Mexico City, México

Evaluation of Electric Buses for Eje 8 Sur

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Prepared by:

C40 Cities Finance Facility (CFF) in collaboration with Grütter Consulting.

C40 CITIES FINANCE FACILITY

This report was sponsored by C40 Cities Finance Facility (CFF) to assist Mexico City´s Government in the development of a Zero Emissions BRT along Eje 8 Sur. The support comes as part of an international cooperation agreement between CFF and the Mayor of Mexico City.

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The CFF supports cities in developing bankable investment proposals, and act as an intermediary between cities and potential financiers to facilitate investments. City-based technical experts work to determine the city's capacity needs and the project requirements, while ensuring the city's own project team is fully involved in the project preparation, thereby developing capacity within the city.

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Summary

1. The consultancy is located within the framework of the technical assistance agreement provided by the C40 Cities Finance Facility to Mexico City (CDMX). This consultancy seeks to prepare the investment project to implement an electric bus corridor on the Eje 8 Sur corridor in Mexico City (hereafter referred to as Eje 8 Sur). The objective of the consultancy is to provide support to CDMX with the identification and evaluation of alternative bus technologies that can be initially applied in the Eje 8 Sur Corridor. The study includes an analysis of trolleybuses, buses with opportunity charging systems, and Battery Electric Buses (BEBs).

2. The report compares bus technologies and includes both the environmental impact (greenhouse gases (GHG), local emissions and noise, and the financial and economic impact, comparing investment (CAPEX), operating costs (OPEX) and total costs of ownership (TCO); in turn, the economic analysis includes environmental costs. A comparison is also made between electric buses and new Euro IV and VI diesel buses. GHG emissions from electricity production are included as indirect emissions.

3. Eje 8 Sur has a route length of 15.8 km with 47 buses currently operating on the corridor and a minimum distance between buses of 2.5 minutes. Buses operate distances of about 250 km per working day. The calculations are based on 18 m articulated buses, without AC, a 10% reserve fleet, a 12 year term and a discount factor of 8%, equivalent to the WACC (Weighted Average Capital Cost) in Mexico's transportation sector.

4. Electric buses generate a reduction of about 6,000 $tCO2_e$ per year in Eje 8 Sur based on direct and indirect emissions, including Black Carbon (BC). Emissions of $PM_{2.5}$, NO_x and SO_2 are also reduced with 50% less noise compared to diesel buses. In economic terms, diesel buses have environmental costs of 0.16 USD/km (50% caused by GHG, 25% by local emissions and 25% by noise), while electric buses (independent of electrical technology) reach 0.05 USD/km, or 3 times less. The emissions caused by the manufacture of batteries are important, however, diesel buses have the same level of emissions in terms of mileage over the commercial lifetime of the vehicle itself.

5. Eighteen-meter (18 mts) **trolleybuses** are manufactured by multiple companies and have been used in many cities for decades, including Mexico City. Modern electric trolleybuses can operate over 50km, without overhead lines, and currently only 50-80% of the route is served by overhead lines. A trolleybus system for the Eje 8 Sur requires an initial CAPEX of 40 M USD more than diesel buses; 60% of the CAPEX is for the buses and 40% for infrastructure, considering that only 60% of the route is equipped with overhead lines. Operating costs of trolleybuses are lower than diesel buses due to lower energy costs (maintenance costs are slightly higher than those of diesel buses). The service life of trolleybuses is 20 years, while for diesel buses it is 12 years, as they have fewer moving parts and less vibration. The financial TCO of trolleybuses is 30% higher than that of diesel buses. These figures are significantly improved by making use of the existing infrastructure.

6. **Opportunity charging** (OC) systems for electric buses are characterized by buses that operate by charging either throughout the route or at the final stop. They have the advantage of requiring fewer batteries in the buses (less investment, less weight), but require on intermediate charges. These are relatively new systems, but there are already commercial fleets operating mainly in Europe. In general, the system that recharges the bus at the final stops operates with 12m buses on short routes and with a low frequency, therefore having enough time at the end of the route to charge the bus without requiring buses with large sets of batteries. It is possible to operate with BEBs of 18m in the Eje 8 Sur, but there is limited experience with pilot fleets with this size of bus (e.g. in Barcelona). The system requires at least 2 400 kW load points at each final stop, charging the bus for about 4 minutes. The

buses need about 200 kWh of batteries to guarantee the operation, while the system needs additional buses for charging at the end of the route, and a reserve fleet of 5 percentage points higher for a lower availability of buses. Buses have a life cycle of about 16 years when considering a battery life of 8 years. The system requires an initial CAPEX investment of USD 20 M higher than for a diesel bus system, mainly due to the higher investment in buses. Compared to diesel buses, the financial TCO is the same, but the economic TCO is lower.

7. The **ultra-fast opportunity charging system** is used in Geneva, Nantes, Graz and several Chinese cities, but is also currently at the planning stage for other cities around the world. It is characterized by charging the bus at an ultra-fast rate with a 600 kW charger at the stations for 15 or 30 seconds, while passengers are getting on and off the bus. The buses have super capacitors or small batteries because they run only about 2km before they are charged again, and therefore operate like a wireless trolleybus. Unlike the first opportunity charging system, the investment is higher in the infrastructure and lower in the bus (because it has fewer batteries), which makes the system more profitable on high frequency routes as it expands, since many buses use the same infrastructure. The additional CAPEX compared to diesel buses is about 25 MUSD (70% for buses and 30% for infrastructure) and the financial TCO is lower than for diesel buses.

8. **Battery Electric Buses (BEBs)** have enough batteries on board to operate all day long with a night charge, or alternately one can place fewer batteries on board and make one or more quick charges during the day. The first type of system (slow night charge) is traditionally used, however, it is useful for smaller buses, which have low mileage per day and short operating hours. The second system is more popular due to the fact that it reduces the number of batteries needed on the bus (and therefore the investment in the bus), and due to the availability of fast chargers at affordable prices. When determining the number of batteries required on the bus, it is important to consider the actual bus consumption (about 1.8 kWh/km in an articulated bus with no AC and no slopes), a minimum battery charge (SOC) of 10% (to maintain its life cycle and be able to operate without issues) and the reduction of SOC during the battery life, reaching up to 70% in 8 years. The maximum distances indicated by the manufacturers do not take the minimum SOC or the life cycle SOC into account, which means that in practice the operating range will not be sufficient. There are fleets of thousands of BEB units in China, however, less than 10 units are 18m long and the vast majority consists in buses ranging between 6 and 12m in length. The largest fleet of 18m BEBs is found in Eindhoven (from 12/2016 with 43 units). These consist in BEBs that charge quickly (30 to 40 minutes) with a pantograph in the tank after about 3 hours of operation. An important factor in BEBs is the electricity tariff, which has a consumption component (differentiated tariff by night, base and peak) and a power tariff. In this regard, especially the night rate favors a slow charging system, however, the power rate - often forgotten - is decisive in Mexico, as it requires a large number of high power chargers to charge the bus for only a few hours.

9. A **slow-charging BEB system** for the Eje 8 Sur requires buses with a set of batteries of about 700 kWh to operate the 250 km, also in year 8, and with a reserve of 10%. 200 kW chargers are required to charge the buses at night, which means high installed power (11 MW), and a high electricity tariff. BEBs are expensive because of the large number of batteries they require; in fact, the additional CAPEX for diesel buses is about 30 MUSD (90% for buses, 10% for infrastructure) and the financial TCO is 40% higher than diesel buses. The system is therefore uneconomical and more expensive than other electrical options, and the large number of batteries on board adds more weight to the vehicle, which can result in less passenger capacity.

10. A more beneficial alternative system would be to use **BEBs with fewer batteries** and charge them twice during 30 minutes throughout the day (with 400 kW chargers, system used in Eindhoven). This

requires fewer batteries (350 kWh instead of 700 kWh) and therefore a lower bus investment. Otherwise, the system has the same advantages and disadvantages as slow-charging BEBs. The additional CAPEX is around 20 MUSD (90% on buses) and the financial TCO is 10% higher than for diesel buses. The economical TCO is comparable to diesel buses.

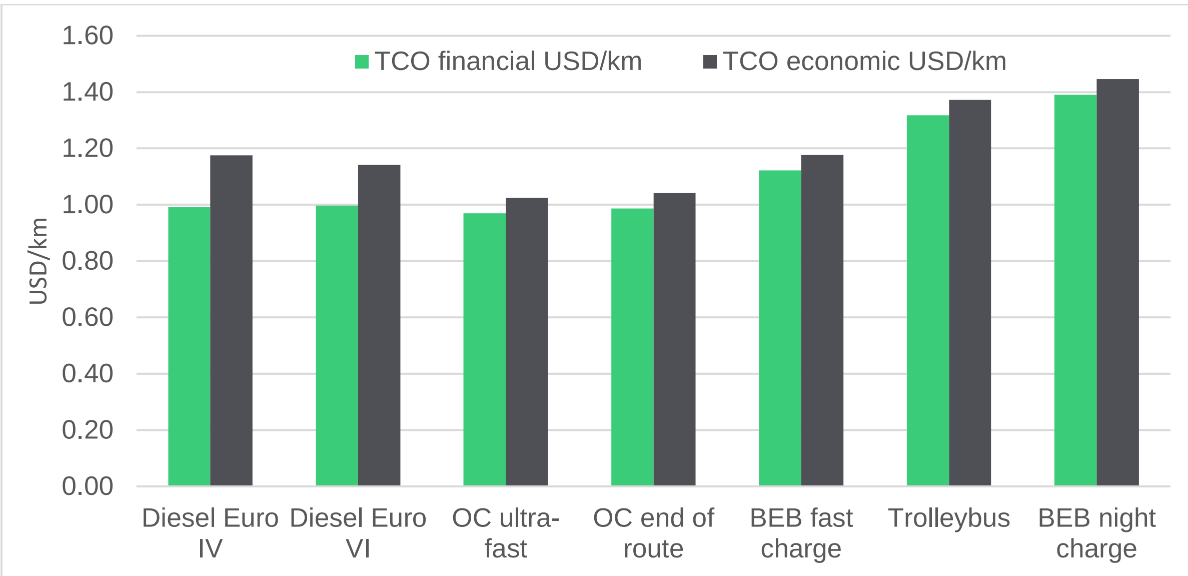
11. Electrical systems are characterized by having a higher CAPEX, however, the financial and economic TCO for opportunity charging systems is lower than for diesel buses. In spite of this, many times transport operators make the decision basically considering the initial investment and not the TCO, in addition to the fact that electric buses represent a greater risk due to the lack of previous experiences. In the end, it is important to consider financial instruments that can reduce the initial CAPEX investment and risk.

12. Potential financial options to improve the attractiveness of electric buses include:
    - The electricity company's investment in chargers and charging according to all electricity consumers in the city. This is justified by positive environmental effects (air quality and noise) benefiting all inhabitants, and not only by transport users.
    - Access carbon finance instruments because of to difference in the financial TCO between electric and diesel buses. The marginal costs of reducing CO_2 from opportunity charging systems are negative or very low. It will not be possible to cover the entire CAPEX difference, but only a contribution to compensate, for example, for increased risks.
    - Establish a leasing system with mileage payment or an ESCO (Energy Saving Company) and combine it with a performance guarantee fund to cover the risk of a financial TCO of the electric bus that ends up being lower than the initially projected one. Considering the TCO instead of the CAPEX, facilitates the operator’s decision when opting for a technology.

13. The main conclusions are:
    - Trolleybuses present a low-risk investment because they are an already well-known technology, with multiple manufacturers and previous experience in Mexico. However, financially it is only an attractive option only a large part of the existing infrastructure can be used without requiring new investments.
    - The ultra-fast opportunity charging system is the most financially attractive electrical system, as the financial TCO is comparable to that of diesel buses, and the economic TCO is lower than that of diesel buses due to its positive environmental impact. Expanding the system also generates fewer costs, because the same infrastructure can be used by a larger number of buses, yet the main risk is in terms of lack of experience in larger applications.
    - End-of-route opportunity charging systems can initially seem as an interesting option, yet expanding the fleet increases the cost difference against an ultra-fast charging system since more investments are required for the buses and the infrastructure; however, the ultra-fast charging system can operate with the same investment in infrastructure and with more buses.
    - BEBs require a very large investment for acquiring the buses, and very high installed power in chargers, thus raising electricity prices. In conclusion, they are not a technically and financially interesting option to electrify Eje 8 Sur. In any case, it would be better to install BEBs with fast charging during the day, as they require fewer batteries and therefore require less investment in buses, not to mention that they use less power installed in chargers.

The conclusions of the study show that, for a high-frequency BRT operating with 18m buses, it is better to use trolleybuses (as they have existing infrastructure) or opportunity charging buses, but not night charging BEBs; this result is consistent with the investments already made in European cities for new systems. Even in China, the tendency is for BEBs to be charged quickly several times a day or almost permanently at stations or at the end of the route, which reduces costs, the weight of the bus and its environmental footprint. It should be noted that this is a conclusion for high-frequency routes. In the case of Eje 8 Sur, the best option would be BEBs with night charge, especially for routes that operate with 12m buses.

Graph 1 Summary of financial and economic TCOs in different systems



Source: Grütter Consulting.

1 Introduction

The consultancy is located within the framework of the technical assistance agreement provided by C40 Cities Finance Facility (CFF) to Mexico City (CDMX). This consultancy seeks to prepare the investment project to implement an electric bus corridor on the Eje 8 Sur in Mexico City. The objective of the consultancy is to provide support to CDMX in the identification and evaluation of alternative bus technologies that can initially be applied in the Eje 8 Sur Corridor. In the first report, an inventory of alternative bus technologies was made, compared against diesel buses in general; in contrast, this second report focuses on electric buses for use in the Eje 8 Sur. Electric buses included in the study are Battery Buses (BEBs), trolleybuses and opportunity charging buses.

The report is structured as follows:

- Methodological summary;
- Main characteristics of Eje 8 Sur;
- Comparative environmental, financial and economic impact of electrical technologies;
- Potential financial structuring.

It is worth emphasizing that the study analyzes the effects of using different technologies for new buses that will operate on Eje 8 Sur; in other words, it does not compare new buses of alternative technology with the current fleet of buses, but rather studies the impact of using electric buses instead of diesel buses. Therefore, a new diesel baseline bus is compared to a new electric bus. The calculated impact refers to this technological change, and not to the environmental, financial and economic impact of establishing a mass transport system on Eje 8 Sur.

2 Methodology and General Parameters

2.1 Introduction

The report makes a comparison between bus technologies including:

1. Environmental impact: analyses climate change impacts, in addition to local impacts in terms of $PM_{2.5}$, NO_x, SO_2 and noise pollution. Greenhouse Gas (GHG) emissions are calculated as direct emissions (tank-to-wheel or TTW) and indirect emissions (Well-to-Tank or WTT), which in the case of electricity also include emissions from the Mexican electricity grid. Indirect emissions, caused by black carbon (BC), are also considered. Only combustion emissions are included.

2. Financial and economic impact: investment (CAPEX), operating costs (OPEX) and total cost of ownership (TCO) are compared. The monetary value of environmental impacts is included in the economic analysis.

The comparison is made between a baseline diesel bus and electric buses of different technologies. The baseline diesel bus is defined as the bus that would be purchased to operate in the corridor, without considering the environmental aspects of other technologies, that is, it is defined as the Business as Usual (BA) technology. Buses that currently operating in CDMX are not considered; yet new buses that comply with the environmental regulations in force in the country at the time of purchase are considered. In 2018, Mexico still uses the Euro IV standard for buses; however, Metrobús Euro V buses are already circulating in the city, and, in addition, it was required that buses running on the line 7 corridor of the Reforma Metrobus comply with Euro VI[1]. Euro VI is also expected to soon become a national requirement[2]. However, for comparison purposes and at the request of C40, electric buses are compared with Euro IV and Euro VI diesel buses.

