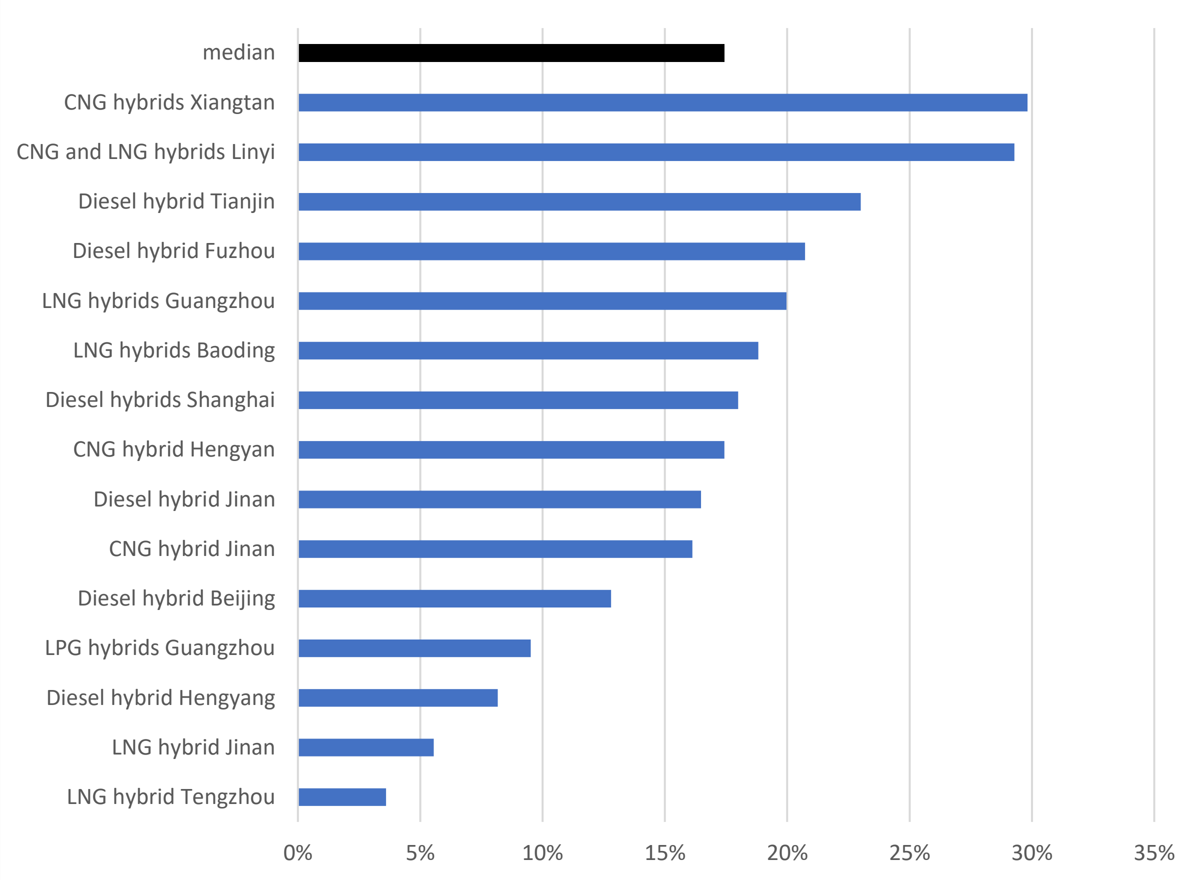
Hybrid buses are a proven and reliable technology and are also extensively used outside China. They are available in all sizes and all fuel combinations (e.g. diesel-hybrid or gas-hybrid). Average fuel savings of a hybrid bus are around 20%. The following figure shows the energy savings attributed to

---

[18] https://www.sustainable-bus.com/news/450-electric-buses-on-moscow-mosgortrans-kamaz/
[19] https://www.eafo.eu/vehicles-and-fleet/m2-m3
[20] (ACEA, 2020)
[21] BYD has also various joint ventures in other countries for e-bus production e.g. in the UK with ADL or in India with Olectra
[22] Chatrou – CME solutions, 2020; see Sustainable Bus, April 2020, https://www.yumpu.com/en/document/read/63263584/sustainable-bus-2020-04
[23] Realizarán planta de ensamble de buses ecológicos en México (metalmecanica.com)
[24] Volvo planea armar autobuses eléctricos en México - Alianza Flotillera

the usage of hybrid buses in China. On average, savings of 17% are achieved in cities in China which operate hybrid buses on a large scale with rates varying from 4%–30%.

Figure 10: Energy Savings of Hybrid Buses in China



CNG = compressed natural gas; LNG = liquefied natural gas; LPG = liquefied petroleum gas
Note: Comparison of hybrid buses of the same size and same fuel withconventional buses operating in the same city on comparable routes; minimum fleet size per city of 100 hybrids operating during a minimum period of 12 months.
Source: (ADB, 2018)

Measurements conducted in other cities with hybrid buses reveal slightly higher average savings with Swiss cities and Bogota, Colombia having an average savings of 20%–25%, while London, which uses double-deckers, had an energy savings of 35%–40%[25].

The energy savings of 20% translate into GHG and local pollutants reductions of the same magnitude. The investment cost of hybrid buses is around 20% higher compared to conventional units. However, hybrid buses are primarily produced in Europe and China i.e. regional and local bus manufacturers e.g. in Latin America do not produce such units. In such regions either European or Chinese products would need to be imported. This resulted e.g. in the case of Bogota of a sur-cost of the hybrid bus compared to the conventional unit of 90%[26] - largely due to the fact that the hybrid bus was imported from Europe which has, also for diesel units, higher price levels than Latin America. The maintenance cost of hybrid buses is comparable to fossil units but will require battery replacement after around 8 years.

[25] Data from Swiss cities based on annual monitoring reports to the government for obtaining domestic emission reduction certificates; data from London from TfL operations department; data for Bogota hybrid bus operators from TransMilenio; All data collected by Grutter Consulting
[26] (Grutter Consulting, 2015)

Hybrid buses have no range anxiety and can potentially recover the incremental investment with fuel savings. With the average world-market price of diesel (0.93 USD/l as of December 2020)[27] and an average mileage as well as bus investment costs typical for Latin America and many regions in Asia the incremental investment can be recovered in 6-8 years. Thus, its not a loss making approach but also not hugely profitable with a relatively long payback period.

Plug-in Hybrids

Thousands of plug-in hybrids in all sizes and with all types of fuel are operating in China. In Europe some plug-in hybrids are used basically on opportunity charged routes. Plug-in hybrid buses are very popular in China due to the phase-out of subsidies for standard hybrids. The main technical difference between plug-in hybrids and standard hybrids is that the former can be charged directly at the grid. Plug-in hybrids typically have a battery size of 25-40 kWh battery. The distance the bus can run on electric mode depends upon the characteristics of the route, charging frequency, and energy systems configuration.

The overwhelming share of operators in China never recharge their plug-in hybrids and operators frequently do not even have chargers. Plug-in hybrids are not recharged at the grid due to operational complexity and too small battery sets used on the buses (ADB, 2018). Thus, bus operators use them in the same manner as standard hybrids and as resultant plug-in hybrids have the same environmental and energy saving impact as a standard hybrid[28]. Even if the battery is re-charged at the bus depot during the night the energy (and resultant emissions savings) will not be more than 30-40% as re-charging during the day is complex, and batteries have a limited size. Exceptions are routes for opportunity charging buses as for example designed for the BRT Peshawar in Pakistan where a large fleet of plug-in hybrid buses is operating.

Plug-in hybrids have an incremental cost of 40% on average compared to same-size, same-fuel conventional units. This excludes chargers which can be costly if used on opportunity charged routes. This sur-cost can in general not be recovered during the life-time of the bus.

Conclusions concerning Hybrid and Electric Buses

Hybrid and plug-in hybrid buses are typically an intermediate technology as long as battery electric buses were not yet technologically ripe. Hybrid buses can recover their incremental investment but only have a limited environmental impact. They still remain a largely fossil technology and continue having environmental impacts which are only slightly less than a fossil bus. Plug-in hybrid buses have never really been popular outside China and within China only due to subsidy policies which made them cheaper than hybrid units. Their limited re-charging make their environmental impact the same or only marginally better than hybrid buses whilst having a sur-cost of 40% compared to diesel buses. They thus neither make financial nor environmental sense. Using plug-in hybrid buses on opportunity charged routes only makes in exceptional cases sense as fully electric buses could do the same job with a much higher environmental impact. Exceptional cases where such buses even today can make sense are in countries or cities with electricity supply problems and frequent prolonged black-outs[29] or on very demanding routes (e.g. very low temperatures, high gradients, long routes) where pure battery electric buses would require a very large battery set or would not be able to operate safely.

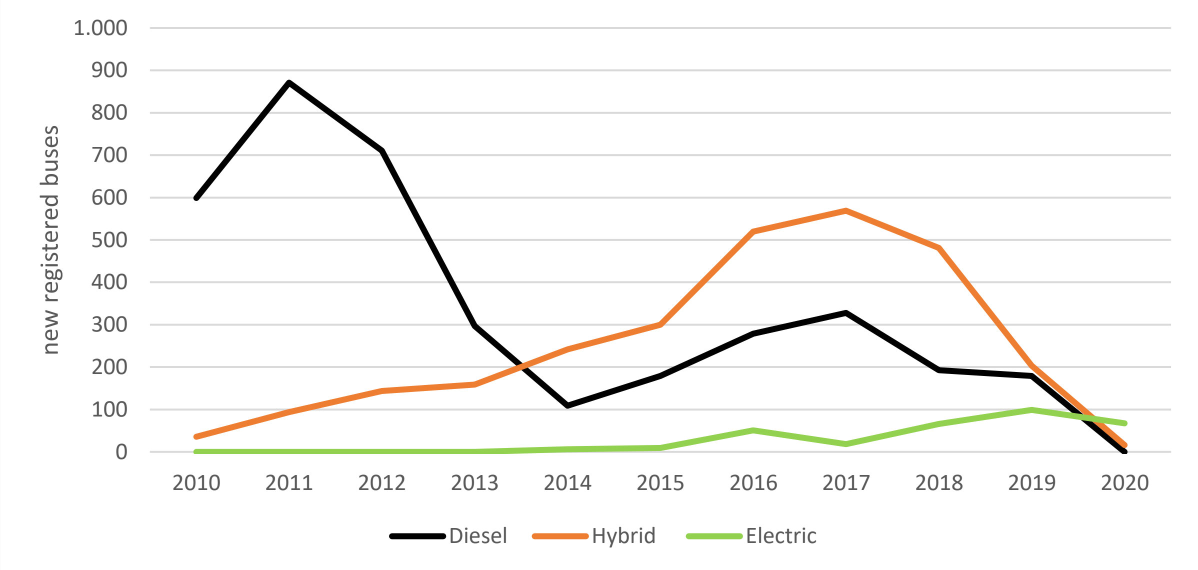
[27] Diesel prices around the world, 14-Dec-2020 | GlobalPetrolPrices.com

[28] The reason why cities in China purchased plug-in hybrids and not hybrids is that subsidies of hybrid buses were discontinued whilst plug-in hybrids continued receiving subsidies – therefore it was cheaper to purchase a plug-in hybrid bus than a hybrid or even a conventional unit.

[29] This is the reason why plug-in hybrid buses and not full electric buses were purchased in Peshawar.

Clearly hybrid or plug-in hybrid buses are no longer the option of choice for urban bus operators. China as well as most European countries no longer subsidize such units. The largest fleet of hybrid buses in Europe, London[30], started in 2012 with 300 hybrid buses. Originally plans were to fully hybridize the fleet. This plan was dropped in favour of switching towards electric buses. No more single-deck hybrid buses have been purchased by operators in the city since March 2018[31].

Figure 11: New Bus Registration TfL



Note: to 31st of March each year
Source: TfL Fleet Audit report 31/03/2020; fleet-audit-report-31-march-2020.pdf (tfl.gov.uk)

The fast development of the e-bus technology has clearly made hybrid and plug-in hybrid urban bus technology obsolete. Fostering of such buses is therefore not recommended except for special circumstances like limited and unreliable electricity supply.

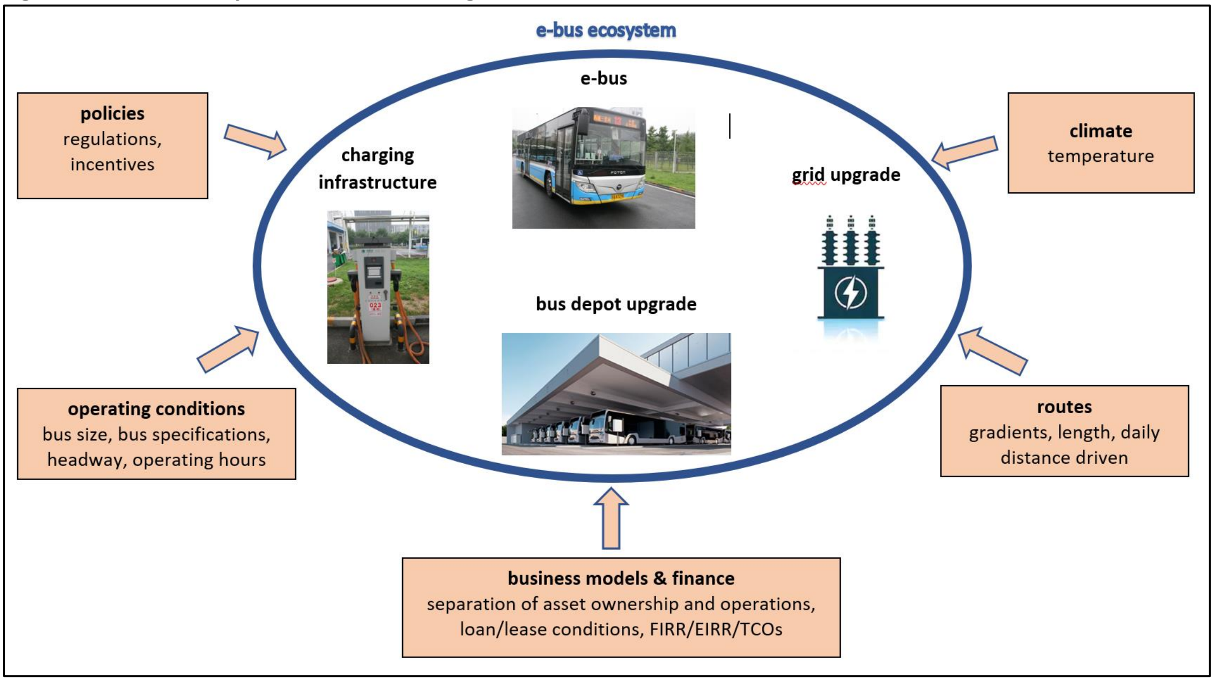
3.3. Technology Approaches

To identify the optimal e-bus type the ecosystem within which e-buses move has to be assessed. This requires optimization of the e-bus technology jointly with the charging infrastructure and the required grid and potentially bus-depot upgrades. The e-bus ecosystem is influenced by a range of factors such as operating conditions, climatic conditions, routes, policies, business models and finance structures (see figure below).

[30] 3,770 hybrid buses out of a fleet of 9,100 units as of March 2020 (Bus fleet data & audits - Transport for London (tfl.gov.uk))

[31] Double-deckers which represent the largest fleet share of TfL are only being electrified gradually – electric double-deckers are more complex technically than other bus types as batteries cannot be put on the roof.

Figure 12: E-Bus Ecosystem and Influencing Factors



Source: Grutter Consulting

Basic e-bus technology types are (i) overnight/slow or depot charged buses; (ii) fast-charged buses; (iii) ultra-fast charged buses; (iv) trolleybuses including hyrbid trolleybuses and (v) battery swap buses.

Overnight or Slow-Charged Buses

Such buses use in general Lithium-Iron Phosphate (LFP) which are low-cost and strong in terms of safety and life span but which have a lower energy density compared to Lithium Manganese Oxide (LMO) or Lithium Nickel Manganese Cobalt Oxide (NMC) batteries. Buses are typically charged at less than 100kW for 4-8 hours during the night. Slow charging is the "oldest" Battery Electric Bus (BEB) technology as previously batteries were not capable of receiving high-power charges. More than 300,000 such buses are in operations. The majority of slow-charged BEBs are midi 7-9m and standard 10-12m buses[32]. However, some slow-charged articulated 18m units also operate. Major advantages of such buses are their route flexibility, their simple operations and relatively simple chargers with charging of buses realized during off-peak power periods at night. Also electricity costs are potentially lower at night than during the day or during peak hours. The major disadvantages of slow-charged BEBs are a high bus investment cost due to the large battery set, a high bus weight due to having a large quantity of batteries on-board, a higher tyre usage of such units (due to increased bus weight) and the risk of not being able to comply with the required range and thus not being fully operational. Also, the large battery set required on such buses will result in a significant power demand at the bus depot as many buses will be charged at the same time. Many cities in China using such buses had to increase their bus fleet by on average 30% compared to the fossil bus fleet due to range problems, especially during winter and summer months when the HVAC (Heating, Ventilation and Air Conditioning) system was used or after some years when the State of Health (SOH) of batteries had

[32] Grutter Consulting for Clean Bus Leasing Program of ADB in China including monitoring of e-bus fleets in 20 cities of China

dropped resulting in a reduced range. This problem has pushed Chinese cities towards purchasing increasingly fast-charged buses[33].

Fast-Charged Buses

The common feature of fast-charged buses is that batteries are capable of receiving in a short period a large power charge. Bus batteries are often NMC. NMC can be modified to be optimized for energy or for power. Chargers range from 150-600 kW with a trend towards using higher powered units thereby reducing charging time and battery size requirement. Buses can be equipped with a variety of battery sizes which differ in their charge rate (defining the potential power uptake per unit of time). Different system versions of fast charged buses exist:

- One to 2x per day re-charging is done for 15-30 minutes during off-peak bus operation periods. This can be done at the bus depot (if close to the route) or at charging stations located in proximity of routes. This is mostly done with plug-in chargers.
- “Opportunity” charging at the end of the route with pantograph, plug-in or inductive[34] during 3-10 minutes. The battery set on-board the bus is smaller and the bus is re-charged more frequently. This requires chargers at the end of routes and sufficient headway between buses to prevent a backlog of buses and to prevent an increase of bus fleet size.

