Design Project – SIE 2025

Life Cycle Assessment of Decarbonising the Urban Bus Network of Fribourg & Surroundings

Students: Alexandra Knoblauch & Maurus Lozza
EPFL Supervisor: Jérôme Payet
Company: Agglomeration of Fribourg
Guillaume Grandchamp & Sven Köhli

CONTEXT

- **Urban transport:** 8% of global **GHG emissions** [1]
- **Decarbonisation** of urban public transport can support achieving sustainability goals [2]
- Agglomeration of Fribourg aims to **decarbonise** their **urban bus network by 2032**
- Analysed **scenarios**:
  - **Baseline: fossil-based** thermal-electric trolleybuses & diesel buses
  - **Decarbonised: electrification** through in-motion charging (IMC) trolleybuses & battery-electric buses (BEBs)

OBJECTIVES

- Establish an **LCA framework** specific to the Agglomeration of Fribourg
- Compare the bus **network, line & technology** life cycle environmental **impacts** under **baseline & decarbonised** scenarios
- **Evaluate decarbonisation strategies** in terms of technical and environmental feasibility

METHODOLOGY

- **Cradle-to-grave LCA:** 2 scenarios, 4 bus technologies, 8 bus models, 2 battery types
- **Functional unit:** Transport 1 person over 1 km on the bus network = **1 pkm**
- **Bus network:** 11 lines, 41'272'026 pkm/yr
- **Modelling:** SimaPro software & ecoinvent database; IMPACT World+ (6 selected midpoint indicators, focus on **short-term climate change** → kg CO_2-eq/pkm)
- **Process tree & system boundary:**

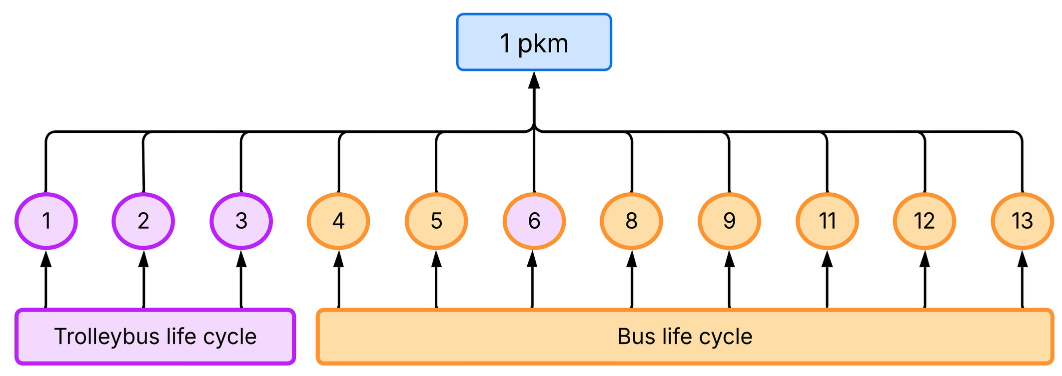

Fig. 1: System overview for the delivery of 1 pkm (functional unit) across the bus network.
Purple: Trolleybus lines; Orange: Regular bus lines

