Supporting the transition to electric minibuses in Lusaka, Zambia

A preliminary analysis using the GTFS4EV model

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Content

This short report presents **preliminary findings**[1] **to support the electrification of minibuses in Lusaka**, Zambia, using the new open-source simulation tool **GTFS4EV**, developed at **EPFL PV-Lab**.

This tool, created as part of the **EU OpenMod4Africa project**, is specifically designed to facilitate the electrification of public transport systems by using open-source data.

More specifically, this report aims to demonstrate how GTFS4EV can support electrification of minibuses, taking **Lusaka, Zambia** as an example case study. More specifically, this report showcases how open-source data can be leveraged for:

— Characterization of the existing minibus network.
— Feasibility study, considering a set of various charging schemes.
— Identification of potential pilot routes.
— Assessment of impacts, benefits and long-term sustainability.

About GTFS4EV

GTFS4EV is an **open-source tool** designed to support electrification studies of (formal and informal) public transport systems. Leveraging the widely available **GTFS format**, it enables high-level analyses of **feasibility, benefits, challenges, and optimal electrification pathways**.

The tool includes features such as GTFS data analysis and preprocessing, fleet operation simulation, electrification scenario modeling that accounts for charging behavior, vehicle properties, and charging options, as well as the analysis of synergies with solar energy.

These simulations provide valuable insights into the feasibility and impacts of different strategies, supporting informed decisions for sustainable transport planning. More information is available on GitHub.

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[1] The results presented in this report are preliminary and are partly based on assumptions made by the author. They are subject to refinement and validation as the research progresses. Please do not distribute, reproduce, or cite this work without properly crediting the author.
Minibus picture by Dave Kim on Unsplash.

Fleet Operation Simulation Reveals a Strong Opportunity for Minibus Electrification

Lusaka's minibus transport system

Lusaka, the rapidly growing capital of Zambia, relies on various informal and decentralized public transport modes, including **14- to 18-seater minibuses**. According to the recent GTFS data used in this study [2], these minibuses typically operate between 08:00 and 18:00. They serve a large portion of the city, with a particularly dense network in the city center (see Fig. 1), operating along **110 routes** and serving **735 stops**.

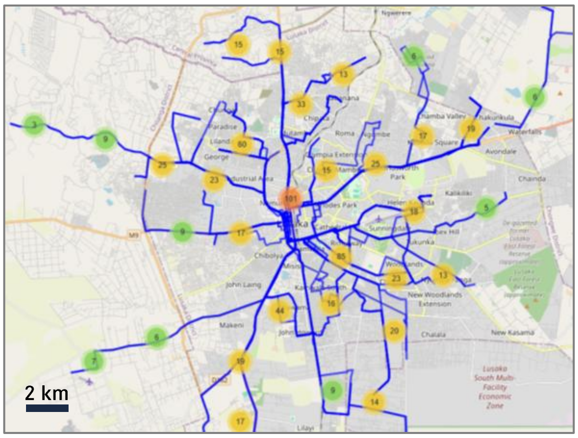

Fig. 1 : Map of the minibus routes and stops in Lusaka, obtained with GTFS4EV.

Short distances, long idle times

Using our model, we simulated the operation of Lusaka's minibuses to gain initial insights into electrification feasibility. The results point to a favorable case: the estimated 2,684 minibuses[3] cover an average of only **100 km per day**, suggesting that relatively **small battery capacities** could be used (see next page).

2684 minibuses
Estimated number of minibuses in operation

19 h
Average daily idle time – 17 h not in operation and 2 h at stops and terminals

100 km
Average daily travel distance

As shown in Fig.2 , vehicles spend **considerable time idling at depot, stops, and terminals,** opening the way for diverse charging strategies. Additionally, many minibuses are also **not continuously in operation** throughout the day, creating opportunities for daytime solar-powered charging strategies.

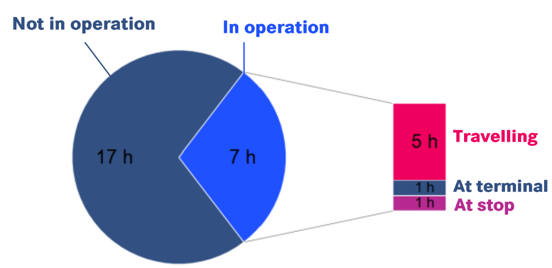

Fig. 2 : Average time spent by minibuses at various locations throughout the day

Benefits of electrification

While adding only ~1% to the city's daily electricity demand, electrification could bring major benefits:
– **Reducing CO_2 emissions** by 15 ktCO_2 annually.
– **Improved air quality**, decreasing exposure to tailpipe emissions for about 1,9 million people.
– **Cost savings** for operators (2,000 USD per year), driven by low electricity prices compared to diesel.