Fast charged BEBs have become the most popular electric buses in China (mainly plug-in systems with 1-2 re-charges done primarily at the bus depot) as well as in Europe (opportunity charging is in Europe very popular). Fast-charged BEBs are available in all sizes including 18m units. Batteries of fast-charged BEBs can be charged at a higher power than slow-charged BEBs thus enabling an additional driving range. This allows to operate the buses without major range anxiety and risk as simply additional or slightly longer charges can be made.

Plug-in chargers typically have a conversion efficiency of 90-95% at standard temperatures whilst pantographs have a charging efficiency of 75-80%. This results in slightly longer charging times using pantographs and a higher electricity bill. Plug-in chargers are less expensive than pantograph chargers and do not require equipment on-board the bus. Reasons why overhead charging is preferred by many bus operators is that the bus driver does not need to leave the bus for charging, that overhead charging at bus depots requires less space and the usage of higher powered chargers (connectors get very thick due to required cooling with charges >400kW). The higher the charging power the more flexibility in operations as less time is lost for charging and therefore less disruption of services, lower risks (if one charger fails re-charging at other chargers is very fast) and the possibility of choosing smaller battery sets. The drawback is that higher powered chargers mean more stress on the grid (higher power demands in short intervals; the energy consumption is the same and also the overall power demanded is comparable), higher costs of chargers and higher battery costs. Batteries with a very high charging or C-rate are also more expensive and have a lower energy density.

---

[33] Grutter Consulting for Clean Bus Leasing Program of ADB in China including monitoring of e-bus fleets in 20 cities of China and tender development for e-bus purchase in Chinese cities.

[34] Inductive charging uses electromagnetic waves to charge batteries. The charge pad is in general installed directly underneath the road surface. The technique delivers significant amounts of power, but the link between the coils can be delicate. Disturbing the system changes the frequency of the magnetic vibration, breaking the wireless connection for such setups in general i.e. if the bus is moved slightly during charging the process is interrupted. Results of bus inductive charging are mixed and cities have moved to pantograph or plug-in fast charging.

Ultra-Fast Charging

Ultra-fast charging is done at bus stops whilst passengers board and de-board the bus with 600-1,000 kW during 10-20 seconds. This requires a different technical approach from standard fast or opportunity charged buses as latter need to establish the communication protocol between the bus and the charger unit which takes up to 20 seconds thus not allowing for charging at a bus stop. Ultra-fast charging technology has the charger on-board the bus and the connection time is <1 second i.e. the bus receives power virtually during the entire stopping time at the station. The typical application of ultra-fast charging is for Bus Rapid Transit (BRT) systems operating with short headways and with large buses which do not have sufficient time at the end of the route for re-charging and/or where space lacks at the end of the route to charge multiple buses. Ultra-fast charged buses typically have a very small battery set of Lithium-Titanite Oxide (LTO) batteries able to capture and retain in a very short time period a large amount of energy. LTO is superior in terms of charge rates, life span and safety, but has a low energy density and a high cost. Such systems have been established e.g. in Geneva, Brisbane or Nantes (with bi-articulated buses) as well as various Chinese cities e.g. Ningbo[35].

Photo 1: Ultra-Fast Charging System

Trolleybuses

With trolleybuses continuous charging is realized via catenaries. “Hybrid” trolleybuses include a battery which allows them to operate partially without catenaries e.g. towards the end of routes or in areas where due to cost or other criteria no catenaries are desired. Such systems are basically used in cities which have a catenary infrastructure which is still in good shape and which does not require major overhaul. In other cases trolleybus systems, even when using hybrid trolleybuses, lack flexibility and result in higher costs than using fast or ultra-fast charged systems.

Battery Swapping

Fully automated battery-swap stations for buses were established nearly 10 years ago in various Chinese cities, including Beijing, Jinan, Tianjin, and Zhengzhou. Instead of charging the batteries on the bus, batteries are removed by robots and replaced with new units in a process that takes around

[35] The charging and power system provider ABB works for example together with various bus manufacturers including e.g. Kinglong

10–15 minutes. Battery swap stations are very costly. Bus swapping systems and bus battery type, location and size are not standardized and operators are thus locked-in with certain bus and battery types and the corresponding manufacturers. Also a large amount of batteries is required.[36] Transport operators have therefore abandoned this approach in favor of fast charging systems that have lower investment and operating costs and are far more flexible (the same charger can be used by multiple bus brands with different battery types). Battery swapping for buses has thus not further evolved.

Conclusion

For specific charging technologies specific batteries are required. Batteries used for slow-charging cannot be used for fast or ultra-fast charging (the reverse is possible). Energy densities and costs also vary between battery technologies. Therefore, an optimization needs to be made of the e-bus system taking into account operational conditions, technical requirements of the bus operator, the grid situation, investment costs of the bus, charging system, depot upgrades and grid adjustments. The following table summarizes core advantages and disadvantages of e-bus systems.

Table 4: Comparison e-Bus Systems

E-Bus System	+ points	- points	Optimal Applications
Slow-charged BEB	simple to operate; proven technology; low electricity cost	Large battery set; high bus weight and cost; range limitations; high operational risks; potentially high power demand @ depot	Buses up to 12m running on shorter routes
Fast-charged plug-in BEB	proven technology; range flexibility; moderate battery size and bus weight/cost	Requires re-charging during the day; additional space for chargers required	Buses up to 18m on any standard routes
End-of-route opportunity charged BEB	range flexibility; moderate battery size and bus weight/cost	Requires sufficient time at end of route; buses can only be used on equipped routes; power outages can affect the system	Buses of any size on routes with headways >6 minutes for 18m buses (>4 minutes for 12m units)
Ultra-fast charged BEB	range flexibility; small battery; low bus weight; low risk; high system redundancy	buses can only be used on equipped routes; high infrastructure costs; new technology	18-28m buses on BRT routes with short headways
Battery swap BEB	range flexibility; moderate battery size and bus weight/cost	Requires re-charging during the day; very high system costs; lock-in with certain bus-models and manufacturers	System not recommended due to minus points
(Hybrid) trolleybus	range flexibility; small battery size and low bus weight;	Very high infrastructure cost; limited flexibility; potentially high electricity costs; power outages can affect the system	System only recommended in cities with a relatively new trolleybus infrastructure already in place

[36] Both the bus as well as the battery swap station need to have batteries.

3.4. Profitability of E-Buses

The total cost of ownership (TCO) is often used as indicator to assess different bus technologies. TCOs are dependent on the assumptions, the methodology (e.g. constant real costs versus nominal costs) and a variety of parameters. They are also dependent on the systems analysed (e.g. many e-bus analysis only include overnight charged buses). Core assumptions which influence the TCOs include:

- Lifespan of buses: e-buses have less vibrations and moving parts and can thus have a lifespan which is 20% longer than of fossil units[37]. However, the largest e-bus suppliers are from China and the average usage of buses (not only e-buses) in China is 8 years with less than 500,000km i.e. much less than in other countries (ADB, 2018). Standard Chinese e-buses might thus have a limited life-span and bus specifications need to ensure that buses can comply with the lifespan proposed.
- Lifespan of batteries and battery replacement costs: most battery and e-bus suppliers today guarantee 8 years battery lifespan with 80% SOC (State of Charge). This warranty is in general also linked to a maximum mileage (e.g. 8 years of 600,000 km whichever occurs first) i.e. high mileage buses might have a shorter battery life-span. The cost of replacement batteries depends on the size of the battery pack, the battery type and the estimated reduction of battery costs. Adjustments of the battery management system might also be required.
- Constant or changing real energy prices: Projections of real fossil fuel prices are notoriously difficult and also depend on price setting mechanisms in the country. Electricity prices, depending on the fossil production share, might be linked to fossil fuel price development. One aspect frequently disregarded in TCOs with increasing fossil fuel prices is that passenger tariffs or service rates charged by bus operators are in general linked to fossil fuel price development i.e. whilst costs and TCOs might increase for fossil buses with increasing fuel prices, this not necessarily affects the profitability rate of fossil bus operators and is thus not necessarily an advantage of e-bus operators.
- Maintenance costs are in general assumed to be 20-50% lower of e-buses in most TCO calculations based on e-bus manufacturer claims or based on initial experiences[38]. In theory the maintenance costs of BEBs should be well below diesel buses due to having fewer moving parts. However, in practice there are some components which increase the cost of BEBs such as the demand for higher qualified personnel, more expensive spare parts (no secondary spare parts market yet available) and longer delivery times for spare parts increasing standstill times of buses. Operators of large fleets of BEBs have noted a 20% lower mileage of tires compared to diesel buses due basically to the increased weight of a BEB[39]. On the other side brake maintenance costs are lower and no oil or filter changes need to take place. Large BEB operators still experience a larger number of failures of BEBs compared to diesel units. However, in the medium term, maintenance costs should be lower than for diesel buses. However, practical long-term experience is mixed as is shown from various Chinese cities (only cities in China have practical long-term experience with e-buses). Only few cities in China (e.g. Guangzhou) have long-enough records to compare year-by-year repair and maintenance costs of e-buses with conventional units. Results show that e-buses have equal or up to 20% higher

[37] E.g. based on experience of Swiss operators with e-buses which circulate for 20 years whilst CNG and diesel buses are operated for 12-15 years; the lifespan of bus usage is however also linked to the battery lifespan e.g. replacing batteries 1x during the usage time.
[38] (Landerl, 2017) 50% to 100% of diesel; (CARB, 2016) 30% lower;
[39] E.g. Tianjin with 1,350 BEBs of 10.5 y 12m since 2013

tyre costs (due to higher weight of overnight charged BEBs and sharper acceleration and deacceleration), lower overall maintenance cost and higher repair parts costs (due primarily to a lack of a secondary spare parts market). Lower overall maintenance costs are primarily due to less maintenance staff (ADB, 2018). This will only materialize in the medium term and with a large fleet. Thus assumptions in this area need to be critically reviewed.

Major parameters which influence the TCOs and which are in most cases of a local nature are:

- Capital Expenditure (CAPEX) of buses, charging infrastructure, bus depot upgrades and grid connections[40]; Battery replacement, if required, is also a CAPEX component for the future.
- Distance driven: E-buses have lower Operational Expenditures (OPEX) compared to fossil units. The higher the distance driven the more profitable e-buses will result. On the other hand, due to range issues and battery size, e-buses are often used on shorter routes, thus reducing their advantage. In China for example e-buses run on average only 50% of the annual mileage of fossil buses, although the gap is decreasing. This not only influences the OPEX savings but also results in the necessity to purchase additional buses (ADB, 2018).
- Energy prices: electricity prices for medium tension consumers include in general a power and a consumption charge which can vary depending on time of usage. Different e-bus technologies can thus have different electricity costs. Also, within the same system, the way buses are charged will influence the electricity bill.
- Finance costs and conditions;
- Maintenance and repair costs for buses plus infrastructure;
- Lifespan of bus usage;
- Additional fleet of e-buses (if required) resulting in additional CAPEX as well as OPEX (drivers, insurance, finance, management).

Insurance costs only have a minor influence. Other major costs of bus operators such as drivers, ticketing, management and overhead costs are the same as for fossil buses and do do not influence differential costs between electric and fossil buses as long as no additional fleet is required due to operating e-buses.

TCOs can therefore vary widely between countries, between e-bus systems and between assumptions made. Whilst TCOs are important, they are only one of various arguments which will influence the purchase decision. TCOs are built on forecasts savings with medium to long-term payback periods, whilst transit authorities and transport operators have immediate needs, limited capital and budgets. The purchase of e-buses also involves following points[41]:

---

[40] Fossil fuel prices already include these components; grid adjustments up to sub-stations normally need to be paid by the system owner for medium-tension connections; bus depot upgrades can include paving bus depots, charger installation incl. protection roofs, as well as additional space requirements in the depot due to usage of e-buses.

[41] The following section is based on the experience of grutter Consulting in monitoring deployment of 70,000 buses in 20 cities of PR China under an ADB Clean Bus Loan based on actual ex-post costs and tender offers (cities of Baoding, Beijing, Changde, Fuzhou, Guangzhou, Gui'an, Hengyang, Ji'an, Jinan, Linyi, Shanghai, Tengzhou, Tianjin, Xiangtan, Yan'an, Yanzhou, Yangzhou, Zhengzhou, Zunyi); monitoring and structuring of e-bus deployment for the Swiss cities of Basel, Baden, Bern, Fribourg, Geneva, Lausanne, Schaffhausen, St. Gallen, Zug; feasibility studies including tender documents and market review for e-buses for Armenia (Yerevan), Costa Rica (San Jose), Ecuador (Quito), Georgia (Tbilisi), Indonesia (Jakarta; DAMRI as well as Transjakarta), Ivory Coast (Abidjan), Jordan (Amman), Kyrgyzstan (Bishkek), Mexico (Mexico City), Rwanda (Kigali), and Vietnam (HCMC).

- **Higher CAPEX:** the total e-bus system will require an investment 2-3x higher than purchasing fossil buses[42]. This incremental investment might be recovered due to lower OPEX (as reflected by the TCOs) – however, the fact remains that more capital is required. For a traditional bus operator this results in a higher equity demand (buses are normally financed @ 60-80%) a higher debt load, and a higher guarantee demand (e-buses due to insecure re-sale value are not necessarily accepted by financial institutions at the same guarantee level; charging infrastructure and bus depot infrastructure are to a large part sunk costs). The operator/municipality could purchase with the same investment 2-3x more diesel buses and thus either expand public transport operations or renovate quicker a large part of the fleet. The large incremental CAPEX thus poses more risk and more financial burden on private entities purchasing buses or on municipalities which might also have maximum lending levels related to their tax revenue base. The importance of this parameter is shown for example by a recent decision of the municipality of Bishkek to purchase 300 CNG buses with an EBRD loan instead of 130 e-buses with an ADB loan, although latter had significantly lower TCOs next to reducing dependency on imported fossil fuels. The argument given by the major was that with limited available finance and debt levels of the city a large fleet renovation was preferred relative to having a more profitable and environmentally friendly fleet.
- **Low profitability of the incremental investment for e-buses:** The TCO of an e-bus might be higher than of a fossil bus but the incremental investment is only recovered over a long time period and the Financial Internal Rate of Return (FIRR) of the incremental investment is low and potentially lower than of alternative investments as expressed e.g. in the WACC (Weighted Average Capital Cost).
- The **risks** of the new technology are not adequately reflected in the TCO. Loan payments for e-buses are well known – however, savings are based on assumptions concerning electricity usage, the future development of diesel prices, maintenance costs as well as bus performance including bus availability rates. High upfront investments of e-buses are thus a fact whilst savings over lifetime are a possibility and not a given. Risks include those related to (i) technology performance (e.g. actual electricity consumption influenced strongly by heating/cooling which can result in operational problems as electricity consumption will influence the bus range); (ii) risks related to the lifespan of equipment (including bus, batteries and charging equipment); (iii) risks related to a change of bus providers (major e-bus providers from China are not common bus providers in many countries); (iv) risks related to maintenance and repair costs including costs of spare parts; (v) risks related to bus availability rates; (vi) operational risks due to reduced flexibility (e.g. buses cannot be used on all routes and at all times).
- **Business models** of private bus operators which have as important income source sale of spare parts or bulk fuel purchase and sale without continuation of these financially often important side-businesses at the same scale.

The core business of a bus operator is the transport of passengers and switching technologies can potentially pose a risk to the profitability of the core business itself (e.g. if routes cannot be served identically). TCO's might paint a picture favourable for e-buses – however, bus operators will not invest in such units if involved risks, uncertainties and financial burdens are not cushioned and/or compensated.

[42] This includes the e-bus, charging infrastructure, grid connection and bus depot upgrade see section 3.5. for incremental cost components

Some of the problems identified can be resolved with alternative business models (see following chapter), others with government policies. The economic and environmental benefits of e-buses are basically of a global nature (reduced GHG emissions) and at city level (reduced air pollution). Incremental costs are born by the investor whilst environmental benefits are public goods or externalities. This also justifies the usage of public monies or financial incentives to compensate investors for risks and incremental costs when purchasing e-buses.

3.5. Business Models for e-Buses

The major business models proposed for e-buses are structured around bulk purchase and splitting asset ownership and operations. Unbundling ownership and operation can also include the provision of power, chargers and bus depots. Leasing by fleet owners can be limited to the vehicle or include also maintenance and energy. Leasing can effectively reduce the barrier of upfront investment. Various models are used separated in the type of leasing, the type of leasing company or components leased.

Bulk purchase as well as splitting of ownership and management are not new business models. They are used e.g. in the logistics industries since many years where major logistics companies lease vehicles (including maintenance in general) from fleet management companies. Also many bus operators lease since long their (fossil) buses either directly from facilities set-up or managed by large bus manufactures[43] or through specialized leasing companies[44]. The importance of these business models for e-buses relies in their ability to reduce upfront CAPEX barriers which are larger than for fossil vehicles.

Bulk Purchase

Bulk purchase of buses reduces investment costs per unit and can also reduce maintenance and repair costs if this is managed collectively. Bulk purchase is not specific for e-buses. Changes of public transport operational systems in many Latin American cities from atomized systems of individually owned and operated buses to a structured system of larger companies with concession contracts results in bulk purchasing. Bulk purchase agreements between different companies or cities however in general fail as no agreement can be found on bus specifications and manufacturer.

Bulk purchase through the government and thereafter lease or hand-over to various concessionaries is being used successfully in various places e.g. Karachi, Pakistan. Municipality based bulk purchase has advantages such as lower cost, uniform fleet, or simpler access to concessional loans. However, it has the limitations of scarce public funding, complex public tendering processes and also possible debt ceilings. Whilst bulk purchase can be applied to any technology, it is of increased importance with e-buses due to their high CAPEX which results in much higher absolute savings of bulk purchase compared to fossil units thereby reducing the profitability gap.

