C40 CITIES FINANCE FACILITY

ELECTRIFYING BUS ROUTES: INSIGHTS FROM MEXICO CITY'S EJE 8 SUR TECHNOLOGY ASSESSMENT

Executive Summary

This report aims to illustrate how a city can assess different electric bus technology options, by providing a summary of an analysis conducted in Mexico City by the C40 Cities Finance Facility (CFF). This summary explores how data on the buses' financial costs, environmental impacts and on existing infrastructure on the route, led to the choice of trolleybuses as the best solution for the Eje 8 Sur route. This summary aims to inform similar analyses by other cities and practitioners.

Key insights:

1. It is critical that future bus procurement decisions are based on the Total Cost of Ownership of the bus to avoid choosing diesel technologies because of their lower upfront costs.
2. Integrating environmental impacts into technology assessments can drastically change the Total Cost of Ownership comparisons and allow for consideration of alternative bus technologies.
3. Specific city characteristics and experiences can help to overcome the operational risks associated with zero-emission technologies such as Mexico City's experience with operating trolleybuses.
4. Alternative financing mechanisms may be needed to allow cities to borrow more and manage this debt to overcome the higher upfront costs.

Mexico City's Eje 8 Sur route

Mexico City is one of the world's largest cities: its metropolitan area is home to nearly 21 million people. Since 1946, a public transport agency, *Servicio de Transportes Eléctricos* (STE), operates all trolleybuses and light-rail services in Mexico City. STE has been mandated to establish a new bus route along Eje 8 Sur, a 22km corridor in the south of the city. Trolleybus Line E operated along Eje 8 Sur from the 1980s until 2009, when it was discontinued. The technology assessment focused on the westernmost 15.8 km of the corridor, between Mixcoac and Constitución de 1917. STE currently operates eight trolleybus lines, but most trolleybuses covering the network are over 30 years old.

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Implementing agencies: giz Deutsche Gesellschaft für Internationale Zusammenarbeit (GIZ) GmbH; C40 Cities

Objectives of the report

The study was part of a wider package of support provided by the C40 Cities Finance Facility to Mexico City, to help develop the Eje 8 Sur project technically and financially. The technology assessment was conducted to compare the various technological options for buses on Eje 8 Sur. Titled '*Evaluation of Electric Buses for Eje 8 Sur*', the assessment was carried out in collaboration with Grütter Consulting. A previous report ('Analysis of Alternative Bus Technologies') aimed to develop the capacity of city officials and the administration to understand and choose between different electric bus technologies. Both reports are available on the CFF website at: https://www.c40cff.org/projects/mexico-city-eje-8.

Main characteristics of Eje 8 Sur (Mixcoac to Constitución de 1917)	
Route length	15.8km
Average bus speed	18 km/h
Type of buses and specifications	18m articulated buses, capacity of 140 passengers, without AC/heating[1]
Minimum bus fleet size (without reserve fleet)	47 buses
Percentage of reserve fleet	10%, i.e. 5 buses
Total fleet required including reserve fleet	52 buses
Minimum distance between buses (headway)	2.5 minutes
Annual mileage per bus	73,000 km
Total annual mileage of buses	3,775,000 km

[1] Mexico City's buses do not require heating and cooling due to its moderate climate.

Daily mileage	250km per working day and 150km per non-working day – 260 working days per year

Table 1: Main characteristics of the Eje 8 route.

Bus Type	Description
Diesel – Euro IV	Diesel engine with a Euro IV compliant engine.
Diesel – Euro VI	Diesel engine with a Euro VI compliant engine.
Trolleybus	Electric engine charged via overhead cables.
Opportunity Charging - Ultrafast	Electric engine which is charged at several stops along the route.
Opportunity Charging – End of route	Electric engine which is charged at the end of the route.
Battery Electric Bus – Daytime fast-charging	An electric bus with a battery charged a few times a day.
Battery Electric Bus – Overnight Charging	An electric bus with a battery large enough to operate for a full day. Charging is done at night at the depot.

Table 2: Bus options analysed for the Eje 8 Sur route.

The evaluation compared these different bus technologies based on their:

- Environmental impacts
- Financial Total Cost of Ownership
- Economic Total Cost of Ownership

Environmental impacts
Cumulative over 12 years and not discounted over time: a) Emissions (CO_{2e}, PM, NO_X, and SO_2) b) Noise pollution

Financial TCO
a) Capital costs (buses and refuelling/charging infrastructure and associated costs) b) Net Present Value of operating costs, i.e. energy and maintenance costs, cumulative over 12 years
Economic TCO
Financial TCO plus environmental impacts.

