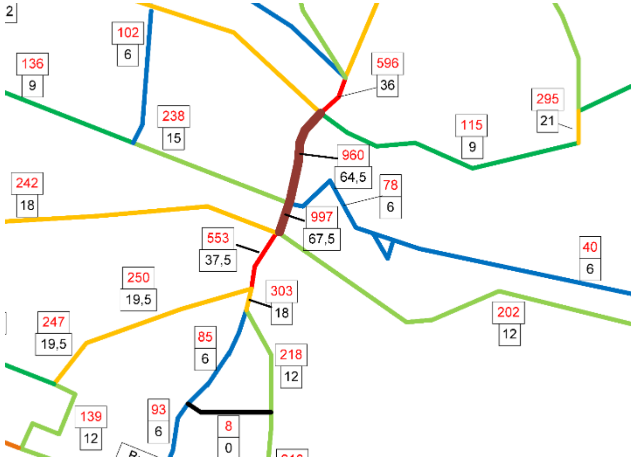
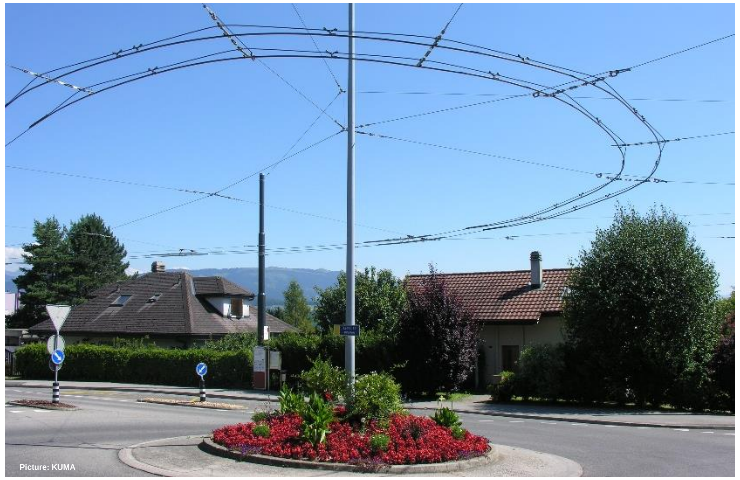
Application of OpenTrack and OpenPowerNet for a Feasibility and Cost Effectiveness Study





Introduction of a Hybrid-trolleybus system in a large European city

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Work contents of the feasibility study