[43] E.g. Yutong, BYD, VDL, Volvo all have leasing branches.
[44] E.g. in China a very large number of buses are leased through financial leasing companies such as Far East Horizon, Everbright, , IBFL etc.

Leasing of E-Buses by Established Leasing Companies

In China a large number of e-buses are acquired by bus operators through leasing companies. Operating lease is more popular – however, also capital or finance lease is realized[45]. This system was already commonly used previously for fossil buses i.e. does not represent a new business model. As subsidies in China cover the incremental cost of e-buses leasing companies need not provide higher finance and also do not incur in additional risks with e-buses. Leasing companies strongly involved in bus leasing include Far East Horizon Ltd, Industrial Bank Financial Leasing Company Ltd and Everbright Financial Leasing Company Ltd. i.e. all are established leasing companies with experience in bus-leasing. Leasing companies offer an effective financing model to supplement traditional bank loans and subsidies, and support the operators in times of subsidy delays without putting pressure on their cash flows. Bus leasing in China only includes the bus (including batteries) and not the charging infrastructure which is in general owned and operated by a 3rd party. The average tenor of a lease to a bus operator in China is only 5 years whilst buses are used in large cities for 8 years. Maintenance is in general done through contracts with third parties or by the bus manufacturer paying a fixed fee per kilometre. Also for tyres it is common to have lease contracts with large tyre companies which supply, maintain and exchange tyres with a fixed payment per kilometer.

Leasing companies are normally reluctant to offer leasing for equipment which has no secondary market as this makes it very difficult or even impossible to resell a repossession. This inability to determine a future valuation can result in leasing companies assessing the future value as zero. This situation does not automatically result in any application for a lease for an electric bus being declined but it will certainly result in only the most credit worthy bus operators being able to conclude lease agreements with the local commercial lessors and probably only by pledging additional assets as collateral and by increasing down-payments. Leasing firms are in general willing to finance e-buses in the same manner as they finance diesel buses. However, they will tend to increase the risk fee as the value of used e-buses is difficult to determine due to lack of a secondary market (at least initially). E-buses can thus only be used partially as collateral and bus operators themselves in general lack sufficient real guarantees for large fleets (BID, 2020). Guarantees, such as offered by the Chilean government to e-bus leasing companies are thus a critical part. Also default of the bus operator is possible with high leasing fees. Bus operators on the other hand are reluctant to sign-up for high fixed (leasing) fees as long as bus performance is unknown as e-buses could turn out to be more costly with this scheme than diesel units.

There are several methods of reducing a lease rental namely: increase the down-payment, reduce the interest rate, increase the residual value, or increase the tenor:

- Leasing companies normally request a 20% down-payment from the lessee (as their way of mitigating their risk). A 20% down-payment for an electric bus would however be around the same value as a 30 – 35% down-payment for a diesel unit.
- No commercial financial services provider will willingly reduce its interest margin. The only way for any leasing company to offer a low interest rate to the lessee would be if the funding cost for the lessor was reduced e.g. through an e-mobility fund.
- If the maximum age of buses to be used on routes is expanded for e-buses this would help increase the residual value of used buses.

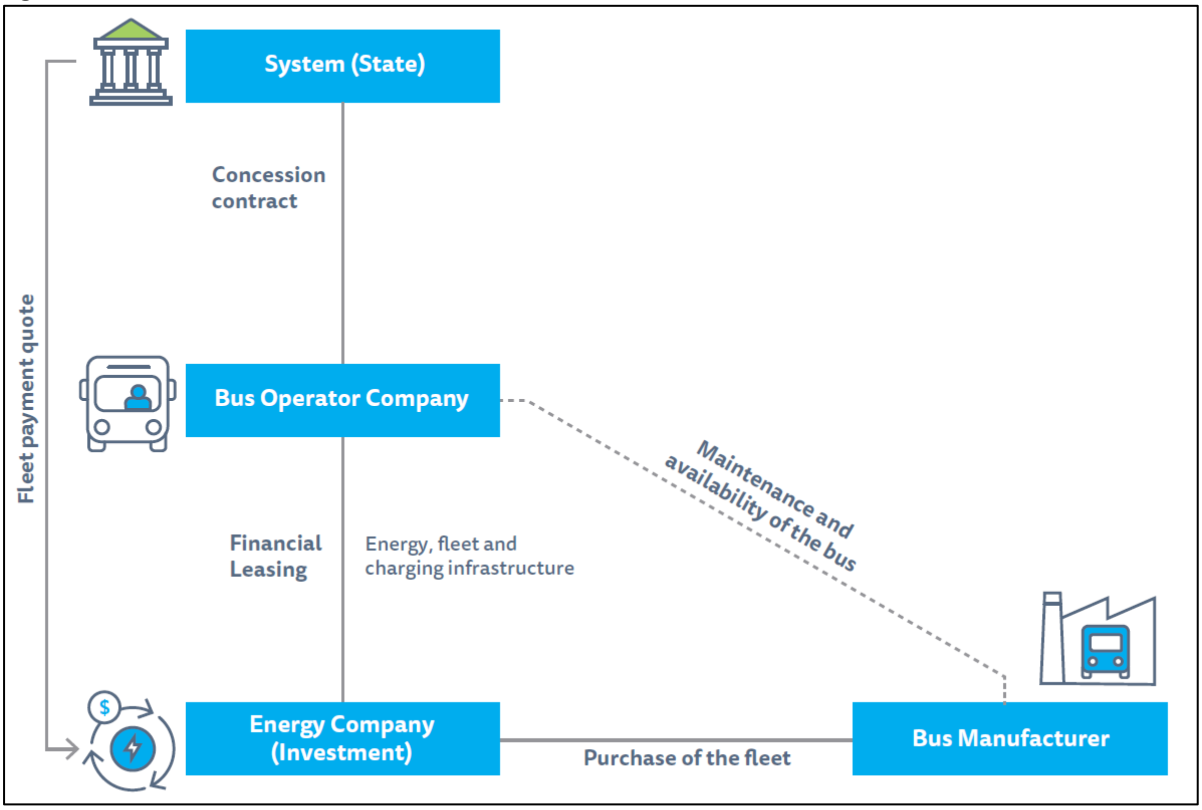
[45] A financial lease is basically like a borrowing agreement and an operational lease like a rent agreement. In operational leases in general the residual values are kept very low so that lessees purchase the equipment at the end of the leasing period instead of returning it.

- A longer tenure reduces monthly payments. However, most vehicle leasing companies currently offer leases with a maximum tenor of 5-7 years which is relatively short for e-buses.

PPP Models with Leasing through Energy Utilities and 3rd Party Investment Funds

The business model used for the implementation of e-buses in Santiago consists of a public-private partnership (PPP) between the state and private companies. The Ministry of Transport and Telecommunications and the participating private companies have so far introduced around 400 e-buses. The energy companies Enel and Engie, in order to boost their core business (energy sales and the installation of charging infrastructure), have financed the provision of buses and electric charging infrastructure using leasing contracts with the private bus operator companies (World Bank, 2020)[46].

Figure 13: PPP Actors



Source: (World Bank, 2020, p. Figure 4.5)

The lease contracts are built on fixed monthly payments to cover fleet provision, charging infrastructure (not in all cases) and energy supply (also in some cases arranged separately). Maintenance in some cases was provided based on a fixed per-km fee by the bus manufacturer and in other cases is realized by the bus operating company. In the initial cases the energy company provided buses, the charging infrastructure and the energy supply i.e. grid connections. However, in

[46] Metbus, one of Santiago's private operators had initially 100 and now 285 e-buses and realizes the daily maintenance, the bus manufacturer BYD realizes the main maintenance including that of batteries and the electric drive train and Enel X a subsidiary of the Italian utility Enel acted as the financial agent and energy provider and realized a 10-year finance lease of buses, charging infrastructure and grid upgrades for 2 bus depots to Metbus[46]. A similar agreement was made with the French utility Engie, the bus manufacturer Yutong (represented by a local automobile dealer) and two operators (Buses Vule and STP) for 100 e-buses and in March 2020 with NEoT Green Mobility, an investment platform dedicated to financing zero-emission mobility in cooperation with King Long and Redbus. STP also added with Enel X 215 additional e-buses of Foton (Galarza, 2020).

some cases the operator decided to finance directly the charging infrastructure and also realize a separate energy contract i.e. leasing in this case is limited to buses.

Energy companies are interested in boosting EVs and in establishing charging infrastructure. They entered the market of bus leasing in Chile as national banks were not willing to enter this new business or assume associated risks. They thus considered this as a kick-off investment. However, they have clearly stated that they will not finance future bus purchases as their core business is providing energy and infrastructure. Thus energy companies can be an important partner for kick-starting the business – however, it is a transitory and not a sustainable business model (BID, 2020). In the medium term, energy companies will pull-out of vehicle leasing again and leave this field to specialized companies and investment firms as can be seen by the new entries of investment firms in this area in Chile, where NEoT Capital as investment company entered the field recently. Also in September 2020, Enel X, the Enel Group's advanced energy services business line, and AMP Capital, a global investment manager, have entered into an agreement to establish a joint venture (JV) for the development of electric public transportation infrastructure in the Americas to provide financing to operators and manufacturers of e-buses, both in Chile and in the rest of America where the company has presence (Argentina, Brazil, Colombia and Peru)[47]. The parties will jointly invest in the development and leasing of e-buses and associated infrastructure for the vehicles' storage, charging, repair and operation. AMP Capital holds an 80% controlling interest and Enel X holds a 20% interest in the joint venture[48]. The JV has raised approximately USD 130 million in debt financing from private banks with a 10-year term loan for an additional 433 e-buses to be operated by Metbus in Chile[49].

The first entry of a significant fleet of e-buses (200 units) in Chile was facilitated by some favourable circumstances:

1. Based on previously signed concession contracts, the government covers the difference between the cost of a new technology and the old buses if new buses correspond to a fleet increase. This is made by an update of the monthly payment to the bus operator company. Due to special circumstances the initial fleet of 200 e-buses was all considered as fleet increase. Thus, for the first 200 e-buses, the state assumed the increase in capital costs associated with the new technology. The amount paid as incremental cost is equivalent to 1,500 USD per month per bus during 10 years or non-discounted 180,000 USD for the incremental system cost increase[50]. Thus the operators got compensated for the increase in CAPEX whilst they could keep the full decrease in OPEX which is financially very attractive and a compensation for the risk related to the deployment of a new technology.
2. The current contracts allow the operators' quotes for fleet provision to be paid directly to the bus provider (and investor). The financial entity in charge of collecting revenue and managing operators' payments deducts, from each operator's payment, the amount corresponding to the leasing contract. This reduces the risk for leasing companies cum investors.
3. The providers and the operators sign provision contracts, approved by the state, that specify that, no matter what company is operating the e-buses, the state guarantees that the buses will remain in the system until the debt is paid. This also minimizes the risk to the financing

[47] Enel X and AMP Capital establish joint venture to boost electric public transportation in the Americas | Enel X

[48] AMP Capital is a global investment manager with 143 billion US dollars in funds under as of December 31st, 2019.

[49] Allen & Overy advises on AMP Capital and Enel X joint venture to advance electric public transportation in Chile - Allen & Overy

[50] Bus investment differences for the first lots of e-buses were 100,000 USD (World Bank, 2020, pp. table 4-4)

entity, as the loan is secured by the state and ensures the continuity of the business beyond the current private bus company in charge of operations. It thus allows the buses to be funded in a larger time frame than the concession contact period remaining to the individual operator.

4. Electric companies were willing to invest outside their core business area (thereby fostering indirectly their main business). This was critical as neither national nor international banks were willing to invest in e-buses.

In the new contracts, if no fleet expansion is involved, the differential CAPEX of buses is not paid by the government. However, other incentives are provided with the new bidding process which gives separate contracts for fleet suppliers and fleet operators:

- Fleet suppliers, responsible for the purchase of buses and the spare parts, get contracts for 14 years if they offer e-buses – 4 years more than for diesel units;
- Fleet suppliers offering e-buses get additional points in tenders which is an equivalent to a financial subsidy as they can compensate points lost on prices with “technology” points. Tenders weight 70% financial and 30% technical criteria.
- Energy efficiency measured in kcal is also included as an element in tender contracts. E-buses consume 3-4x less energy than fossil units and can thus gain considerable extra points in this area. E-buses can achieve the maximum of 100 points given for units which consume less than 4 MJ per km equivalent to less than 1.1 kWh/km achievable for a standard 12m bus[51]. The weighting of energy efficiency of the total bidding is 7.5% and an e-bus can achieve, compared to a diesel bus, around 2-3 additional percentage points.
- Operators that choose to provide services with a fleet composed of more than 50% e-buses get a 7-year instead of a 5-year concession contract.

Advantages of the PPP system which are partially specific to Chile are:

- Enel used as fee rate for leasing the same rate as in the system traditionally as loan rate (7.8%). At a later stage competition increased and the rate dropped to 7.3%. With the involvement of new actors including investment banks a further reduction in the rate is expected.
- Santiago requires fossil buses to comply with Euro VI. This means that baseline diesel buses are relatively expensive compared to countries with lower emission standards. Also maintenance costs of Euro VI diesel buses are significantly higher than of diesel buses with lower emission standards. This results in a smaller CAPEX difference and a larger OPEX advantage of e-buses compared to diesel buses for Santiago compared to most other Developing countries.
- Low country financial risk of Chile which was also key for the energy companies when investing. The high and stable rating of Chile demonstrated the countries ability to uphold financial agreements, offering a favourable business environment and lowered uncertainty costs.
- Chile has free trade agreements with China, which is the largest provider of e-buses thus allowing the entry of e-buses at no additional cost.
- The electricity price offered under the contracts of 6 USD cent per kWh is very favourable.

[51] 3.6 MJ are equivalent to 1 kWh

A disadvantage of e-buses as used in Chile (especially of BYD buses) is their up to 10% lower carrying capacity of passengers. However, newer models, have equivalent passenger carrying capacities as fossil units.

Bus Battery Leasing

Various bus manufacturers offer leasing of batteries. Through that measure upfront investment in an e-bus is lowered. The US manufacturer of e-buses Proterra for example offers a battery lease over a 12-year period, including a midlife battery replacement. On a percent basis, this takes the upfront premium for an electric bus from 50% to zero[52]. The model is specifically designed for the US market where federal grants provided for the bus cover the CAPEX of a conventional bus, but not the incremental cost of batteries. Proterra thus developed this model to allow operators to have a similar financial structure as with conventional buses. However, it does increase operational costs potentially beyond those of a diesel bus as operators need to pay for the battery lease. The slow uptake of the offer from Proterra shows that the barriers of limited profitability of e-buses and of performance risks are still prevalent and hinder operators to take a positive decision.

Battery leasing was also realized by the majority of operators for the first batch of hybrid buses in TransMilenio, Bogota (Volvo offered an all-inclusive leasing fee for batteries with a payment per kilometre of bus usage). This reduced the upfront cost of the bus and took away the performance risk of batteries from the operator[53]. However, the lower risk and investment of operators was paid with high leasing fees per kilometre.

Battery leasing can create a problem for financing or leasing the remaining bus through a financial intermediary as batteries alone as well as the bus alone have a limited value. Usage of the bus as collateral without batteries can therefore create a problem.

Conclusions Concerning Leasing Models

Leasing-models have the clear advantage of reducing upfront capital investment for operators and for cash-strapped cities. They reduce the risk for operators. However, leasing of e-buses to private operators has also problems related to payment risks and lack of real guarantees of operators, issues related to the lack of a secondary market and estimation of re-sale prices of used e-buses (related also to e-buses being linked with specific charging infrastructure and grid upgrades e.g. an ultra-fast charged bus or an opportunity charged bus cannot be used on a route without the matching charging equipment or an overnight charged bus with a specific battery size might only be usable for another operator on specific routes) and the cost of leasing itself.

To be successful leasing models either require additional upfront or operational subsidies, guarantees (to reduce the risk for leasing companies thus also reducing the leasing fee) and/or incentives such as longer bus usage or regulations which ask for a certain share of e-buses. The following chapter shows incentives used in different countries with a significant share of e-buses.

---

[52] https://www.greentechmedia.com/articles/read/proterra-rolls-out-bus-battery-leasing-program-with-mitsui#gs.yfqny3

[53] Latter can however also be managed with traditional guarantee conditions asking for a specified service life of batteries with a guaranteed State of Charge.

3.6. Incentive and Support Systems for E-Bus Promotion

China

In China e-bus promotion kick-started with a subsidy of the full incremental cost[54] of e-buses (estimated 5 years ago at around 150,000 USD per standard-size 12m urban bus). E-buses can be purchased by bus operators since various years at a lower price than comparable diesel or Compressed Natural Gas (CNG) units. Additionally, chargers are subsidized and some cities also subsidize the electricity cost (e.g. by not applying a power tariff for the initial 5 years). This policy was implemented basically to foster e-bus manufacturing and to position the country as a leading player in electric mobility. The economic incentive policy started in 2009 with the release of the "Ten Cities, Thousands of Vehicles" demonstration program. The economic incentive was gradually reduced in scope (e.g. hybrid buses do not qualify anymore for subsidies since 2013) and more targeted to specific performance criteria (e.g. subsidies are related to energy density of battery, driving range and charging type). Since 2017 subsidies are also given increasingly for operations and not anymore upfront with the goal of ensuring a high usage of e-buses[55]. The subsidy levels 2020 for e-buses depends on criteria such as bus length, technology used (slow or fast charged) and for slow-charged units the energy consumption efficiency (expressed in Wh/km*kg)[56] and for fast charged buses the C-rate of batteries[57]. Maximum subsidy levels per bus >10m from the central government are in 2020 10-15,000 USD (lower level for fast and higher for slow-charged units) (ICCT, 2020). These subsidies are matched in general with equal level subsidies by the Province government and the city government, thus resulting in 30-50,000 USD of subsidy which matches largely the current incremental cost difference in China of a fossil and an electric bus (separate subsidies are giving for the charging infrastructure as well as bus depot changes).

