C40 CITIES FINANCE FACILITY

Estimating Climate Impacts:
Case Study - Bus Electrification in Quito

Project Description

The C40 Cities Finance Facility (CFF) is supporting the City of Quito in the development of two zero-emission bus projects that will be implemented in the coming years:

1. Electrification of the Ecovía bus rapid transit (BRT) corridor, including the installation of strategic charging stations and the acquisition of 193 battery electric buses.
2. A 9-kilometre (km) extension of the Central Trolebús Corridor, including the construction of two terminals and the acquisition of 69 zero-emission trolleybuses and 83 battery electric buses.

These two projects form part of Quito's remodelling of its public transportation system and are treated as separated projects.

The Empresa Pública Metropolitana de Transporte de Pasajeros de Quito (EPMTPQ), the company managing and operating these corridors, has extensive experience in this field, including with zero-emission buses, which will guarantee the sustainability of the project and will help towards the goals of electrifying approximately 40 kilometres of public transit routes.

Ecovía BRT corridor electrification

The Ecovía bus corridor covers the eastern section of the city's integrated public transport system, starting at the Río Coca terminal in the north and ending at the recently constructed Guamaní terminal in the south. It is the city's longest corridor, covering a distance of over 30 km and provides an affordable alternative to commuting by taxi or private car.

Prior to the COVID-19 pandemic travel demand figures were stable with an average of 183,371 passengers transported per day. This analysis assumes that bus ridership will rebound in the post-pandemic period. It is also assumed that the new metro (opening in 2022) is expected to further boost bus transit demand.

The 148 buses operating on the Ecovía corridor run on diesel and are nearing the end of their useful lives. The City of Quito has therefore prioritised the gradual transition of its fleet toward electric buses, starting in 2022. The goal is to switch to 100% zero-emission buses once all diesel and hybrid powered buses have been retired.

Trolebús BRT line electrification and extension

The Trolebús corridor was inaugurated in 1995, at which time it had 39 bus stops and two terminals. Later, a south extension was added to reach Quitumbe station and another extension to El Labrador station. Travel demand figures pre-pandemic showed that 193,767 passengers were transported daily.

The Trolebús line currently operates 51 hybrid-diesel trolleybuses and 70 diesel buses which are also nearing the end of their useful lives. A similar approach has been chosen for the Trolebús project with a gradual transition of the fleet toward electric trolleybuses and standard electric buses, starting in 2022. Again, the goal is to operate 100% zero-emission vehicles once all diesel and hybrid powered buses have been retired.

Additionally, the Trolebús bus corridor will be extended by a further 9 km between El Labrador station and Carapunga station (see Figure 1) starting from 2027. This extension is expected to further increase ridership on the Trolebús corridor and encourage commuters to use public transportation instead of taxis or private automobiles.

Objectives of the project

The main objective of the two projects is to improve air quality in Quito and contribute to Quito's commitments to reduce its GHG emissions. The projects are also expected to improve the quality of transportation services in the city and lead the transition to more sustainable transit systems in Quito and Ecuador.

Impact on air pollution

Due to Quito's high altitude, high levels of air pollution have more drastic consequences on the health of residents than in lower-lying cities. Both projects are expected to improve the health and quality of life of users and of residents in the area impacted.

The use of zero emission buses in some of the city's core transport route systems will have a positive impact in terms of air quality. A reduction in PM2.5 concentrations and other air pollutants along those routes is expected, lowering the risks of cardiovascular and respiratory diseases among city dwellers.

Impact on greenhouse gas emissions

The transition of diesel and hybrid-diesel buses to zero-emission buses is expected to reduce greenhouse gas (GHG) emissions from Quito's public transportation system. With this project, the City of Quito is contributing to the fulfilment of international agreements and commitments, such as the Green and Healthy Streets Declaration and Deadline 2020.

Improvement of the transit system

The introduction of new buses and the extension of the BRT line will also result in improved public transport service, with greater attention paid to the needs of users and gender considerations. The project will create a more sustainable public transit system, which is an important step in creating the future Quito envisioned with its "Vision 2040" plan. By procuring the first cable-less electric buses in the city this project will lead the transition process for the country to switch from fossil-fuel buses to electrically powered buses.

Data & Methods

General methodological considerations

The emission mitigation potential of a project is determined by comparing the difference between the GHG emissions generated in the baseline scenario and the project scenario.

The baseline scenario evaluates the conditions in the community that would occur if the planned intervention (in this case, a switch to electric bus and the construction of a new BRT line) was not implemented. The project scenario on the other hand reflects changes in conditions that the project will create.

Activity for an EV bus project is generally defined in terms of km travelled by baseline and project buses and the related energy consumption.