OpenPowerNet

- **Market research regarding the state-of-the-art technology**

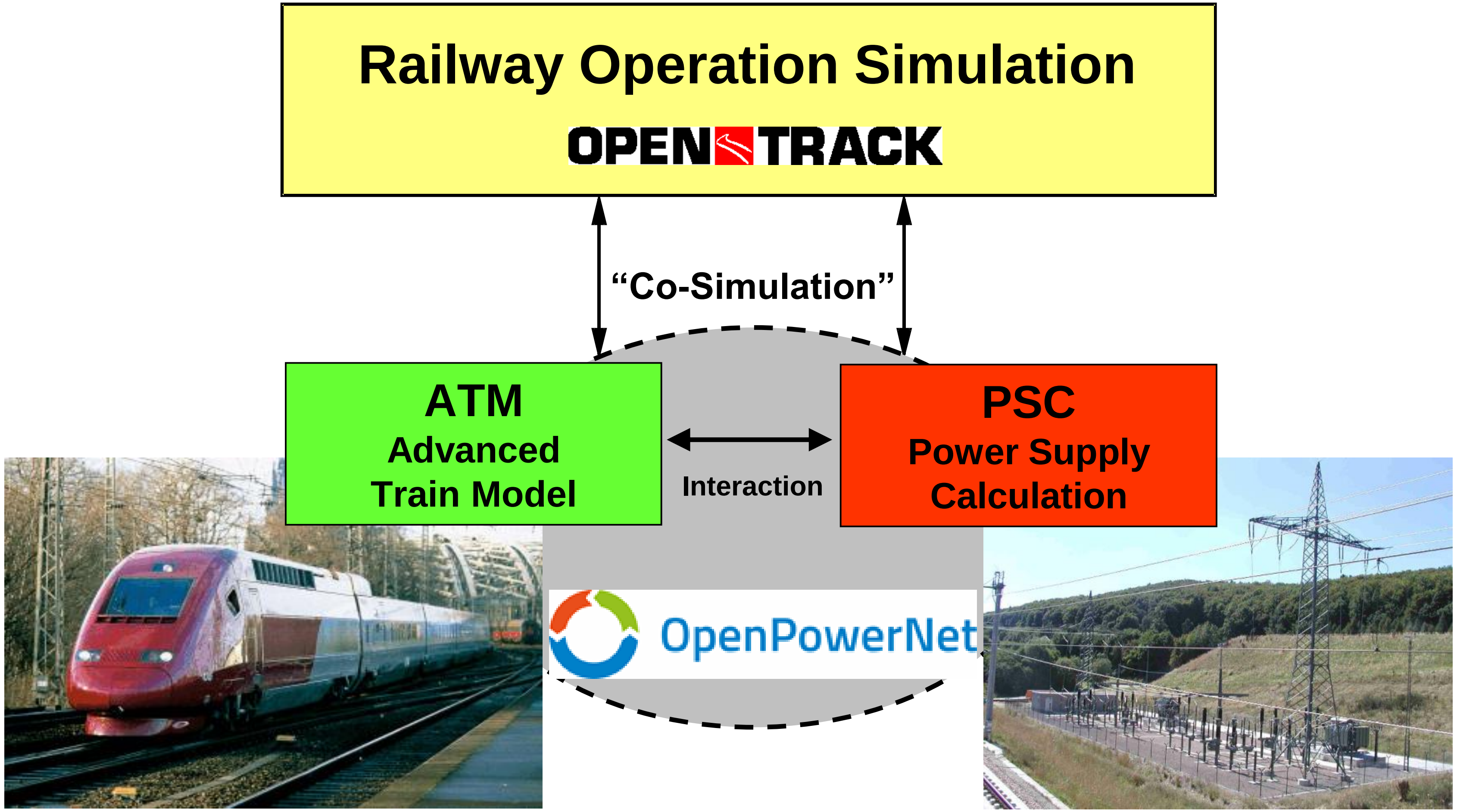
- **Technical design of the Traction Power Supply system**
  - Selection of **vehicle and propulsion technology** for vehicles charged while driving under consideration of line topology and density of traffic
  - **Rating of the vehicle propulsion systems**: traction power, auxiliary systems, traction motors, inverter, **battery**
  - Concept of **traction power and recharging infrastructure** considering the operation planing and the vehicle and propulsion technology for **three scenarios**
  - **Dimensioning of traction power and recharging infrastructure:** Rating and location of grid connection and feeding points as well as of the network structure: traction power substations, overhead line equipment, stationary recharging points; Verification with dynamic traction power simulation: Timetable, driving dynamics, power and energy demand
  - **Compilation of Bill of Quantity** for vehicles and facilities

- **Suggesting a scenario for implementation including scheduling**

- **Cost-effectiveness and sustainability compared to Diesel and Battery-electric-bus scenarios**

Preparation of Traction Power Supply Simulation with

- Operation simulation software OPEN TRACK
- Traction Power Supply simulation software
- Simulations performed on the basis of iterative loops in terms of assessment of the required normative limits
- Identification of worst case scenario, comparison with the required normative limits
- Defining of electrical devices for adequate rating



Propulsion Technology

Power Supply System

Investigated Network

- **Existing bus network of approx. 250 km network length, 14 bus lines**
  - Dense bus traffic over the whole day
  - Long line lengths
  - High passenger load with expected increase
- The bus traffic shall be electrified to meet legal requirements regarding climate protection
- Not the whole network shall be electrified

→ Investigation of hybrid trolleybuses:

→ Conventional trolley buses equipped with energy storage

→ Hybrid trolleybuses are charged while moving under catenary

→ Less amount of catenary than for conventional trolley buses, in particular switches, crossings and curves