The policy was very successful in terms of bus numbers and industrial production capacity with numerous Chinese manufacturers acquiring the know-how and experience on e-buses. E-bus incremental costs could be reduced significantly in few years. Operators gained a lot of experience in managing e-bus fleets without taking financial risks. The subsidy levels could be reduced gradually reaching today 1/3 of the level given 5 years ago and with a complete phase-out expected by 2022.

India

The Phase-II of the Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles (FAME-India) Scheme, managed by the Ministry of Heavy Industries and Public Enterprises proposes to give a push to electric vehicles (EVs) in public transport and seeks to encourage adoption of EVs by way of market creation and demand aggregation. It is similarly structured to the scheme of China trying to catch up with China in being a leading country in manufacturing EVs. The scheme envisages the growth of EV industry, including providing for charging infrastructure, research and development of EV technologies and push towards greater indigenization. After an initial pilot with around 450 buses in 9 cities launched October 2017, the Department of Heavy Industry approved in August 2019 the sanction of around 5,600 electric buses to 64 Cities of which 400 electric buses for intercity operations and the rest for urban bus service[58]. Each of the 64 cities selected shall have at least 25 e-buses each. 5 metropolitan cities namely, Delhi, Mumbai, Hyderabad, Bangalore and Ahmedabad received 300

[54] Incremental costs refer to the price difference between an electric and a diesel or CNG bus; (ADB, 2018)
[55] See also http://www.sustainabletransport.org/archives/5770
[56] The more efficient the higher the subsidy
[57] The higher the C-rate the higher the subsidy
[58] https://dhi.nic.in/writereaddata/UploadFile/Press%20Release%20Final.pdf

buses each. India subsidizes under the FAME II scheme up to 40% of the total bus cost (Phase I with the pilot scheme had a subsidy level of 60%)[59]. Chargers are also subsidized.

Germany

Germany subsidizes since February 2018 up to 80% of the total incremental cost of e-buses and 40% of all other costs for charging infrastructure, grid connection, bus depot upgrades[60], plus training costs (for drivers or maintenance staff) and costs for the establishment of new maintenance centers[61]. In absolute terms this amounts to subsidies per e-bus incl. related infrastructure of 250-500,000 Euro. As of 10/2020 620 million Euro have been reserved for subsidies. In contrast to China and India the subsidies in Germany come from the Ministry of Environment (financed from an energy and climate fund). The impact of the program is visible from the fact that prior to program start the total number of e-buses in Germany was less than 100 units, whilst as of 10/2020 the number of e-buses was 1,240 units[62].

United Kingdom

The UK ran a Low Emission Bus Scheme followed by an Ultra-Low Emission Bus Scheme (2018-2021). The first scheme subsidized up to 90% of incremental costs of hybrid and e-buses (including buses as well as charging infrastructure)[63]. This resulted in a large hybrid bus fleet, especially in London[64]. Under the 2nd, [65] the subsidy covers as maximum 75% of incremental bus costs[66] and 75% of infrastructure costs. In 2019 with the 2nd scheme around 250 electric buses received an average subsidy of 160,000 USD per bus and 230,000 USD per bus including charging infrastructure. Additionally low carbon buses receive an 8 USD cent Bus Service Operator Grant incentive per km amounting to an additional subsidy of 60-70,000 USD for the lifetime of buses[67]. The interesting part of the scheme is that it is based on a competitive bidding process following a reverse auction scheme with winners being the companies asking for the lowest subsidy they would accept to purchase e-buses i.e. the authorities do not fix the subsidy amount of share but use the market mechanism to determine the minimum required subsidy to ensure market participants to invest in e-buses. This therefore could give an indication what market players consider as total financial incremental cost of an e-bus including the perceived risk of such buses. In practice however the winning bids were all close to the maximum subsidy level offered by the fund in round 1 and 2.

Switzerland

Numerous Swiss cities only want to purchase electric buses from a given date onwards. The country also has the largest share of electric trolleybuses (relative to total of urban buses) worldwide. For example, Basel in Switzerland will replace all fossil units by 2025 with e-buses. Urban public transport

---

[59] Maximum of 80,000 USD for a 10-12m bus and 50,000 USD for a 6-8m bus; https://economictimes.indiatimes.com/industry/auto/auto-news/centre-seeks-proposals-for-5000-electric-buses/articleshow/69658042.cms?from=mdr

[60]see Förderung von Elektrobussen (BMU) (bundesregierung.de) and Das Förderprogramm Erneuerbar Mobil | Drupal (erneuerbar-mobil.de)

[61] Incremental costs include also battery warranty or battery leasing costs

[62] As of 10/2020 projects in 48 communities worth 439 million Euro had already been approved

[63] Electric buses in the UK are fitted, comparable to most buses in Sweden, with diesel heaters and are thus not 100% e-buses.

[64] See e.g. https://www.lowcvp.org.uk/Hubs/leb/scheme.htm

[65] https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/774207/ultra-low-emission-bus-scheme-winning-bidders.csv/preview

[66] Estimated at 210,000 USD; Ultra Low Emission Bus Scheme (lowcvp.org.uk)

[67] Ultra Low Emission Bus Scheme (lowcvp.org.uk)

is in general provided either by municipal operators or in some cases by concessionaries. The municipality also purchases in most cases the buses. In cases where the city decides to only purchase e-buses the investment budget is made for such buses and is thus simply increased compared to purchase of fossil buses. Next to direct payment of the full e-bus system costs other financial support systems available are (i) infrastructure such as charging stations are basically grant financed with local state money (e.g. ultra fast charging infrastructure for the Geneva ultra-fast charging system); (ii) climate funds are available: transport operators which want to purchase e-buses can register their units under a domestic GHG offset program and get national credits based on the CO_2 reduction achieved. These are sold to the national offset market paying until 2020 around 130-170 USD/tCO_2 and from 2021 onwards up to 250 USD/tCO_2 during the bus lifetime. The system allows you to receive an upfront payment upon purchase of around 100,000 USD for a standard e-bus plus another 100,000 USD during the usage time of the bus (result-based finance). This covers around 80% of incremental bus investment costs in the Swiss context.

Poland

Poland is one of the countries in Europe with the largest number of e-buses in relation to the country population and the largest e-bus fleet in Eastern Europe. The Polish Ministry of Climate Change promotes the purchase of urban electric buses with a total volume of 75 million euros to enable the purchase of up to 300 e-buses and 75 charging stations i.e. a subsidy of 250,000 Euro per e-bus (incl. charger)[68]. This effectively covers 100% of incremental investment costs of the entire e-bus system.

USA

In the US the Federal Transit Administration (FTA) runs a Low- or No-Emission (Low-No) Grant program for either fuel cell or battery-electric bus projects and their relevant infrastructure[69]. The FTA, which provides grants to public transportation agencies, requires that transit buses acquired with federal public transportation funding undergo final assembly in the United States and that at least 65% of the cost be manufactured domestically. This threshold rises to 70% for buses delivered in FY2020 or later[70]. Buses can be purchased or leased by operators. The Federal share in the purchase or lease of new electric buses including infrastructure is up to 90% of the total cost. In the different projects, the funds are being allocated for the purchase of new vehicles, the purchase and/or installation or upgrading of charging systems. The BEBs that are purchased or leased through these projects are supported by a combination of on-route overhead charging and plug-in depot chargers.

Colombia

Metroplus in **Medellin** purchased in 2019 64 13.5m electric buses for services as feeder buses for its BRT system. Metroplus is part of the Metro company which is a public enterprise. The buses worth 340,000 USD per unit (including 16 chargers) were purchased and fully paid by the Municipality i.e. the full investment and incremental cost of e-buses relative to diesel units was paid by the government. This is in line with the local governments target to transform by 2030 towards e-mobility. The Municipality used for this purchase a surplus available through the sale of a public enterprise in 2019 i.e. it is considered an exceptional case that funds are available for purchasing buses with a significant additional cost.

---

[68] Polish Ministry of Climate launches e-bus support schemes - electrive.com

[69] https://www.electrive.com/2019/07/29/usa-grants-awarded-for-electric-buses-and-infrastructure/ or https://www.transit.dot.gov/

[70] Currently only the Chinese company BYD, the Canadian company New Flyer and the US company Proterra manufacture or assemble e-buses in the US (see https://fas.org/sgp/crs/misc/IF10941.pdf)

The private operator MDO (Empresa Masiva de Occidente) in Medellin purchased 12 electric buses (8m units) in 2019, 4 of which are already in operations. Buses where financed through a concessional loan (compensation to the financial intermediary through Findeter) with an interest rate 2-3% points below standard market rates. The financial intermediary financed 80% of the investment cost. Empresas Publicas de Medellin paid for the grid connection and a substation for charging 20 buses. MDO purchased the buses as they consider that the OPEX of e-buses is much lower and due to receiving the following incentives:

- Concessional interest rate (2-3%);
- Tax incentives: 25% lower income tax for environmental investment and no payment of VAT.

In **Bogota** TransMilenio (TM) changed its financial model in 2017 after serious financial problems of multiple operators resulting in FIs not lending anymore to them for bus purchase. This created problems for TM for renewal of bus fleets. TM therefore opted to separate fleet provision and fleet operations including bus depots. Fleets are paid on a monthly base per available bus whilst operations is paid per kilometre and depending on usage area per passenger transported.

The Phase I tender floated in 2019 (5 zones) was for electric buses i.e. no fossil units could be presented. At this stage TM also provided the bus depot including chargers and grid connections paying this separately to the energy utility i.e. the bus fleet offer only included buses. TM paid thereby the full sur-cost of e-buses (as mentioned no fossil buses were allowed in this tender). In total 483 electric buses were acquired of which 73 9m units and 392 12m units. All units are operated in zones or as feeders i.e. no trunk buses (all 18m and 24m units) are included. 133 of the 483 units are already in operations since end 2020 and the remaining units will enter operations until March 2021.

Photo 2: TransMilenio Electric Bus

Source: TransMilenio

The Phase II tender also floated in 2019 (3 zones) allowed companies to offer any bus technology. All contracts were awarded to Diesel and CNG Euro VI buses (in total 701 buses of which 534 CNG and the rest diesel; 167 9m units and 534 12m units). The tender clearly showed that under pure market conditions e-buses are not (yet) competitive even if they had certain tax benefits.

City authorities however wanted that new buses be electric. For the Phase III tender issued in 2020 (6 zones) therefore the tender conditions were adjusted so that e-buses would be competitive or would win. The tender did allow for any bus technology but e-buses received between 38 and 43 additional technical points (out of a total of 100 points see figure below for points of tender) which is more than the total of points which could be received for the financial offer.

Table 5: Point System for Phase III Tender TransMilenio

Criteria	TMSA-LP-03-2020 max. points	TMSA-SAM-14-2020 max. points
Financial offer based on normalized NPV	36	41
Extended warranty of manufacturer[71]	10	10
Technology of buses: 100% of points are awarded for e-buses and 0 points for fossil units	43	38
Support of national industry	10	10
Protection of disabled persons	1	1
Total	100	100

Source: Grutter Consulting based on published tender documents[72]

Electric buses thus had a strong advantage and all contracts awarded were in Phase III for electric buses. The additional technical points were decisive. Also e-buses easier got the extended warranty than fossil units. The tender resulted in the award of 1,003 electric buses of which 672 are 9m units and the rest 12m units[73]. These buses will enter operations between November 2021 and April 2022 thus extending the electric bus fleet of Bogota to 1,485 units. In Phase III fleet offerers had to include also the chargers and the bus depot plus connection within their costs. E-bus providers in this tender also have the advantage of 15 instead of 10 year concession contracts for fleet provision as well as for operations. Modelling realized by TranMilenio indicates that the incremental cost of TransMilenio for fleet provision plus operation is in total 16%. As this includes CAPEX as well as OPEX it is an indication that the TCO of e-buses in Bogota is 16% higher than of fossil units. The municipality was willing to pay this incremental cost due to the decision to go electric. The tender documents were thus modified to create competition with fossil units but including additional points for e-buses which made them more competitive than fossil units.

Following points can be summarized from the Colombian experience with e-buses:

- E-buses have an incremental cost and are not competitive with fossil units if tenders are not exclusively for e-buses or if latter do not receive additional points;
- In Medellin as well as Bogota the government has paid the incremental cost for e-buses;
- The incremental lifetime cost of e-buses in Bogota is estimated at 16% i.e. this is the sur-cost paid by TransMilenio over the concession period compared to using fossil units.

Only medium (9m) and standard (12m) size buses have been electrified to the moment. Bogota also wants to electrify articulated and bi-articulated trunk buses for which tenders will be floated in 2023. However, this will require a technology analysis to identify the most appropriate technological approach. This might also result in different business models e.g. in case of using ultra-fast charging systems a separation might be made in provision of charging infrastructure and provision and operation of buses.

---

[71] For fossil units 2 additional points per year for warranties going beyond 3 years (i.e. from year 4 onwards) up to a maximum of 10 points and for e-buses 1 additional point for each additional year of guarantee going beyond 5 years up to a maximum of 10 points (for 10 additional years)

[72] Tender TMSA-SAM-14-2020:
https://community.secop.gov.co/Public/Tendering/ContractNoticeManagement/Index?currentLanguage=es-CO&Page=login&Country=CO&SkinName=CCE
Tender TMSA-SAM-15-2020:
https://community.secop.gov.co/Public/Tendering/ContractNoticeManagement/Index?currentLanguage=es-CO&Page=login&Country=CO&SkinName=CCE

[73] One zone was declared deserted in the tender.

Chile[74]

As seen in the previous chapter the initial 200 e-buses profited from a full coverage of the differential CAPEX (bus, charging infrastructure and grid connection) by the government. This was due to special circumstances surrounding contract renewals. For new operations this subsidy is not given anymore. However, e-buses still profit from incentives including longer concessions contracts (for fleet providers 14 instead of 10 years and for bus operators with a 50% e-bus fleet 7 instead of 5 years i.e. 40% longer contract periods), and additional points in the bidding process for offering e-buses and for lower energy usage of e-buses compared to conventional units. All these components represent effectively a subsidy although their cost is difficult to estimate (additional technology points in tenders compensate higher price offers and higher concession periods reduce competition of new entries and thus also increase costs).

Uruguay

Uruguay has acquired in 2020 30 electric buses operated by 2 companies. The central government through the Transport, Finance Ministry, Energy and Environmental Ministry subsidize the purchase of e-buses by paying the full incremental cost of e-buses compared to diesel units including bus plus charging system[75]. The subsidy is paid in monthly payments during 7 years. The government estimates that e-bus subsidy is equivalent to the diesel subsidy the government is currently paying i.e. the government itself has no additional financial cost[76]. The process was also supported through a GEF6 project on electric mobility.

Summary Incentives

All countries with a e-bus fleet which go beyond pilots have put significant incentives in place. As bus costs vary widely based on the region (fossil as well as e-buses) the incremental CAPEX of an e-bus system is relevant. The following table summarizes incentives provided by different countries.

Table 6: Incentives for E-Bus Purchase (Subsidies)

Country	Incentive
China	100% of incremental bus cost subsidized; chargers and grid connection up to 100% subsidized; electricity price initial 3-5 years subsidized; decreasing rates since program start in 2009
India	80-100% of incremental bus cost subsidized in Fame II; chargers subsidized. FAME I 2015-2019 had 20 percentage points higher subsidy levels compared to FAME II
Germany	80% of the total incremental cost of e-buses and 40% of all other costs for charging infrastructure, grid connection, bus depot upgrades, plus 100% of training costs (for drivers or maintenance staff) and 100% of costs for the establishment of new maintenance centers subsidized.
Switzerland	80-100% of incremental costs of buses and 100% of charging infrastructure and grid connection costs subsidized
UK	75% of incremental bus and charging infrastructure costs subsidized; under Phase I (2016-2019) 90% of incremental costs were financed
Poland	100% of incremental cost of entire e-bus system subsidized
USA	90% of incremental cost of entire e-bus system subsidized
Colombia	100% of incremental CAPEX of entire e-bus system was paid in Medellin and Phase I in Bogota. 100% of incremental total lifetime cost of e-bus system (CAPEX plus OPEX) subsidized Phase III in Bogota (16% incremental cost compared to fossil units)

[74] See chapter 3.5 for more details
[75] Se incorporan 30 buses eléctricos a Montevideo - Información - 18/05/2020 - EL PAÍS Uruguay (elpais.com.uy)
[76] Llegan a Uruguay los primeros 30 ómnibus eléctricos – pv magazine Latin America (pv-magazine-latam.com)

Chile	100% of incremental cost of entire e-bus system for Phase I (200 buses) subsidized with monthly installments during 10 years; phase II longer concession periods for e-buses compared to conventional units (+40%) and additional points in tenders
Uruguay	100% of the incremental cost of e-bus plus chargers is paid in monthly installments during 7 years; the government subsidy for e-buses equals the government savings on subsidies saved on diesel fuel

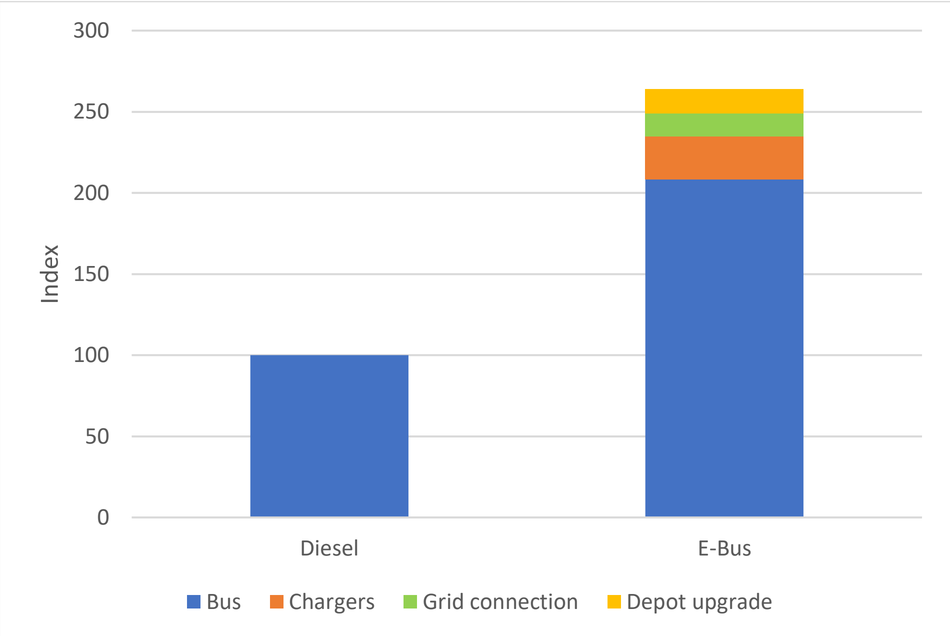
Source: Grutter Consulting

Countries thus consistently subsidized 80-100% of the entire e-bus system incremental cost for the initial phase. Interesting is however also the fact that countries decreased their subsidy rates significantly within few years (e.g. China, India, UK, Chile). The importance of significant upfront investment subsidies – independent of TCOs – to kick-start deployment of e-buses is thus clear. It also shows however that once a large fleet is established subsidies can be reduced gradually and even be eliminated with 5-10 years due to more competitive prices of e-buses combined with the experience of mass operations of e-buses.