For BRT projects, activity is generally defined in terms of km travelled by passenger in baseline (private automobile, bus, motorcycle, etc.) and project modes (BRT bus) and the related energy consumption. The perimeter of the analysis is defined by the number of passengers that would be transported by the BRT project, for both baseline and project scenario.

More detailed documentation and discussion of the methods used in the calculation (including equations definition of terms) can be found in the accompanying document 'Estimating Climate Impacts - A Methodology for Estimating

Baseline scenario data

Baseline scenario definition for the Ecovía project

The baseline scenario for the Ecovía project is defined by the operations of the fleet of existing buses, their fuel efficiency and the average distance travelled per day. The Ecovía fleet is composed of 117 articulated, of three different types, and 29 bi-articulated diesel buses running on the Ecovía route.

The Quito Transport Company provided fleet operational data, which consisted of the number of buses operating with the associated fuel consumption and km travelled per year. Table 1 notes the data used to derive the following fleet composition.

This also allowed the project team to estimate the average distance travelled per bus to be around 184.2 km/day.

The city plans to procure **only** zero-emission buses from 2025.

Baseline scenario definition for the Trolebús project

A similar approach was used for the defining the Trolebús corridor baseline scenario. Using data from the existing fleet's fuel consumption by bus type and technical assistance provided by the CFF on the yearly kilometres travelled by bus type, the energy efficiency of each diesel bus type running on the corridor was computed.

On the existing Trolebús corridor 51 diesel-hybrid trolleybuses are currently active. For computing the energy efficiency of the hybrid buses, the percentage of kilometres travelled was estimated using the diesel engine and the percentage running on electricity to create a plausible efficiency of the diesel motor. For the electric engine efficiency, literature was available noting values for trolleybuses in mild climates. Table 1 notes the data used to derive the following fleet composition.

The technical assistance conducted by the CFF forecasts a decrease in passengers transported by nearly 10% (37,191 psg/day) in 2022 due to the opening of the metro line. This assumption is reflected with a decrease of service and of the number of articulated buses (from 19 to 15) and bi-articulated buses (from 51 to 40) in operation on the corridor from 2022 onwards.

For the Central Trolebús extension, it is forecasted that baseline scenario would have 23,847 daily BRT passengers and these future passengers would continue to use their current pre-project mode of transport. This data is normally obtained from project specific intersect surveys, asking potential BRT users about their current travel choices and how they would be impacted if BRT is extended to the area.

Because such surveys were not available the analysis used approximate values using the average mode share for trips taken in Quito. Similarly, the average distance travelled for trips taken in Quito was used to approximate the average distance travelled for the BRT project.

Project scenario data

For the Ecovía and Trolebús existing bus fleet electrification, the project scenario reflects the activity of the electric buses that will replace the existing diesel buses and trolleybuses that run on the three routes identified.

The EV buses being procured have fuel efficiency of 1.83 kWh/km, a value obtained from an early pilot in Quito using BYD buses. This number may still vary with technology improvement and by bus maker. It is important to obtain real-life estimates of the fuel efficiency for the electric buses purchased because this value is heavily affected by traffic, temperature and weather conditions and topography.

For both bus zero-emission sub-projects, the transition schedule from diesel buses to zero-emission buses commences when a diesel bus reaches its 15-year lifespan.

For both the Ecovía and Trolebús sub-projects the EV buses will be of standard size with smaller occupancy values compared to the baseline diesel buses. Therefore, to ensure that demand is met by the service in future years an increase in the number of buses and of their frequency is required. On the Ecovía route the fleet will transition according to the fleet replacement schedule described in Table 2.

Route	Model	Bus type	Number of buses	Fuel efficiency [kWh/km]
Ecovía	Volvo B10m	Articulated Bus	23	5.54
	Mercedes-Benz O-500	Articulated Bus	35	7.82
	Volvo B12m	Articulated Bus	59	10.67
	Volvo B340m	Bi-Articulated Bus	29	10.73
Trolebús	Volvo B10m	Articulated Bus	4	5.54
	Mercedes-Benz O-500	Articulated Bus	5	7.82
	Volvo B12m	Articulated Bus	10	10.67
	Volvo B340m	Bi-Articulated Bus	51	10.73
	Trolebús MB	Hybrid Trolleybus	51	Diesel – 9.28 Electric – 2.08

Table 1 - Current bus composition of the Ecovía and Trolebús routes.

Route	2022	2027	2033
Ecovía	- 23 Articulated buses	- 59 Articulated buses +10 Bi-Articulated buses	- 35 Articulated buses - 40 Bi-Articulated buses
	+ 35 BE buses	+ 60 BE buses	+ 98 BE buses
Trolebús	- 51 diesel hybrid Trolleybuses - 4 Articulated buses	- 10 Articulated bus	- 5 Articulated bus - 40 Bi-Articulated bus
	+ 51 Zero-emission Trolleybuses + 2 BE buses	+ 10 BE bus	+ 80 BE bus

Table 2 - Replacement schedule of the buses on the Ecovía and Trolebús routes.