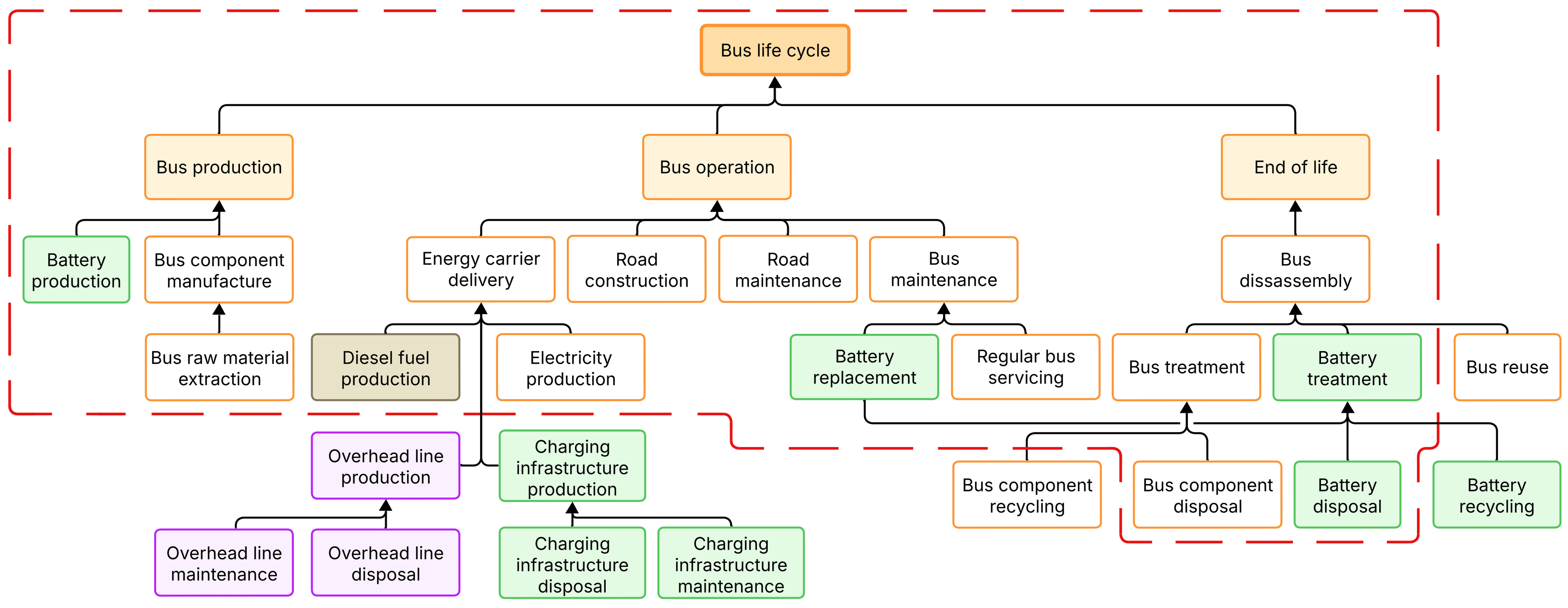

Fig. 2: Process tree of life cycle stages. Orange: All buses; Purple: Trolleybuses only; Green: Decarbonised scenario; Red line: System boundary.

RESULTS

1. Network-wide climate change impacts

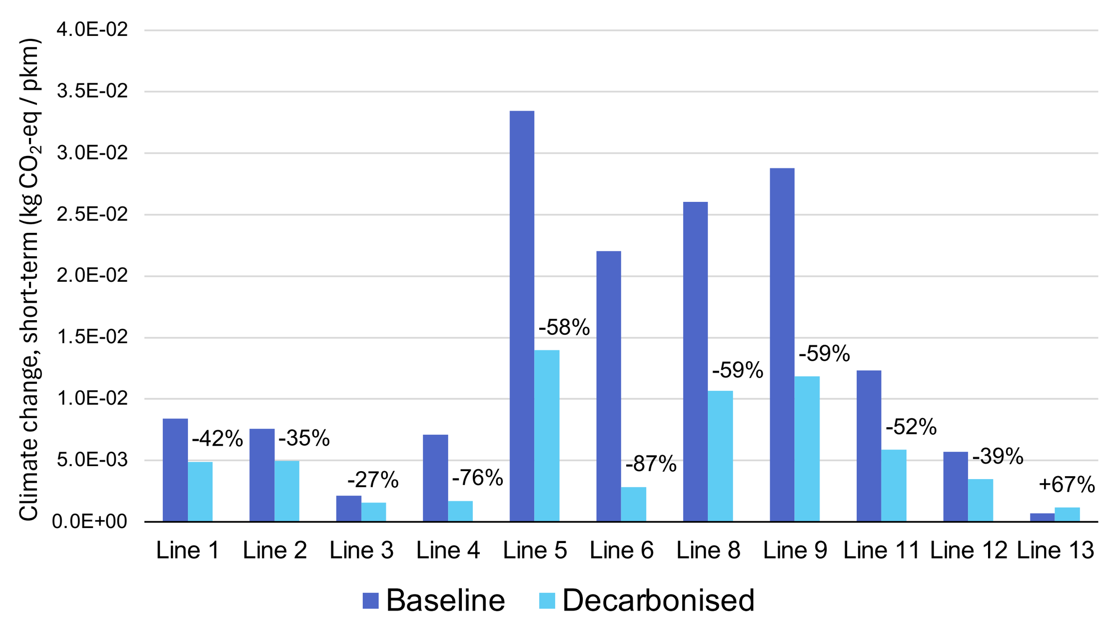

Fig. 3: Comparison of absolute network-wide short-term climate change impacts for baseline and decarbonised scenarios in kg CO_2-eq/pkm.