2.2 Environmental Methodology.

2.2.1 Greenhouse Gases (GHG).

2.2.1.1 Combustion emissions.

Greenhouse Gases (GHGs) included under the United Nations Framework Convention on Climate Change (UNFCCC) are carbon dioxide (CO_2), methane (CH_4), nitrous oxides (N_2O), perfluorocarbons (PFCs), hydrofluorocarbons (HFCs), sulphur hexafluoride (SF_6) and trifluoride nitrogen (NF_3). Only CO_2, CH_4 y N_20[3] are relevant for the transport sector, but according to UNFCCC methodologies for determining emissions from the transport sector, N_2O and CH_4 emissions are marginal for non-gas vehicles and therefore only CO_4 emissions are included[5].

CO_2 emissions are determined on the basis of energy consumption according to the IPCC (2006) methodology, which is also used in all approved UNFCCC methodologies[6]:

$$E_{CO2,C} = FC_x \times NCV_x \times EF_{CO2,x}$$

where:

$E_{CO2,C}$	CO_2 by combustion emissions
FC_x	Fuel consumption type x
NCV_x	Net Calorific Value of fuel type x
$EF_{CO2,x}$	CO_2 emission factor of fuel type x

2.2.1.2 Black Carbon (BC) Emissions.

Black Carbon (BC) is an important GHG. A scientific assessment of BC emissions and their impacts determined that BC comes second to CO_2 in terms of climate impact[7]. After 20 years, BC is on average 2,700 times more powerful than CO_2, and becomes 900 times more powerful after 100 years. Since BC is a part of particulate matter (PM) emissions from diesel engines, the emission values of $PM_{2.5}$, the fraction of BC in $PM_{2.5}$, and the GWP100 of BC, are used to determine BC CO_{2e} emissions.

2.2.1.3 Electricity Emissions.

GHG emissions caused by electricity production are included as indirect emissions. The carbon emission factor of electricity production is based on the average emission factor of the current grid, which is published by SEMARNAT, as the value to be used to determine indirect emissions from electricity consumers[8]. The

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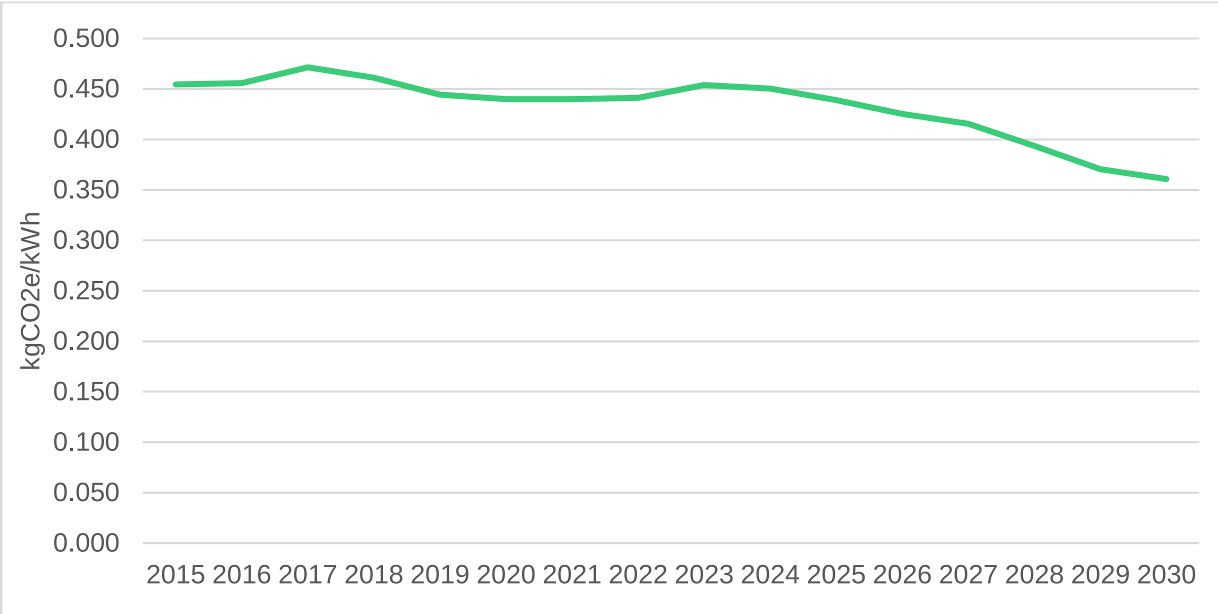
1 CDMX, 2016a, Art. 14.III
2 See http://transportpolicy.net/index.php?title=Mexico:_Heavy-duty:_
3 See IPCC, 2006, chapter 3
4 See, for example, ACM0016 or AM0031 in https://cdm.unfccc.int/methodologies/PAmethodologies/approved
5 See, for example, ACM0016 or AM0031 in https://cdm.unfccc.int/methodologies/PAmethodologies/approved
6 The IPCC also includes CO_2 emissions from the use of urea in catalysts for diesel engines. However, the resulting values show CO_2 emissions from urea that are between 0.1 and 0.2% of combustion emissions - which is why they are not included in this report as they are not considered significant.
7 See Bond 2007 & 2013 and World Bank, 2014
8 https://www.gob.mx/semarnat/acciones-y-programas/registro-nacional-de-emisiones-rene

following graph shows the projected trend of this factor, which on average, decreased at a rate of 1.5% per year, showing that the electricity grid is increasingly decarbonized.

Graph 2 Projected trend of electricity emissions in Mexico (in kgCO2/kWh)



Source: Calculated based on WWF, 2017 and with data from SENER and PRODESEN.

For buses that consume electricity, electricity emissions are calculated as follows:

$E_{CO2,E} = EC \times EF_{elec}$

where:

$E_{CO2,E}$	CO_2 emissions from electricity consumption
EC	Electricity consumption
EF_{elec}	Electricity Emission Factor

2.2.1.4 Upstream Fuel Emissions.

In general, indirect emissions are not included in UNFCCC calculations. They can be caused within or outside the country; however, indirect emissions caused by fossil fuels are included in this report, as are indirect emissions caused by electricity production. The upstream emissions of fossil fuels (Well-to-Tank, WTT[9]) are based on their extraction, refining, transport, and distribution.

The indirect emissions from diesel are calculated as follows:

[9] WTW = WTT + TTW (Well-to-Wheel = Well-to-Tank + Tank-to-Wheel)

$$E_{CO2,WTT} = E_{CO2,TTW} \times MF$$

where:

$E_{CO2,WTT}$	Well-to-Tank CO_2 emissions
$E_{CO2,TTW}$	Tank-to-Wheel CO_2 emissions
MF	Mark-up factor from TTW emissions

2.2.1.5 Emissions from vehicles and their components.

GHG emissions caused by the production of vehicles and their components, specifically batteries, are not included in this report[10]. Estimates of GHG emissions caused by kWh of battery have a very strong variation ranging between 56 and 494 $kgCO_{2e}$/kWh with average values of studies for the 110 $kgCO_{2e}$/kWh[11] equivalent to 0.2g CO_{2e} per kWh and km of battery installed in a bus[12]. This would result in additional indirect emissions of 80 gCO_{2e}/km with a 400 kWh battery bus. These are significant emissions and therefore minimizing the amount of batteries is not only a financial imperative but also important from an environmental point of view. However, the relevance of GHG emissions caused by battery production and their impact when comparing electric versus diesel buses is reduced by the following important factors not taken into consideration in the studies described above:

- Due to the fact that they have lower vibrations and fewer moving parts, electric buses have a longer life cycle than diesel buses, and therefore manufacturing emissions are estimated at about 100tCO_{2e}[13] per 18m urban bus, and are distributed over 16 to 20 years for electric buses, instead of the average 12 years for diesel bus. That means that an electric bus has between 30 and 50 gCO_{2e} less emissions per kilometer from manufacturing than a diesel bus (excluding battery) [14].
- Batteries used in electric buses are still used for up to 15 years in fixed applications as power reserves. In transport, a battery state of charge (SOC) of at least 70% is generally required, whereas this value may be much lower for fixed applications that do not have significant space problems. Therefore, emissions caused by the production of batteries cannot be allocated to buses alone.
- A good part of the battery elements are recycled, which reduces the use of energy for the production of raw materials. This fact was not considered in studies of GHG emissions caused by battery production.

When considering differences in commercial life cycles and attributing only 50% of the battery emissions to the bus, it turns out that the indirect emissions from manufacturing the diesel bus per km are comparable to an electric bus, including batteries having the diesel bus 120 gCO_{2e}/km and an electric bus based on batteries about 130 gCO_{2e}/km[15].

2.2.1.6 GHG Summary.

The report includes the following parameters per GHG.

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[10] See report 1 for a discussion of these impacts.
[11] ICCT, 2018
[12] Based on 8 years of use of batteries in the bus and 70,000km/yr of circulation.
[13] ecoinvent and mobitool database used in the EU
[14] Based on 70,000km/yr and 12 years of commercial life of a diesel bus versus 16 to 20 years of an electric bus.
[15] Calculated on the basis of 110 kgCO2e/kWh and a BEB of 400 kWh and 16 years of useful life (8-year batteries with 50% attributed to the bus); diesel bus with 12 years life cycle; 70,000km per year of circulation

- Direct emissions (TTW);
- Direct and indirect emissions (WTW) including BC, emissions caused by the production of electricity, and WTT fossil fuel emissions not including indirect emissions caused by manufacturing the bus and its components or infrastructure[16].

The value of direct and indirect emissions is used to determine the environmental economic costs and the marginal cost of CO_{2e} reduction.

2.2.2 Local Emissions and Noise.

The most common air pollutants, known in the United States and Mexico as criterion pollutants, are carbon monoxide (CO), lead (Pb), ground-level ozone, particulate matter (PM), sulfur dioxide (SO_2) and nitrogen dioxide (NO_2) [17]. Ground level ozone is not emitted directly into the air, but is created by chemical reactions between nitrogen oxides (NO_x) and volatile organic compounds (VOCs) in the presence of sunlight. The toxic compounds included in the emissions inventory of the Metropolitan Area of the Valley of Mexico (ZMVM-according to its Spanish acronyms) are[18]:

- Toluene: in mobile sources comes from the combustion and evaporation of gasoline;
- Xylene: in mobile sources comes from the combustion and evaporation of gasoline;
- Ethylbenzene and MTBE: in mobile sources comes from the combustion and evaporation of gasoline;
- Benzene: in mobile sources comes from the combustion and evaporation of gasoline

Lead and SO_2 emissions are related to the use of fossil fuels by vehicles and are controlled through the use of unleaded gasoline and maximum sulfur levels in fuels, mainly diesel. Other air pollutants are regulated by exhaust emission standards.

Bus diesel engines basically cause emissions of SO_2, PM and NO_x. The other critical pollutants are not predominantly produced by diesel engines[19].

The COPERT[20] model Tier 3 methodology is used to determine $PM_{2.5}$ and NO_x emissions, and SO_2 emissions are calculated based on the diesel's sulfur content and the bus' consumption. In Tier 3, emissions are determined according to operating conditions, including bus usage (urban bus), bus size, Euro category, traffic speed, occupancy rate, and average geographic slope. Only emissions from combustion are considered, and not the emissions caused by abrasion of brakes, rims and by re-suspension of particles caused by abrasion[21].

Noise emissions are determined by the noise differences between technologies and only the noise from the engine is taken into account (other noise sources are not differentiated between different technologies).

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[16] Fuel stations, chargers etc.

[17] https://www.epa.gov/criteria-air-pollutants, see also CDMX, 2016b; in Mexico ammonia (NH_3) is also included as a criteria pollutant and Total Organic Carbon (TOC). The contribution of mobile sources to NH_3 emissions in the MCMA is 3.5% in 2014 (table 5) and 11.3% in TOC. Within mobile sources, buses including Metrobus/Mexibus contribute 1% to NH3 emissions and 2% to TOC emissions, i.e. diesel motorbuses are not a major source of these emissions (in PM2.5 buses contribute e.g. to 23%) (Table 6 CDMX, 2016b).

[18] , p. 57ff

[19] See also UNECE, 2013

[20] EEA, 2016

[21] See for a discussion of uncaused emissions from combustion report 1 (Grutter, 2017).

2.3 Financial and Economic Methodology.

2.3.1 Financial Analysis.

Parameters included in the financial analysis are capital costs (CAPEX) and operating costs (OPEX), limited to those that differentiate between diesel technology and electric buses (energy costs and maintenance costs). Other OPEX costs, such as the driver or management, are not differentiated between technologies, and are thus not included in this study focusing on comparing the technologies.

CAPEX includes the investment costs of the bus as well as the additional infrastructure required (e.g. energy charging stations) plus the costs of partial replacement of the investment (e.g. batteries). The diesel prices used in the report already include the costs of the service station infrastructure, i.e. they are consumer prices; however, the electricity prices do not include additional infrastructure, such as chargers for electric buses or transformers, and therefore these costs are separately included[22]. Also included are potential differences in life cycle, according to bus technology based on the residual value in year 12.

The bus CAPEX has many variations according to the place of purchase and specifications of the bus. For example, in China there are 12m BEBs costing USD 250,000 (Fuzhou), while in the same year, in Washington, a 12m BEB cost USD 880,000[23]. In addition, even with the same bus brands there are factors of double difference depending on the place of purchase, quantities purchased and specifications of the operator and the country. Based on the above, the methodology for determining the CAPEX value of buses is based on the following steps:

1. The referential CAPEX is determined, including VAT for an 18m diesel bus. This reference value is obtained from purchase contracts for 18m Metrobus buses used in its corridors. As a result, these are the real values for buses Mexico’s specifications.

2. There is the incremental cost or extra cost of electric buses depending on the technology of cities that operate electric buses and diesel buses, such as18m diesel buses and 18m trolleybuses. From this, there is a percentage of incremental bus CAPEX depending on the technology. An average incremental cost is taken from different cities, with information mainly from Europe, China and the USA. Mexico's base diesel bus cost multiplied by the incremental factor provides an estimate of the CAPEX for an electric bus in Mexico.

3. To this basic CAPEX, costs are added or deducted according to specific electrical technology, considering a smaller or larger amount of batteries and whether or not they have a pantograph.

In order to compare different technologies, a discount factor is used to determine the Net Present Value (NPV) for the CAPEX and OPEX and the total cost of ownership (TCO) per kilometer.

The reference[24] discount factor is determined on the basis of the Weighted Average Cost of Capital (WACC):

$$WACC = r_e \times W_e + r_d \times W_d \times (1 - T_c)$$

Where:

[22] The calculation is not affected by who finances the infrastructure (e.g. the electricity company may finance it and make it available to the transmission operator, but will charge an extra service charge - this model is often used in Chinese cities, for example).

[23] Washington State Department of Enterprise Services, 2014

[24] The calculations are also made with a lower value and a higher value being the social discount rate.

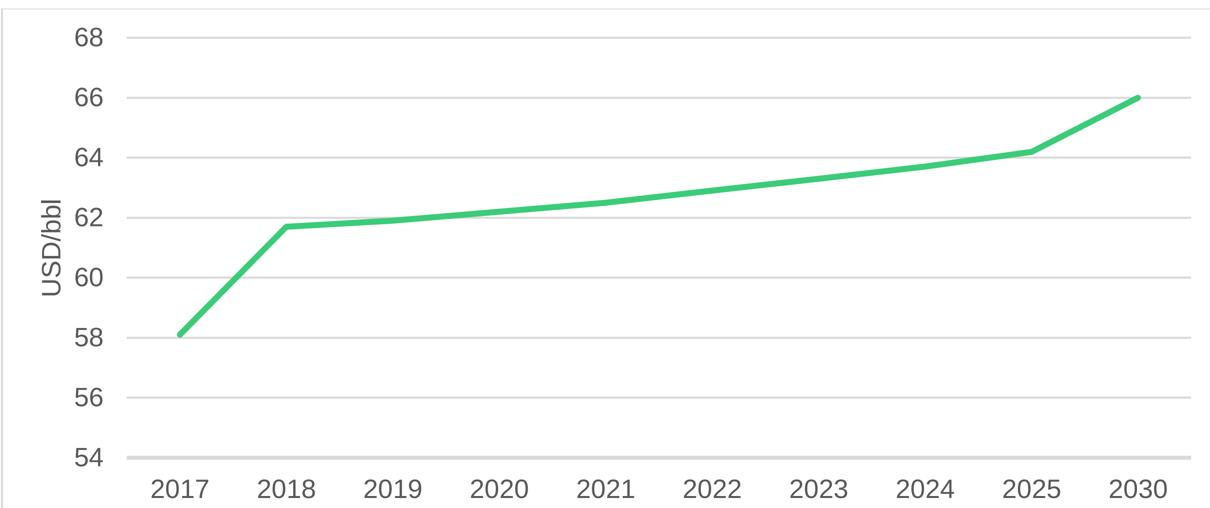
WACC	Weighted Average Cost of Capital
r_e	Cost of equity capital
W_e	Percentage financed with equity capital
r_d	Cost of credit
W_d	Percentage financed with credit
T_c	Corporate Tax Rate

All calculations are made with real values in constant 2017 USD, and not in nominal values. In other words, neither the effects of inflation, nor the tax effects are considered.

