Route-level total cost of ownership (TCO) analysis framework in São Paulo

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ZEBRA
ZERO EMISSION BUS
RAPID-DEPLOYMENT ACCELERATOR

tumi
E-Bus Mission

Route-level analysis facilitates the technology choice of bus operators

- How do **routes and operational characteristics** affect bus **energy consumption**?
- How do **electric buses' ranges** vary among the different routes of the bus operators?
- How do the **estimated ranges** of e-buses compare to the daily utilization of diesel buses currently in service?
- Considering a **cost and operational perspective**, which routes make sense to **electrify first**?

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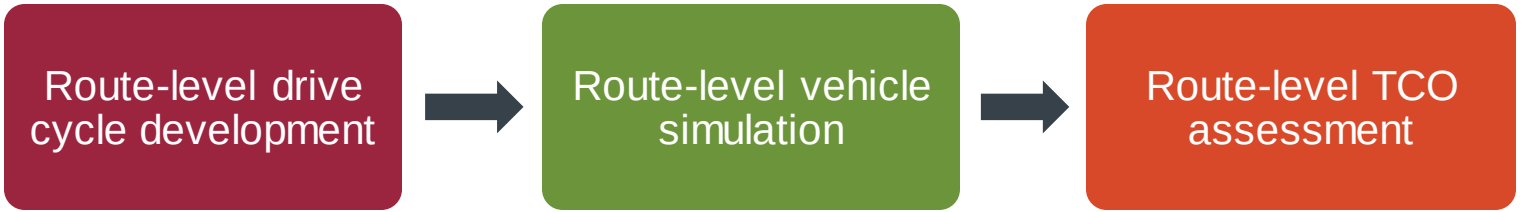
ICCT's Route-level TCO Modeling Framework



(Inputs)	*Real-world operational data (GPS) of buses servicing individual routes*	*Drive cycles and technical specifications of different technology options*	*Energy consumption per route and costs data (capital, energy, maintenance, labor)*

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Example: Zero-emission buses in São Paulo, Brazil

- São Paulo's urban bus fleet: **>13,000 buses,**
- More than **1,300 routes**
- **Zero-emission technology**:
  - **201 trolleybuses** and **18 battery e-buses**
- 10-yr and 20-yr emissions reduction targets set in 2018 (Climate Change Law). By 2038:
  - 100% tailpipe fossil CO2
  - 95% NOx and PM
  - Baseline: 2016 emission levels
- Goal of the mayor: 2,600 e-buses until 2024
- Recently, the city has forbidden the purchase of diesel buses (except for smaller buses)

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Bus operator studied: Transwolff

- One of the 23 concessionaires under the supervision of **SPTrans**.
- > 1000 buses and 135 routes
- Smaller buses: “Mini”, “Midi” and “Básico” (8.6 m - 12.5 m)
- Pilot project since 2019:
  - 18 e-buses
  - Length: 12.9 m (“Padron” bus)
  - 1 route (route 6030-10: Unisa/T. Sto. Amaro)

Which other routes could also be operated by e-buses?

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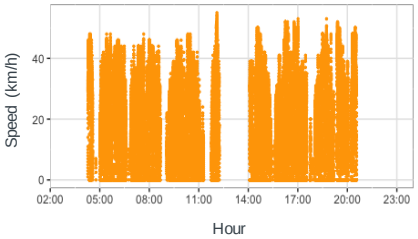
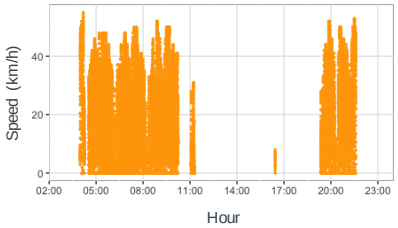
1) Route-level drive cycle development: Using real-world operational data to construct a representative duty cycle

Data for the drive cycle development:
i) GPS data of the buses in service (ideally frequency of 1 Hz),
ii) Elevation