Table 3: Summary of the parameters used to evaluate the performance of buses

Environmental impacts:

Greenhouse gas emissions include (a) direct emissions ('tank to wheel') and (b) indirect emissions ('well-to-tank').

- (a) Direct emissions are the emissions produced by the bus through fuel combustion.
- (b) Indirect emissions are the emissions resulting from the production of electricity used to charge electric buses, or, in the case of diesel buses, the upstream emissions of fossil fuels (i.e. extraction, refining, transport, and distribution).

The emissions accruing from the production of electric buses and their batteries and of diesel buses were not included in the assessment: indirect emissions resulting from the manufacturing of a diesel bus (120g CO_2e\km) are estimated to be comparable to those of manufacturing an electric bus, including batteries (130g CO_2e\km)[2].

Local emissions (PM, NO_X, SO_2) from combustion and vehicle wear and tear are factored in, as well as the impacts of noise pollution.

Unlike other costs, the environmental costs are not discounted over time.

Financial Total Cost of Ownership:

The financial analysis considered:

[2] Emissions are comparable due to the longer commercial lifecycle of an electric bus and the expected re-purposing of batteries at the end of their life.

1. Capital expenditure (CAPEX): This included the upfront costs[3] of the bus, any additional infrastructure (e.g. chargers or land acquisition costs) and the cost of partial replacement of the investment, e.g. batteries. Diesel prices included the costs of building service stations. CAPEX did not include the cost of power infrastructure, e.g. transformers which may be required to supply sufficient electricity. Diesel buses were expected to last 12 years, electric buses between 16 and 20 years and trolleybuses 20 years: the longer lifetimes are due to the reduced vibrations rates and fewer moving parts. Factoring these longer lifetimes into the TCO is essential to accurately compare technology options.
2. Operating expenditure (OPEX): The analysis only included those that differ between diesel technology and electric buses, namely the costs of energy and maintenance. Operating expenses such as the cost of drivers and management were excluded from the study since they do not differ across technologies. Electricity prices vary across electric bus technologies (e.g. depending on the time of consumption and installed power): a reference electricity price was calculated for each type of electric bus technology.

The financial Total Cost of Ownership (TCO) is the sum of CAPEX (buses and infrastructure) and the Net Present Value of OPEX (discounted at a rate of 8% per year - the Weighted Average Capital Cost in the transport sector in Mexico).

Economic Total Cost of Ownership:

The economic Total Cost of Ownership includes the costs associated with greenhouse gas emissions, local emissions and noise pollution.

- The costs of greenhouse gas emissions were calculated as an estimate of the economic damages linked to an increase in CO_{2e} emissions, known as the social cost of carbon. On Eje 8 Sur, shifting to electric buses would result in a reduction of around 6,000 tonnes of CO_2e per year.
- The costs of local emissions are calculated based on the Tier 3 methodology of the COPERT model[4]. Only PM, NO_X, SO_2 are assessed as they are the main pollutant resulting from diesel buses.

[3] Upfront costs are based on data available in 2017 on bus prices in Mexico.
[4] EEA (2016a), Air pollutant emission inventory guidebook Version 2016 update December 2016

- The costs of noise pollution are calculated based on international experience collected in a report by the Victoria Transport Policy Institute[5].

