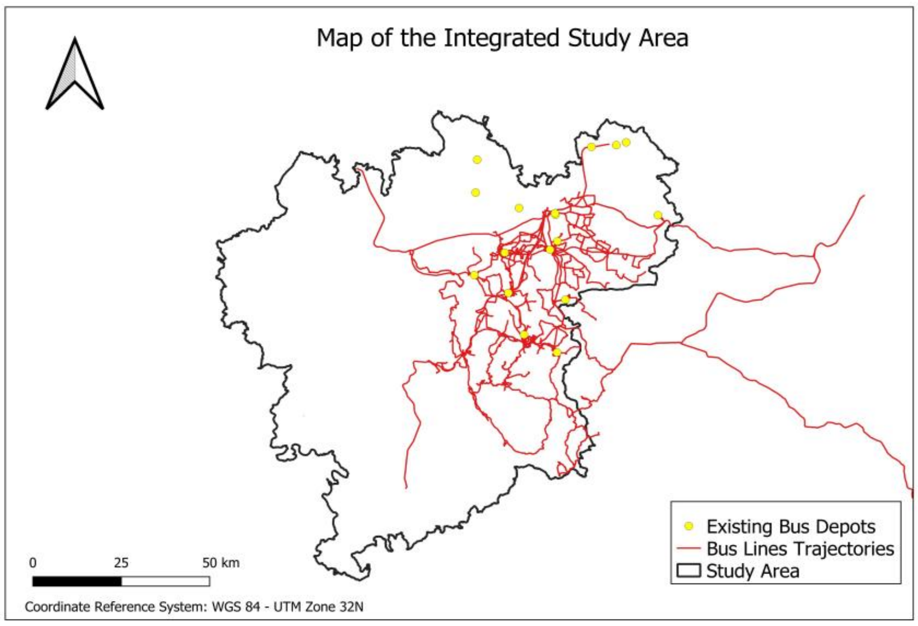
Optimizing Energy Efficiency in Electric Bus Networks: A Scenario-Based Analytical Framework for Transition to Electric Buses Based on Energy Consumption

Master‘s Thesis of Juan Pablo Guillén

Mentoring:
Dr.-Ing. Antonios Tsakarestos
M.Eng. Markus Fischer

External Mentoring:
M.Sc.-Ing. Fabien Laurent (KCW)
M.Sc.-Ing. Knud Trubbach (KCW)

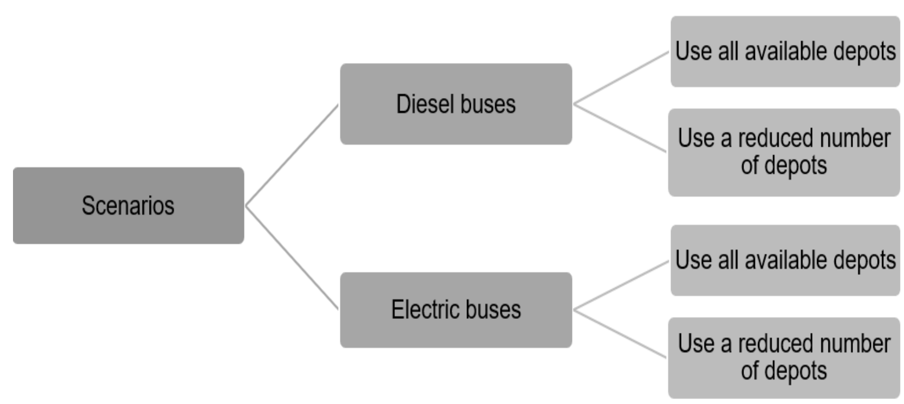


Objective & scope

This thesis develops a replicable, scenario-based analytical framework to evaluate the technical and economic feasibility of electrifying a regional bus network. Focusing on energy consumption and depot configuration, the framework combines spatial analysis (QGIS) and macroscopic simulation (PTV Visum) to quantify how depot location, battery capacity and charging infrastructure affect dead-heading, fleet needs and lifetime costs. The core research questions are: (1) Which planning elements most influence electrification costs? (2) How can Visum-based scenarios support cost-focused decision making for battery-electric bus (BEB) deployment?

Methodology

1. Spatial preprocessing (QGIS): expand/clean road network, extract route start/end points and compute network-based shortest-paths (QNEAT3) to assign each line to its nearest depot.
2. Scenario design: keep original routes constant and vary (a) available depots and (b) propulsion (diesel vs BEB) to compare operational impacts.
3. Simulation (PTV Visum): run line-blocking and compute KPIs per scenario (empty km, operating km, CostDistance, CostTotal, fleet size).
4. Infrastructure costing: compute required charging points and medium-voltage connection costs and integrate these into the scenario cost model.



“Structure of scenario design for model evaluation.”

“Calculated total cost of the project, combining infrastructure and operational costs, and projected to 12 years.”

Key results & policy messages

• Depot distribution is a critical structural factor: some depots serve many lines (e.g., Depot 23 → 19 lines) while others are never closest and can be deprioritized.

• Electrification infrastructure cost (charging stations + grid connection) was estimated at ≈ €37,581,496.68; grid connection is the largest share.

• Reducing the number of active depots raises empty (dead-heading) kilometres strongly — in extreme reduced-depot scenarios empty km increased by >50%, especially for BEB — which can erase infrastructure savings.

Recommendations: prioritize decentralised depot electrification close to substations, include real grid capacity data in planning, and use this QGIS+Visum workflow for multi-scenario, evidence-based electrification decisions.