The price of electricity is not the same for all technological alternatives, as it depends on the time of consumption, and the installed power. For example, a BEB that is charged at night uses energy at night and requires a specific installed power, while an opportunity charge bus has a different installed power and uses energy throughout the day. Therefore, a reference electricity price is calculated for each type of electrical technology.

Calculations are made on the basis of projections of actual future diesel and battery/capacitor prices[25]. The graph below shows the World Bank's projection in constant USD crude oil prices.

Graph 3 Oil price projections (in constant USD per bbl).



Source: World Bank, Commodity Price Forecast Price data, April 2017 (http://pubdocs.worldbank.org/en/662641493046964412/CMO-April-2017-Forecasts.pdf)

The battery price projection is based on studies conducted by the US DOE (Department of Energy), based on studies by Bloomberg New Energy Finance, Total Battery Consulting, Clean Energy Manufacturing Analysis Center, and Roland Berger.

[25] See http://www.cmegroup.com/trading/energy/crude-oil/light-sweet-crude.html

2.3.2 Economic Analysis.

The economic analysis includes the monetization of external benefits and costs. A monetary cost is allocated to $PM_{2.5}$, NO_x, SO_2, CO_{2e} and noise emissions. The costs of emissions are taken from an International Monetary Fund (IMF) publication for Mexico and are based on local levels of pollution at ground level, their impact on health, and the costs caused by this type of pollution. This is based on people's exposure to pollution, and on how an increase in pollution increases mortality risks, using World Health Organization (WHO) functions to respond to the concentration of the pollutant. The increased risk of mortality, or the value for premature death, is economically assessed based on OECD stated preference studies. The cost of CO_2 is expressed by the social cost of carbon (SCC). The latter is an estimate of the economic damage associated with an increase in CO_2 emissions. The IMF values are updated to USD 2017.

The economic effects of noise are based on averaged economic costs from different studies and countries, according to a recent report by the Victoria Transport Policy Institute[26]. It determines an economic cost per noise for a diesel bus, and the reduction of noise from using electric buses.

The marginal reduction costs per tCO_{2e} are calculated on the basis of the differential financial TCO[27] between the diesel and electric bus, and the resulting differences in GHG emissions:

$$MAC = \frac{TCO_E - TCO_D}{EGEI_D - EGEI_E}$$

Where:

MAC	Marginal costs of CO_{2e} reduction (USD/km)
TCO_E	Total Cost of Financial Ownership per electric bus kilometer (USD/km)
TCO_D	Total Financial Cost of Ownership per diesel bus kilometer (USD/km)
$EGEI_D$	GHG emissions (WTW incl. BC) per diesel bus kilometre (gCO_{2e}/km)
$EGEI_E$	GHG emissions (WTW incl. BC) per kilometre electric bus (gCO_{2e}/km)

2.4 Parameters and General Values.

The following table shows parameters not related to specific technologies

Table 1 The following table shows parameters not related to specific technologies

Parameter	Value	Source
Diesel net calorific value	43 MJ/kg	IPCC, 2006, table 1.2

[26] VTPI, 2017

[27] Financial means that the monetized environmental costs are not included

Diesel CO_2 emission factor	74.1 gCO_2/MJ	IPCC, 2006, table 1.4
Diesel WTT factor	23%	UNFCCC, 2014, table 3
GWP100 Black Carbon	900	IPCC, 2013, table 8.A.6; also see Bond, 2013
Emission factor of the Mexican electricity grid	0.426 $kgCO_2/kWh$	Projected average value for the period 2018-2030, WWF, 2017[28]
Sulfur content in diesel	15 ppm	NOM-016-CRE-2016
Sulfur conversion factor	0.025 gSO_2/l	Calculated on the basis of molecular equivalence

Table 2 Financial and Economic Parameters

Parameter	Value	Source
Diesel Price	0.98 USD/l	Price during 26.2.2018[29]
Projected real average increase (GARR) in diesel price	2.5%	World Bank, 04/2017; projected prices for 2030 66USD/bbl; price 06/2017 48 USD/bbl[30]
Battery cost	500 USD/kWh	Price in 2017 in China for batteries
Bus battery life cycle	8 años	Based on manufacturer warranties
Residual value of the battery	20%	Based on the price of a replacement battery at the time; for use in fixed applications
Projected actual average increase in battery cost	-12%	US DOE projections 2017[31]
SOC Battery at the end of commercial life	70%	Minimum value to be able to operate; guaranteed by the manufacturer
Minimum SOC in operation	10%	Minimum required to maintain commercial battery life and to operate safely in commercial operations
Price per installed power	11.9 USD/kW/month	CDMX, 12/2017 based on data from STECDMX 01-11/2017 CFE applied tariffs

[28] The carbon emission factor of electricity production is based on the average emission factor of the current grid, which is published by SEMARNAT as the value to be used to determine indirect emissions from electricity consumers (https://www.gob.mx/semarnat/acciones-y-programas/registro-nacional-de-emisiones-rene). The projected trend of this factor is that it decreases on average by 1.5% per year.

[29] See: https://www.globalpetrolprices.com/Mexico/diesel_prices/

[30] See https://ycharts.com/indicators/average_crude_oil_spot_price

[31] https://energy.gov/sites/prod/files/2017/02/f34/67089%20EERE%20LIB%20cost%20vs%20price%20metrics%20r9.pdf

Peak hour electricity price	0.128 USD/kWh	
Base hour electricity price	0.067 USD/kWh	
Night hour electricity price	0.056 USD/kWh	
Peak hours per working day	4 hours	
Base hours per working day	14 hours	
Hours per night per working day	6 hours	
Projected real average increase in electricity prices	0%	Based on SENER, 2013, Figure 4.3 (projection until 2027)[32]
Cost per $PM_{2.5}$ contamination	226,920 USD/t	IMF, 2014, Annex 4.2 (updated USD values for Mexico from 2010 to 2017)
Cost of NO_x pollution	1,750 USD/t	
Cost of SO_2 pollution	8,580 USD/t	
Cost of CO_2 pollution	40 USD/tCO_2	IMF, 2014 updated to 2017 USD
Cost per diesel bus noise[33]	0.048 USD/km	VTPI, 2017, table 5-11.7.1
Social discount factor	10%	SHCP, 2016; real terms
Cost of own capital (r_e) [34]	10.5%	UNFCCC, 2017; value for the transport sector in Mexico
Percentage of own capital (W_e)	30%	Typical bus financing value
Actual cost of credit (r_d)	9.5%	CAT of 16.5% nominal (Banamex) minus inflation of 7%[35].
Percentage of borrowed capital (W_d)	70%	Typical bus financing value
Corporate tax rate (T_c)	30%	Deloitte, Corporate Tax Rates, 2017
WACC	8%	Calculated; reference value for discount factor
TC MXN per USD 03/2018	18.8	https://www.oanda.com/currency/converter/
MXN TC per USD average 2017	18.7	

3 General Characteristics of Eje 8 Sur.

The following table summarizes the main characteristics of Eje 8 Sur.

Table 3 Main Characteristics of Eje 8 Sur

Parameter	Value
Route length	15.8 km
Bus traffic speed	18 km/h

32 https://www.gob.mx/cms/uploads/attachment/file/62949/Prospectiva_del_Sector_El_ctrico_2013-2027.pdf
33 Average value from different sources
34 Reflects the risk premium, the country risk premium based on the Moody country risk rating plus the sector risk level.
35 https://tradingeconomics.com/mexico/inflation-cpi/forecast

Type of buses	18m articulated buses, without AC, capacity of 140 passengers
Minimum distance between buses	2.5 minutes
Operational baseline buses without reserve fleet	47 buses
Percentage of reserve fleet	10 %
Total fleet required including reserve fleet	52 buses
Total annual mileage of buses	3,775,000 km
Annual mileage per bus	73,000 km includes all buses
Daily mileage per working day per operational bus	250 km (calculated on the basis of 260 working days[36] and 60% mileage on a non-working day)
Investment time	12 years

Source: EMT, 2018 and author's calculations.

4 Baseline: Diesel Bus Operation.

The baseline bus is defined as the bus that would be purchased to operate in the corridor without considering environmental aspects of other technologies, that is, it is defined as the Business as Usual (BAU) technology. Buses that currently operate are not considered, but new buses that comply with current environmental regulations in the country.

The following two tables show the characteristics of the diesel buses considered.

Table 4 Technical parameters for diesel buses (articulated, 18m, without AC).

Parameter	Euro IV Bus	Euro VI Bus	Source
Diesel consumption	70 l/100km	70 l/100km	Values reported by BRT Edomex and BRT Metroplús
$PM_{2.5}$ Emissions	0.0927 g/km	0.0095 g/km	EEA, 2016; COPERT Tier 3 model with 15km/h, 100% load, 0% lift
NO_x Emissions	11.65 g/km	0.71 g/km	
SO_2 Emissions	0.0177 g/km	0.0177 g/km	Calculated on the basis of diesel consumption
BC faction of $PM_{2.5}$	75%	15%	EEA, 2016, table 3-117
TTW CO_{2e}	1,882 gCO_2/km	1,882 gCO_2/km	Calculated on the basis of diesel consumption
CO_{2e} WTW incl. BC	2,378 gCO_{2e}/km	2,317 gCO_{2e}/km	Includes WTT and BC

[36] Value used in Metrobus financial models

BRT consumption with 18m buses in Mexico is well above the estimates for 18m COPERT buses (between 55 and 63 l/100km), however, this may be caused by Mexico City's altitude and traffic conditions.

Table 5 Financial and economic parameters for diesel buses (articulated, 18m, without AC).

Parameter	Euro IV Bus	Euro VI Bus	Source
CAPEX diesel bus	365,000 USD	370,000 USD	Value paid by Metrobús incl. VAT updated to USD 2017[37]; incremental cost of Euro VI bus based on ICCT, 2017
Cost of tires	0.047 USD/km	0.047 USD/km	Based on Metrobús Insurgentes Financial Model, 2005 updated to USD 2017, does not include cleaning, management, and non-diesel related maintenance; ICCT, 2017 estimates that Euro VI buses have an additional maintenance cost of USD 0.001/km.
Maintenance costs incl. lubricants	0.065 USD/km	0.065 USD/km	
Bus service life	12 years	12 years	Standard by operator; approx. 1 million km
Economical cost of local and noise emissions	0.090 USD/km	0.052 USD/km	Calculated on the basis of emissions and unit cost per emission
Economic cost of GHG emissions (WTW incl. BC)	0.095 USD/km	0.093 USD/km	
Total economic costs	0.185 USD/km	0.144 USD/km	

The following table shows the environmental impact for Eje 8 Sure per year of using diesel buses.

Table 6 Environmental impact of implementing diesel buses on Eje 8 Sur (in t/year).

Parameter	Euro IV Diesel Buses	Euro VI Diesel Buses
$PM_{2.5}$ emissions	0.35	0.04
NO_2 emissions	43.96	2.67
SO_2 emissions	0.07	0.07

[37] 18 m bus at MXN 4,278,000 including 15% VAT purchased on 26.11.2008 with an exchange rate of 12.71 MXN per USD valid on the day of purchase (Interbank) equivalent to USD 336,000; USD 2008 updated to USD 2017 based on GDP deflator http://stats.areppim.com/calc/calc_usdlrxdeflator.php

CO_2 (TTW) emissions	7,105	7,105
CO_{2e} WTW emissions incl. BC	8,976	8,745

Emissions from Euro VI buses are significantly lower than those from Euro IV buses, in terms of NO_x and $PM_{2.5}$; they are also slightly lower in terms of GHG emissions (since they generate less Black Carbon (BC)).

The following table shows the financial and economic impacts of using diesel buses. The CAPEX includes the total fleet (operational plus reserve fleet).

Table 7 Financial and economic impact of implementing diesel buses on Eje 8 Sur (in constant 2017 USD).

Parameter	Euro IV Diesel Buses	Euro VI Diesel Buses
CAPEX	19.0 MUSD	19.2 MUSD
NPV OPEX cumulative 12 years	25.9 MUSD	25.9 MUSD
Financial TCO	**0.99 USD/km**	**1.00 USD/km**
Cumulative environmental costs 12 years	8.37 MUSD	6.53 MUSD
Economical TCO	**1.18 USD/km**	**1.14 USD/km**

Notes:
a). OPEX includes only energy, tire and direct maintenance costs.
b). TCO calculated on the basis of CAPEX+OPEX Net Present Value for 12 years.
c). Economical TCO includes environmental costs (emissions and noise).
d). Environmental economic costs are not discounted over time.

In terms of financial costs, the Euro IV and Euro VI buses are similar, while the economical TCO is significantly lower for Euro VI buses; it is worth mentioning that it would be a better economic option for CDMX to invest a little more and have the benefits of Euro VI buses.

The table below shows the different financial TCOs as two critical parameters vary, i.e. the projected annual increase in the price of diesel and the discount rate. The other values are considered more stable and less prone to significant variations.

Table 8 Financial TCO sensitivity to variations[38].

Varation Parameters	Pessimistic Value[39]	Regular Value[40]	Optimistic Value[41]
Discount rate	1.09 USD/km	0.99 USD/km	0.93 USD/km

[38] Average value between Euro IV & Euro VI
[39] Discount Value of 5%, CAGR diesel 5%
[40] Discount Value of 7.8%, CAGR diesel 2.5%
[41] Discount Value of 10%, CAGR diesel 0%

CAGR diesel price	1.07 USD/km	0.99 USD/km	0.93 USD/km

What you can see is that a higher discount rate reduces TCOs per km by making the costs of the future less expensive.

5 Trolleybuses

Trolleybus is a well-known technology nowadays used in different countries[42]. Modern electric trolleybuses can operate without overhead lines up to 50km due to a set of batteries. For example, 18m trolleybuses typically have a battery set of 70 kWh or more[43]. Eje 8 Sur has the infrastructure for trolleybuses along 60-70% of the route, yet it has not been used since 2012[44]; however, battery-powered trolleybuses could operate the system by taking advantage of this percentage of overhead lines, as they have sufficient range of autonomy to cover these distances[45].

Image 1 18 m Trolleybuses

Source: Lucerne, Switzerland and Bratislava, Slovakia.

The following table shows the technical and environmental characteristics of trolleybuses.

[42] For a list of cities, see: http://www.trolleymotion.eu/www/index.php?L=3&id=36&land=all
[43] The 18m Yutong trolleybus has e.g. a 147 kWh battery set which guarantees a range of 75km depending on the manufacturer, more realistically calculated as the range is about 50km (SOC minimum of 10%, SOC after 8 years 70%, 1.8kWh/km consumption.
[44] STE information from 2017
[45] See Yutong trolleybus with a minimum range of 50km; Skoda represented in Mexico by DINA offers trolleybuses that need only catenary for 50% of the route.

Table 9 Technical parameters for trolleybuses (18m articulated without AC).

Parameter	Value	Source
Electricity consumption	1.8 kWh/km	Average value Quito and Lucerne, 2015 without AC is 1.8; Consumption can be lower and reach 1.4 kWh/km without slopes, at a constant speed of 15-20 km/h, without AC, with drivers trained in Eco-driving etc.; see chapter 7.1 for more details.
Diesel Bus Relative Noise Reduction	50%	ABB Information, 2017
TTW CO_{2e}	0 gCO_2/km	No direct emissions
CO_{2e} WTW incl. BC	767 gCO_{2e}/km	Includes emissions from electricity production
Total fleet of buses required (Including reserve fleet)	52 buses	Same availability and capacity of the bus as a diesel unit

Large fleets of trolleybuses have been operating in approximately 300 cities for decades, but the technology has evolved, making the systems more reliable, more robust in operation, and more flexible in operating partially without overhead lines. Their degree of availability is therefore similar to that of diesel buses.