→ Smaller and lower mass of energy storage than for conventional battery buses

Investigated Network
Service frequency of bus operation

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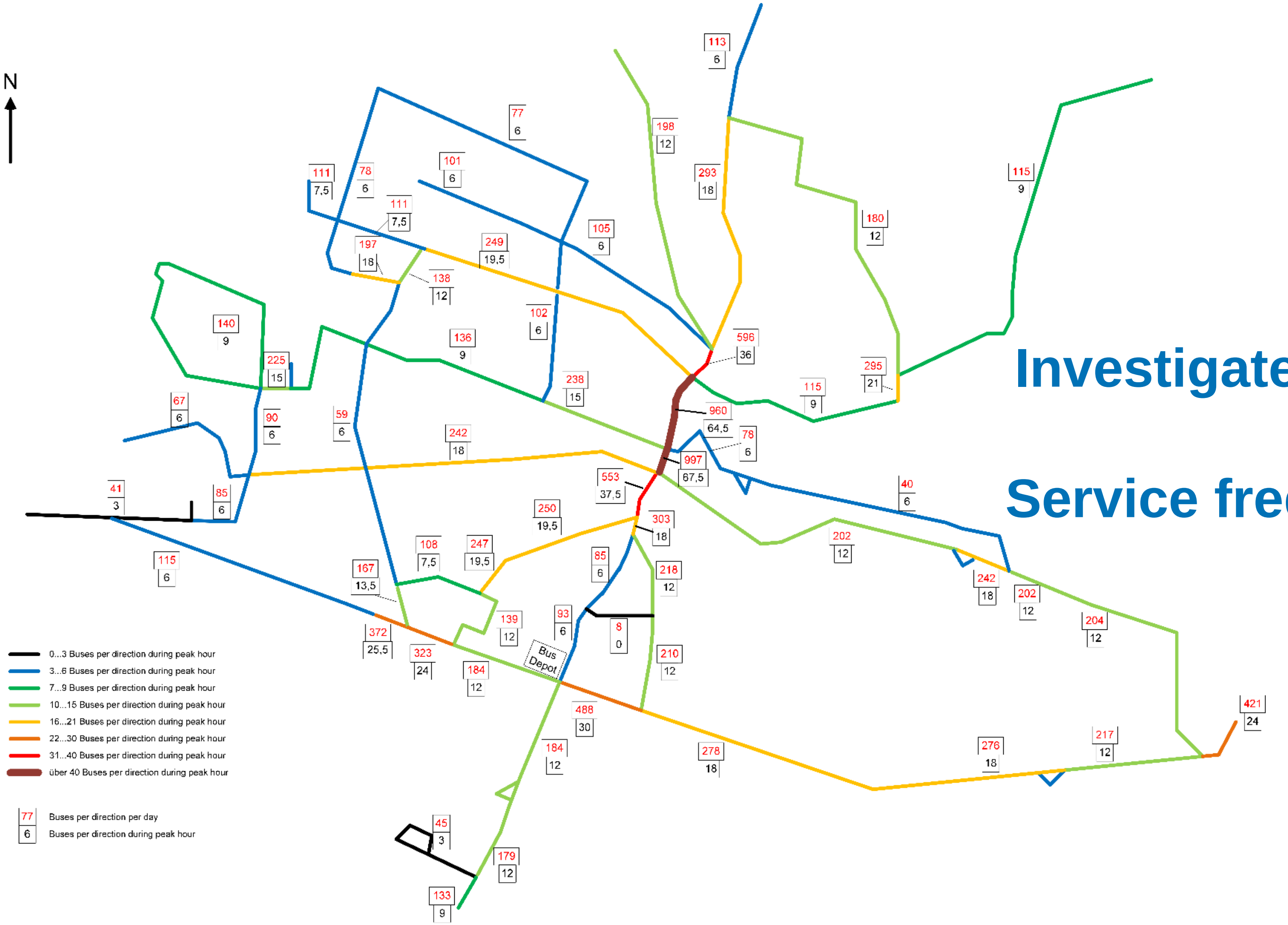

~250km Network length

Investigated Network (not to scale)