Components of Incremental Investment Costs

The following graph shows based on indexed numbers the components of incremental investment costs. The figure is indexed as base bus costs vary between countries[77]. The figures are based on a detailed feasibility report realized for the purchase of 120 electric buses for Bishkek, Kyrgyz Republic, under an ADB loan in 2020. Similar cost structures were found in other countries. Variances of course exist depending on the type of bus and charging infrastructure, or the existing bus depot. However, it serves as indication on the components of incremental costs which have to be taken into consideration when establishing an e-bus system.

Figure 14: Incremental Cost Components



Source: (Grutter Consulting, 2020); based on 12m urban fast-charged Battery Electric Buses; CAPEX diesel bus USD 120,000: CAPEX electric bus USD 250,000; CAPEX charging infrastructure per bus USD 32,000; CAPEX grid upgrades per bus USD 17,000; CAPEX bus depot upgrades per bus USD 18,000

[77] E.g. Frost&Sullivan reported diesel bus costs for standard urban buses of worldwide on average 200,000 USD with costs below 100,000 in India or China and at 300,000-400,000 USD per unit in Europe or the US with the rest of the world in-between; this is basically due to bus specifications and market competition (Frost & Sullivan, 2012).

In the example the e-bus investment is factor 2.1 higher than of a diesel bus whilst the entire e-bus system has an investment cost factor 2.6x of a diesel-based system due to additional costs for chargers, grid connections (up to sub-stations i.e. no deep investments in the grid itself but only costs which need to be absorbed by the bus owner or operator) and the required upgrades for the bus depot to accommodate for e-buses. Depending on the e-bus system the relations can vary e.g. bus costs will be higher for overnight charged e-buses whilst charging system costs are a bit lower.

Applying the 80% subsidy on incremental e-bus costs as offered by various countries listed above this can be translated into a 50% subsidy of the incremental total e-bus system cost.

As mentioned, actual incremental CAPEX as well as profitability of e-bus operations based on a total cost of ownership (TCO) approach need to be established per country and can have very large variations depending on country circumstances.

4. E-Taxis

3.1. E-Taxi Deployment / Technology Considerations

PHEVs as Taxis

Hybrid taxis have become very popular worldwide, especially Toyota Prius models. The fuel savings of 20-30% make them an attractive option for high-mileage taxis which can recover the incremental investment quickly. Also usage in urban surroundings supports fuel savings due to recovery of brake energy – in contrast to private car users taxis will not be used frequently on inter-urban highways where hybrids do not offer fuel savings.

Plug-in hybrid vehicles (PHEVs) are however not popular as taxis. This is due to the limited financial attractiveness related also to their usage. The battery size of PHEVs is limited resulting in an electric driving range of 30-50km depending also on Air Conditioning (AC) usage and gradients. Alone AC usage reduces the range on average by 20% (heating by 40%) (ICCT, 2020b). Most PHEVs models can also only use AC slow chargers. AC charging requires an on-board rectifier to convert AC power to DC required for battery storage. The size of the on-board rectifier limits the maximum AC charge rate to 3.6kW or less for many current PHEVs which means charging of more than 1 hour to re-charge their already small batteries.

A recent study of ICCT revealed that company PHEVs only run 20% of real-world driving on electricity (ICCT, 2020b). Vehicle running costs, in particular electricity, are much lower than for a conventional car, but only when the vehicle is operated in electric drive mode. Operating the vehicles without charging them will result in far higher running costs, at least as much as a petrol or diesel equivalent. Also PHEVs are more complex and expensive to maintain due to having both electric and internal combustion powertrain. Therefore the incremental cost of PHEVs compared to hybrids is not compensated with a significant reduction of operational costs.

Table 7: Performance Data of Popular Plug-In Hybrid Models

PHEV Vehicle	Price Difference to HEV or Conventional	WLTP range electric[78]	Battery Size	Max. charging Rate	Charges for 150km electric range
Hyunday Ioniq	+ 20% compared to hybrid	60 km	8.9 kWh	3.3 kW	3 charges of 2.5 hours each
Mitsubishi Outlander	+60% compared to basic fossil model	57 km	13.8 kWh	22 kW	4 charges of 20 minutes each
Toyota Prius	+35% compared to hybrid	40 km	8.8 kWh	3.3 kW	5 charges of 2 hours
VW Passat	+35% compared to fossil model	55 km	13 kWh	3.6 kW	3 charges of 3 hours

Source: Grutter Consulting; http: zap-map.com for maximum charges per vehicle type; manufacturer website for other data

If a taxi with a daily mileage of 300km wants to run 50% electric it would need to take 3-5 charges per day each with a duration of 2-3 hours (with exception of the Mitsubishi Outlander which allows for faster charging but would still require 4 charges of 20 minutes each for achieving 50% electric mode). Obviously this is unpractical i.e. PHEV taxis would be charged probably only at night as day charges are too slow. This again would mean that with mileages of 300km only around 10-15% of driving would be electric. The GHG impact would thus be small whilst the incremental cost compared to a hybrid or conventional vehicle is significant. This makes neither financial sense for taxi owners nor is it a cost-effective strategy to reduce GHG emissions.

The LVEC TX PHEV London taxi is an exception as it was purpose-built for the city of London and the new license requirements of taxis with a minimum 50 km 0-emission range. This taxi has an electric range of around 100 km with a 31 kWh battery which can be charged with a rate of 50kW. However, a 30 minute charge will only be capable of adding another 80 km i.e. if the entire daily driving of 300km shall be completed the taxi needs to be charged also 4 times for 30 minutes per day. The retail price of this taxi is around 70,000 USD (30% more than a conventional model) and thus above many electric vehicle models. In January 2018 Transport for London (TfL) introduced new emission based licensing requirements for taxis. All newly registered taxis must be able to drive a mandatory zero emissions range of at least 30 miles (around 50km) to operate within London. As this measure cannot be achieved by hybrid vehicles a shift has occurred to plug-in hybrids which are supported by the government and which are not dependant on a charging infrastructure. To reduce the additional cost of the initial investment, Transport for London (TfL) contributes up to USD 10,000 per PHEV taxi. Tfl has also commissioned 300 fast-charge points in London of which 150 exclusively for taxis[79].

Electric Taxis and Charging Systems

Important factors for e-taxi deployment include daily distance driven, hours of usage rate and ownership structure. Daily distances driven of taxis varies from 200-500km. Not surprisingly cities with high daily distances have a high driver to taxi ratio[80]. The average ratio in cities is 1.5 driver per taxi (UITP, 2020). High mileage and high drivers to taxi ratios means that taxis only have a limited standstill time. Charging electric taxis at home is thus not feasible as home connections will not be sufficient for fast-charging the battery[81]. Basically taxis are thus dependant on a public fast-charging infrastructure

[78] WLTP city (Worldwide Harmonized Light Vehicles Testing Procedure)

[79] Emissions standards for taxis - Transport for London (tfl.gov.uk)

[80] Hong Kong, China taxis drive for example on average 400km per day with 3.2 drivers per taxi.

[81] The Nissan leaf with the larger battery set (62 kWh) and assuming remaining 20% SOC can be charged at home with an AC 6.6 kW charger at maximum. It will thus for a full charge around 9 hours (even if you would

capable of re-charging the taxi during breaks of 20-30 minutes. This will require 100-150kW fast-chargers[82] and vehicles respectively batteries capable of receiving such charges (EVs manufactured since 2019 are in general capable of receiving such charges). Public charging infrastructure is however in general – as of today – not at such power levels, as its also not targeted towards taxis but private passenger cars which require much less range. In most cities, the share of DC public fast chargers was below 10% although some cities such as Helsinki, Glasgow and Zurich have shares of 15-29% (ICCT, 2020a). Most cities have focused in urban areas on regular-speed charging whilst fast-charging is more applied to inter-urban sites e.g. on highways. The charging requirements and demands of private cars and of taxis clearly do not match. Establishing a dense network of high powered chargers in urban areas is not only costly from the perspective of charger investment but also land requirements and grid stress. Sites for taxi-charging might also not match well with sites used for private charging (latter is typically located in urban areas at malls, restaurants and dwelling points of private persons) whilst taxis would require fast-charging points at typical stopping/waiting areas. Also, taxis want to be sure that distances they need to drive to chargers are limited and that chargers are not blocked by private users. Due to these points around 50% of fast-chargers in London are dedicated to taxis (Major of London, 2019). Key implications for an e-taxi delivery plan are thus that taxis are a priority user of rapid charge points. Convenient access to rapid charging while working will be an important requirement for taxi drivers. A high electric driving range will not be a real solution for taxi drivers as home chargers have limited capacities. As example a Nissan Leaf E+ with a range of maximum 380 km (in practice with a 20% operational security margin and a drop of SOH of batteries of 10% closer to 280km) requires 11 hour of charging with a (high-powered) home charging unit. Re-charging an additional 100km can be realized in 40 minutes. With a Tesla Model 3 and a Tesla supercharger an additional 100km can be added in less than 10 minutes. For taxi systems to work well for taxi owners, especially if the taxi is used by more than 1 driver and used for more than 12 hours per day, a good selection of vehicles is required (fast-charging capabilities are more important than battery size and range) and the necessity of having sufficient high-powered chargers located in the city. Relying on home-charging will not work. High-ranges of vehicles overlook the issue that a full charge at home will take far too long as capacity of home-chargers is limited i.e. such vehicles are interesting for private users but criteria for taxis are basically the charge rate and the availability of fast-chargers.

Battery Swapping for E-Taxis

EV battery swap technology has been trialled in a number of countries (e.g. China, India, Israel, Taiwan Province of China, Sweden) and across different vehicle types. The well-known tech start-up, Better Place – formed in 2007 – attracted significant global investment and developed a network of battery swap stations, designed initially for the Renault Fluence. The company closed in 2013. Key challenges were the significant cost of battery swap stations, and of establishing a sufficiently standardised and readily removable battery across enough vehicle manufacturers and different EV models to sustain their business model (Major of London, 2019).

In Beijing the local manufacturer BJEV (Beijing Electric Vehicle) installed around 100 battery exchange stations in the city.

install a 22kW charger the AC charging is limited to single phase 6.6kW). Some models e.g. the new Nissan Ariya allow Ac charging up to 11kW – still home charging will require for full charging 5 or more hours. Level 3 or DC fast-chargers are very expensive and home grid connections will not support such chargers .

[82] Based on 2 -3 charges per 24 hours of 20-30 minutes; this is also considered as the new standard for fast chargers

Photo 3: Battery Swapping Station in Beijing

Source: news.cgtn.com

Each swapping station excluding land required an investment of around 1.5 MUSD (2/3rd for the station and 1/3rd for the battery inventory) and 150-200 m^2 of land (MIT, 2019). Battery swapping takes about 5 minutes. With fast-chargers of 100-150 kW supported by most modern EVs charging time would be around 2-4x more but such chargers cost only around 20,000 USD and require only $5m^2$ – with land being a critical and very costly resource. The number of battery swapping stations due to their size and cost will also be limited in a city resulting in larger dead-kilometres and time lost to be driven by taxis to reach such stations. Additionally battery swapping stations are linked to vehicle types. With the surge of low-cost high-powered chargers and EV batteries capable of taking high power chargers the option of battery swapping for taxis (and also for buses) has become obsolete[83].

3.2. Business Models and Incentives

Electric Taxis in Chile

The NDC of Chile has as target to have 100% of taxis electric by 2050. Since 2014 the country is trying to foster the usage of electric taxis with multiple incentives[84]:

- The program "Renueva tu Colectivo" launched 2014 by the Ministry of Transport (MOT) gives an incentive when purchasing a new and more energy efficient taxi. For electric taxis the subsidy level was 9,000 USD. No e-taxi was purchased under the program.
- In 2019 a similar program was announced for the metropolitan region with a subsidy level of 10,500 USD for an electric taxi. With COVID-19 the program has stopped. No e-taxi was purchased under the program.
- New taxi licenses reserved for electric taxis: this instrument was launched 2017 and resulted in some 50 electric taxis. 30 taxi licences were assigned to the energy company ENGIE (operating the taxis with operating companies) and 30 to the start-up E-MOVE (not all licenses were used i.e. the number of vehicles is lower than the number of licenses).
- The Ministry of energy wants to launch a program including 50 e-taxis and 50 home chargers. The subsidy amount shall be defined through a reverse auction process – government expects

[83] It can however still be an interesting strategy for motorcycles and 3-wheelers with standardized battery sets.
[84] See for details (Grutter Consulting, 2020)

the subsidy to not surpass 10,500 USD but this levels is indicative as the program has not yet been launched (previewed for 2021).

- Special credit line for electric taxis launched 2020 by the public bank "Banco del Estado de Chile"[85]. The subsidy of the government is considered as owners financial contribution i.e. no owners capital is required. Loan tenor is currently 5 years, 3 months grace period and a monthly interest rate in local currency of 0.56% equivalent to 6.9 APR (annual percentage rate) or 60% lower than the current interest rate charged for financing vehicles (0.89%; see Crediautos | Crédito Automotriz, Ahorra y no pagues de más.) No e-taxis have yet been financed.

The cost of an electric taxi in Chile is between 31,000 and 34,000 USD (for the most popular models being Nissan leaf, BYD 7005 BEV and Hyundai Ioniq). A standard taxi as used in Chile has a cost of USD 17,000 i.e. including a home charger the investment cost of an e-taxi is around double. The subsidy of 9,000 USD proposed by the government has not been considered sufficient by taxi operators to realize the change. Also, authorities might sub-estimate the problematic of charging. As example the Hyundai Ioniq has a drive range of 270km. However, this is under optimal conditions. Including increased heating or cooling usage plus a reserve of 20% to not get stranded and a conservatively assumed battery degradation of 10% the actual save operational range without intermediate charging is around 180km which is below the standard of 200km daily which means in practice that without re-charging options the driver of an e-cab will loose 20% or more of business[86]. If taxis are used on double shifts e.g. during profitable festive days or Friday/Saturday then home-charging will simply not do the job as the car requires 6 hours to get re-charged with a home-charger. In short, without a dense urban network of fast-chargers switching to e-taxis is in general a bad business decision.

Electric Taxis in Colombia

In the city of Medellín, some 60 electric taxis have been put in circulation since 2019. Thanks to a voucher from the local authority, those taxi drivers who choose to replace their gasoline taxi that is more than five years old with an electric one, receive financial support to make the purchase. The local government subsidy is about USD 5,000. Additional benefits are that electric taxis can circulate all days whilst fossil ones have driving restrictions based on number plates and that the tariff charged by an electric taxi is around 25% higher than of a conventional unit.[87] The plan is to introduce more units – however, the city has not announced how it will manage taxi charging. It is thus questionable if this initiative will fair better than that of Bogota, launching 2013 a similar amount of electric taxis with the goal of having 3 years later 600 units but with no additional e-taxis roaming the streets since then. Taxi drivers claim that they are losing money with the electric units due to the lack of public fast charging infrastructure and the lack of fast-charging capability of the vehicles used (BYD E6)[88].

---

[85] The same bank also offers a comparable credit line for personal electric vehicles, see BancoEstado Personas | ElectroMovilidad

[86] An average of 200km daily means that you have days with higher mileage as well as days with lower mileage.

[87] https://www.elcarrocolombiano.com/noticias/medellin-dara-bonos-de-18-millones-para-cambiar-taxis-viejos-por-electricos/

[88] https://www.elespectador.com/noticias/bogota/taxis-electricos-se-quedan-sin-energia-y-sin-respaldo-articulo-682709

Electric Taxis in Uruguay

As of May 2020 Montevideo had around 70 electric taxis circulating with 3 public charging stations[89]. The target of 10% of units being electric by early 2020 (300 e-taxis) has not been met. March 2018 30 electric taxi licences were tendered with a subsidy of around 10,000 USD per vehicle[90] plus paying no import tax[91] and no circulation tax for the initial 2 years[92]. In September 2019 the superintendency of Montevideo announced a subsidy of 16,000 USD plus the mentioned benefits[93].

Electric Taxis in Amsterdam

There are around 4,000 taxis in Amsterdam, covering many miles and almost exclusively running on diesel. The city council agreed in 2016 with Amsterdam's taxi companies that all taxis should be fully emissions free by 2025 (City of Amsterdam, 2016). The Clean Taxis for Amsterdam Covenant has been signed by all licensed taxi companies in Amsterdam. By 2020 more than 1,000 taxis are electric. Drivers and companies are supported with subsidies of up to 5,000 Euro per vehicle to purchase electric cars. E-taxis have for example - at least initially - priority status at the Central Station or the airport taxi rank. Fast charge points have been installed for electric taxis at the Central Station rank and at other strategic locations in the city. While queuing at the Central Station rank, taxis can use the available fast charging points. The number of public rapid chargers mainly intended for taxis will be increased from 20 at present to around 60 in 2025 (City of Amsterdam, 2020). The most popular taxi brands in Amsterdam are different Tesla versions or the Hyundai Kona – not surprisingly EVs which can be charged with 100kW or more i.e. have good fast-charging capabilities.