The following table shows the financial parameters of an 18m trolleybus.

Table 10 Financial and economic parameters of trolleybuses (articulated, 18m, without AC).

Parameter	Value	Source
Incremental trolleybus cost compared to diesel bus	90%	Based in Beijing, Lucerne, Geneva, Bern, Pilsen; trolleybus with 70 kWh battery set
CAPEX trolleybus	700,000 USD	Calculated on the basis of incremental cost relative to diesel bus
Cost of electricity	0.15 USD/kWh	Average price incl. power load paid by STE in 2017 for trolleybus operation
Battery capacity	70 kWh	Sufficient to operate 30-40% without catenary
Diesel Bus Maintenance Cost	+10%	Experience of trolleybus operators in Europe
Maintenance cost	0.123 USD/km	
Trolleybus life cycle	20 years	Less vibration and moving parts; see Trolley, 2013 and operators in Switzerland
CAPEX infrastructure for Eje 8 Sur	25.2 MUSD	IDOM, 2018 not including station costs per 28km (2.7 MUSD per km), based on 60% of the route with overhead lines[46]

[46] Total IDOM cost with 100% catenary and stations 42.5 MUSD (stations 0.5 MUSD)

Cost of infrastructure maintenance	0.5%	Infra, 1996; percentage of investment in infrastructure
Infrastructure useful life	20 years	Trolley 2013
Economical cost of local emissions and noise	0.024 USD/km	Calculated on the basis of emissions and unit cost per emission Based in Beijing, Lucerne, Geneva, Bern, Pilsen; trolleybus with 70 kWh battery set
Economic cost of GHG emissions (WTW incl. BC)	0.031 USD/km	
Total economic costs	0.055 USD/km	

Trolleybus maintenance costs are about 10% higher than for diesel buses. In general, operators in Europe indicate that trolleybus maintenance costs are between 10 and 30% higher than those of diesel buses[47], mainly due to the higher number of failures, and more complex repairs required, in addition to the lower availability of spare parts on the market. The following table shows the annual environmental impact for Eje 8 Sur when using trolleybuses.

Table 11Environmental impact of using trolleybuses in Eje 8 Sur (in t/year).

Parameter	Value in t/year
$PM_{2.5}$ emissions	0.0
NO_2 emissions	0.0
SO_2 emissions	0.0
CO_2 (TTW) emissions	0.0
CO_{2e} WTW emissions incl. BC	2,894

On the other hand, the following table shows the financial and economic impacts of using trolleybuses. The CAPEX includes the total fleet (operational plus reserve fleet) and infrastructure.

Table 12 Financial and economic impact of using trolleybuses on Eje 8 Sur (in constant 2017 US

Parameter	Value
CAPEX buses year 1	36.4 MUSD
CAPEX infrastructure year 1	25.2 MUSD
CAPEX cumulative VPN incl. residual value and battery replacement	47.4 MUSD
OPEX VPN cumulative 12 year buses	11.3 MUSD

[47] See Trolley, 2013 and Infras, 2006

OPEX VPN cumulative 12 years infrastructure	0.9 MUSD
Financial TCO	**1.32 USD/km**
Cumulative environmental costs 12 years	2.48 MUSD
Economical TCO	**1.37 USD/km**

Notes:
a). OPEX includes only energy and direct maintenance costs.
b). TCO calculated on the basis of CAPEX+OPEX Net Present Value for 12 years.
c). Economical TCO includes environmental costs (emissions and noise).
d). Environmental economic costs are not discounted over time.

The following table below shows the variations in financial TCO by changing the critical parameters, which are trolleybus CAPEX, infrastructure CAPEX, discount rate and electricity consumption.

Table 13 Financial TCO sensitivity to changes.

Variation Parameters	Pessimistic Value[48]	Regular Value[49]	Optimistic Value[50]
Discount rate	1.31 USD/km	1.32 USD/km	1.31 USD/km
CAPEX bus	1.41 USD/km	1.32 USD/km	1.22 USD/km
CAPEX infrastructure	1.47 USD/km	1.32 USD/km	1.15 USD/km
Power consumption	1.34 USD/km	1.32 USD/km	1.28 USD/km

With optimistic values, the trolleybus still has a financial TCO above that of the diesel bus; however, this difference is narrowing, despite the fact that the additional investment required as well as the infrastructure costs are central. Currently, costs are estimated at around 2.7 MUSD per kilometer, which appear to be very high; however, it is possible to reduce costs by 50% by installing overhead lines on only 60% of the trolleybus route, so that this system could have costs similar to those of the diesel bus, and the marginal cost of reducing GHG is 205 USD/tCO_{2e} with trolleybuses[51].

6 Opportunity Charging Buses.

6.1 Introduction.

Opportunity charging systems are characterized by operating with charging during different times throughout the bus route, or at the end stops. There are multiple types of opportunity charging systems that vary in terms of time and amount of charging; in fact there are several systems in operation or being tested in multiple countries in Europe, USA, Korea and China, among others. There are basically two systems of opportunity loading:

[48] Discount value of 5%, CAGR diesel 5%
[49] Discount value of 7.8%, CAGR diesel 2.5%
[50] Discount value of 10%, CAGR diesel 0%
[51] Based on financial TCO differential with diesel buses and WTW emissions incl. BC

1. System that charge the bus at the final stops. There is an opportunity charging system compatible with different makes and models of buses, which can be used with either electric or hybrid (OppCharge) buses[52].
2. Ultra fast loading system with short loads at intermediate stops.

The two systems have the following operational and financial differences:

- Number of fast chargers and their power,
- Bus investment due to differences in battery capacity, and
- Cost of electricity, as it has different installed power;

6.2 End-of-Route Opportunity Charging System.

Most of these types of systems operate with 12m buses; however, pilot systems are being tested with 18m electric buses, such as in Barcelona.

Image 2 End-of-route opportunity charge Bus in Barcelona.

Source: El Periódico.

The following table summarizes the technical and environmental characteristics of opportunity charging buses.

[52] See https://www.oppcharge.org/

Table 14 Technical parameters of buses with end-of-route opportunity charge (18m articulated without AC)

Parameter	Value	Source
Electricity consumption	1.8 kWh/km	Same value as trolleybuses (without AC); consumption can be lower and reach 1.4 kWh/km without slopes, at a constant speed of 15-20 km/h, without AC, with drivers trained in Eco-Driving etc.; see chapter 7.1 for more details.
Battery capacity per bus	200 kWh	Calculated on the basis of 250km per day of operation and a 4-minute load at the end of the route that is not sufficient to cover 100% of the electricity demand[53]; SOC 10% reserve and SOC 70% reserve at the end of the batteries' useful life.
Percentage of reserve buses	15%	5% higher than diesel buses based on experience of BEB availability; see Foothill Transit, 2017 5% lower availability; pilots in Europe up to 20% lower availability (VDV, 2016); large fleets in China 1-5% lower availability (Fuzhou, Jinan, Beijing)
Total fleet of buses required (incl. reserve fleet)	59 buses	4 additional buses per loading time at the end of the route (the time between buses in peak hours is less than the required loading time) and 15% of the reserve fleet
Number of fast loaders at the end of the route	2	At each end of the route or 4 in total; based on 4 minutes of charging
Power of fast chargers	400 kW	Power required to be able to charge enough electricity in 4 minutes; the Barcelona system has this power (load of approx. 5 kWh per minute based on 80% load capacity)
Number of slow chargers	30	1 charger with two guns for simultaneous charging of 2 buses (based on the total fleet of buses required)
Power of slow chargers	50 kW	Capacity required to fully charge the batteries in 4 hours
Diesel Bus Relative Noise Reduction	50%	ABB, 2017
TTW CO_{2e}	0 gCO_2/km	No direct emissions
CO_{2e} WTW incl. BC	767 gCO_{2e}/km	Includes emissions from electricity production

Basically, the system is operated with Battery-Electric Buses (BEBs), which, when charged, reduce the number of batteries required in the bus. It should be noted that this number of batteries was calculated according to route distance, power consumption, time and amount of electricity received in the fast charge,

[53] Average electrical requirement per 15.8 km lap is 28.4 kWh based on average consumption of 1.8 kWh/km

minimum battery backup SOC, and the minimum bus SOC in year 8. The following table displays the financial parameters of the system with opportunity charge buses.

Table 15 Financial and economic parameters for an end-of-route opportunity charging system.

Parameter	Value	Source
Incremental opportunity load bus cost compared to diesel bus	100%	Lower range of additional BEB cost of 12m with a 350 kWh battery set (several cities in China, Washington, Piedmont)
CAPEX bus	680,000 USD	Calculated on the basis of incremental cost relative to diesel bus less batteries + 20,000 USD per pantograph
Cost of electricity	0.14 USD/kWh	Average price incl. load per power output[54]
Diesel Bus Maintenance Cost	-30%	Based on BEBs based on Landerl, 2017 (0-50% less costs), CARB, 2016 (30% less costs), cities in China; slightly higher tire usage, but fewer moving parts and less maintenance, more expensive parts and more qualified personnel
Maintenance cost	0.078 USD/km	
Bus life cycle	16 years	2x battery life, less vibration and therefore longer life than diesel buses
CAPEX slow charger	15,000 USD	CAPEX in China for loaders with 2 50 kW guns
CAPEX fast end of route charger	250,000 USD	Based on ARB with New Flyer (250,000 USD[55]); ABB Switzerland 300,000 USD
CAPEX infrastructure	1.45 MUSD	Calculated based on the number of chargers per type of charger; no land costs
Cost of infrastructure maintenance	0.25%	50% of trolleybus infrastructure investment maintenance costs
Infrastructure useful life	20 years	ARB, CARB, 2017
Economical cost of local emissions and noise	0.024 USD/km	Calculated on the basis of emissions and unit cost per emission
Economic cost of GHG emissions (WTW incl. BC)	0.031 USD/km	
Total economic costs	0.055 USD/km	

[54] Calculated on the basis of the total installed power and the load per power plus the use of electricity during the whole day for the differentiated rates according to the schedule.
[55] https://www.arb.ca.gov/msprog/bus/4thactwgmtng_costs.pdf

Considering that consumption is based on 18m trolleybuses without AC, 12m BEBs have an average consumption of 1.2 kWh/km[56], which is why this figure is considered realistic. It is important to remember that the consumption of electricity is done considering a bus without AC, since the consumption of electricity can increase more than 50% in electric buses with AC. This means that a set of batteries of approximately 350 kWh should be installed instead of a 200 kWh battery set to ensure operation in summer months when using the AC[57]. This would have a significant impact on CAPEX (approx. USD 80,000 per bus) and TCO. The following table shows the environmental impact for Axis 8 South per year of using opportunity freight buses.

Table 16 Environmental impact of using opportunity freight buses at the end of the route on Eje 8 Sur (in t/year).

Parameter	Value t/año
$PM_{2.5}$ emissions	0.0
NO_2 emissions	0.0
SO_2 emissions	0.0
CO_2 (TTW) emissions	0.0
CO_{2e} WTW emissions incl. BC	2,894

The following table shows the financial and economic impacts of investing in an opportunity bus system. The CAPEX includes the total fleet (operational plus reserve fleet) and infrastructure.

Table 17 Financial and economic impact of using the opportunity charging system at the end of the route on Eje 8 Sur (in constant 2017 USD).

Parameters	Value
CAPEX buses year 1	40.1 MUSD
CAPEX infrastructure year 1	1.5 MUSD
CAPEX cumulative VPN incl. residual value and battery replacement	35.2 MUSD
OPEX VPN cumulative 12 year buses	9.5 MUSD
OPEX VPN cumulative 12 years infrastructure	0.03 MUSD
Financial TCO	**0.99 USD/km**
Cumulative environmental costs 12 years	2.48 MUSD
Economical TCO	**1.04 USD/km**

Notes:

[56] Average consumption value of 12m BEBs from multiple cities in China with large fleets, from several cities in Germany with pilot fleets and from Foothill Transit in California (see Grutter, 2017).
[57] See report 1 e.g. in the Fuzhou database of BEBs all year round, the Barcelona system reports bus consumption of 2.5 to 3.9 kWh per km (ZeEUS, 2015).

a). OPEX includes only energy and direct maintenance costs.
b). TCO calculated on the basis of CAPEX+OPEX Net Present Value for 12 years.
c). Economical TCO includes environmental costs (emissions and noise).
d). Environmental economic costs are not discounted over time.

As can be seen, the financial TCO is equal to that of diesel buses, while the economic TCO is below that of diesel buses. The table below shows the variations in financial TCO when changing critical parameters, i.e. bus CAPEX, maintenance costs, energy consumption and discount rate. The other values are considered more stable and less prone to significant variation.

Table 18 Financial TCO sensitivity to changes.

Variation Parameters	Pessimistic Value[58]	Regular Value[59]	Optimistic Value[60]
Discount rate	1.01 USD/km	0.99 USD/km	0.97 USD/km
CAPEX bus	1.06 USD/km	0.99 USD/km	0.91 USD/km
CAPEX infrastructure	1.01 USD/km	0.99 USD/km	0.97 USD/km
Power consumption	1.05 USD/km	0.99 USD/km	0.87 USD/km

The profitability of the system is sensitive to the bus CAPEX as well as the energy consumption of the bus; the latter is very relevant since it also has an effect on the number of batteries and therefore on the CAPEX of the bus required to operate. For example, with 1.4 kWh/km of consumption the battery set decreases from 200 kWh to 50 kWh, and the CAPEX of the bus goes from 680,000 USD to around 600,000 USD. The marginal cost of GHG reduction is -4 USD/tCO_{2e} with an end-of-route opportunity charging system[61].

6.3 Ultra-fast opportunity charging system.

The second opportunity charging system considered is where the bus is charged via ultra-fast charging at the stations for 15 to 30 seconds while passengers get on and off the bus. In Geneva, for example, an ultra-fast charging system called "flash charging", with articulated and bi-articulated electric buses, has been implemented following a 2-year pilot phase (Trolleybus Power System Optimization - TOSA according to its French acronym) with the characteristics described in the following table.

Table 19 TOSA System

[58] 5% discount value, CAPEX bus 120% higher than diesel bus and maintenance costs same as diesel bus
[59] Discount value of 7.8%, CAPEX bus 100% higher than diesel bus and maintenance costs 30% lower than diesel bus
[60] 10% discount value and CAPEX bus 80% higher than diesel bus and 50% lower maintenance costs than diesel bus
[61] Based on financial TCO differential with diesel buses and WTW emissions incl. BC

Parameter	Geneva Case
Route characteristics	12km route with 13 stations with 10 minute reach between buses in peak hours (10,000 passengers per day)
Bus characteristics	12 articulated electric buses
Loading system characteristics	13 ultra-fast 600kW charging stations and 15-20 seconds charging time. In total 3 charging systems of 400kW in the final stations with a charge of 4-5 minutes fully recharging the batteries. The depot has 4 45kW slow charging stations to cover the distance from the depot at the beginning of the route.

Source: http://new.abb.com/grid/technology/tosa and http://ge.ch/transports/actualites/tosa-ligne-23-cest-parti-lunion-partenariale-publique-privee-au-service-du-bus-du-futur

Image 3 TOSA Geneva, Switzerland

Source: Grutter Consulting.

The city of Nantes in France is installing a TOSA system for a BRT line with 20 24-meter double-articulated buses, and several cities in Europe are about to install similar systems, for example, Bern in Switzerland. China's high-speed train manufacturer, China South Locomotive & Rolling Stock Corporation (CRRC, a CSR bus subsidiary), also produces an ultra-fast charging system, which requires 30 seconds for the batteries to be fully charged; these systems have been installed in several cities in China, such as Shanghai or Ningbo, and in other cities such as Graz, Austria, with 2 18-meter buses.

Image 4 CRRC/CSR in Graz, Austria and Ningbo, China.

Source: CRRC/CSR.

The advantage of this system compared to end-of-route charging system is that it requires fewer on-board batteries (in fact, supercaps are used) as well as less investment and fewer buses, as it does not have to wait for the end of the route; on the other hand, the disadvantage is that the station investment is greater.