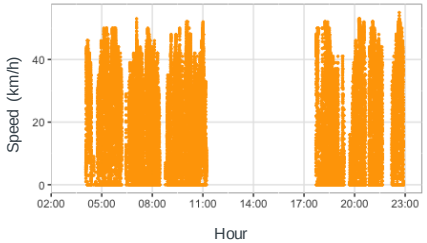
Bus 1, day 1



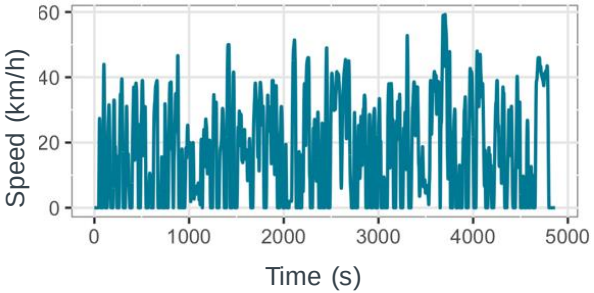
Bus 1, day 2



... Bus 1, day n



Representative drive cycle Route 6030-10



Duty cycle represents typical operating conditions of a given route and maintains those aspects which have the greatest influence over fuel/energy consumption (e.g. average speed, stops per km, % Idle).

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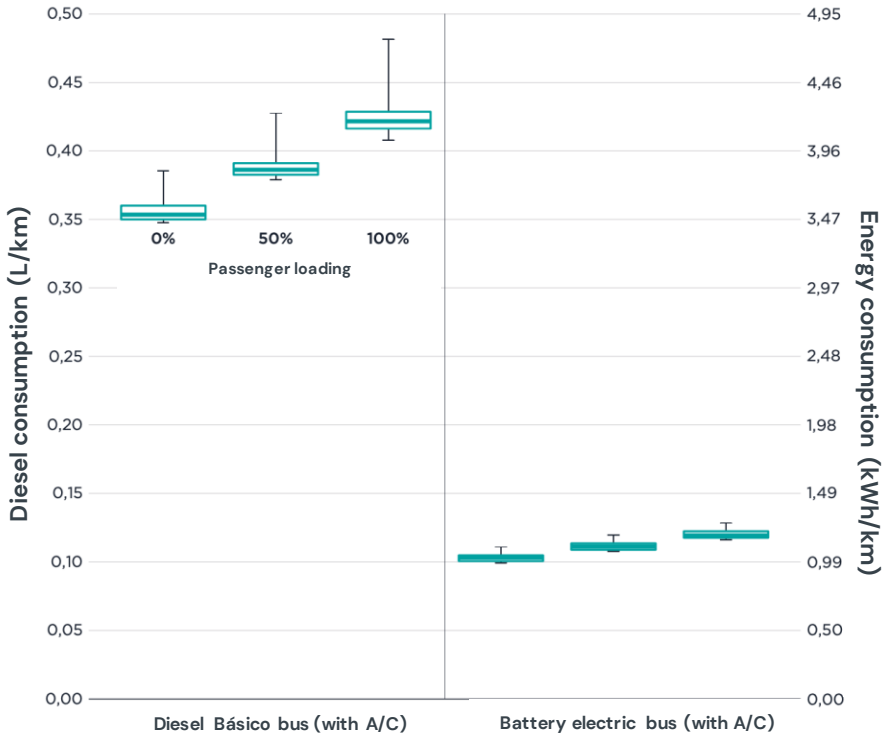
2) Route-level vehicle simulation: Energy consumption estimation

Energy consumption estimated using Amesim, a vehicle simulation software.
Data: Drive cycles and **technical specifications** of buses