- **Baseline**: 0.154 kg CO_2-eq/pkm
- **Decarbonised**: 0.063 kg CO_2-eq/pkm
- **59.2% reduction** equivalent to **3764 t CO_2-eq/yr total annual savings**
- Decarbonised: 10 out of 11 lines with reduced impacts
- Smaller % reduction on trolleybus lines (1, 2, 3)

3. Technology climate change impacts by life cycle stage

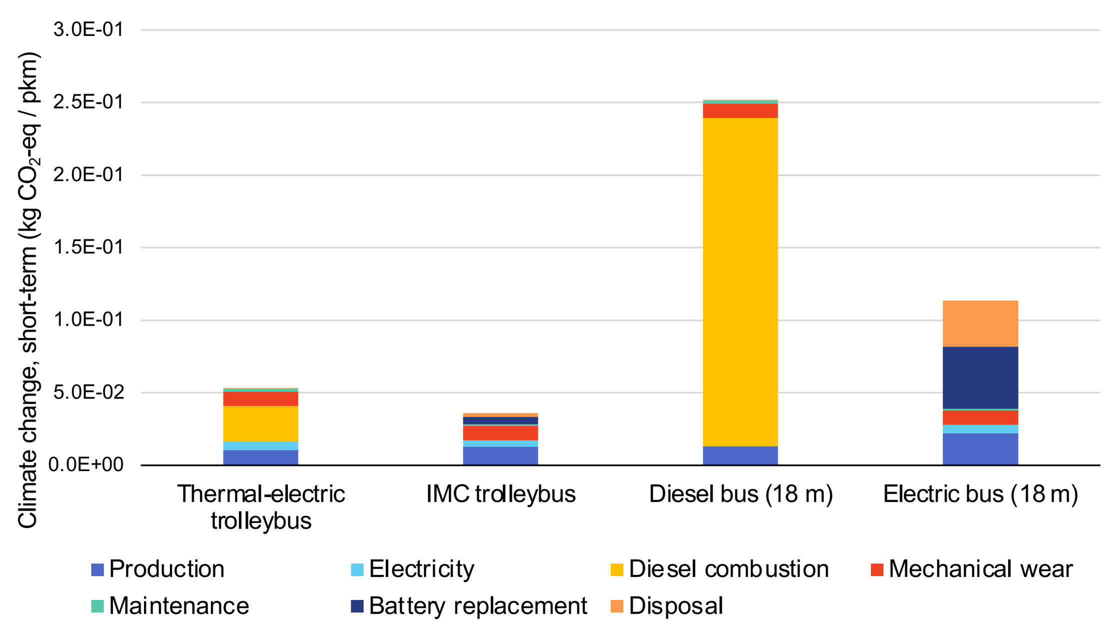

Fig. 5: Comparison of absolute short-term climate change impacts across bus technologies in kg CO_2-eq/pkm. Colours represent different life cycle stages. All technologies are modelled with an equal annual vehicle distance of 50'000 km.

- Thermal-electric → IMC trolleybus: -32%
- Diesel → BEB: -55%
- Decarbonised: **impacts shift from operation to production & disposal**
- Significant contribution from battery replacement
- **Efficient trolleybus** technology

2. Further network-wide midpoint category impacts

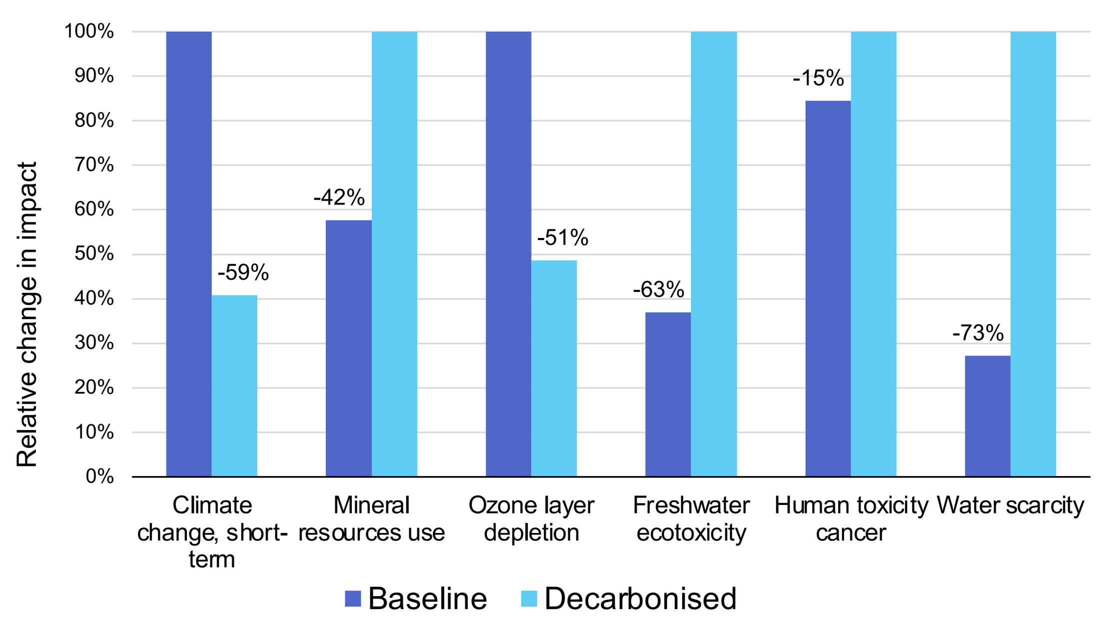

Fig. 4: Comparison of impacts for 6 selected midpoint indicators for baseline and decarbonised scenarios. Impacts are normalised to the scenario with the worst impact (100%).