Implications of minibus electrification

27 GWh

Annual energy consumption of electric minibuses in Lusaka
→ Adding only about 1% to the current electricity consumption[4]

-15 ktCO_2

Annual fuel GHG emission reduction by switching diesel buses to electric buses

-1.9 million people exposed to air pollution

Number of residents leaving at less than 300 m of a minibus route.

~2,000 USD yearly fuel savings

[2] Data source: *https://gitlab.com/digitaltransport/data/africa/lusaka*
[3] *Value in line with reported number of registered minibuses in Lusaka (see "Making public transport in Lusaka city more efficient and effective", ZIPAR, 2013)*
[4] *Assuming an annual consumption of 0.709 MWh/capita (IEA 2022) and 3.0 million inhabitants. We also assume 260 operating days.*

Comparing Electric Minibus Charging Schemes

The charging scheme – Why it matters

A well-designed charging scheme is **essential for the successful deployment of electric minibuses**, ensuring feasibility, cost-effectiveness, and maximizing environmental benefits. From a cost and infrastructure perspective, it should assess the trade-offs between installing **large batteries or relying on fast/frequent charging**. Beyond technical and economic feasibility, the charging scheme should also aim to reduce grid stress and enhance environmental impact by aligning charging demand with periods of high renewable energy availability, particularly daytime solar production.

Here, we compare **three charging schemes** using GTFS4EV, providing a basis for assessing infrastructure needs and implications.

S1 - Depot night: Charging is restricted to **overnight hours**. Each vehicle charges at a **central depot,** using **11 kW chargers** (one charger per simultaneously charging EV).

S2 - Depot day and night: In addition to overnight charging, vehicles are allowed to **charge during the day** when idle. Charging locations and power remain the same as in S1.

S3 - Terminal and depot: Building on S2, this scenario enables daytime charging at **ten high-use terminals** (vehicles × idle times), using **100 kW chargers** to provide energy “top-ups”. At each terminal, the number of chargers matches the model’s estimate of vehicles expected to charge simultaneously (see Fig.4).

Even under the most constrained scheme (S1), equipping minibuses with a **small battery capacity** (~40 kWh on average) is sufficient to electrify their operation.

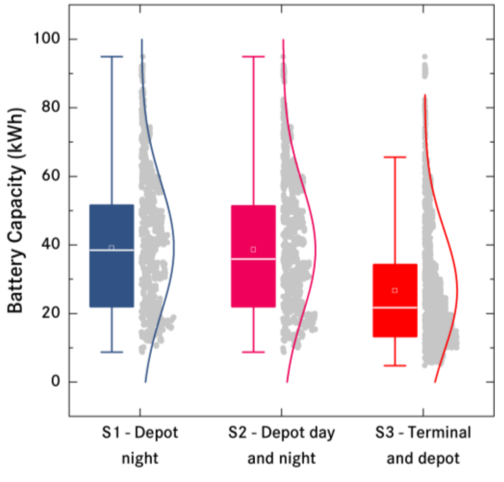

Fig. 3: Required battery capacity per vehicle for the three charging schemes. In S2 and S3, top-ups reduce the battery size.

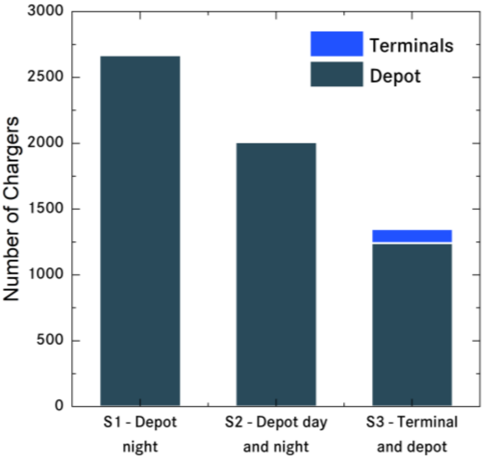

Fig. 4: Required number of chargers at different locations under the three charging schemes.

Equipping **10 terminals with fast chargers allows 20% of the minibuses to fully charge at terminals**, significantly reducing the overall number of required chargers.