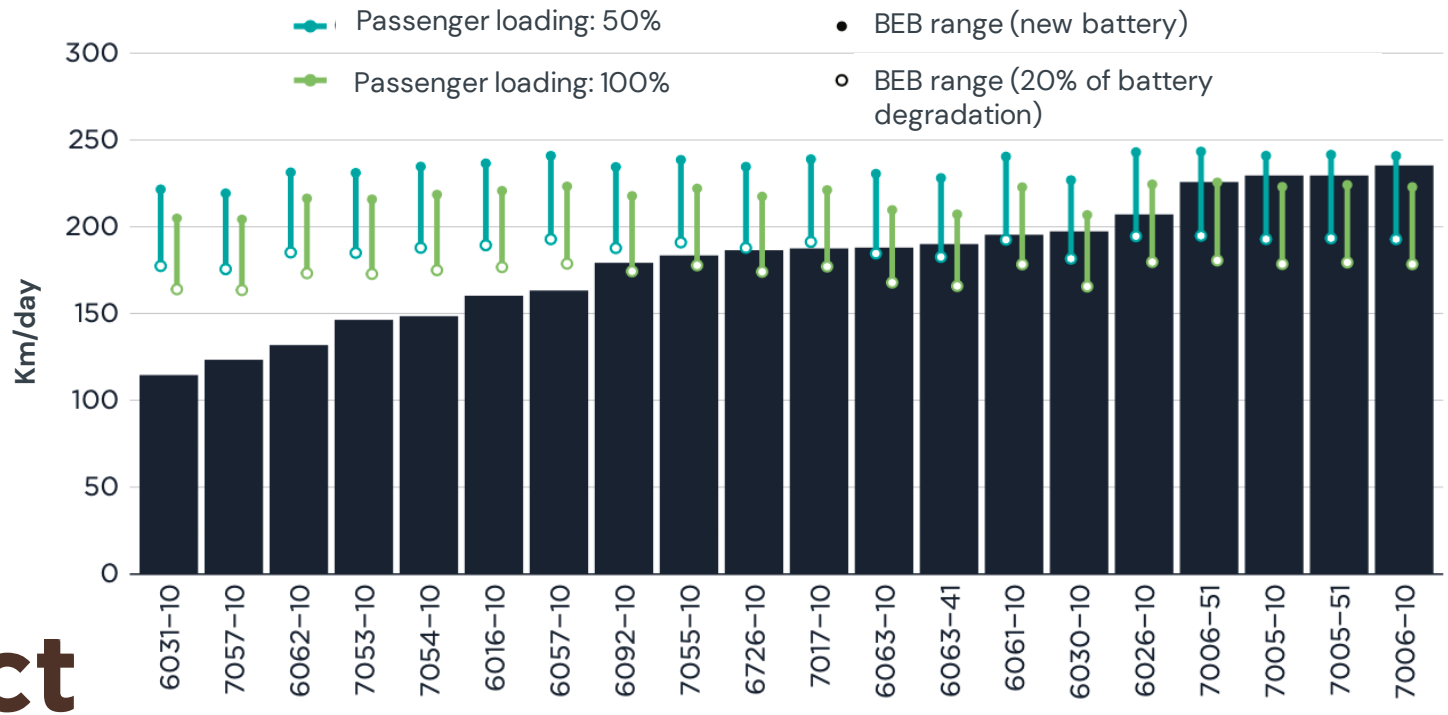
The e-bus energy consumption is ~1/3 of the equivalent energy consumption of the diesel bus

*The energy cost per km of the e-bus is between 30% and 40% of the diesel bus' energy cost per km.**

* *Considering the electricity and diesel costs in May 2021.*



Comparing the estimated ranges of e-buses with the daily utilization of diesel buses