Electric Taxis in Bhutan

Bhutan has 100% renewable electricity generation and needs to import all fossil fuel from India. Therefore since various years the country has the intention to use electric vehicles in the transport sector. The Global Environment Facility (GEF) approved in 2018 an e-taxi project with 2.6 MUSD of GEF financing with the goal to increase the number of electric taxis by 300 units until February 2021[94]. The poorly designed project had made (wrong[95]) calculations that electric taxis had far lower TCOs than fossil units. The GEF project subsidized 20% of the purchase cost of electric taxis based on a used Nissan Leaf (5,500 USD subsidy). It did not include sufficient provisions for fast-charging nor did it discuss the issue of fast versus home charging for taxi drivers recommending e.g. used Nissan Leaf taxis which lack fast-charging capabilities. As of 2020 70 additional taxis had been purchased[96]. The UN funding is not sufficient to attract taxi owners.

---

89 Todo más verde: el transporte colectivo de Montevideo incorporó 30 buses eléctricos : Autoblog Uruguay | Autoblog.com.uy
90 Movilidad Eléctrica - UTE
91 23% for other vehicles (however this is on the company import price and not the sales price i.e. the savings relative to a gasoline version could be in the order of 2,000 USD)
92 Worth annually in Montevideo 250 USD (see Patente de rodados | Intendencia de Montevideo.)
93 Nueva convocatoria para taxis 100% eléctricos | Intendencia de Montevideo.
94 Project Document - Deliverable Description (moic.gov.bt)
95 Basically by not taking unit account the type of fossil taxi primarily used in Bhutan but comparing it to a far more costly option of vehicle. The most popular taxi unit used in Bhutan is Maruti Alto 800cc which has a very low purchase cost whilst also profiting from import tax benefits due to the trade agreement with India. Using appropriate cost figures the TCO of electric taxis in Bhutan is significantly higher than of fossil units (Grutter Consulting, 2017).
96 Road to electric vehicles in Bhutan is paved with hurdles |The Third Pole

Electric Taxis in China

A large number of electric taxis operate in Chinese cities. Various factors which favour this development are:

- Many Chinese built taxis have batteries capable of receiving high-powered charges of 100kW or more.
- A public fast-charging network has been built in many cities. In Shenzhen the vehicle manufacturer (BYD) teamed up with the electric utility for promoting e-buses and e-taxis by jointly investing in and operating charging stations. Charging stations are frequently centralized in China with bus depots or other sites: as example Shenzhen has an EV charging station with a total of more than 600 fast chargers operated by the power company Southern Power Grid, in collaboration with state-owned Potevio and BYD[97]. The station has the ability to service almost 5,000 taxis per day using a total of 160 MWh of energy per day on average.
- Electric taxis receive preferable licenses and are often heavily subsidized by government. In Beijing for example electric taxis receive a subsidy of up to 11,000 USD per vehicle upon purchase which covers 100% of the incremental cost of the electric taxi compared to a fossil unit[98]. This is around 3x more than the subsidy offered to purchase a private electric passenger car (ICCT, 2020).
- Public transport operators are often also large-scale taxi operators. They have good access to finance and the charging infrastructure at the bus depot is also used by taxis. In some cities, e.g. Ji'an, this is also combined with urban truck fleets. This has the advantage of using better the charging infrastructure ("slow" chargers of 50-100 kW are used during the day by taxis).

Photo 4: Taxi Charging at Bus Depots

Source: Grutter Consulting; Taxis being charged at the bus depot of Changde (the same chargers are also used by buses)

[97] World's largest charging station in Shenzhen powers all-electric taxi fleet (thedriven.io)
[98] Beijing offers subsidies to encourage taxi operators to use EVs (autonews.com)

Uber Electric Vehicles

The Uber collaborative mobility platform has announced that 100% of the vehicles affiliated to the platform will be electric by 2040. By 2030 it plans to have this transition in the USA, Canada and the main cities of Europe. However, as they do not have their own vehicles, they are encouraging drivers to change in different ways. Currently, only 1,000 Uber vehicles in London are electric. By 2025, they plan to have all 45,000 of them electric. In 2018, the platform offered a voluntary additional passenger charge of approximately USD 0.2 per km, in order to finance the transition to a 100% electric fleet. That additional charge has cumulated as of 2020 to over 100 MUSD. The company has realized recently a deal with Nissan to facilitate the purchase of 2,000 Nissan Leafs at a price discount for its drivers[99]. In addition, it has committed to invest more than 6.5 MUSD between now and 2023 in charging infrastructure.

Luxury and Airport Services

In various cities airport services and luxury services are being provided with electric taxis. Examples are Bangkok or Jakarta using BYD E6 as well as Tesla's. An extra rate is charged for using these taxis. Airports were chosen due to being able to charge at the airport whilst awaiting customers and clients willing to pay an extra fee for using electric taxis. However, the number of EVs used is dwarfed relative to the number of fossil taxis: In Jakarta for example, the Blue Bird taxi company comprises more than 25,000 taxis of which 30 are electric and the car hailing firm Grab has 50 electric taxis.

Special Credit Lines for E-Taxis

The Octopus group in London offers pay-per mile loans for PHEVs and EVs [100]. Contracts have established a minimum annual mileage i.e. you will need to pay for this amount of mileage also if your mileage is less. There is no upward ceiling as you pay per mile and can include maintenance. Energy agreements are offered with Octopus Energy including the installation of a home charger.

In Costa Rica the three state banks have since October 2019 credit lines with preferential conditions[101] for the purchase of private electric vehicles, taxis and buses. The loans have longer payment terms (up to 10 years), can finance up to 90% of the investment (fossil units 80% i.e. the capital investment of the owner is around the same as the electric vehicle costs around double) and a reduced commission with incentives depending on each bank.[102] The credit lines are obviously not sufficiently attractive for taxis and buses as no units have been purchased since then.

In Ecuador a 43 MUSD concessional credit line was started December 2020 for electric taxis and buses[103]. The financing is given by the IDB through the public development bank "Corporacion Financiera Nacional" with concessional monies from the Clean Technology Fund (CTF). Old vehicles shall be retired. The program also includes technical assistance worth 1 MUSD[104]. The loan shall cover 70% of the vehicles cost.

[99] Uber signs electric car deal with Nissan in UK as it fights London ban (cnbc.com)
[100] Pay per mile loans for zero emission capable taxis (octopusgroup.com)
[101] Costa Rica launches special credits for electric cars, taxis and buses - (ticotimes.net)
[102] Banco Nacional presenta línea especial para transporte amigable con el ambiente (elmundo.cr), Bancos públicos ofrecen tasas diferenciadas para vehículos, taxis y autobuses eléctricos - El Financiero (elfinancierocr.com)
[103] 10 MUSD ordinary IDB loan and 33 MUSD concessional CTF loan; Project Details | IADB
[104] Ecuador impulsará adquisición de buses y taxis eléctricos con apoyo del Banco Interamericano de Desarrollo | Ecología | Noticias | El Universo

Summary Incentives

Countries with a e-taxi fleets which go beyond pilots have put significant incentives in place. The following table summarizes incentives provided by different countries.

Table 8: Incentives for E-Taxi Purchase (Subsidies)

Country	Incentive
China	Subsidy of 11,000 USD in Bejing covering 100% of the incremental investment cost
Chile	Subsidy of 10,500 USD covering 60-70% of the incremental investment cost
Colombia	Subsidy of 5,000 USD plus no driving restrictions plus ability to charge 25% higher fee
Uruguay	Subsidy of 10-15,000 USD plus 0 vehicle import tax (worth around 2,000 USD) plus no annual registration fee for 2 years (worth annually around 250 USD)
Netherlands	Subsidy of 6,000 USD per vehicle plus establishment of fast-charging stations for taxis. By 2025 only 0-emission taxis are allowed to operate.
UK	Purchase subsidy for electric taxi of 9,000 USD per vehicle[105] plus requirements in cities such as London that taxis since 1.2018 need to have a 30-mile 0-emission capability for a new licence, plus subsidies for home-chargers plus establishment of fast-chargers in urban areas partially exclusively for taxis.

Source: Grutter Consulting

Initial subsidies cover at least 50% of the incremental cost. The case of various countries however also clearly shows that investment subsidies only for vehicles are insufficient. Home-charging is not a solution for most taxi drivers as they require in many days driving distances which go beyond those offered by e-taxis, taxis are used by 2 or more drivers (especially during financially attractive weekends) and home charging simply takes to long. This has been recognized by cities such as Amsterdam or London which are offering a full package including subsidized vehicles, an urban fast-charging network with DC chargers of 50-150kW plus non-financial incentives or regulations which give preference to e-taxis at attractive sits (e.g. airports) or which restrict usage of fossil vehicles. Stand-alone vehicle subsidies are clearly not a solution to the problem.

4. Electric Urban Freight

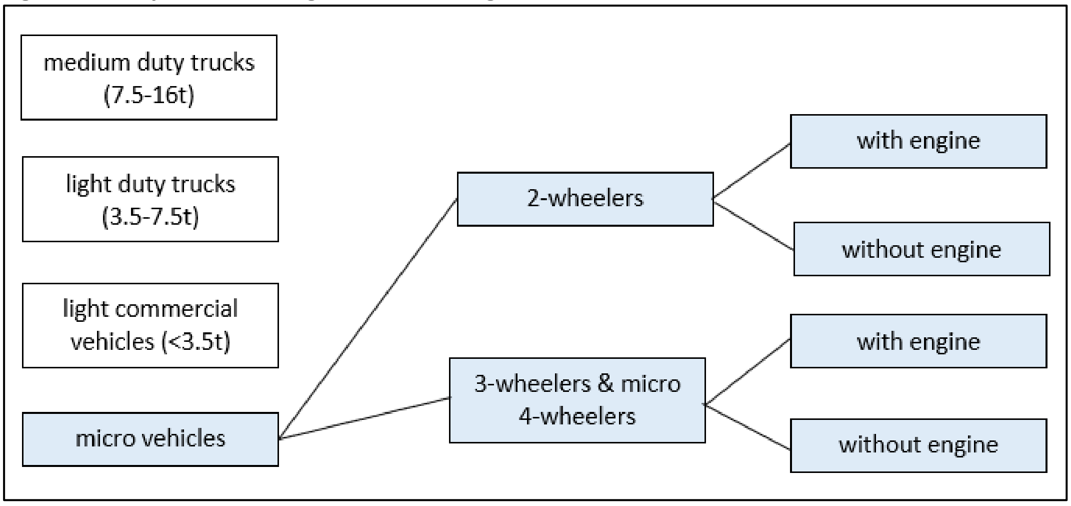
4.1. Overview

The relevance of urban freight vehicles for GHG and local pollutants emissions was clearly shown in a recent report for Hanoi based on vehicle counting and emission modelling. Urban freight vehicles account in 2020 only for 5% of all circulating vehicles but are projected to increase to 15% of all vehicles by 2030. In 2020 they are responsible in Hanoi for 13% of total GHG emissions, 19% of $PM_{2.5}$ and 25% of NO_x emissions and it is projected that by 2030 urban freight transport is responsible for 31% of transport GHG emissions and 40-50% of local pollutants i.e. reducing urban freight emissions will be crucial to curb GHG and local emissions (Grutter Consulting, 2020c).

Urban freight is characterized by transient loads with high-power peaks for acceleration with low loads in slow traffic and standstill. Daily distances driven are much lower than for long-haul trucks and stops are more frequent. Vehicles used also have a much lower payload. The market can be segregated in 4 categories of vehicles from medium sized trucks to micro-vehicles with or without engine (see following figure).

[105] EV and EV Charger Incentives in Europe: A Complete Guide for Businesses and Individuals (wallbox.com)

Figure 15: Major Urban Freight Vehicle Categories



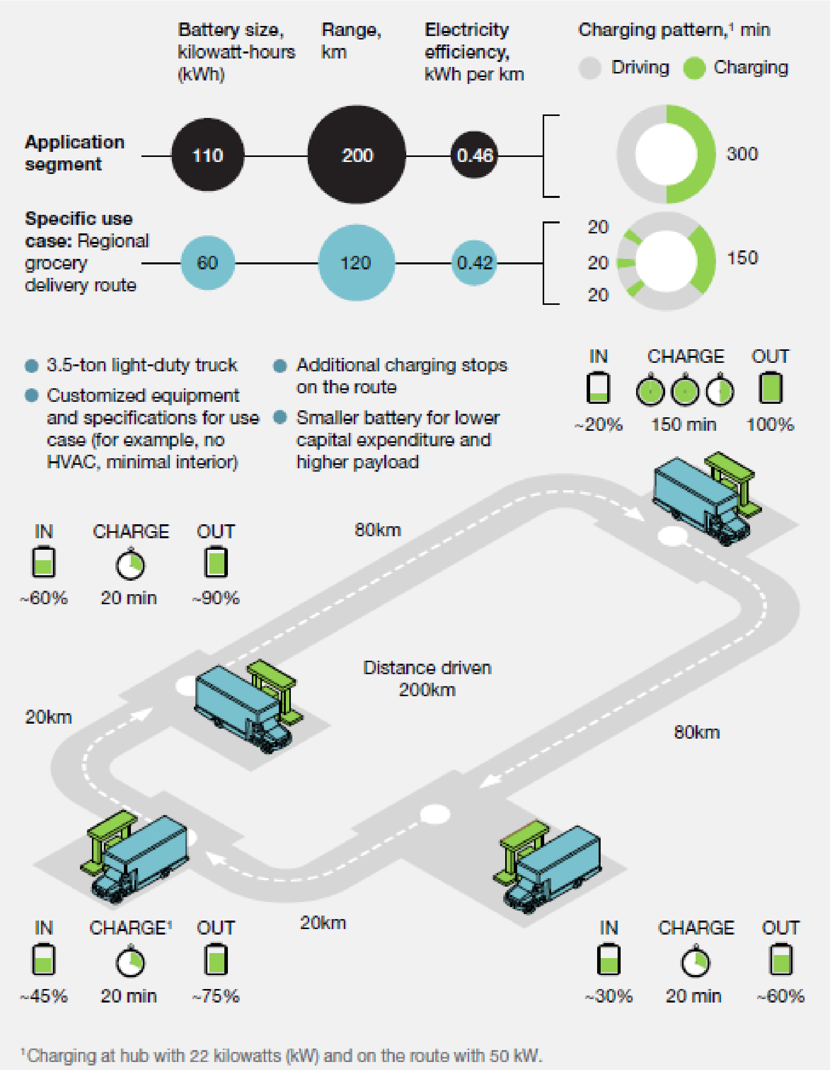
Source: Grutter Consulting

EVs are available for all vehicle sizes. Micro vehicles are by far the largest vehicle segment for last mile-delivery services (LMD).

Medium Duty Trucks (7.5-16t)

This vehicle segment is popular amongst retailers for regular routes to fixed sites e.g. supermarkets. It can also be the vehicle used to distribute loads to last-mile delivery centers. Medium duty trucks have a similar issue like buses: Vehicle battery size must be optimized to not reduce the payload whilst maintaining a sufficient range. Intermediate fast-charging at de-loading sites is a possible option to reduce vehicle battery size (and thereby vehicle cost). However, this requires fast-charger located at stopping sites of vehicles to avoid loss of time and additional distance driven of vehicles for charging (see the following figure).

Figure 16: Charging Options for Large Delivery Trucks



Source: (McKinsey&Company, September 2017)

Light Duty Trucks (3.5-7.5t)

Light duty trucks are also used frequently for larger distribution centres or deliveries along fixed routes. However, the most popular segment for such usage are clearly light commercial vehicles (LCVs) or vans.

Light Commercial Vehicles (<3.5t)


In this vehicle segment multiple sizes and types of EVs are already available and running on the streets. Amazon announced e.g. in September 2019 that it was purchasing 100,000 electric delivery vans as part of its effort to eliminate the carbon footprint of the company by 2040. Amazon plans to have make its first deliveries with the vehicles by 2021 and have all of the new trucks on the road by 2030[106]. Many postal services worldwide are already managing large fleets of electric delivery vans. A wide range of payload volumes is thereby available (typical used range is 4-8m^3 payload).

Various manufacturers also offer the same van as diesel or as electric version (e.g. Fiat Ducato, Renault Kangoo or Nissan NV200) which make one-to-one comparisons possible[107]. Comparing annualized costs between same-type electric and fossil fuel vehicles EVs are often competitive. This depends however on relative energy prices (fossil fuel and electricity price), vehicle purchase costs and vehicle taxation (e.g. tax incentives for EVs), finance schemes and costs including leasing options and vehicle tax costs (also here often incentives exist with lower annual vehicle tax costs for EVs) as well as annual vehicle mileage. Operating costs of EVs are clearly lower (energy plus maintenance costs) whilst purchase costs and therefore also finance costs are higher. A London pilot program for electric delivery vans compared for various companies the electric and same-type (same manufacturer, same vehicle) fossil version with annual costs per kilometre being comparable. Lease costs were on average double for the electric vehicle but annual running costs 1/5th (Major of London, 2019).

The following table compares a new diesel and a new same category electric van (Nissan NV200 respectively ENV200).