The following table shows the technical and environmental characteristics of ultra-fast opportunity charging buses.

Table 20 Technical parameters for ultra-fast opportunity charging buses (18m articulated without AC).

Parameters	Value	Source
Electricity consumption	1.8 kWh/km	Same value as trolleybuses (without AC); Consumption can be lower and reach 1.4 kWh/km without slopes, at a constant speed of 15-20 km/h, without AC, with drivers trained in Eco-Driving etc.; see chapter 7.1 for more details.
Battery capacity per bus	70 kWh	Same as trolleybuses; may be super-cap
Percentage of reserve buses	10%	Just like trolleybuses
Total fleet of buses required (incl. reserve fleet)	52 buses	Same availability and capacity as diesel buses or trolleybuses
Number of fast loaders on the route (round trip)	16	Every 2km
Power of fast chargers	600 kW	ABB Geneva or Nantes or CSR system in several cities; allows 100% electric operation by charging for 20 seconds at each station and 1 minute at the end of the route (with 90% charger power)
Number of slow chargers	26	Each charger with 2 guns to simultaneously charge 2 buses resulting in 1 charger for 2 buses
Power of slow chargers	25 kW	Capacity required to fully charge the batteries in less than 4 hours
Diesel Bus Relative Noise Reduction	50%	ABB, 2017
TTW CO2e	0 gCO_2/km	No direct emissions
CO2e WTW incl. BC	767 gCO_{2e}/km	Includes emissions from electricity production

The power of the installed fast chargers is 600 kW; however, the installed peak power is only between 10 and 20% of the nominal load (in Nantes, for example, it is 10%), as the super capacitors or the batteries installed in the stations flatten the demand and reduce the current demanded from the network. This also has a positive impact on the electricity tariff by reducing the cost per installed power. The following table indicates the financial parameters of the system with opportunity charging buses.

Table 21 Financial and economic parameters for ultra-fast opportunity loading systems.

Parameter	Value	Source
Incremental opportunity load bus cost compared to diesel bus	70%	20% lower than a trolleybus (also because it has fewer batteries)
CAPEX bus	620,000 USD	Calculated on the basis of incremental cost relative to diesel bus
Cost of electricity	0.13 USD/kWh	Average price incl. load per power output[62]
Diesel Bus Maintenance Cost	-10%	Between BEBs and trolleybuses
Maintenance cost	0.101 USD/km	
Bus life cycle	20 years	Same as trolleybuses; supercaps also have this service life
CAPEX slow charger	15,000 USD	CAPEX in China for loaders with 2 50 kW guns
CAPEX ultra-fast charger	750,000 USD	Based on ABB (TOSA Geneva) and CSR China
CAPEX infrastructure	12.39 MUSD	Calculated based on the number of chargers per type of charger; no land costs
Cost of infrastructure maintenance	0.25%	50% of trolleybus infrastructure investment maintenance costs
Infrastructure life cycle	20 years	ARB, CARB, 2017
Economical cost of local emissions and noise	0.024 USD/km	Calculated on the basis of emissions and unit cost per emission
Economic cost of GHG emissions (WTW incl. BC)	0.031 USD/km	
Total economic costs	0.055 USD/km	

The following table shows the environmental impact for Axis 8 South per year by using an ultra-fast opportunity loading system.

62 Calculated on the basis of the total installed power and the load per power plus the use of electricity during the whole day for the differentiated tariffs according to the schedule; installed power of fast chargers 20% of the nominal power.

Table 22 Environmental impact of the implementation of ultra-fast opportunity freight buses (in t/year) on Eje 8 Sur.

Parameter	Value in t/year
$PM_{2.5}$ emissions	0.0
NO_2 emissions	0.0
SO_2 emissions	0.0
CO_2 (TTW) emissions	0.0
CO_{2e} WTW emissions incl. BC	2,894

The following table shows the financial and economic impacts of investing in an ultra-fast opportunity busload system. The CAPEX includes the total fleet (operational plus reserve fleet) and infrastructure.

Table 23 Financial and economic impact of implementing an ultra-fast opportunity charging system on Eje 8 Sur (in constant 2017 USD).

Parameter	Value
CAPEX buses year 1	32.2 MUSD
CAPEX infrastructure year 1	12.4 MUSD
CAPEX cumulative VPN incl. residual value and battery replacement	34.2 MUSD
OPEX VPN cumulative 12 year buses	9.5 MUSD
OPEX VPN cumulative 12 years infrastructure	0.3 MUSD
Financial TCO	**0.97 USD/km**
Cumulative environmental costs 12 years	2.48 MUSD
Economical TCO	**1.02 USD/km**

Notes:
a). OPEX includes only energy and direct maintenance costs
b). TCO calculated on the basis of CAPEX+OPEX Net Present Value for 12 years
c). Economical TCO includes environmental costs (emissions and noise)
d). Environmental economic costs are not discounted over time

As can be seen, the financial TCO is slightly lower than the TCO of diesel buses and the economic TCO is significantly lower than the TCO of diesel buses.

The table below shows the variations in financial TCO by changing critical parameters such as bus CAPEX, power consumption and discount rate. The other values are considered more stable and less prone to significant variation.

Table 24 Sensitivity in financial TCOs to changes in critical values.

Variation Parameters	Pessimistic Value[63]	Regular Value[64]	Optimistic Value[65]
Discount rate	0.97 USD/km	0.97 USD/km	0.96 USD/km
CAPEX bus	1.04 USD/km	0.97 USD/km	0.91 USD/km
Energy consumption	0.98 USD/km	0.97 USD/km	0.95 USD/km

With an optimistic CAPEX bus value an ultra-fast opportunity charging system has a significantly lower financial TCO than a diesel bus. The profitability of the system is basically sensitive to the CAPEX of the bus. It is not very sensitive to bus consumption because it does not affect the investments in the system but only the operating cost (in contrast to BEBs or opportunity charging systems where lower consumption affects the amount of batteries that must be on board).
The marginal cost of GHG reduction is -16 USD/tCO2e with an ultra-fast opportunity charging system[66].

7 Battery-Electric Buses (BEBs).

7.1 Introduction.

In this section we analyze two different solutions with Battery-Electric Buses (BEBs):

- Buses with a sufficient number of batteries on board to be able to circulate all day without the need to charge the batteries. In this type of bus, buses are charged overnight, and one of its advantages is that the price of electricity is cheaper during this time, in addition to requiring less investment in chargers, and its relatively simple operation. Disadvantage include a high investment for the bus due to therefor the amount of batteries required, which in turn increases the weight of the units, which can limit the number of people transported.

- BEBs with a smaller set of batteries, which are charged once or several times a day, either by plug or pantograph.

In this context, some important aspects to consider for the specific case of Eje 8 Sur are:

- On working days buses travel up to 250 km, so the bus must be able to travel this distance.

- Because of the service schedule there are 4 hours available for night charging, i.e. the buses must be fully charged in that short period of time.

To determine the number of batteries required as well as the power of the chargers, there are several critical factors, such as:

[63] 5% discount value and 90% higher CAPEX bus than diesel bus
[64] Discount value of 7.8% and CAPEX bus 70% higher than diesel bus
[65] 10% discount value and CAPEX bus 50% higher than diesel bus
[66] Based on financial TCO differential with diesel buses and WTW emissions incl. BC

- The actual electricity consumption of the bus;
- Minimum battery SOC;
- SOC of the battery during its life cycle.

Electric bus manufacturer, such as Yutong or BYD, state that an articulated bus can achieve a range of autonomy between 260 and 280km, with a set of batteries of about 450 kWh[67]. The reason why these figures should be taken with caution will be explained below.

7.1.1 Electricity Consumption.

Consumptions reported by manufacturers are calculated under optimal conditions. It may be that the manufacturer reports the data using the UITP E-SORT (Standardised On-Road Test Cycle) [68], which has the advantage of being a standardized measurement allowing comparison between different manufacturers. However, the UITP itself has clearly mentioned that actual consumption may be significantly different from the consumption established in the SORT[69]. A guarantee for the consumption offered by the manufacturer always refers to the consumption under the conditions of the test; that is to say, the SORT-test can be reproduced and verified if the manufacturer's values coincide with the values measured in the test (it does not refer to the real values of the operator's consumption). In light of this, it is important to review the actual consumption data from operators with large fleets[70]. 12m BEBs have an average consumption of 1.2 kWh/km, consistent with reported values of electric 12m trolleybuses; therefore it is considered appropriate to take the consumption data of 18m trolleybuses, where there is enough experience[71]. In order to reach the consumption of 1.8 kWh/km, considered a conservative value (the same as in the consumption of diesel, which, being a high value, avoids financial surprises in the operation), the following elements have been taken into consideration:

- In Eindhoven, the Netherlands, operates since 2017 the largest fleet of 18m BEBs in the world (43 units), with a system that operates with rapid opportunity charging during the day (at 300 kW), which means that after operating for 3 hours the units are charged for 40 minutes, while at night they are charged by 30 kW chargers[72]. The buses have an operating range of 80km, operate on short routes of 4 to 12km without elevation with a speed of 19 to 28km/h, have a maximum capacity of 136 passengers and operate similarly to a BRT. It is worth mentioning that the drivers were trained in Eco-driving, in addition, the system reaches values of 1.5 kWh/km[73].
- The results of 18m BEB pilot bus operations show bus consumption values between 1.8 kWh/km and 3 kWh/km (Barcelona[74], Graz[75], Beijing[76]).

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[67] Yutong E18 & BYD K11A specifications
[68] http://www.uitp.org/news/E-SORT-addendum
[69] UITP, 2014
[70] Large fleets because there is a lot of variation in consumption even on the same bus route by the driver, bus conditions, traffic conditions, environmental conditions, etc.
[71] Based on values from multiple cities in China, Foothill Transit in California and pilot fleets in Europe; see Grutter, 2017; Solaris reports on SORT basis for a 12m electric bus a value of 1.28 kWh/km without AC and without heating and 2.52 kWh/km in difficult conditions (www.solarisbus.com)
[72] The system has 22 300 kW fast chargers and 10 30 kW slow chargers for a total of 43 buses.
[73] https://www.limburger.nl/cnt/dmf20161206_00029565/trambel-op-43-elektrische-bussen-in-eindhoven
[74] ZeEUS, 2017
[75] Jungmeier, 2017
[76] Beijing Bus Group

- 18m trolleybuses operating without AC have an average consumption of 1.8 kWh/km[77].
- The manufacturers Yutong and BYD estimate consumption between 1.6 to 1.7 kWh/km[78].

The conservative value is taken to be 1.8 kWh/km. Eindhoven records lower values, but with lighter buses (fewer passengers on average, buses with a small set of batteries and therefore less weight to charge the buses after 3 hours again, high commercial speeds, and drivers trained in eco-driving). However, calculations are also made with a more optimistic value of 1.4 kWh/km.

It is very important to emphasize that this value does not include the use of AC or heating, as the use of AC would increase electricity consumption by up to 50%. In the case of Eje 8 Sur, the use of buses with AC is not contemplated, and so this variable has been excluded.

7.1.2 Battery SOC.

The following factors must be considered:

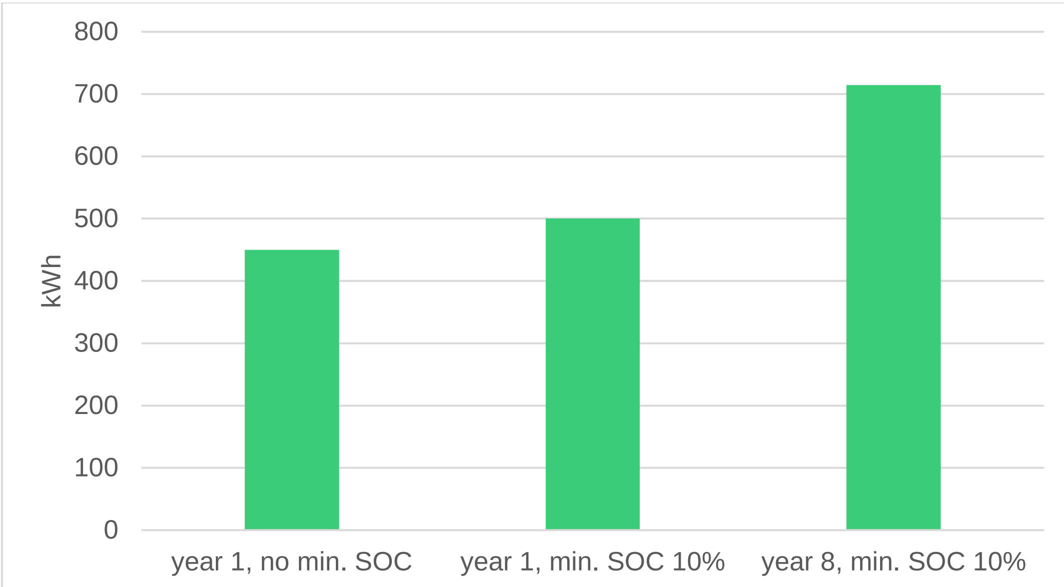
- The batteries have a minimum State of Charge (SOC) of around 10% so that they will not be damaged and the warranty will be maintained, in addition, even if there is no potential damage limitation to the battery, the bus must be operated with a reserve, in order to prevent them from being stranded halfway due to a lack of electricity. Therefore, a 10% reserve range is calculated, which would be enough for a little less than one complete turn in a bus with 500 kWh, to this must be added the time required to reach the tank and be able to load the bus[79].

- The SOC of the battery deteriorates significantly over time. The manufacturer's stated operating range is potentially correct in the first year of operation, but not in the fifth or eighth year; however, the transport operator must be able to operate in the same manner throughout the battery life cycle, which is estimated at 8 years. To be certain of the calculations, it is essential that the operators require a minimum SOC guarantee in year 8. For the purposes of this report a SOC of 70% has been calculated for year 8, although many manufacturers offer a guarantee only up to year 6 and with lower SOC values.

The following graph shows the performance impact, minimum SOC, and life cycle SOC on the number of batteries required.

[77] In trolleybuses if you have enough experience operating with 18m buses
[78] Yutong model E18 280km of autonomy with 459 kWh of battery according to manufacturer and BYD K11a Mexico 260km of autonomy with 438 kWh of battery.
[79] In addition, the SOC indications are not very precise

Graph 4 required battery capacities.



Note: Battery capacity for bus 18m, 250km daily with a performance of 1.8kWh/km.

7.2 BEB night charging.

BEBs with sufficient autonomy to cover the entire daily requirement are popular in many cities in China and Europe, where there are pilot fleets[80]. It should be taken into consideration that buses operating under this scheme are mainly 6 to 12m buses operating on short routes; it should also be considered that the hours of operation in most Chinese cities are shorter than in Mexico.

Image 5 Night Charging BEBs

Source: Grutter Consulting, BEBs in Shenzhen and Tianjin.

[80] However, BEB buses in Europe of 18m operate on an opportunity charge and not on a night-only charge-only basis - see ZeEUS, 2017

The following table shows the technical and environmental characteristics of BEBs with night-time charging.

Table 25 Technical parameters of BEBs with night load (18m articulated w/o AC)

Parameter	Value	Source
Electricity consumption	1.8 kWh/km	Same value as trolleybuses (without AC); Consumption can be lower and reach 1.4 kWh/km without slopes, at a constant speed of 15-20 km/h, without AC, with drivers trained in Eco-Driving etc.; see chapter 7.1. for more details.
Battery capacity per bus	710 kWh	Calculated on the basis of 250km daily operation, performance of 1.8 kWh/km, a minimum SOC of 10% and a battery SOC in year 8 of 70%
Percentage of reserve buses	15%	5% higher than diesel buses based on experience of BEB availability; see Foothill Transit, 2017 5% lower availability; pilots in Europe up to 20% lower availability (VDV, 2016); large fleets in China 1-5% lower availability (Fuzhou, Jinan, Beijing)
Total fleet of buses required	54 buses	Includes reserve fleet
Number of slow chargers	54	1 charger per bus
Power of slow chargers	200 kW	Capacity required to fully charge the batteries in 4 hours (2 100 kW inputs per bus)
Diesel Bus Relative Noise Reduction	50%	ABB, 2017
TTW CO_{2e}	0 gCO_2/km	No direct emissions
CO2e WTW incl. BC	767 gCO_{2e}/km	Includes emissions from electricity production

The consumption of this type of BEB is potentially 10% higher because it weighs more (between 4 and 6 tons) than a trolleybus, as it must charge the battery set. This also leads to a reduction in passenger capacity, as the weight per axle is too high.