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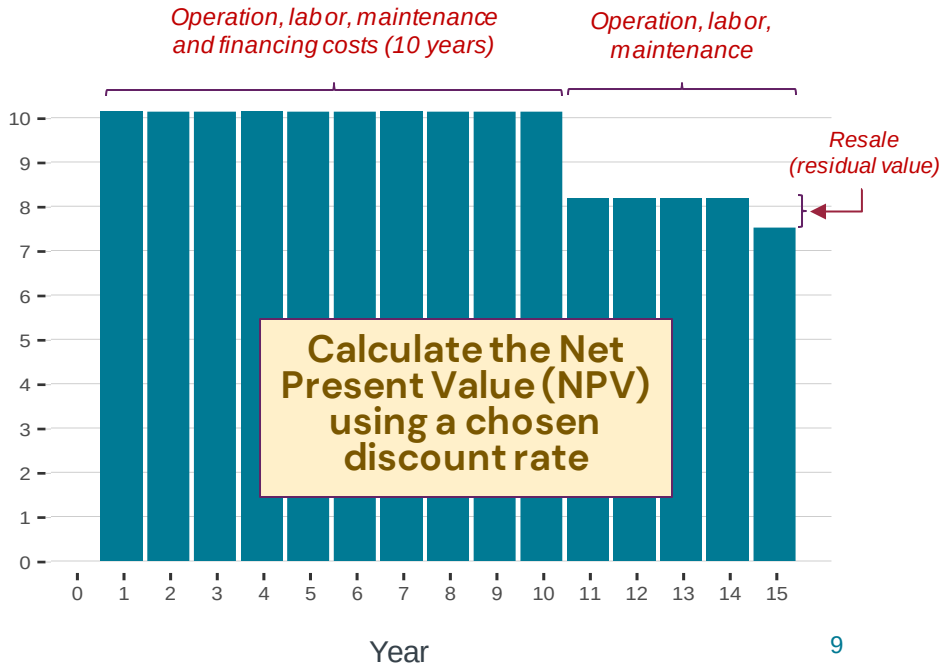
3) Route-level TCO assessment

TCO is defined as the sum of the costs to **acquire**, **operate**, and **maintain** the vehicle over a specified ownership period

- Case of São Paulo:
  - Ownership period: **15 years**
  - Lifetime of the e-bus: 15 years
  - Battery leasing
  - **Financing duration:** 10 Years
  - No upfront payment
  - **Residual value:** 5%

How the TCO is calculated?

Example: Costs for 1 e-bus (15 years)



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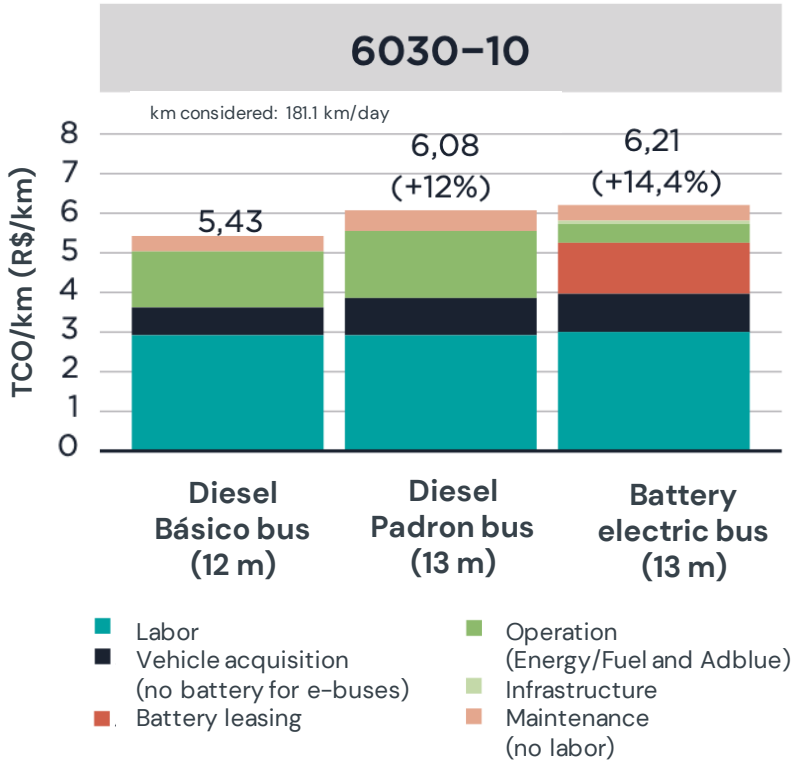
3) Route-level TCO assessment