Service frequency of bus operation

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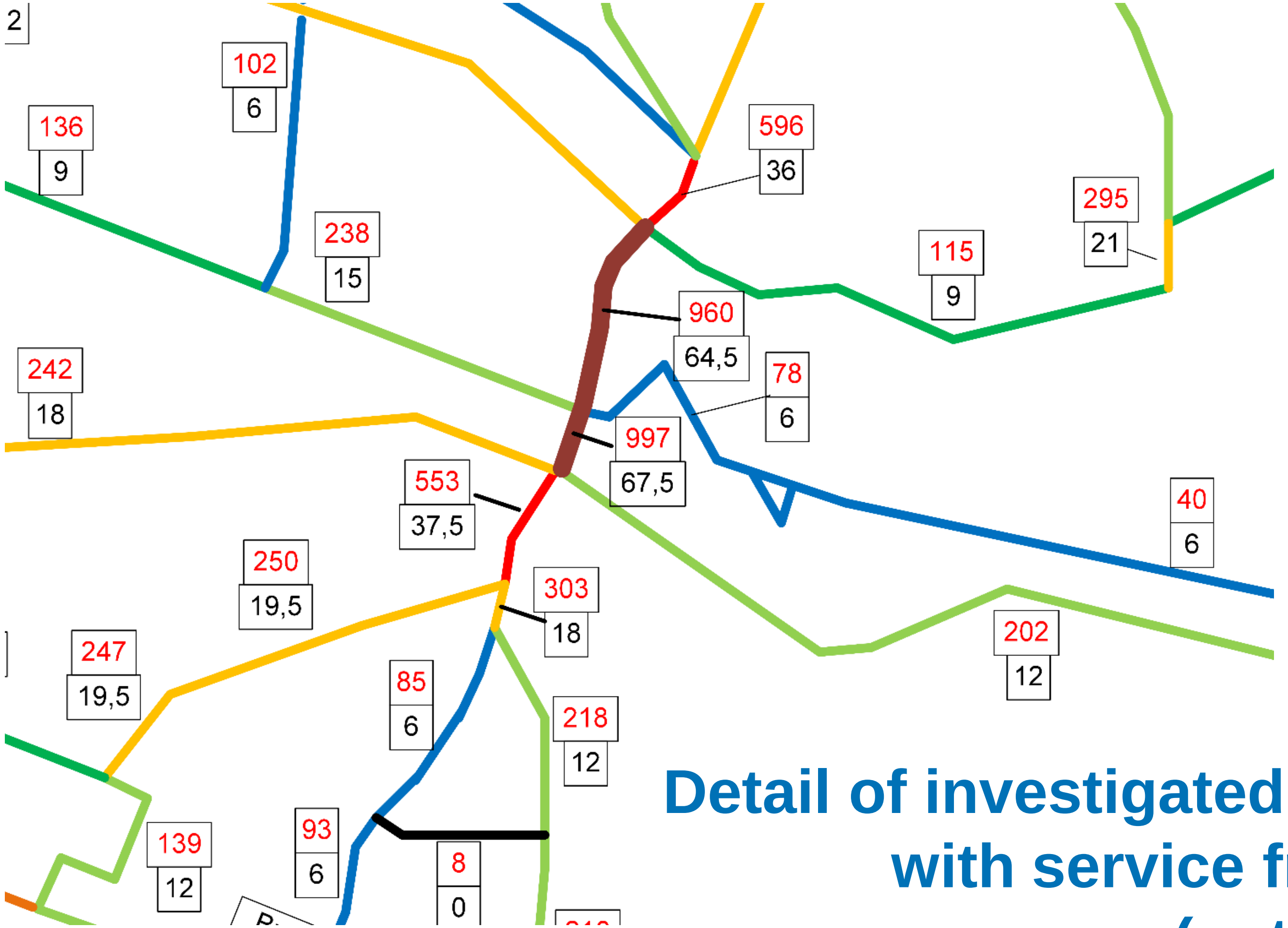
Investigated Network
Service frequency of bus operation

OpenPowerNet

Buses per direction during peak hour
- 0...3 Buses
- 3...6 Buses
- 7...9 Buses
- 10...15 Buses
- 16...21 Buses
- 22...30 Buses
- 31...40 Buses
- More than 40 Buses



77	Buses per direction per day
6	Buses per direction during peak hour

Detail of investigated network, with service frequency (not to scale)