There are manufacturers that already offer 18m buses with this amount of batteries, but those offered for the Mexico market have between 440 and 460 kWh, while in the U.S.A there are 18m buses with batteries between 550 and 660 kWh[81]. The following table presents the financial parameters of slow charging BEBs.

[81] BYD & Proterra

Table 26 Financial and economic parameters for slow loading BEBs

Parameter	Value	Source
Incremental BEB cost compared to diesel bus	100%	Average incremental cost of BEB of 450 kWh
CAPEX BEB	870,000 USD	Calculated on the basis of incremental cost relative to diesel bus plus cost of higher battery set
Cost of electricity	0.28 USD/kWh	Average price incl. load per power output[82]
Diesel Bus Maintenance Cost	-30%	Landerl, 2017 (0-50% less costs), CARB, 2016 (30% less costs), cities in China; slightly more tire wear, fewer moving parts and less maintenance, more expensive parts and more qualified personnel
Maintenance cost	0.078 USD/km	
Bus service life	16 years	2x battery life, less vibration and therefore longer life than diesel buses
CAPEX chargers	100,000 USD	CAPEX in China for 200 kW chargers
CAPEX infrastructure	5.4 MUSD	Investment in loaders; no land costs and no transformers
Cost of infrastructure maintenance	0.25%	50% of trolleybus infrastructure investment maintenance costs
Infrastructure useful life	20 years	ARB, CARB, 2017
Economical cost of local emissions and noise	0.024 USD/km	Calculated on the basis of emissions and unit cost per emission
Economic cost of GHG emissions (WTW incl. BC)	0.031 USD/km	
Total economic costs	0.055 USD/km	

The cost of electricity is significantly higher than for trolleybuses or opportunity charging buses, even though it is charged only at night and at the lowest rate. The reason for this increase is due to the cost per installed power, as it greatly increases the cost of electricity per power by requiring 200kW chargers and one charger per bus, making the installed power almost 11 MW, and it is very likely that it will be necessary to install transformers in the yard. In other cities with slow charging systems, chargers of 50 kW or less[83] are used, however, the 200 kW power is required because of the number of batteries in the bus and the few hours available at night to charge the bus.

The following table shows the environmental impact per year of using BEBs in the Eje 8 Sur.

[82] Calculated on the basis of total installed power and load per power plus electricity consumption at night
[83] In the case of Mexico this would lead to electricity costs of USD 0.11/kWh or less than for trolleybuses.

Table 27 Environmental impact generated by implementing BEBs (in t/year) on the Eje 8 Sur.

Parameter	Value t/year
$PM_{2.5}$ emissions	0.0
NO_2 emissions	0.0
SO_2 emissions	0.0
CO_2 (TTW) emissions	0.0
CO_{2e} WTW emissions incl. BC	2,894

The following table shows the financial and economic impacts of investing in slow loading BEBs. The CAPEX includes the total fleet (operational plus reserve fleet) and infrastructure.

Table 28 Financial and economic impact of implementing slow loading BEBs on Eje 8 Sure (in constant 2017 USD).

Parameter	Value
CAPEX buses year 1	47.0 MUSD
CAPEX infrastructure year 1	5.4 MUSD
CAPEX cumulative VPN incl. residual value and battery replacement	46.1 MUSD
OPEX VPN cumulative 12 year buses	16.8 MUSD
OPEX VPN cumulative 12 years infrastructure	0.2 MUSD
Financial TCO	**1.39 USD/km**
Cumulative environmental costs 12 years	2.48 MUSD
Parameter	**1.45 USD/km**

Notes:
a). OPEX includes only energy and direct maintenance costs.
b). TCO calculated on the basis of CAPEX+OPEX Net Present Value for 12 years.
c). Economical TCO includes environmental costs (emissions and noise).
d). Environmental economic costs are not discounted over time.

The financial TCO is much higher than the TCO of diesel buses and higher than the other electrical options. The table below shows the variations in financial TCO by varying some critical parameters such as bus CAPEX, maintenance costs, infrastructure CAPEX, energy consumption and discount rate. The other values are considered more stable and less prone to significant variation.

Table 29 Sensitivity of financial TCOs to variations

Variation Parameter	Pessimistic Value[84]	Regular Value[85]	Optimistic Value[86]
Discount rate	1.45 USD/km	1.39 USD/km	1.35 USD/km
CAPEX bus	1.46 USD/km	1.39 USD/km	1.31 USD/km
Maintenance costs	1.41 USD/km	1.39 USD/km	1.38 USD/km
CAPEX infrastructure	1.42 USD/km	1.39 USD/km	1.34 USD/km
Energy consumption	1.45 USD/km	1.39 USD/km	1.28 USD/km

Even with optimistic variations, the TCO is significantly higher for BEBs than for other electrical options. On the other hand, the marginal cost of GHG reduction is 251 USD/tCO_{2e} for slow charging BEBs[87].

7.3 Intermediate Charging BEBs.

It is the most widely used system in Chinese cities that opted to 100% electrify operations, since it reduces the investment in buses, makes the operation more flexible (the bus can be charged 1 to 3 times a day as needed), and has a greater availability of high power fast chargers at a much lower cost, which also allow buses to be charged in lapses of 15 to 30 minutes during operating periods.

Image 6 *360Kw fast charging stations in Beijing and Hengyang.*

Source: Grutter Consulting,

[84] 5% discount value, CAPEX bus 120% higher than diesel bus, maintenance costs same as diesel bus, CAPEX infrastructure 120,000 USD per 200kW charger, consumption of 2.0 kWh/k

[85] 7.8% discount value, CAPEX bus 100% higher than diesel bus, maintenance costs 30% lower than diesel bus, CAPEX infrastructure 100,000 USD per 200kW charger, consumption of 1.8 kWh/km

[86] 10% discount value and CAPEX bus 80% higher than diesel bus, maintenance costs 50% lower than diesel bus, CAPEX infrastructure 50,000 USD per 200kW charger, consumption of 1.4 kWh/km

[87] Based on financial TCO differential with diesel buses and WTW emissions incl. BC

The following table summarizes the technical and environmental characteristics of fast loading BEBs.

Table 30 Technical parameters for fast loading BEBs (18m articulated w/o AC).

Parameter	Value	Source
Electricity consumption	1.8 kWh/km	Same value as trolleybuses (without AC); Consumption can be lower and reach 1.4 kWh/km without slopes, at a constant speed of 15-20 km/h, without AC, with drivers trained in Eco-Driving etc.; see chapter 7.1 for more details.
Battery capacity per bus	350 kWh	Calculated on the basis of 250km daily operation, performance of 1.8 kWh/km, a minimum SOC of 10% and a battery SOC in year 8 of 70% with 2 charges in the day of 30 minutes each with a 400 kW charger (180 kWh charge in the day)
Percentage of reserve buses	15%	5% higher than diesel buses based on experience of BEB availability; see Foothill Transit, 2017 5% lower availability; pilots in Europe up to 20% lower availability (VDV, 2016); large fleets in China 1-5% lower availability (Fuzhou, Jinan, Beijing)
Total fleet of buses required	54 buses	Includes reserve fleet
Number of night chargers	27	1 charger with two guns for every 2 buses
Power of night chargers	200 kW	Capacity required to fully charge the batteries in 4 hours (1 100 kW input per bus)
Number of fast loaders	9	Calculated on the basis of 6 hours available during the day to charge buses, 1 hour charge per bus (2x 30 minutes or 1x 1 hour) and 54 units
Power of fast chargers	400 kW	Capacity required to fully charge the batteries in 60 minutes (2 200 kW inputs per bus)
Diesel Bus Relative Noise Reduction	50%	ABB, 2017
TTW CO_{2e}	0 gCO_2/km	No direct emissions
CO2e WTW incl. BC	767 gCO_{2e}/km	Includes emissions from electricity production

The following table shows the financial parameters of fast-charging BEBs.

Table 31 Financial and economic parameters of fast-charging BEBs.

Parameter	Value	Source
Incremental BEB cost compared to diesel bus	100%	Average incremental cost of BEB of 450 kWh
CAPEX BEB	690,000 USD	Calculated on the basis of incremental cost relative to diesel bus plus cost of lower battery set
Cost of electricity	0.25 USD/kWh	Average price incl. load per power output[88]
Diesel Bus Maintenance Cost	-30%	Landerl, 2017 (0-50% less costs), CARB, 2016 (30% less costs), cities in China; slightly more tire use, but fewer moving parts and less maintenance, more expensive parts and more qualified personnel
Maintenance cost	0.078 USD/km	
Bus service life	16 years	2x battery life, less vibration and therefore longer life than diesel buses
CAPEX night chargers (200 kW)	100,000 USD	CAPEX in China for 200 kW chargers
CAPEX fast chargers (400 kW)	150,000 USD	CAPEX in China for 200 kW chargers
CAPEX infrastructure	4.1 MUSD	Investment in shippers; no land costs
Cost of infrastructure maintenance	0.25%	50% of trolleybus infrastructure investment maintenance costs
Infrastructure lifecycle	20 years	ARB, CARB, 2017
Economical cost of local emissions and noise	0.024 USD/km	Calculated on the basis of emissions and unit cost per emission
Economic cost of GHG emissions (WTW incl. BC)	0.031 USD/km	
Total economic costs	0.055 USD/km	

The cost of electricity is significantly higher than for trolleybuses or buses with opportunity load because of the higher installed power. The cost per kWh is similar to that of the slow loading BEBs, although it consumes electricity during the day (the total installed power is lower).

The following table shows the environmental impact per year of using BEBs on Eje 8 Sur.

[88] Calculated on the basis of total installed power and load per power plus electricity usage at night and day base rate

Table 32 Environmental impact of implementing BEBs (in t/year) on Eje 8 Sur.

Parameter	Value t/year
$PM_{2.5}$ emissions	0.0
NO_2 emissions	0.0
SO_2 emissions	0.0
CO_2 (TTW) emissions	0.0
CO_{2e} WTW emissions incl. BC	2,894

The following table shows the financial and economic impacts of investing in fast-loading BEBs. The CAPEX includes the total fleet (operational plus reserve fleet) and infrastructure.

Table 33 Financial and economic impact of implementing fast-loading BEBs on Eje 8 Sur (in constant 2017 USD).

Parameter	Value
CAPEX buses year 1	37.3 MUSD
CAPEX infrastructure year 1	4.1 MUSD
CAPEX cumulative NPV incl. residual value and battery replacement	35.4 MUSD
OPEX NPV cumulative 12 year buses	15.3 MUSD
OPEX NPV cumulative 12 years infrastructure	0.1 MUSD
Financial TCO	**1.12 USD/km**
Cumulative environmental costs 12 years	2.48 MUSD
Economical TCO	**1.18 USD/km**

Notes:
a). OPEX includes only energy and direct maintenance costs.
b). TCO calculated on the basis of CAPEX+OPEX Net Present Value for 12 years.
c). Economical TCO includes environmental costs (emissions and noise).
d). Environmental economic costs are not discounted over time.

The financial TCO is higher than the TCO for diesel buses and other electrical options. The following table shows the changes in the financial TCO by varying critical parameters such as bus CAPEX, maintenance costs, discount rate, infrastructure CAPEX and energy consumption. The other values are considered more stable and less prone to significant variation.

Table 34 Financial TCO sensitivity to changes.

Variation Parameters	Pessimistic Value[89]	Regular Value[90]	Optimistic Value[91]
Discount rate	1.17 USD/km	1.12 USD/km	1.09 USD/km
CAPEX bus	1.19 USD/km	1.12 USD/km	1.04 USD/km
Maintenance costs	1.14 USD/km	1.12 USD/km	1.11 USD/km
CAPEX infrastructure	1.14 USD/km	1.12 USD/km	1.10 USD/km
Energy consumption	1.23 USD/km	1.12 USD/km	1.01 USD/km

Fast charging BEBs are clearly better than night charging only BEBs, as they have lower energy consumption, and with lower CAPEX their financial TCOs are comparable to those of diesel buses. The marginal cost of GHG reduction is 81 USD/tCO2e with fast-charging BEBs[92].

With an optimistic CAPEX bus value, an ultra-fast opportunity charging system has a significantly lower financial TCO than a diesel bus. The profitability of the system is basically sensitive to the CAPEX of the bus. It is not very sensitive to bus consumption because it does not affect the investments in the system, but only the operating cost (in contrast to BEBs or opportunity charging systems where lower consumption affects the amount of batteries that must be on board). The marginal cost of GHG reduction is -16 USD/tCO2e with an ultra-fast opportunity charging system[93].

8 Comparison.

8.1 General Comparison.

The following table compares the key parameters between the different technologies.

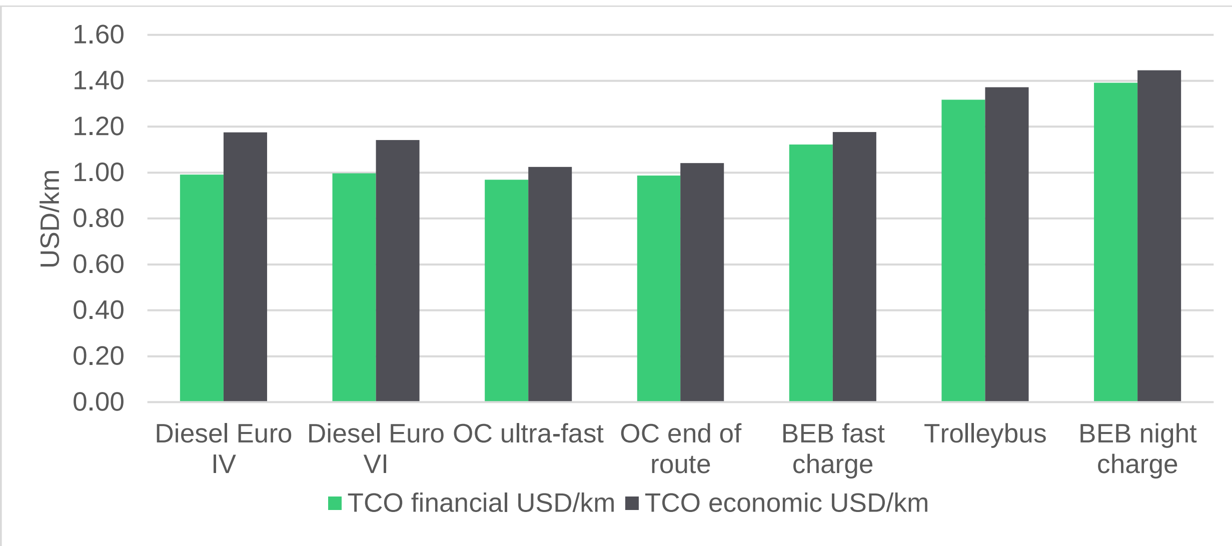
Table 35 Technologies Comparisons

Parameter	Unit	Euro IV Diesel	Euro VI Diesel	Trolleybus	End-of-route OC	ultra-fast OC	BEB night charge	BEB fast charg

89 5% discount value, CAPEX bus 160% higher than diesel bus and maintenance costs same as diesel bus
90 7.8% discount value, CAPEX bus 120% higher than diesel bus and 30% lower maintenance costs than diesel bus
91 10% discount value and CAPEX bus 80% higher than diesel bus and 50% lower maintenance costs than diesel bus
92 Based on financial TCO differential with diesel buses and WTW emissions incl. BC
93 Based on financial TCO differential with diesel buses and WTW emissions incl. BC

CAPEX year 1	MUSD	19.0	19.2	61.6	41.6	44.6	52.4	41.3
VPN CAPEX	MUSD	19.0	19.2	47.4	35.2	34.2	46.1	35.4
OPEX VPN	MUSD	25.9	25.9	12.2	9.5	10.2	16.9	15.4
Financial TCO	USD/km	0.99	1.00	1.32	0.99	0.98	1.39	1.12
Economical TCO	USD/km	1.18	1.14	1.37	1.04	1.04	1.45	1.18
Annual GHGs	tCO_{2e}	8,976	8,745	2,894	2,894	3,216	2,894	2,894
MAC	USD/tCO_{2e}	n.d.	n.d.	205	-4	-10	251	81

Graph 5 Financial and economic TCO between different systems.