- **Baseline**: lower impact in 4 categories
- **Decarbonised**: lower impact in 2 categories
- **Trade-off** between climate-related benefits (CO_2, ozone) and higher impacts on mineral resources use, ecosystem quality, human health & water scarcity

4. Sensitivity analysis of climate change impacts

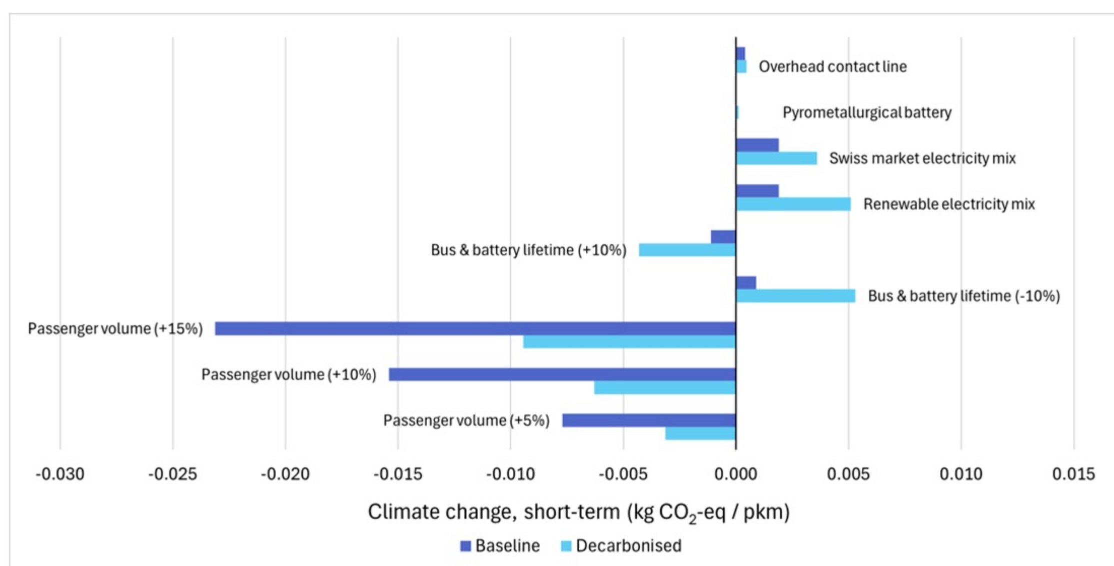

Fig. 6: Sensitivity analysis of network-wide short-term climate change impacts for baseline and decarbonised scenarios, expressed in absolute change of kg CO_2-eq/pkm from the respective reference models.

- **More passengers** reduce impacts / pkm
- **Bus & battery lifetime** variation with stronger influence under decarbonised scenario
- Critical role of **electricity mix** in decarbonised scenario

LIMITATIONS

- Uncertainties from modelling, ecoinvent & data
- Differences in material composition of buses
- Exclusion of overhead contact lines (trolleybuses)
- Uncertainty about vehicle & battery EoL
- Exclusion of vehicle weight on road maintenance
- Mechanical wear & road impacts modelled by vehicle distance only

RECOMMENDATIONS & CONCLUSIONS

Recommendations

- Prioritise decarbonisation on high-impact lines (network perspective)
- Consider extension of trolleybus lines
- Aim for longer battery & bus lifetimes
- Align decarbonisation strategy with evolving population needs

Conclusions

- Decarbonisation shifts impacts from operational to production and disposal
- Co-benefits of electric buses in urban setting (air quality, noise)
- Trade-off between impact categories and transfer of impacts abroad

Sciences et ingénierie de l'environnement

[1] Jakub, Szczurowski, Lubecki Adrian, Bałys Mieczysław, Brodawka Ewelina, and Zarębska Katarzyna. "Life Cycle Assessment Study on the Public Transport Bus Fleet Electrification in the Context of Sustainable Urban Development Strategy." *Science of The Total Environment* 824 (June 10, 2022): 153872.
[2] IPCC, ed. "Transport." In *Climate Change 2022 - Mitigation of Climate Change*, 1st ed., 1049–1160. Cambridge University Press, 2023.