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Scenarios and approach

Scenario 1: with high percentage of catenary wire
Scenario 2: minimised reduced catenary wire
Scenario 3: reduced catenary wire and reduced bus lines
→ two scenarios with minimised percentage of catenary wire developed

- The following analyses were performed:
  - minimum line voltage (EN 50163),
  - ability to recognise short-circuits within the TPS compared to maximum operational currents,
  - Load of electrical components versus load capabilities, and
  - Battery State of Charge (SoC) during operation and lifetime analysis

- Based on the simulation results, the design was optimised → analyses were repeated

- Iteration until all scenarios were approved for all outage scenarios

Scenario 2 with reduced catenary

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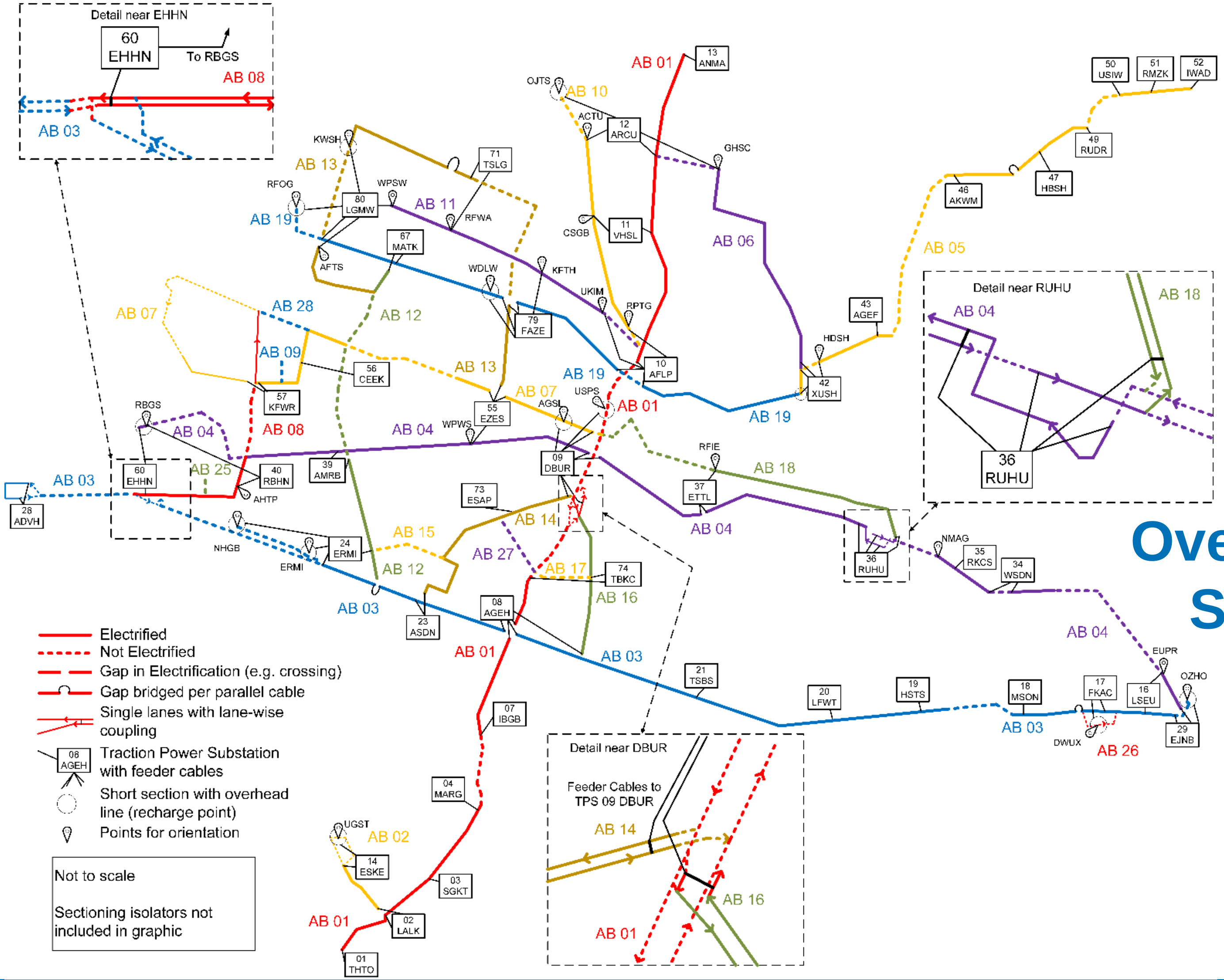