Photo 5: Nissan NV200 and ENV200

[106] https://qz.com/1712151/amazon-orders-100000-electric-delivery-trucks/

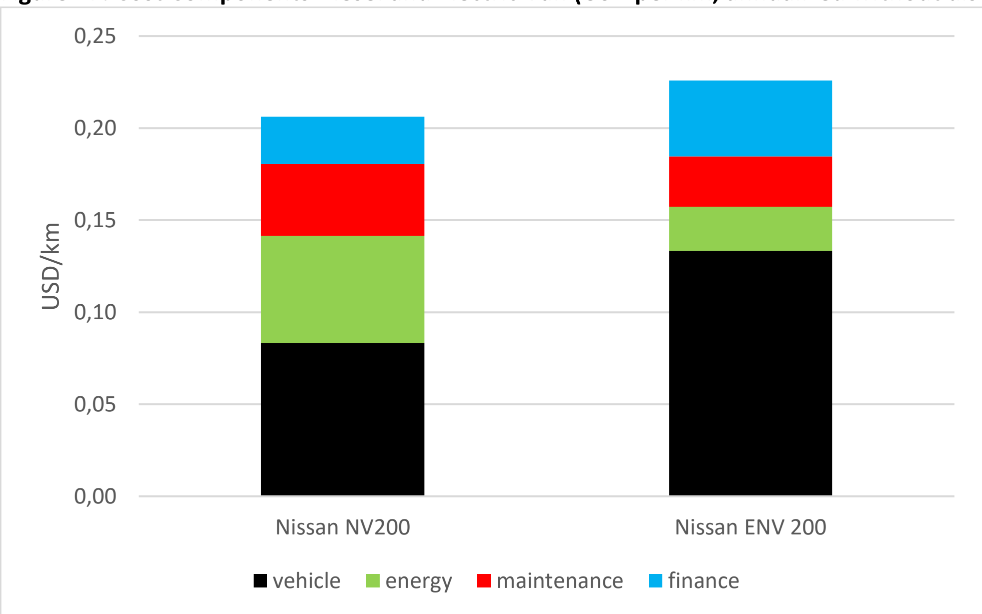
[107] The Nissan eNV200 uses the drivetrain and battery technology of the Nissan Leaf which has the advantage of a widespread technology with spare parts and replacement batteries widely available.

Table 9: Comparison Fossil and Electric Van

Parameter	Diesel Van	Electric Van	Source
Car type	Nissan NV200	Nissan ENV200	2020 model; ENV with 40 kWh battery
Annual mileage	20,000 km		see e.g. UK, USA https://afdc.energy.gov/data/10309
Vehicle lifespan	12 years		lifetime mileage of around 250,000 km see e.g. https://ec.europa.eu/clima/sites/clima/files/transport/vehicles/docs/ldv_mileage_en.pdf (no battery replacement required with 12 years)
Specific energy consumption	7 l/100km	0.20 kWh/km	energy usage based on consumer reports e.g. https://www.spritmonitor.de/en/overview/33-Nissan/1169-NV200.html?fueltype=1
Energy cost	0.83 USD/l	0.12 USD/kWh	average world diesel and commercial electricity price for May 2020 based on https://www.globalpetrolprices.com
CAPEX	20,000 USD	32,000 USD	exclusive of vehicle import and taxes based on average for Europe; excludes battery replacement (currently 6,000 USD)
Annual energy cost	1,160 USD	480 USD	Calculated based on energy usage, energy cost and mileage
Annual maintenance and repair cost	780 USD	550 USD	Progressive annual increase of cost; diesel based on https://usedfirst.com/cars/nissan/nv200/; includes tyres; EV 70%
Annualized finance cost	520 USD	820 USD	based on financing 100% of CAPEX for 8 years; 7% interest rate; finance costs distributed over lifetime vehicle to determine annual average cost
TCO with / without finance	0.21 / 0.18 USD/km	0.23 / 0.18 USD/km	Calculated

Maintenance and repair costs are much lower for the electric unit. Both vehicles use the same components and thus the same spare parts. The electric unit has much fewer moving parts and vibrations, uses less brake pads due to regenerative braking and no engine maintenance. Overall, the two vehicles have comparative life-cycle costs, although the initial investment for the electric van is higher. Important is the financial structuring as this is a major cost component.

Figure 17: Cost Components Diesel and Electric Van (USD per km, annualized without discounting)



Source: see above

Actual TCO depend however very much on country cost structures and vehicle usage and must thus be analysed on a per country base[108].

Micro Vehicles

Smaller electric three wheelers and quadricycles, have proven to be a cost-effective option to reduce carbon emissions in last-mile delivery services - especially when compared to vans or trucks. However, they are not a "one-size-fits-all" for urban freight. In the end, it comes down to the route, the freight volume and other variables to define whether or not Electric Assisted cargo bikes are actually cost effective. They consume less space and can therefore skip through traffic using bike lanes or park on different areas – including sidewalks. However, more vehicles, drivers or trips may be required to move the same volume of goods – which might increase transportation costs (Rappaport & Lane, 2020).

There are many examples of projects around the world that have already managed to scale up from a pilot. Major big courier companies (DHL, UPS, FedEx etc.) have mainstreamed e-Cargo Bikes in their fleets encountering many advantages.

Electric cargo bikes are an agile and active form of transport with an average payload of up to 350kg suitable for mail and parcel delivery services, food delivery and for services in which small volumes are delivered. It can have 2, 3 or 4 wheels, depending on the regulation of each country. The cargo box can go in front or in the back. The decisive characteristic that tells it apart from the moped or the small electric distribution vehicle is, that it must have working pedals. It must be able to be powered also without a running motor.

Photo 6: Electric Cargo Bikes from Urban Arrow

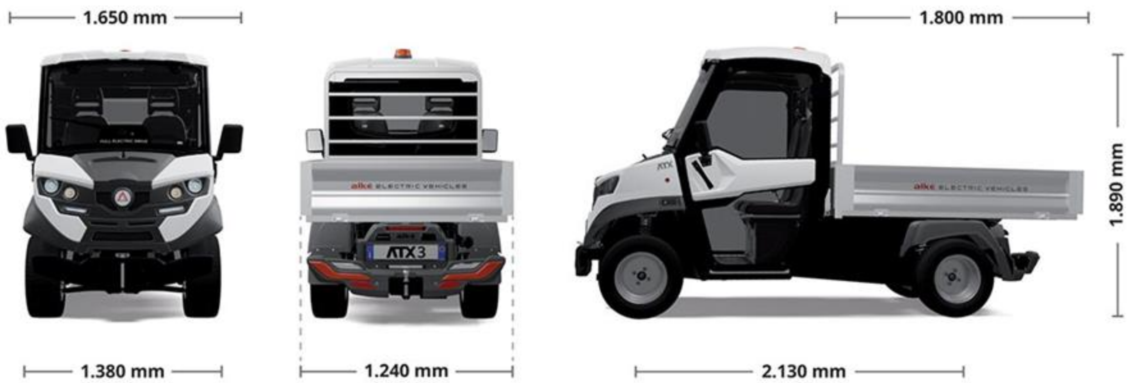
Electric cargo moped or scooter have a payload of up to 500 kilograms suitable for heavier loads such as bulky food deliveries and small amounts of construction materials. No effort is required from the driver, because it has no pedals (unlike the e-cargo bike). They can have two or three wheels. Some offer protection from rain, but many of them don't. They are quite handy, and avoid fatigue, but are more expensive than the cargo bikes.

[108] See country reports on EV demand

Photo 7: Electric Scooters from Scoobic and Silence

Small electric distribution vehicles are mini-vans with a payload of up to 1,000kg suitable for catering, street cleaning and waste collection (residential and retail streams). It is less maneuverable than both the cargo bike and moped, but in comparison with a van, better suited for use in crowded areas and easier to park and maneuver. They come in especially handy for old city centers with very narrow streets. They differ from conventional electric vans because they are much smaller.

Photo 8: Electric Minivan by Alke



Services and retail are segments that already make widespread usage of micro vehicles:

- **Post and parcel logistics:** the number of shipments in postal and parcel logistics is increasing rapidly, offering a big opportunity for Light Electric Freight Vehicles (LEFVs). Overall, the deployment has been successful for bigger package services and also postal companies. Aiming to make trips with cargo bikes even more efficient and sustainable, the KoMoDo initiative in Berlin joined five of the big players in logistics in Germany (DHL, UPS, GLS, Hermes, and DPD). They shared a Micro-Depot at a very convenient central spot in the city. The firms would fill up the depot in the morning and each cargo bike could approach it during the day. The project was a big success and encourages cooperation between delivery services and more city hubs[109].
- **Food logistics:** food deliveries from restaurants to their clients in homes and offices, and also services supplying restaurants, hotels, events etc. make up a big portion of urban deliveries and can be well handled with electric cargo bikes.

[109] https://www.komodo.berlin/

- **Construction logistics:** small articles such as paint, nails, insulation materials etc. required in a short time frame for i.e. for maintenance projects and can be shipped with an electric cargo trike from the wholesaler.
- **Service logistics:** to provide services in maintenance, cleaning, installations and repair requires a wide array of heavy materials. Scarce parking places in inner cities seem to be the major motivation to explore EA cargo bikes in this area.

0-emission Cargo Bikes have been making a comeback in European cities since the early 2000s. Beside reducing pollutants and noise, they have also proven successful from an economic point of view. The cost-effectiveness of this shift, will depend on the vehicle it will replace. Most logistic companies that have successfully adopted these vehicles in their fleets, have done so, in order to replace vans or trucks due to stricter regulations regarding diesel vehicles in city centers.

4.2. Challenges to Deployment of EVs in Urban Freight

In order to have a successful transition to zero emission urban delivery, some challenges need to be assessed first (Transport Decarbonisation Alliance, 2019).

Structure of the Sector

The sector suffers under low margins. In a harsh competitive environment and consumer expectations of free delivery, there remains little margin to invest in zero emission vehicles if latter result in higher costs. Subsidies or tax exemptions are a common way to tackle this challenge. Another way is to levy charges or increase barriers for polluting vehicles e.g. through city access policies. In Europe, an important reason for companies to procure EVs are the introduction of Zero Emission Zones[110] established by local governments. Such measures are realized in various cities (with time and/or spatial restrictions for polluting vehicles) especially with the target to reduce noise and air pollution). With national freight decarbonization plans, land use policies, green urban planning etc. cities and countries can play a more active role easing the way for delivery companies to acquire EVs.

Fragmentation of Vehicle Ownership

High market fragmentation and own account transport is an important feature of the market which can pose a barrier to EVs. The most extreme case is crowd-sourced delivery which has emerged from food delivery systems. This method leverages networks of local, non-professional couriers to deliver packages. They provide their own transportation and are typically paid per delivery or per shift. Neither the retailing company nor the logistic service provider need to worry about warehouse operations, fleet management or employee benefits (Dolan, 2018).

Freight companies tend to be very small. It is estimated that in Europe, 80-90% of carriers have less than five vehicles. China has around 6.8 million trucking companies, 91% are owners and drivers at the same time, only 2% have more than 100 trucks (Smart Freight Centre, 2017). In Vietnam, there are over 61,000 registered logistics enterprises with some 410,000 operational trucks i.e. the large majority of enterprises have 1-3 trucks[111]. The high market fragmentation can cause a problem for the introduction of EVs. EVs require a higher initial investment and pose a risk. Individual owners might lack access to the capital required and tend to be risk adverse. Also, EVs require a charging infrastructure which allows for drivers to complete their daily routine without problems. Investments

[110] Zones where only pedestrians, non-motorized vehicles or EVs are allowed.
[111] Unpublished data of DRV for 2019

in charging infrastructure are however not made without a sufficient demand in form of EVs. A bigger involvement of logistics companies in either owning and operating, sourcing, leasing or facilitating EVs with an adequate charging infrastructure is required.

Vehicle Size

Smaller vehicles allow for more flexibility and on-demand delivery. This has resulted in a surge of motorbike delivery, resulting potentially in high levels of air pollution, noise and accidentality. The surge of electric 3-wheelers has also been driven by their financial attractiveness. Such vehicles are more cost effective and flexible than using vans or small trucks and also more cost-effective in many cases than motorcycles due to higher carrying capacity. Considering the average speed of cars in congested cities, electric 3-wheelers can easily achieve the speed, acceleration and range needed to perform their duties. However, small vehicles are also a good option for non-motorized transport or electrification.

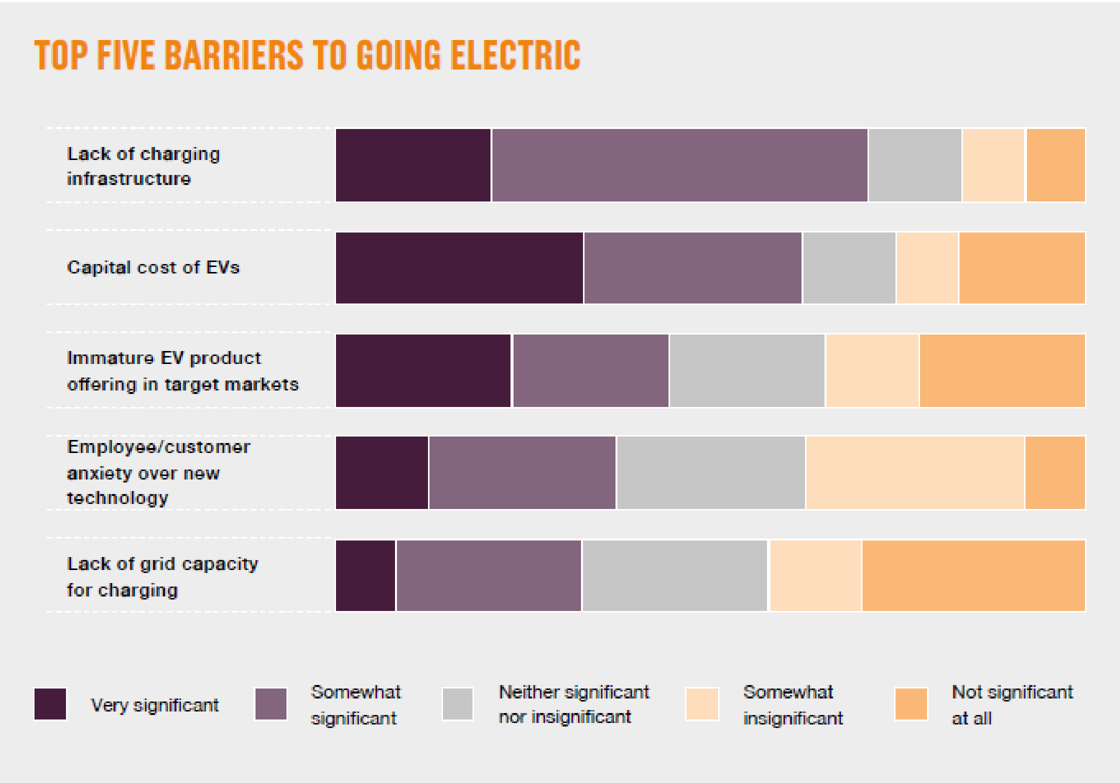
Limited Economically Feasible EV Options

Freight EVs are still more expensive than internal combustion vehicles. EVs do have a lower cost of operation and can have a lower total cost of ownership. However, payback times are long and risks too high to make EVs currently a viable business proposition without support or incentives.

Challenges and Drivers

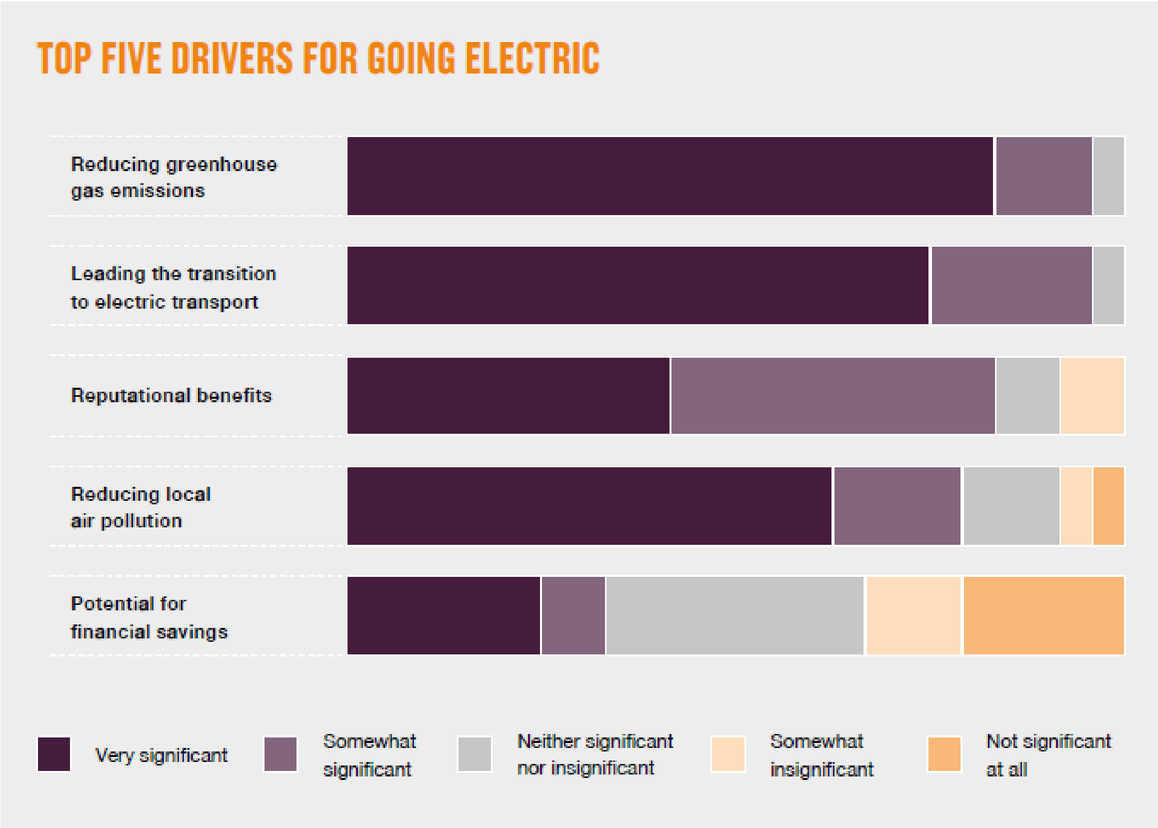
The Climate Group identified the 5 most outstanding challenges and the 5 most important drivers for going electric for companies (see figure below). Core challenges are associated with the charging infrastructure and the cost/availability of EVs. Main drivers for going electric are related with environmental and reputational aspects.