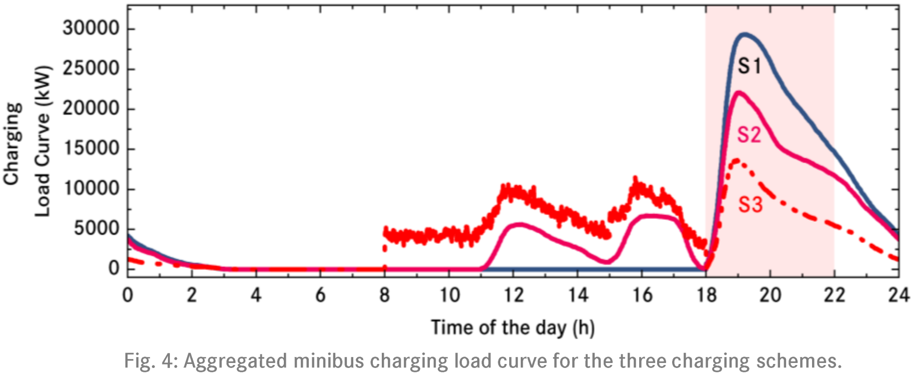

Fig. 4: Aggregated minibus charging load curve for the three charging schemes.

Daytime and terminal charging help **reduce the evening peak** in electricity demand, while terminal charging could also help **spreading the load spatially**.

Conclusions & Outlook

Main takeaways

This preliminary study on the electrification of Lusaka's minibus fleet highlights the potential of the **GTFS4EV model** to support the transition toward electric public transport in Africa.

By applying the model to simulate the operation of over 2,600 active minibuses, several key insights emerged:

– **Lusaka's minibus system presents favorable operational patterns for electrification**: minibuses have relatively low daily energy needs and spend significant time idling at various locations—such as depots, terminals, or stops—that could be leveraged for charging.

– **Electrification could bring substantial benefits** in terms of CO2 emissions reductions, improved health, and fuel cost savings for minibus operators, while adding only a modest increase to Lusaka's overall electricity demand.

– **Optimizing the charging scheme is critical** to minimize infrastructure requirements and reduce evening demand peaks. Enabling charging at a few selected high-use terminals could further reduce battery size needs, creating an additional incentive to shift toward electric mobility.

Identification of pilot routes

The GTFS4EV model can **guide the selection of optimal pilot sites for electrification** by identifying routes that combine high environmental impact with technical feasibility (see Fig. 5).

By analyzing which minibus routes pass through areas with high air pollution exposure, the model helps **prioritize routes where replacing diesel vehicles would deliver the greatest health benefits**. At the same time, it estimates the energy needs and battery capacity required for electrification, ensuring that selected routes are easily electrifiable.

Limitations & Path Forward

This study represents a first step and relies on several assumptions that may limit the accuracy of the results. Key limitations stem from the GTFS data and the operational assumptions required to simulate vehicle movements. These uncertainties could be reduced by refining the model in collaboration with local stakeholders and incorporating more detailed, context-specific data.

Open questions

The model can also help address several **other key questions**, including, but not limited to:

– How are the charging needs distributed in space?
– How many charging stations are required per terminal?
– What is the potential for on-route charging or charging at stops?
– What is the most cost-effective charging scheme?
– How can charging align with solar PV production?

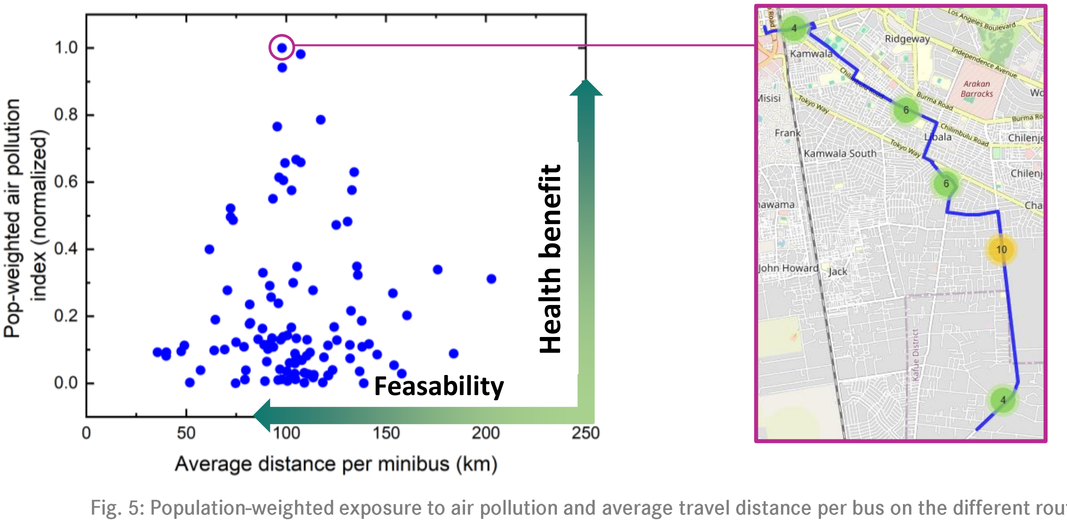

Fig. 5: Population-weighted exposure to air pollution and average travel distance per bus on the different routes.