The BRT extension is treated in the analysis as a separate project, with a new bus fleet. As a result, the new BRT extension' operations and fleet are not accounted for in the previous Trolebús electrification analysis. This new BRT extension project related fleet is composed of 18 zero-emission trolleybuses and 3 BE standard feeder buses operating the new corridor extension. The zero-emission trolleybuses are the same bus type as the BE buses used on the Ecovía and Trolebús corridors with a 1.83kWh/km fuel efficiency. Yearly kilometres travelled by the zero-emission buses for each corridor was examined and reported by consultants.

Emission Factors

Fossil fuels

The emission factor for diesel fuel combustion in motor vehicles was obtained from the IPCC emission factor database (2006). While more local data can be useful, those values are a globally accepted standard.

Electricity

For the implementation of zero-emission bus and zero-emission BRT projects, the project scenario emissions are calculated by estimating the amount of energy required to power the buses over one year, then applying the emission factor for the grid electricity used to charge the buses. For this reason, the electricity grid emission is an important project assumption for all of the sub-projects. Contrary to fossil fuel emission factors, this data has to be collected locally and is susceptible to increase or decrease over years according to changes in national government policy.

For these projects, the current electricity emission factor from was kept constant across time. The Ecuadorian government's national policies relevant to grid decarbonization (e.g. increase in hydro generation and other renewables) were reviewed but could not find clear guidance that allowed future electricity emission factors to be determined. Given this limitation, holding the current year emission factor constant was the conservative and appropriate approach.

Quito's high altitude, results in high levels of air pollution have more drastic consequences on the health of residents than in lower-lying cities.

Results and emission reductions

This section provides an overview of the GHG emissions impacts of the projects. The calculations are completed for each year of operation from 2021 (the assumed initiation year) to 2050 (the final horizon year for the analysis). Table 3 describes the estimated emission mitigation values for each sub-project.

The cumulative mitigation impact for 2021 to 2050 would be 305,267 tCO2e for the Ecovía buses electrification and 329,808 tCO2e for the Trolebús buses electrification and extension. The total cumulative GHG reduction potential would be 635,075 tCO2e.

The magnitude of the GHG mitigation impact of an EV vehicle project is heavily influenced by the grid emission factor. If the grid electricity was generated from 100% renewable energy, then the project scenario emissions of the three sub-projects would be zero. The current grid emission factor in Ecuador is relatively low (approximately 0.2 kg CO2e/kWh) and the country has stated an objective to increase the proportion of hydroelectric generation in the national grid mix. The implementation of this objective would further reduce the electricity emission factor and therefore improve the mitigation impact of the project. However, the stated increase in hydroelectric generation was not taken into account in our calculation as no clear renewable generation portfolio target was declared.

For the BRT extension project, the data from Quito shows that public transport make up a high percentage of the mode share (76.5%). In the baseline scenario, cars are responsible for 33% of emissions, taxis for 8% and buses for 59%. Despite buses having a far higher mode share percentage, emissions from cars are very high because of their low occupancy rate (1.8 people per car). Targeting passenger cars and taxis with campaigns for a higher adoption of public transport will increase the emission savings resulting from the Labrador-Carapungo BRT extension.

Project	2021 Annual Reduction	2027 Annual Reduction	2050 Annual Reduction	Average Annual Reduction
Ecovía - Electrification	0 tCO_2e	6,987 tCO_2e	14,855 tCO_2e	10,176 tCO_2e
Trolebús – Electrification and Extension	2,158 tCO_2e	8,909 tCO_2e	14,650 tCO_2e	12,061 tCO_2e
Total	2,158 tCO_2e	15,896 tCO_2e	29,505 tCO_2e	22,237 tCO_2e

Table 3 - Final GHG mitigation estimates of the Ecovía and Trolebús projects

Challenges and lessons learned

This section describes the process used to generate the GHG mitigation estimate highlighting the challenges encountered and the solutions created which may be utilised by other practitioners.

Modelling framework design

An important early step in a project analysis is to determine which methods and models should be used to conduct the estimation. In the case of this analysis, the overall project consisted of both bus electrification and BRT expansion elements and this required separate methods to be used. The overall project was subdivided into the following three sub-projects:

- 2 zero-emission bus projects: electrification of existing Trolebús and Ecovía fleets respectively
- 1 BRT project: corridor extension of Trolebús (using zero-emission trolleybuses and BE buses).