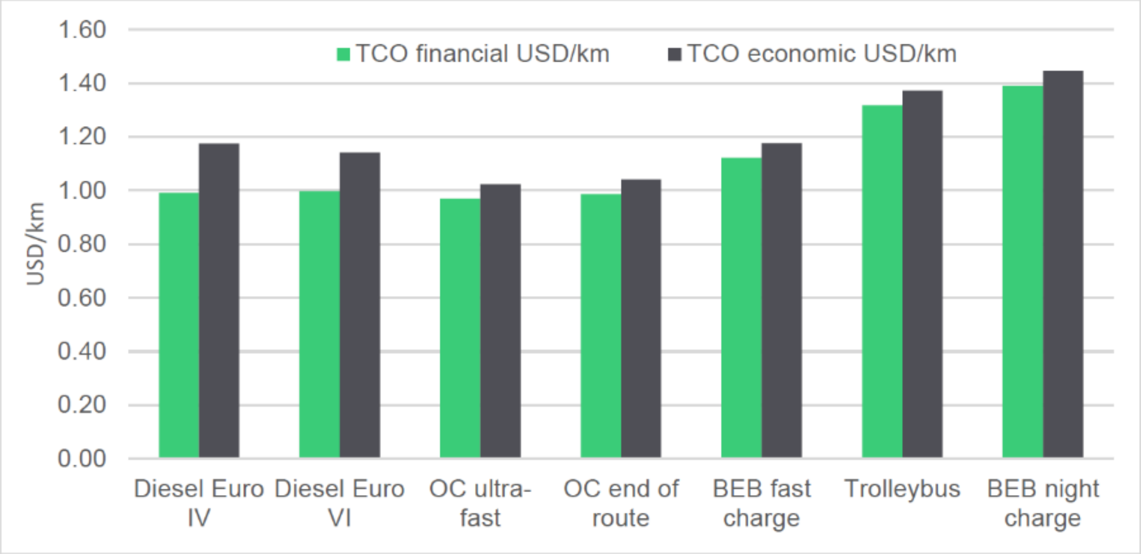

Table 4: Summary of financial and economic total cost of ownership (TCO) for each system

Conclusions of the report

1. Of all the bus technologies assessed for Eje 8 Sur, the analysis demonstrates that electric buses using opportunity charging have the lowest **financial TCO** of all assessed bus technologies (0.98-0.99 USD/km), lower than or equal to diesel bus technologies (0.99-1.00 USD/km). Fast-charging battery electric bus technologies have a higher financial TCO than diesel bus technologies (1.12 USD/km), Trolleybuses (1.32 USD/km) and night-charging battery electric bus technologies (1.39 USD/km) have the highest financial TCO of all the technologies assessed.
2. Electric buses using opportunity charging have by far the lowest **economic TCO** of all assessed bus technologies (1.04 USD/km). By integrating the costs of environmental impacts of greenhouse gas and local emissions, the economic TCO of opportunity charging systems is 15-20% more cost-competitive than traditional diesel (1.14 USD/km for Euro VI; 1.18 USD/km for Euro IV), making a strong case for these technologies. Fast-charging battery electric bus technologies (1.18 USD/km) have a similar or slightly higher economic TCO than diesel bus technologies (see above). Trolleybuses (1.37 USD/km) and night-charging battery electric bus technologies (1.45 USD/km) have the highest financial TCO of all the technologies assessed.

[5] VTPI (2017), Transportation Cost and Benefit Analysis II – Noise Costs.

3. While trolleybuses have much higher upfront costs – an additional USD $40 million for Eje 8 Sur - they can be a financially viable alternative if existing infrastructure can be used. Overhead charging infrastructure is estimated to make up to 40% of the total cost. A separate assessment by STE determined that much of the existing infrastructure on Eje 8 Sur, unused since 2009, could be retrofitted for a new trolleybus line. Given STE's extensive experience with trolleybuses, this technology presents lower operational risks for STE than the other electric bus technologies. Because of these two factors, the technology assessment recommends operating trolleybuses on Eje 8 Sur.

Key insights

1. **Quantifying and procuring based on the financial – or, preferably, the economic TCO – of electric bus technologies is critical to avoid choosing diesel technologies because of their lower upfront costs**. This assessment compared technologies with respect to both the financial and economic TCO, illustrating how electric bus technologies are cost-competitive with diesel if the buses' different lifetimes and maintenance costs are included. By replicating this assessment for other cities and routes, decision-makers can demonstrate the financial advantages of electric buses compared to diesel buses.

2. **Integrating environmental impacts into technology assessments can drastically change the TCO comparisons and allow for consideration of alternative bus technologies.** Electric bus technologies deliver environmental benefits such as reduced greenhouse gas emissions and lower air and noise pollution. The environmental costs of diesel buses are 3 times those of electric buses: 0.16 USD/km versus 0.05 USD/km. Integrating these costs can make more electric bus technologies cost-competitive with diesel.

3. **Specific city characteristics and experiences can help to overcome the operational risks associated with zero-emission technologies.** A concern of many cities when procuring electric buses is the lack of operational experience with new technologies and the challenges they bring in terms of retrofitting existing infrastructure and retraining staff. The choice of trolleybuses over other bus technologies for Eje 8 Sur shows how the recommendations of a technical analysis can change when expanding its scope to include an assessment of the context. STE's expertise in operating trolleybuses and the possibility of retrofitting existing infrastructure can help lower upfront costs and mitigate the operational risks of the transition.

4. **Alternative financing mechanisms may be needed to allow cities to borrow more and manage this debt to overcome the higher upfront costs.** Electric buses can be cost-competitive when their costs and benefits over their lifetime are considered but remain more expensive when only considering upfront costs, due to the cost of the batteries. However, most procurement models are still based on the bus with the lowest upfront cost. Innovative financing models built around TCO comparisons can ensure that cities and operators can access the most cost-competitive technology and not just the one that is cheapest to purchase. Presently, electric buses require higher upfront investment, therefore, cities need innovative financing models to be able to borrow more and manage this debt.