Overview of Traction Power Supply, Scenario 2 with reduced catenary (not to scale)

Scenario 2 with reduced catenary

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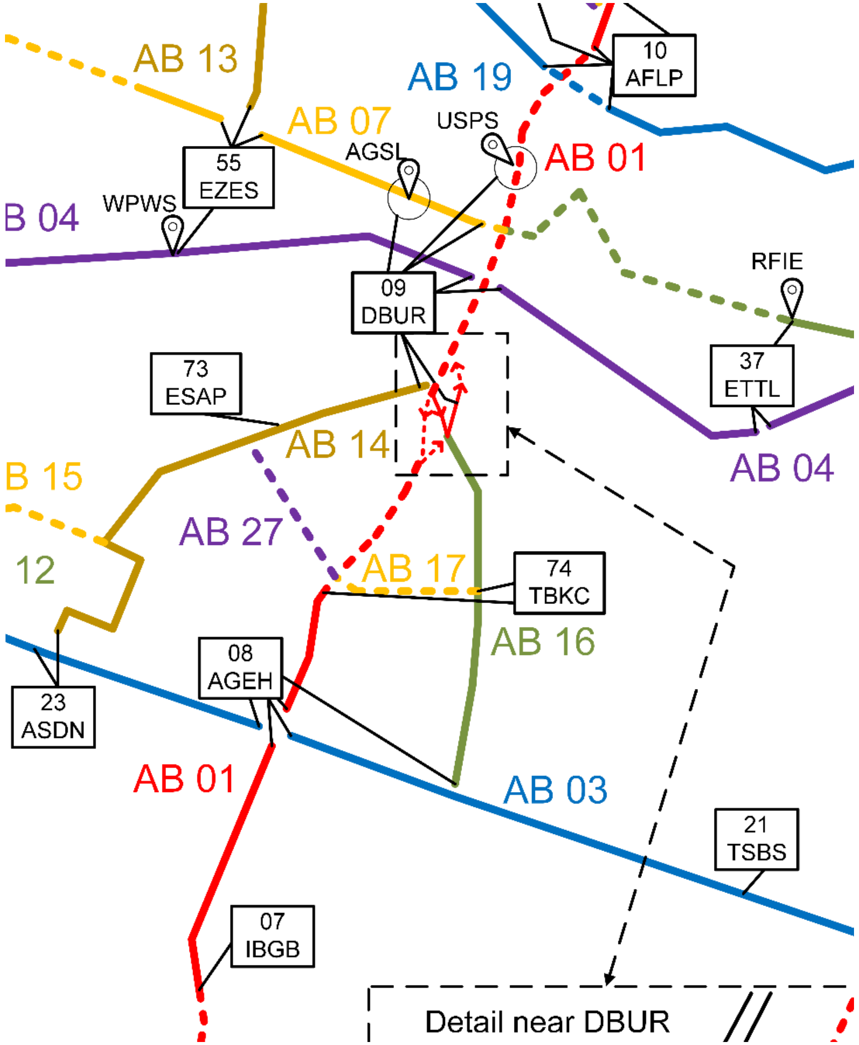
Electrified
Not Electrified
Gap in Electrification (e.g. crossing)
Gap bridged per parallel cable
Single lanes with lane-wise coupling
08 AGEH Traction Power Substation with feeder cables
Short section with overhead line (recharge point)
Points for orientation