- Route-level analysis: different daily km and energy consumption
- Lifetime of the buses: **E-bus (15 years), Diesel bus (10 years)**
- TCO difference (e-bus x padron diesel): **1.1% - 4.9%**



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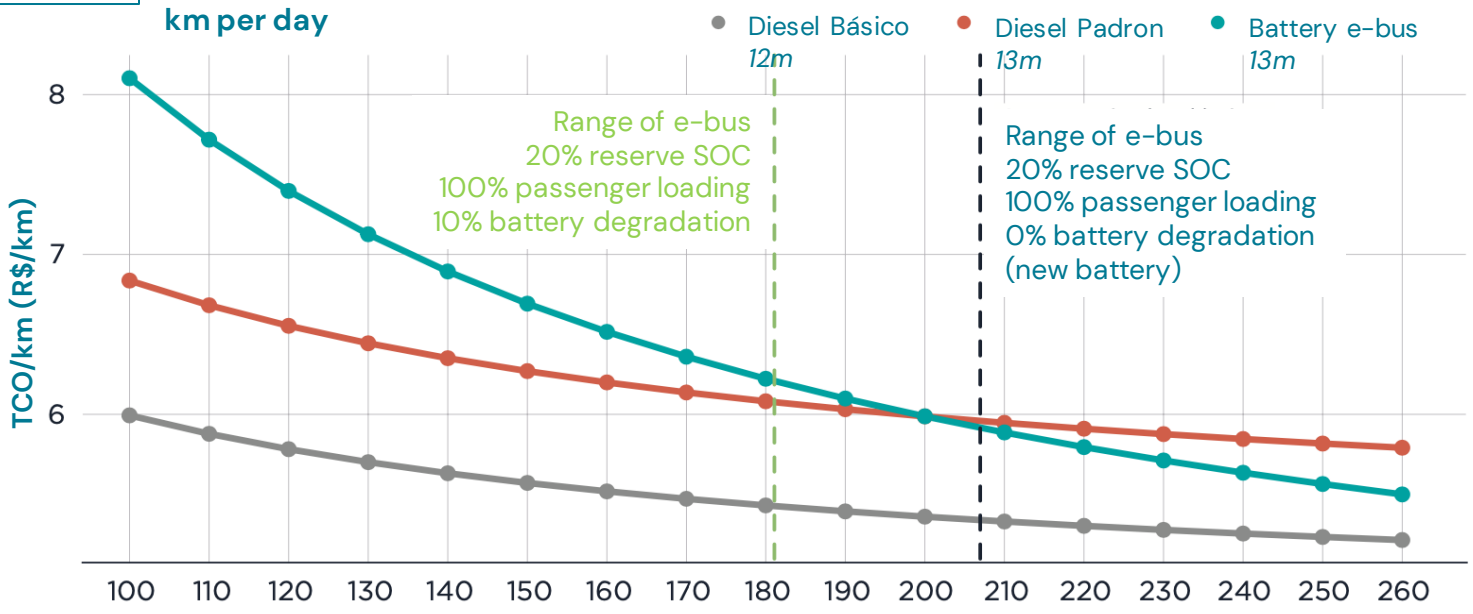
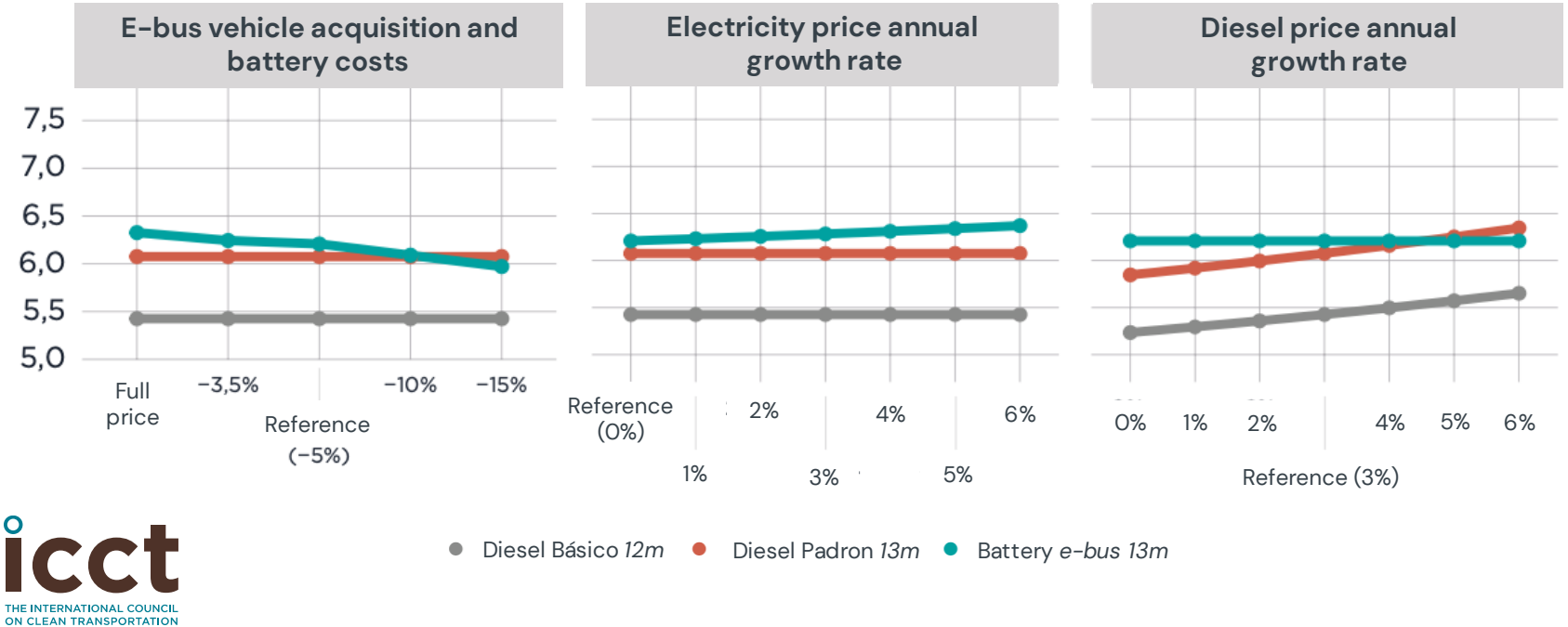
The TCO benefits of e-bus are largest for high daily utilization

Route 6030-10



Sensitivity Analysis

Route 6030-10



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Final considerations

With this tool, bus operators, the city's transit authority and civil society can estimate the **costs and benefits** of the technology transition:

- Estimate the **performance** of the new technology in different routes, and with different operational conditions (e.g., load, a/c)
- Analyze **which routes** should be prioritized, considering operational and cost perspectives
- Analyze in which routes the technology transition would need a different **strategy** (different battery capacity, charging strategy, more buses, …)
- Estimate the **costs** of the system and how different market conditions can affect the costs
- Estimate the **emissions reduction** that can be achieved

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Related ICCT studies and important links

- Implementation of e-buses in São Paulo (Portuguese), Mexico City (Spanish), and Medellin (Spanish)
- Real-world drive cycles development (Bangalore) English
- Route-level energy consumption and driving range analysis (Bangalore) English
- International evaluation of public policies for electromobility in urban fleets (São Paulo) English Portuguese
- Climate and air pollutant emissions benefits of bus technology options in São Paulo English Portuguese
- E-bus Radar platform monitors the initiatives of LA cities to include e-buses into their urban public transport system

Thank you!

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