Care was taken to define the three sub-projects as separate analyses and also to ensure that there was no overlap or double counting of emission reduction impacts. This work included clearly separating each bus type and establishing the number of buses of each type that run in each corridor. Then, defining how many trolleybuses and buses were to be purchased for the Trolebús and Ecovía fleets replacements and how many for the Trolebús corridor extension.

Clear definition of each sub-project allowed the team to deal with the complexity of the project being assessed. While EV bus project quantification methods (e.g. CDM), allow users to estimate changes in bus fleets, an increase in bus service caused by the project (e.g. from a BRT extension) is outside of the EV bus method's scope. This is because an increase in bus service would draw passengers from other modes of transportation. The increase in bus service had to be estimated using BRT project quantification methods.

Scope changes

The scope of the project has changed several times throughout the project preparation process. Each change had impacts on the assessment effort.

Initial project

When the assessment started in September 2019, the project involved the following:

- the substitution of all 117 diesel buses running on the Ecovía corridor with as many EV buses
- the extension of the Trolebús BRT corridor, using the same diesel buses currently used.

Full project implementation was assumed to happen in 2021.

First scope change

As the assistance and understanding of the project developed, the electrification of the Trolebús corridor rose as a priority. This was motivated by the need to replace the buses currently operating on the Trolebús corridor due to their advanced age and the desire the maximise the project impact.

Further consideration was given to bus replacement by timing the replacement of diesel buses on the Ecovía and Trolebús corridors to match their natural replacement schedule.

These changes led to a revised impact assessment in February 2020.

Impact of the Covid-19 pandemic

Over the course of 2020, financial restrictions caused by the pandemic forced another change of scope for the project to save on costs. This materialised with a delayed implementation and a scale back of the Trolebús extension and a change in the replacement schedule of the Trolebús and Ecovía fleets:

- The replacement of buses operating on the Ecovía corridor will only be focused on the older and most polluting Volvo B10M Euro II buses. Plans to substitute the rest of the fleet were delayed until further notice.
- For the Trolebús corridor electrification, the replacement of buses would be focused on the 51 ageing diesel-hybrid trolleybuses that will be replaced by zero-emission trolleybuses.
- For the Trolebús extension, the fleet was halved from 39 buses to 18 buses, with the start of operations delayed until 2027.

Final project scope

Finally, the project scope was modified to match the current situation with the electrification of both corridors starting in 2021 and gradually transforming the whole fleet and the corridor extension was confirmed to start in 2027.

Data availability and processing

The Quito project is an example of a project with high levels of data availability. Even so there were notable data gaps and a number of assumptions and workarounds were required to carry out the modelling.

Data collected

The majority of the data required to assess emission reductions were collected from the following documents:

- Transportation model from the study Updating the Demand Model for Quito's Metropolitan District, July 2018.
- Daily records of passenger in the stations of the Trolleybus and Ecovía corridors between 2016 and 2019
- Preliminary draft and final design of the Labrador - Carapungo Corridor, April 2015

With the final update, accurate data from the transport company was collected including:

- Current ridership and future projections
- Fleets composition per each corridor
- Buses manufacturing year and lifespan for each bus type
- Bus kilometres travelled for each bus type

With this information and the diesel fleet's fuel consumption communicated in November 2020, the fuel efficiency for each diesel bus type was calculated with a high degree of confidence.

Hybrid trolleybus energy efficiency

A key assumption for baseline emissions on the Trolebús corridor is the efficiency of the diesel-hybrid trolleybuses used. This efficiency had to be accounted for the diesel and electric cycles, taking into account their relative share in the operation of the trolleybuses.

While the diesel consumption and total distance travelled by the trolleybus fleet was communicated in the documents listed above, this was not the case for the electricity consumption. No information was available on the distance travelled on the specific distance travelled on electric or diesel mode.

In order to calculate those missing elements a three-step approach was followed:

- The diesel and electric efficiencies were assumed to be similar to buses of the same size (i.e. articulated 18m buses) using the existing literature.
- Using those assumption, the share of total distance travelled respectively in the diesel and electric modes was derived from total diesel consumption and total distance travelled for the trolleybuses
- Using the average distance travelled and fuel efficiencies, total energy consumption was calculated for the trolleybuses.

Average distance travelled

Average distance travelled is a data point that can vary by bus type, based on factors such as ridership, occupancy or speed. In this example, average distance travelled was provided for all bus types used in the baseline and project fleet. The change in fleet composition across horizons meant that the average distance travelled for the whole fleet could evolve with time.

However, the model used to estimate the GHG impacts assumes that the average distance travelled is fixed in time and consistent across all bus types. As a result, the average distance travelled was defined as the weighted average of distance travelled for each baseline and project bus types used in each specific sub-project. This led to a decrease in the accuracy of the assumptions used but back of the envelope estimate showed that the loss in resolution was not affecting the estimate significantly.

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