Source: Grütter Consulting.

It is obvious that the initial investment for all electrical systems is much higher (an additional $20-$40) than for diesel buses. However, OPEX costs are significantly lower for electrical systems. Opportunity charging systems have financial TCOs comparable to economical diesel and TCO buses, which are clearly lower than diesel buses. Electric trolleybuses, on the other hand, may fall into this category if a significant recovery of the existing system is made.

The comparison also shows that opportunity charging systems have significant economic advantages over BEBs, i.e. that it is better to invest in opportunity charging systems for Eje 8 Sur, rather than in BEBs. It is also clear that, if BEBs are chosen, it is better to implement buses with fewer batteries and charge them quickly once or twice a day. For trolleybuses, profitability basically depends on whether or not a significant part of the existing infrastructure can be used without additional investment. These results are not surprising and are similar to the experiences of the new systems established in many countries with 18m buses:

- All cities in Europe operating with 18m electric buses have opted for trolleybuses or opportunity systems (ultra-fast on higher frequency routes and end-of-route on shorter or lower frequency routes) [94].

- When it comes to purchasing new electric buses, cities in China have a clear preference for buses with fewer batteries and fast daytime recharges, largely due to the reduced cost of high-powered chargers and the availability of buses that can withstand fast loads.

A third parameter is that the marginal costs of CO_2 reduction are negative for opportunity and potentially close to zero for opportunity charges systems in trolleybus when a significant part of the existing investment can be used. This indicates that climate change funds could be used to create a more attractive financial structure for electric buses. The annual reduction of GHG from operating electric buses in the Eje 8 Sur is about 6,000 tCO_{2e} per year, equivalent to a reduction of about 72,000 tCO_{2e} in 12 years[95].

8.2 Variation of key parameters.

8.2.1 Discount Factors.

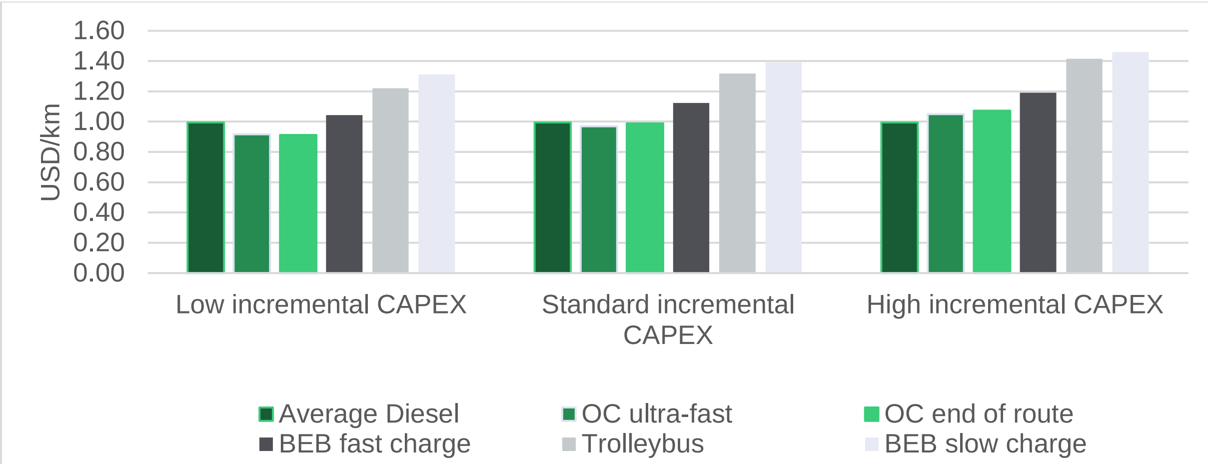
The standard discount factor used is 7.8%, which reflects the WACC of the transport sector. Calculations are also made with a lower discount factor (5%) and a higher value (10%, which is equal to the social discount rate used in Mexico). According to this calculation, the lower the discount value, the better the electrical systems are compared to diesel, as the savings will be heavier in the future; however, the TCO does not change significantly when the discount factor is changed and follows the same sequence between the options.

8.2.1.1 CAPEX variations in buses.

Different levels of additional investment are applied per electric bus relative to the diesel bus.

[94] Ver ZeEUS, 2017
[95] Based on WTW incl. BC (average reduction for diesel Euro IV and Euro VI)

Graph 6 Financial TCO with incremental CAPEX variations of electric buses.

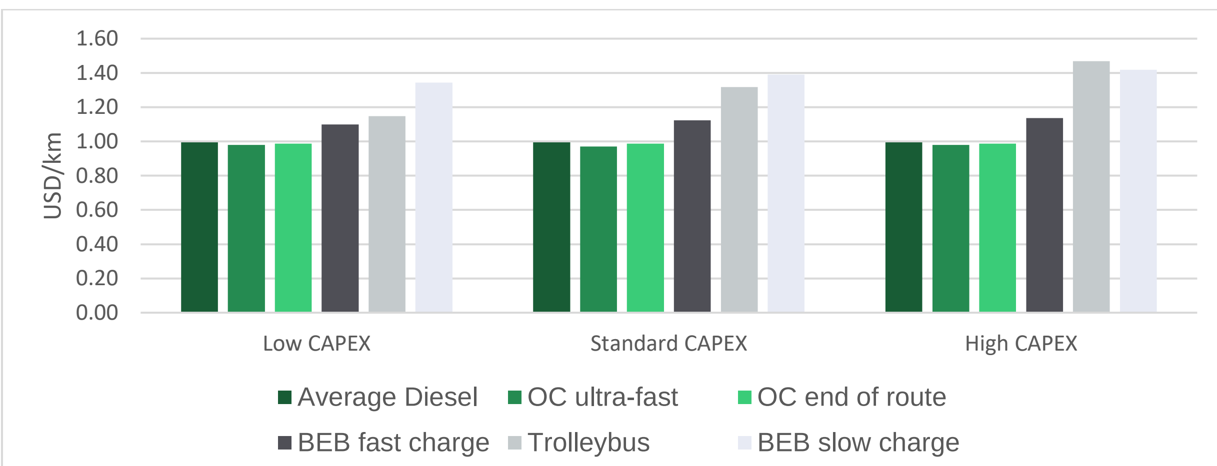


With an incremental CAPEX of the lower bus, opportunity charging systems are much more financially attractive to TCO than diesel buses; in turn, fast-charging BEBs in the daytime approach diesel buses.

8.2.1.2 CAPEX variations in infrastructure.

Different levels of investment in BEB loaders and trolleybus infrastructure are applied

Graph 7 Financial TCO with incremental CAPEX variations of electric buses.

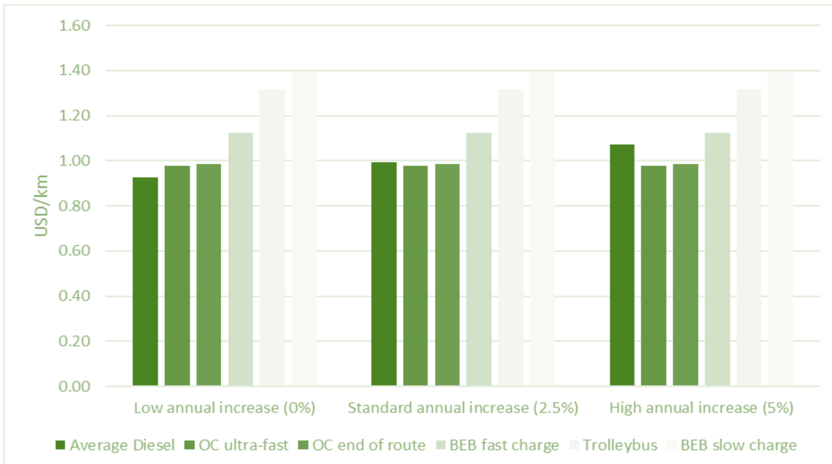


As already mentioned in chapter 5, investment is reduced and profitability is significantly improved by not having to make an investment in new trolleybus infrastructure. If less than 50% of the trolleybus

8.2.1.3 Energy Price Variations.

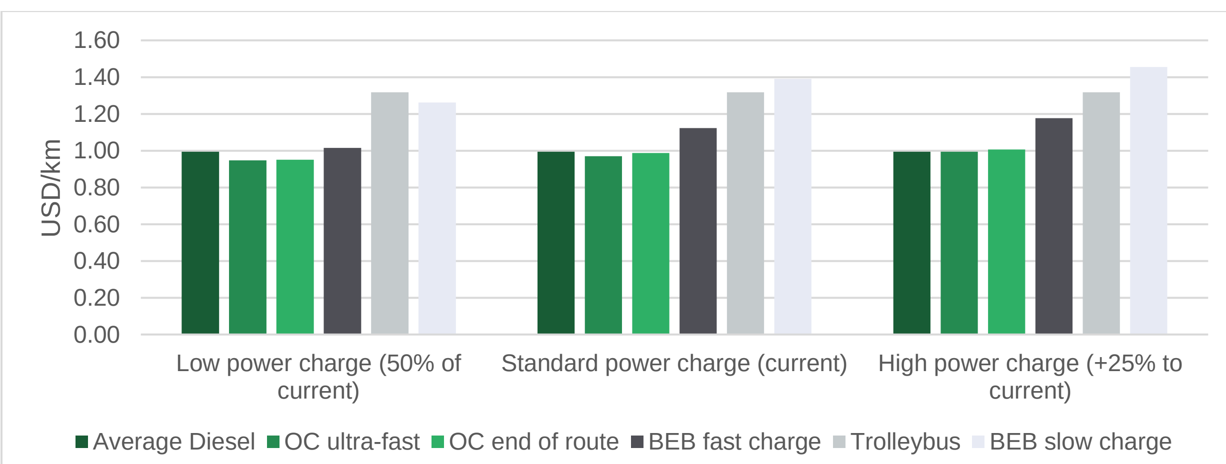
A variation of the projected real annual increase in the price of diesel is applied (0%, 2.5% and 5%) and of the price per power in the electricity tariff (50% of the current price, the current price applied and 25% higher than the current price).

Graph 8 Financial TCO with variations of CAGR diesel price.



By not raising the real price of diesel in the future, electricity systems are not financially profitable; logically, they improve their relative profitability, as there are increases in crude oil in real terms that go above the projected 2.5%.

Graph 9 Financial TCO with variations in the power price of the electricity tariff.

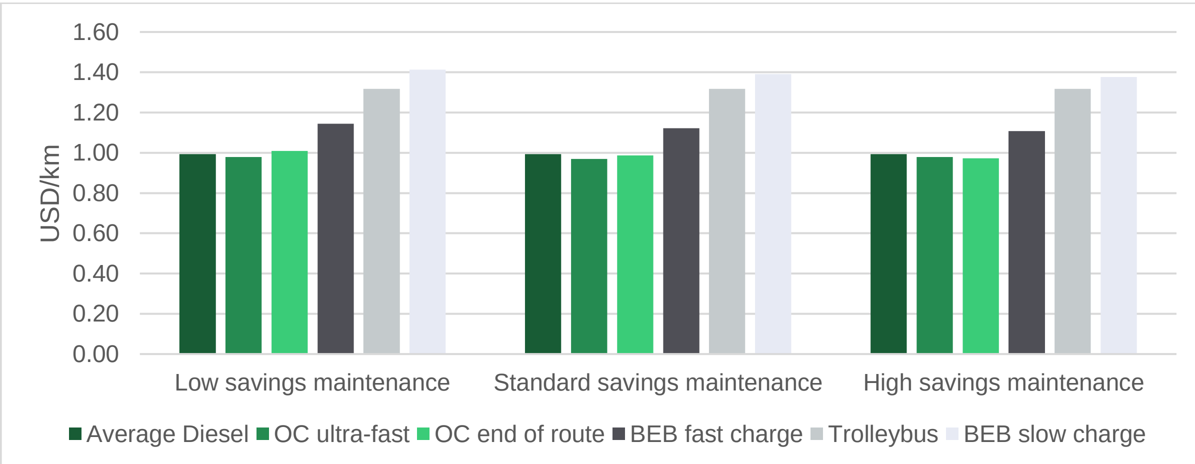


The effect of a change in the power tariff basically has a significant effect on BEBs, but is of less importance for other electricity systems.

8.2.1.4 Maintenance Costs.

A variation is made in the relative costs of electric buses and the absolute maintenance values of diesel buses (80% of the standard value, standard value and 150% of the standard value).

Graph 10 Financial TCO with variations in maintenance cost.



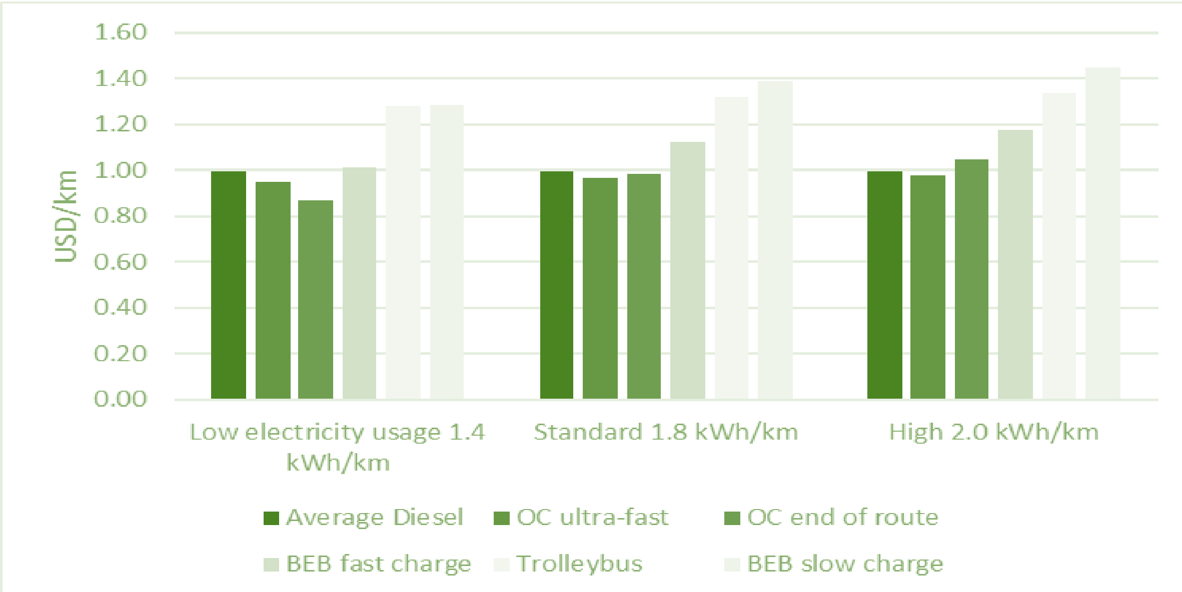
Note: Low maintenance savings with low diesel maintenance costs and BEBs maintenance costs similar to diesel buses; high maintenance savings with high diesel bus costs and 50% lower maintenance costs BEBs

The graph shows that the influence of maintenance costs is not decisive, as they represent a low value relative to energy costs and bus capital costs.

8.2.1.5 Energy efficiency of electric buses.

A variation in the consumption of electric buses is made (1.4, 1.8 y 2.0 kWh/km).

Graph 11 Financial TCO with variations in energy use.