Figure 18: Challenges for EVs in Urban Freight



Source: (The Climate Group, 2019)

Figure 19: Drivers for EVs in Urban Freight



Source: (The Climate Group, 2019)

4.3. Incentives for EVs in Urban Freight

As mentioned before, increased urban freight will result in increased negative externalities (pollution, noise, accidents, congestion). However, cities can implement a series of measures such as congestion charging, promoting off-peak deliveries, carbon taxes etc. in order to tackle this challenge. It is important to note, that urban deliveries will increase even more after the Corona Pandemic. Countries, cities and companies must act on this opportunity to deliver sustainable logistics solution. Regulations enforced by countries or cities worldwide with a positive impact on greening urban freight include:

- **Direct subsidies for electric trucks:** the city of Shenzhen, PR China for example gives subsidies for electric trucks depending on the battery size. A small urban truck with a battery size of 50kWh receives e.g. from the city a purchase subsidy of around 5,000 USD. In order to avoid an abuse of the subsidies, the government introduced the requirement that the vehicles have to operate over 30,000 km per year[112]. Direct subsidies are also given for LCVs in Europe as is shown in the following table. Subsidies given to LCVs thereby cover 75-100% of the incremental CAPEX.

[112] http://www.sustainabletransport.org/archives/6575

Table 10: Subsidies for LCVs in Europe

Country	Purchase subsidy	One-time registration tax subsidy	Annual ownership tax subsidy	Incremental CAPEX of vehicle
Germany	6,000 EUR	---	160-180 EUR for 10 years	7,600 EUR i.e. subsidy accounts for 80%-100% of incremental cost[113]
France	6,000 EUR	260-290 EUR	---	8,500 EUR i.e. subsidy accounts for 75% of incremental cost
UK	6,000-6,400 EUR	190-590 EUR	270 EUR for lifetime	8,200 -8,800 EUR i.e. subsidy accounts for 75%-100% of incremental cost[114]

Source: Grutter Consulting including as source also (Anastasios, 2020) based on Renault Kangoo ZE and Nissan ENV200 (lower levels for Renault and higher levels for Nissan

- **Fiscal incentives for 0-emission cargo vehicles:** In Switzerland 0-emission trucks do not pay the performance-related heavy vehicle duty (a federal charge that depends on the total vehicle weight, the vehicle emissions level and kilometres driven) levied on all motor vehicles and trailers that have a total permissible laden weight of more than 3.5 tonnes and are used to transport goods. This tax is high and will cost the operator more than fuel. O-emission vehicles avoid this tax. This is one of the main incentives which has convinced logistics operators to purchase fleets of hydrogen and electric trucks.
- **Climate related incentives**. O-emission trucks either do not have to pay carbon taxes or can profit from climate finance. As example in Switzerland a program has been approved by the government which allows owners of electric trucks to cash in on GHG reductions[115]. The sale of carbon offsets is equivalent to a subsidy of around 100,000 USD per 36 ton electric truck.
- **Registration restrictions for non-electric trucks:** Since May 2018, when procuring new light duty trucks, logistics companies are only allowed to procure New Energy Vehicles (plug-in hybrid, hydrogen or full electric trucks) in Shenzhen[116].
- **Usage of bus lanes:** Emission-free freight transport in Rotterdam can apply for the shared use of open and suitable bus lanes in the city.
- **Lower cost access for EV:** London's Ultra Low Emission Zone (ULEZ) has been in place in Central London from April 2019 in the same area as the Congestion Charge. Vehicles need to meet new, tighter exhaust emission standards (ULEZ standards) or be liable for a daily charge to drive within the ULEZ area. This gives an incentive to purchase a zero-emission van or truck which does not pay the charge. Similar access permits or advantages for electric trucks are given by many other cities, e.g. Shenzhen.
- **Special credit lines for Electric Trucks:** The Indian company "Shriram Transport Finance Company Limited" has for example received by the Austrian Development Bank OeEB a 20 MUSD concessional credit line for financing CNG and electric trucks for private micro and small enterprises[117].

---

[113] 80% if only investment subsidy is included and 100% by including also annual tax subsidy
[114] 75% if only investment subsidy is included and 100% by including also annual tax subsidy
[115] One program started 2014 with Battery-electric trucks (16 to 36t trucks) – however less than 20 electric trucks of this size are operational; the 2nd program is with H2 trucks (36-40t units) which is under approval stage but 40 trucks are already operational as of 12/2020
[116] http://www.sustainabletransport.org/archives/6575
[117] OeEB-Finanzierung für Erdgas-und Elektrofahrzeuge in Indien (oe-eb.at)

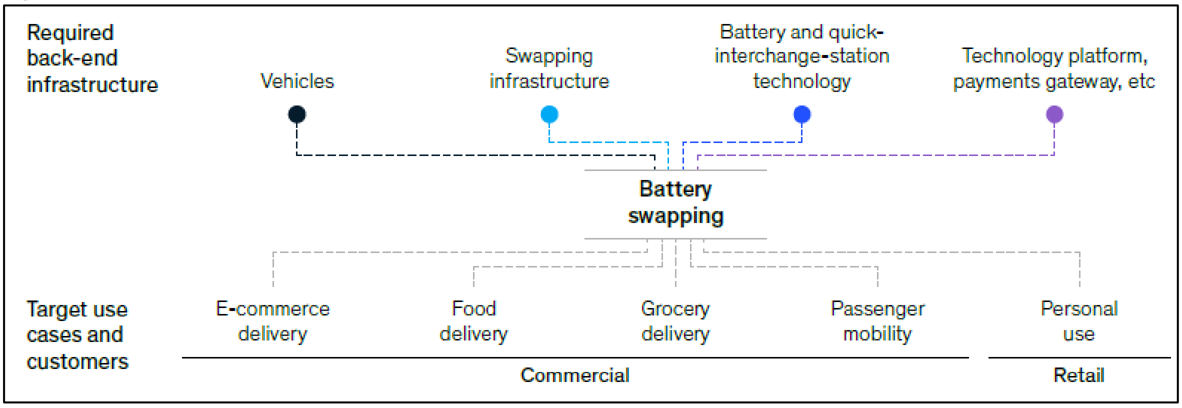
4.4. Entry Points for Promoting EVs in Urban Freight

Micro Vehicles

As mentioned previously the large majority of motorcycles used for last-mile deliveries are owned and supplied by the driver and not by the logistics companies. Logistics companies find this business model financially far more attractive and flexible than investing in their own vehicles. It can thus not be expected that this ownership system will change due to the introduction of EVs. Entry points for an EV fund could thus be financial institutions which lease or give loans to individuals for purchasing vehicles. Multiple such institutions exist especially for loans.

Another option under discussion in Vietnam and Thailand is to work through companies which are establishing battery swap systems / battery-as-a-service systems (BaaS) for motorcycles targeted for last-mile delivery operators. Basically the system works by leasing batteries and charging a swap fee which includes battery and energy. The BaaS model reduces the price tag of e-bikes to a competitive level and allows for refuelling in under one minute. The motorcycle itself costs the same or less than a conventional unit and can be purchased with a loan. Batteries kept at swapping stations can also be used as storing facility for the grid thereby also allowing additional renewable energy to enter the grid and offering additional income by selling electricity during peaks and purchasing during off-peaks. Additionally the used batteries can be used for second life applications. Shared batteries and smart charging are thus combined creating multiple revenue streams. The following graph shows a sample business model for a BaaS provider.

Figure 20: BaaS Business Model



Source: (McKinsey & Company, 2020)

The e-motorcycle costs and specifications are shown in the following table.

Table 11: E-Motorcycle Specifications for LMD Services (example Selex electric motorcycle)

Specification	Value
Performance	
Maximum speed	50 km/h
Nominal power	1.2 kW
Minimum gradient	6%
Energy consumption	0.03 kWh/km
Range	80 km (with 2 batteries)
Additional range with swappable battery	40 km
Dimensions	
Load	150 kg
Weight motorcycle incl. battery	90 kg
Volume of box	0.7 m^3 (0.7-0.8m*0.7-0.8m*1.3-1.4m)
Battery	
Battery chemistry	Li-ion
Battery capacity	1 kWh
Guaranteed battery lifespan	500 cycles (expected 1,000 cycles)
Finance	
CAPEX motorcycle	950 USD
CAPEX box	200 USD
Swap cost battery (includes energy)	0.65 USD
Maintenance cost engine	0 USD/km
Lifespan motorcycle (idem to gasoline)	6 years

Source: Lazada Logistics and Selex, Vietnam

The cost-relation between a gasoline motorcycle and an e-bike with BaaS model based on a swapping fee is shown in the following table.

Table 12: Gasoline versus Electric Motorcycle (MC) Options (USD)

Item	Gasoline MC	E-MC with BaaS	E-MC purchase
CAPEX motorcycle incl. box	1,488	1,144	1,744
Annual battery swap cost	0	451	0
Battery replacement cost	0	0	600
Annual maintenance cost engine	92	0	0
Annual energy cost	296	0	62
Annual finance cost	56	43	66
TCO USD/km	**0.033**	**0.033**	**0.029**

Note: maintenance excludes tyres, lights, brakes, repairs as same costs for gasoline or e-motorcycle

Although BaaS results in a higher cost than purchasing the full electric motorcycle risks are much lower and the owner has more flexibility and less investment. With swapping and with sufficient availability of swapping stations such systems resolve the problems of incremental CAPEX, range anxiety and performance risks.

The swapping systems can be owned by the motorcycle manufacturer (as is the case in Vietnam with Selex) or be 3rd party operations with the ability to accommodate for various motorcycle manufacturers using standardized batteries (as in Thailand). Such companies can serve as investment points for an e-mobility fund[118].

[118] The Thailand project is being prepared for the investment pipeline of ADB's E-mobility fund

LCVs and Trucks

Similar to micro vehicles, LCVs and trucks are in most cases not owned by the logistics or operating company but by fleet management companies[119]. Fleet management companies in general rent vehicles on an annual base or lease them with different lease contracts ranging from financial lease, vehicle + maintenance (most popular) to wet lease including vehicle, maintenance, energy and driver. Fleet management companies and companies financing former are thus core entry points for e-mobility financing. However, a good coordination must be realized with the operating company as chargers might need to be installed at premises of the logistics company or operator. Also public charging infrastructure suitable for fast charging of LCVs is a critical point to ensure wide-spread adoption of such vehicles (Mayor of London, 2020).

[119] Some units might be owned by the operating company itself but in general this is outsourced.

References

ACEA. (2020). *Medium and Heavy Buses (over 3.5t) New Registraitons by Fuel Type in The European Union (Full-year 2019).*

ADB. (2018). *Low-Carbon Buses in the People's Republic of China.*

Anastasios, T. &. (2020). Electric light commercial vehicles: Are they the sleeping giant of electromobility? *Transportation Research Part D*, 86.

Asia Cargo News. (2018, August 30). *DHL E Commerce rolls out green fleet in Malaysia and Vietnam.* Retrieved May 2020, from http://asiacargonews.com/en/news/detail?id=2851

Baker, L. (2020, February 13). *www.freightwaves.com*. Retrieved May 5, 2020, from https://www.freightwaves.com/news/ups-hit-with-22m-in-nyc-parking-fines

BID. (2020). *Análisis y diseño de modelos de negocio y mecanismos de financiación para buses eléctricos en Lima, Perú.*

Blue Bird Group. (2019). *Emission reduction program through electric taxi vehicle Operation (presented to ADB).*

BNEF. (2018). *Electric Buses in Cities.*

Boradbent G.H., e. (2019). An Analysis of Consumer Incentives in Support of Electric Vehicle Uptake: AN Australian case Stduy. *World Electric Vehicle Journal 10,11*.

CARB. (2016). *Advanced Clean Transit Program: Liteature Review on Transit Bus Maintenance Cost.*

City of Amsterdam. (2016). *The Electric City: Plan Amsterdam.*

City of Amsterdam. (2020). *New Amsterdam Climate: Amsterdam Climate Neutral Roadmap 2050.*

Dolan, S. (2018, May 21). Crowdsourced delivery explained: makig same day shipping cheaper through local couriers. *Business Insider*. Retrieved May 2020, from https://www.businessinsider.com/crowdsourced-delivery-shipping-explained

Dow J. (2019). Survey says consumers avoid electric cars due to three myths: range, price, charging. *https://electrek.co/2019/08/20/survey-consumers-avoid-evs-myths-range-price-charging/*.

Fox-Penner P., e. (2019). *Melting the Ice.*

Frost & Sullivan. (2012). *Strategic Analysis of Global Hybrid and Electric Heavy-Duty Transit Bus Market.*

Galarza, S. (2020). *From pilots to scale: Lessons from electric bus deployments in Sntiago de Chile; ZEBRA.*

Gaton B. (2019). What do consumers need to make the switch to an electric car? *https://thedrive.io/2019/04/23/what-do-consumers-need-to-make-the-switch-to-an-electric-car/*.

Grutter Consulting. (2015). *Real World Performance of Hybrid and Electric Buses.*

Grutter Consulting. (2017). *Strategy for Low-Carbon Commercial Vehicles in Bhutan.*

Grutter Consulting. (2020). *DPR: E-Buses for Bishkek.*

Grutter Consulting. (2020). *Experiencias con Movilidad Electrica en Chile.*

Grutter Consulting. (2020). *Last Mile Delivery Services and Potential Impact of their Electrification in Vietnam.*

Grutter Consulting. (2020). *Report Market Survey EVs in Kyrgyzstan.*

Grutter Consulting. (2020c). *Last Mile Delivery Services and Potential Impact of their Electrification in Vietnam.*

Hannappel, B. (2017). DHL-Go Green-Mission 2050 Zero Emissions. *Climate Action in Transport Conference, TCC Week.* Berlin.

Hertzke P., e. (2016). Electric vehicle market. *https://www.mckinsey.com/industries/automotive-and-assembly/our-insights/dynamics-in-the-global-electric-vehicle-market*.

ICCT. (2020). *China announced 2020-2022 subsidies for new energy vehicles; Policy Update July 2020.*

ICCT. (2020a). *Charging infrastructure in cities: Metrics for evaluating future needs; Working Paper 2020-17.*

ICCT. (2020b). *Real-World Usage of Plug-In Hybrid Electric Vehicles.*

IEA. (2020). *Global EV Outlook 2020.* Paris: IEA Publications.

Kim, C., Lee, J., & Bhatt, N. (2019, January 29). *Modernizing Urban Freight Deliveries- Using microhubs and cargo cycles.* Retrieved May 2020, from https://www.pembina.org/pub/modernizing-urban-freight-deliveries

KoMoDo Mikro-Depots und Lastenräder. (n.d.). Retrieved May 2020, from https://www.komodo.berlin/

Landerl, P. (2017). *Stats and Future Perspectives of Electric Buses in Urban Transport.*

Lebeu K., e. (2013). Consumer attitudes towards battery electric vehicles: A large-scale survey. *international Journal of Electric and Hybrid Vehicles 5(1)*, 28-41.

Logit. (2020). *7. Rapport definitiv de l'etude du choix de l'offre de service (design conceptuel).*

Lorentzen E., e. (2017). Charging infrastructure experiences in Norway - the worlds most advanced EV market. *EVS30 Symposium.*

Major of London. (2019). *Gnewt Cargo Electric Vehicle Trial: Operational Costs and Environmental Benefits; Assessment Update Report.* London.

Major of London. (2019). *London electric vehicle infrastructure delivery plan.*

Manali, S., Butrina, P., Goodchild, A., & McCormack, E. (2019). Measuring delivery route cost trade-offs between electric-assist cargo bicycles and delivery trucks in dense urban areas. *European Transport Research Review*.

Mayor of London. (2020). *Mayor of London / Gnewt Cargo Electric Vehicle Trial; Final Report.*

McKinsey & Company. (2020). *Global emergence of electrified small-format mobility.*

McKinsey. (2016). *Electrified Vehicle Consumer Surveys.*

McKinsey. (2017a). *What's Sparking Electric-Vehicle Adoption in the Truck Industry?*

McKinsey&Company. (September 2017). What's Sparking Eelectric-Vehicle Adoption in the Truck Industry? *MyKinsey Center for Future Mobility*.

MIT. (2019). *Insights into Future Mobility.*

Ploos van Amstel, W., Balm, S., Warmerdam, J., Boerma, M., Altenburg, M., Rieck, F., & Peters, T. (2018). *City Logistics: Light and Electric.* Amsterdam: Urban Technology Research Programme, Faculty of Technology, Amsterdam University of Applied Sciences.

Rappaport, N., & Lane, R. (2020). *The Design of Urban Manufacturing.* Routledge.

Seto, W. (2020, Enero 3). Blue BIrd to roll out 200 electric taxis in 2020. *The Jakarta Post*. Retrieved from https://www.thejakartapost.com/news/2020/01/03/blue-bird-to-roll-out-200-electric-taxis-in-2020.html

Smart Freight Centre. (2017). *Developing a Sustainable Urban Freight Plan - a guide. Considerations based on worldwide good practice, with specific reference t ofreight planning in Beijing.* Beijing.

Suhartono , H., & Dahrul, F. (2020, Junio 24). Indonesia’s Largest Taxi Operator Sees Demand Rebound as Virus Curbs Ease. *Bloomberg*.

Swobbee.de. (n.d.). (Swpbbee) Retrieved May 2020, from https://swobbee.de/

The Climate Group. (2019). *Business Driving Demand for Electric Vehicles.*

The Lab. (2018). *Pay As You Save for Clean Transport.*

Topham, G. (2020, October 19). Uber pledges £5m toward electric vehicle charging points in London. *The Guardian*. Retrieved from https://www.theguardian.com/technology/2020/oct/19/uber-pledges-5m-toward-electric-vehicle-charging-points-in-london#:~:text=Only%20about%201%2C000%20Uber%20vehicles,emission%20fleets%20worldwide%20by%202040.

Transport Decarbonisation Alliance. (2019). *Zero Emission Urban Freight.* Retrieved from https://tda-mobility.org/urban-freight-whitepaper/

Transport for London . (2016). *Taxi and Private Hire Action Plan 2016.*

UBS Evidence Lab. (2017). *EBS evidence Lab Electric Car Teardown - Disruption Ahead.*

UITP. (2020). *Global Taxi Benchmarking Study 2019.*

UK DOT. (2016). *Public attitudes towards electric vehicles: 2016 report (revised).*

World Bank. (2020). *Latin America Clean Bus in LAC: Lessons from Chile's Experience with E-mobility.*