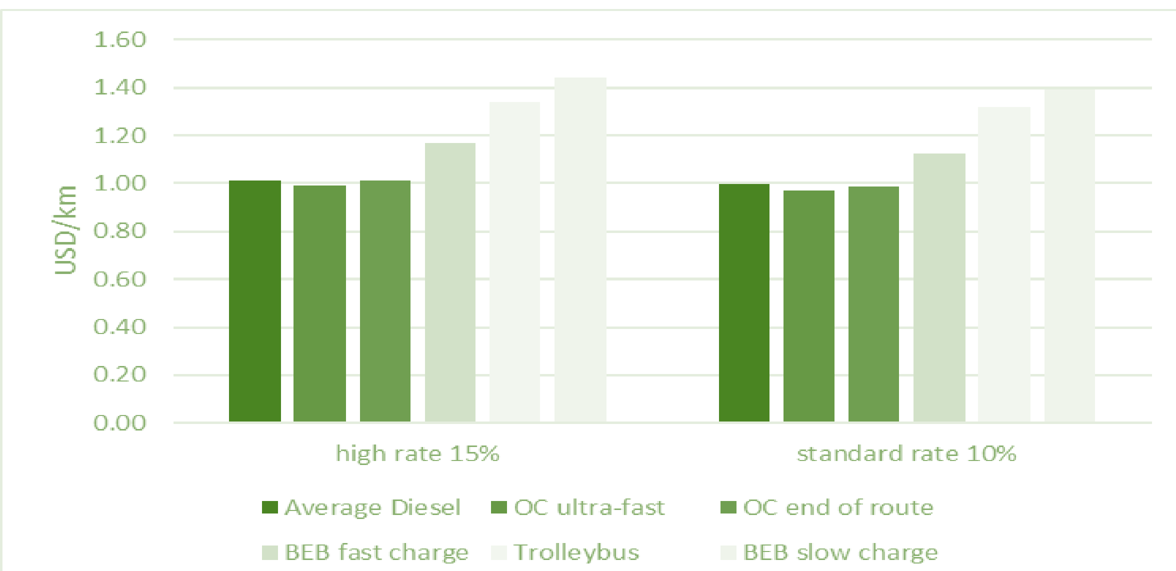


With a lower use of electricity, electric buses become more profitable, while day-charged BEBs are at the same level as diesel buses.

8.2.1.6 Reserve Fleet.

A variation of the percentage of reserve buses is made (10%, respectively, 15% in reserve buses).

Graph 12 Financial TCO with variations in the percentage of reserve buses.



A larger reserve fleet negatively affects the relative profitability of BEBs, but does not have a very significant impact and does not change the sequence of technologies.

8.2.2 Conclusions.

Ultra-fast opportunity charging systems and end-of-route opportunity charging systems have financial TCOs comparable, or better to diesel buses, and clearly lower economic TCOs compared to diesel buses. An ultra-fast charging buses system has more advantages over an end-of-route charging system when expanding the system. Even with more buses there is no need to make more investment in infrastructure, besides the fact that buses are cheaper than in a charging system at the end of the route (because they have fewer batteries), in other words, it requires more investments in infrastructure and less investments in buses, which is becomes advantageous by expanding the frequencies and using more buses. On the other hand, for a system with end-of-route charging, a third charging station should also be built when expanding the bus fleet, because the system is at full capacity with the current fleet and frequency. This means additional investment in infrastructure and increased space requirements. For these reasons the ultra-fast charging system is more attractive than the end-of-route loading system for a BRT such as Eje 8 Sur.

Under all variations it is also clear that **BEBs are less interesting** electrical alternatives. Of the two variations of BEBs, daytime fast charging is better for the Eje 8 Sur than using BEBs that are only charged at night.

Trolleybuses are viable if a large part of the existing infrastructure can be used without major investments, which is the case along the Eje 8 Sur, further analysis on the costs for implementing a new Trolleybuses line must be undertaken to analyze how much of the existing infrastructure along Eje 8 can be repurposed.

The variations with the greatest impact are variations in the CAPEX of buses, projected diesel prices and the use of energy in electric buses. This result is important when preparing financial structure that can use CAPEX variation instruments and guarantees on energy savings.

9 Potential financial structuring.

9.1 Potential Instruments.

The business of a transport operator is to move people, and therefore they require high reliability in their work instrument (the bus) and reliability of costs in order to plan their income and expenses. Electric buses are not a known technology and represent a risk to the operator. In fact, the potential risks faced by operators that might lead him/her to opt for diesel buses instead of an electric bus are:

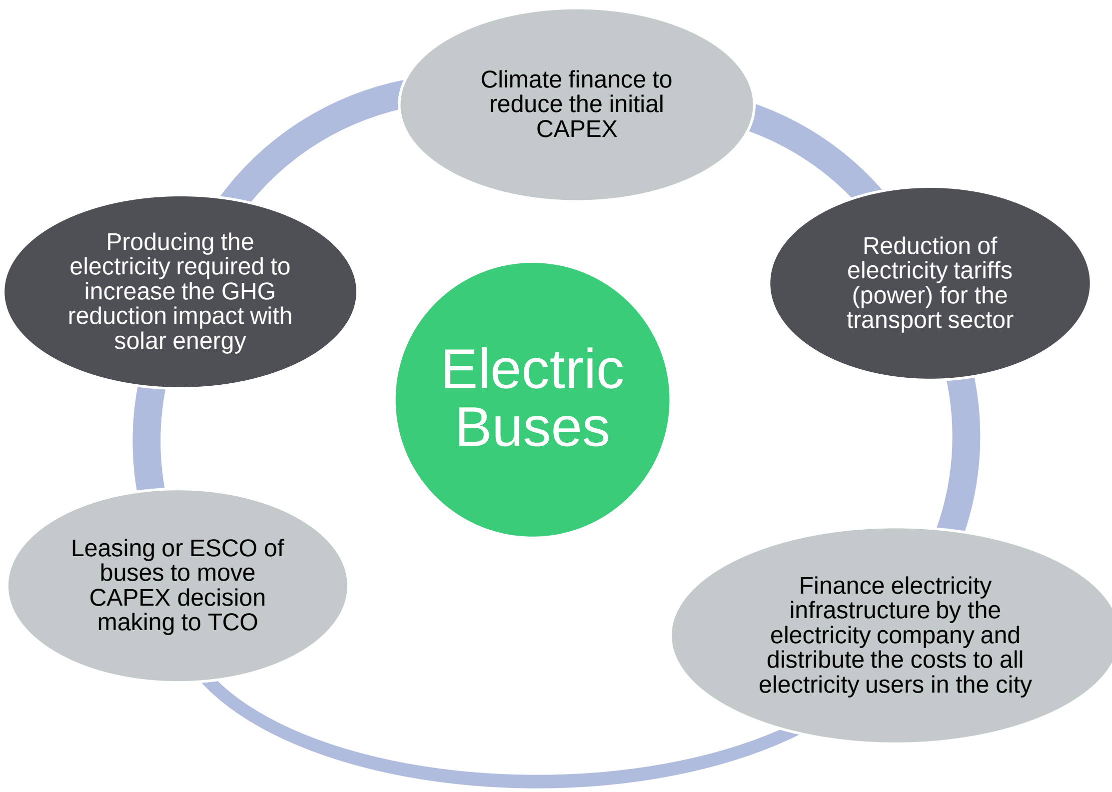
- Doubts regarding the degree of bus availability and the number of faults in operation. On the one hand, the number of faults depends on the operator's maintenance system, but also on the bus technology and brand. Another important element is the availability of spare parts and the time in which they are available. Finally, operational failures lead to losses for the operator, requiring a larger reserve fleet and generating a poor image of public transport.
- Doubts regarding maintenance costs, spare parts and component life cycle, especially for batteries, which make up significant portion of the investment. There is a very large fluctuation between operators in BEB maintenance costs and there is a strong discrepancy between promises from BEB manufacturers and the observed reality of operators. Theoretically, electric buses require less maintenance and supplies since there are fewer moving parts and require almost no engine

maintenance (no oil changes or filter changes). However, repairs or defects in the electrical part and maintenance staff can be more expensive. In addition, requires less maintenance staff, so we have made the average calculation of BEBs with 30% lower maintenance costs.

- Financial profitability depends to a large extent on the projected diesel price, future electricity prices, and the actual CAPEX of the buses.

The following image summarizes the possible options available to increase the attractiveness of electric buses.

Image 7 Financial Options

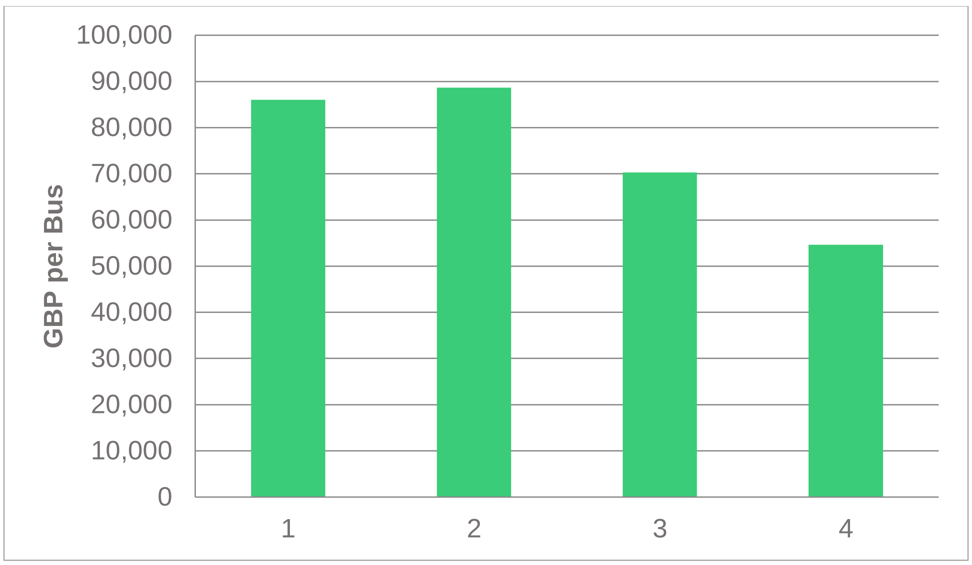


Strategies to make electric buses more attractive are based on a reduction or subsidy of the CAPEX (making the investment more profitable, which justifies taking a higher risk) or a reduction in the risks of operating costs under leasing or ESCO type schemes, in order to offer greater security to the operator regarding its total operating costs and the profitability of its investment. The first instrument tries to reduce the CAPEX until the financial TCO of electric buses is equal to that of diesel buses. The second instrument tries to assure the operator that the financial TCO of the electric bus is really the same, or even lower, than that of a diesel bus.

9.2 CAPEX Incentives.

Financial incentives to cover parts of, or the entire investment gap between electric and conventional buses are successfully used in countries such as the UK and China. The £30 million Low Emission Bus Fund (LEB) was launched in 2015 by the Office for Low Emission Vehicles (OLEV) to support the purchase of low emission vehicles in England and Wales. This scheme replaced a previous low carbon emission bus (LCEB) or Green Bus Fund (GBF) fund, established in 2009, which financed more than 1,200 low carbon (basically hybrid) buses in its four rounds between 2009 and 2013[96].

Graph 13 Average contributions per low-emission bus in the Green Bus Fund.



Lap 1: 2009; Lap 2: 2010; Lap 3: 2011; Lap 4: 2012
Source: calculated by Grütter based on
http://webarchive.nationalarchives.gov.uk/20120606212701/http://www.dft.gov.uk/publications/green-bus-fund-round-1/

In the LEB, the subsidy is granted according to the impact on GHG and noxious gases. It is a payment relating to CO_2/km emissions and local emissions paid ex-ante. Basically, you pay GBP 175 per gram of CO_2/km reduction. There is also financing for infrastructure, including shippers or opportunity charging systems.

In China, subsidies for alternative buses have been provided for several years. Subsidies are no longer provided for hybrids, but plug-in hybrids and electric buses are still subsidized. Until 2015, the national government subsidy for a 12m BEB was 75,000 USD. Many provinces provided the same or even a higher subsidy, and in many cases the city provided another subsidy, making the BEBs cheaper for the operator, or at least the same cost as when purchasing a diesel bus. For example, in the case of Fuzhou, the 12m BEB has a cost of 250,000 USD, but 75,000 USD of subsidy are received from the Central Government,

[96] http://webarchive.nationalarchives.gov.uk/20120606212701/http://www.dft.gov.uk/publications/green-bus-fund-round-1/

75,000 USD from the Province and 35,000 USD of subsidy from the city, reaching a purchase price of 65,000 USD, which is 20,000 USD less than the price of a diesel bus.

Considering the environmental impact of electric buses, one could think of different incentives for the initial investment:

- Absorption of the investment in charging infrastructure by the government or the electricity company and payment of this infrastructure either by state funds or by passing the cost on to the electricity bill of all electricity users. From a social and economic point of view, the total population of the CDMX is justified in paying for this investment because electrical transport has significant positive environmental externalities, and the entire population of the CDMX would benefit from the positive impacts in terms of air quality and noise reduction, not only the users of public transport; in addition, from a social point of view, it is the poorer segments that use it, and so it is also justified from this perspective.

- Request soft funds or donations from multilateral entities to cover a portion of the differential investment. One option would be to apply for funds from the Green Climate Fund (GCF). The program should clearly show its transformational impact and the need for soft funds, although it should be clear that the transformational impact does not occur with an electric corridor; for this purpose it would be necessary to establish a roadmap or a clear electrification strategy for the transport sector.

9.3 Risk mitigation incentives.

One of the barriers for electric buses is that they have a much higher initial CAPEX. The TCO can be the same, or even lower, compared to diesel buses, but the initial investment is very visible, in addition to the fact that the savings in the future are not very visible and are not 100% certain, so the operator chooses to reduce risks and capital invested, so it does not give much importance to the TCO parameter. Another option to reduce the risk and for the operator to make the decision based on the TCO criteria and not the CAPEX is to make a bus rental system, or a system similar to an Energy Service Company (ESCO).

9.3.1 Bus Leasing.

Operational leasing is now quite common with buses, where a fixed monthly sum is paid with mileage conditions. This reduces the risk for the operator, sincethe bus and its batteries are owned by the rental company or manufacturer. In other words, it reduces the risk that the bus and its components will not operate properly during the agreed life cycle, and reduces the initial capital requirement.

Even more interesting is a lease where the producer or a third party company rents the bus to the operator with a mileage payment. A higher or lower number of components can be included in the package and payment, but the vehicle is always included with its maintenance and major repairs (not including daily maintenance and cleaning). Other aspects, such as tires and energy, may be included in more complete packages, but not elements related to transportation service. In several cities in China there are BEBs operated under this type of scheme, where the manufacturer or a rental company makes the vehicle available and is responsible for its operation, repairs and maintenance. There are also companies that have contracts with tire manufacturers, who finance, maintain and change tires in exchange for a flat rate per kilometer from the transportation operator. The advantage for the operator is clear: the risks of vehicle availability and variations in repair and maintenance costs are eliminated and the operator has clear variable costs and very low fixed costs. The additional inclusion of energy use further reduces risk and leaves only manageable risks already known to the transport company, which are related to the provision of the service itself.

9.3.2 ESCO for electric buses.

An interesting option for reducing risk is to manage the provision of buses for urban transport as an ESCO. The electricity company, the bus manufacturer or a third party makes the bus available to the operator at a predetermined cost per kilometer, while all bus costs, including investment, maintenance, energy etc. are covered and are the responsibility of the ESCO. The kilometer rate can be oriented to the cost of a diesel bus with a calculation formula that includes the price of diesel. The ESCO would benefit from the difference in TCO between a diesel bus and an electric bus. This system could be combined with a performance guarantee fund with funds from bodies such as the GCF, which guarantees ESCO its revenues and costs.

- A guarantee linked to the price of diesel to ensure that the carrier's payment is a projected minimum (revenue per km guarantee);

- A guarantee of maximum operating costs for electric buses, justified by technological risks (guarantee of maximum costs per km).

Capital funds for ESCO may come from private or multilateral banks in the form of credit. The credit risk would be very low if it had a performance guarantee fund, which effectively guarantees a certain level of ESCO's profitability.

9.4 Solar Energy Electricity Production.

Electric buses have zero exhaust emissions, yet they still have significant total GHG emissions due to electricity generation; therefore, the option of producing the necessary electricity from renewable sources can be evaluated, using photovoltaic solar energy, which can be installed on the roofs of the depot stations, allowing for zero emission buses.

To cover the totality of the electricity demand (without losses in transmission and storage), approximately 6,800 MWh per year is required, achieving an annual reduction of about 2,900 $tCO2_e$. It is estimated that about 20,000m^2 of PV panels are required to produce this amount of electricity. To be clear about the effectiveness of this investment, it would be necessary to have data on costs, efficiency and available space.

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