Not to scale

Sectioning isolators not included in graphic



Detail from overview of Traction Power Supply,

Scenario 2 with reduced catenary

Input Data – Infrastructure

Example Screenshot of the infrastructure layout in OpenTrack

Input Data – Rolling Stock

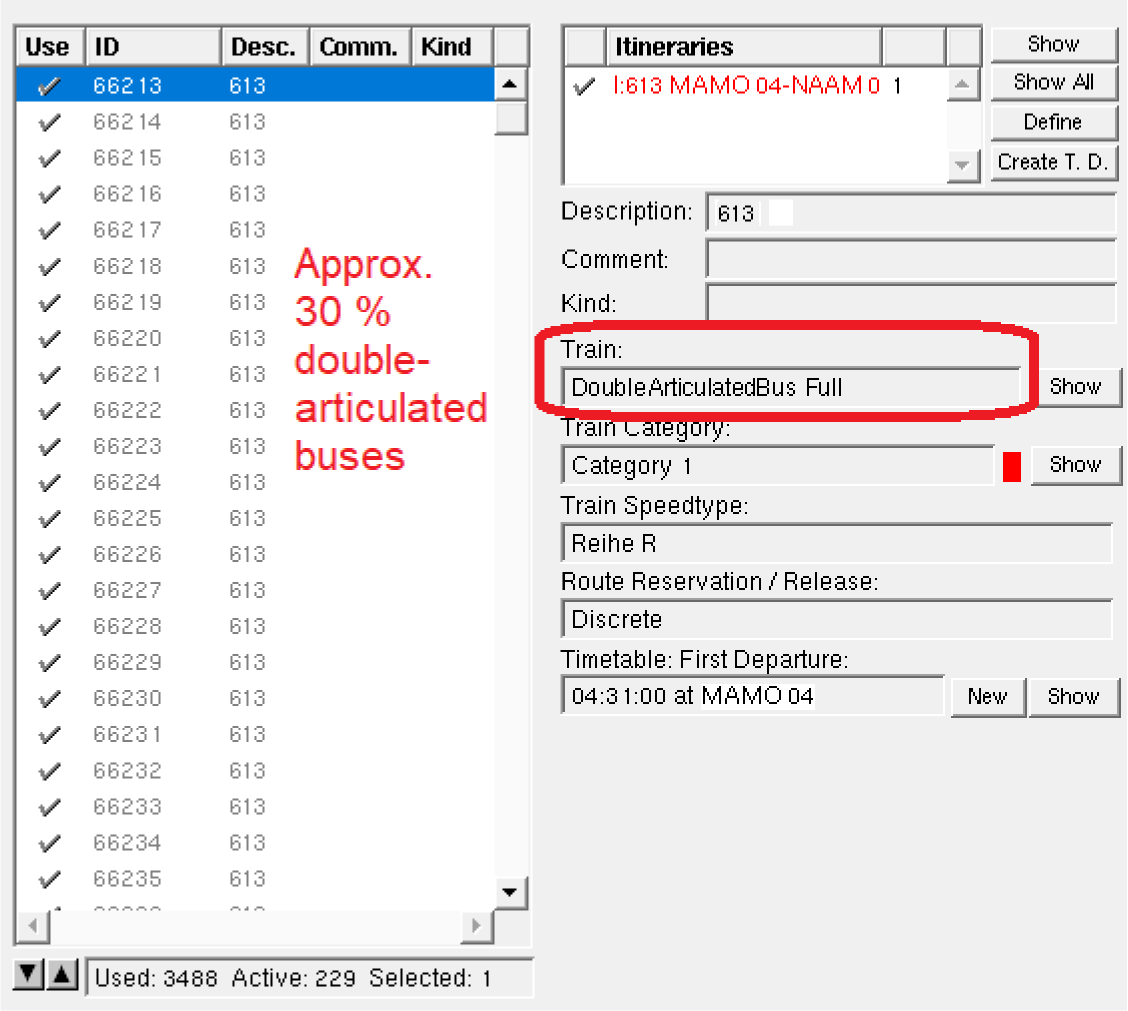
Parameter	Articulated Bus	Double-articulated Bus
Length [m]	18	25
Tare weight [t]	18	24
Maximum permissible weight [t]	28	39
Seats | Standees 4P/m² | 6P/m²	42|76|120	52|104|175
mech. traction power [kW]	240	280
max. auxiliary power[kW]	45	63
Recuperation possible	yes	
Battery capacity [kWh]	app. 72	
Battery type (cell chemistry)	lithium iron phosphate	
Mean State of Charge ±Rate [%]	65 ±25	
End of Life (Capacity in [%] or R_I)	80%	

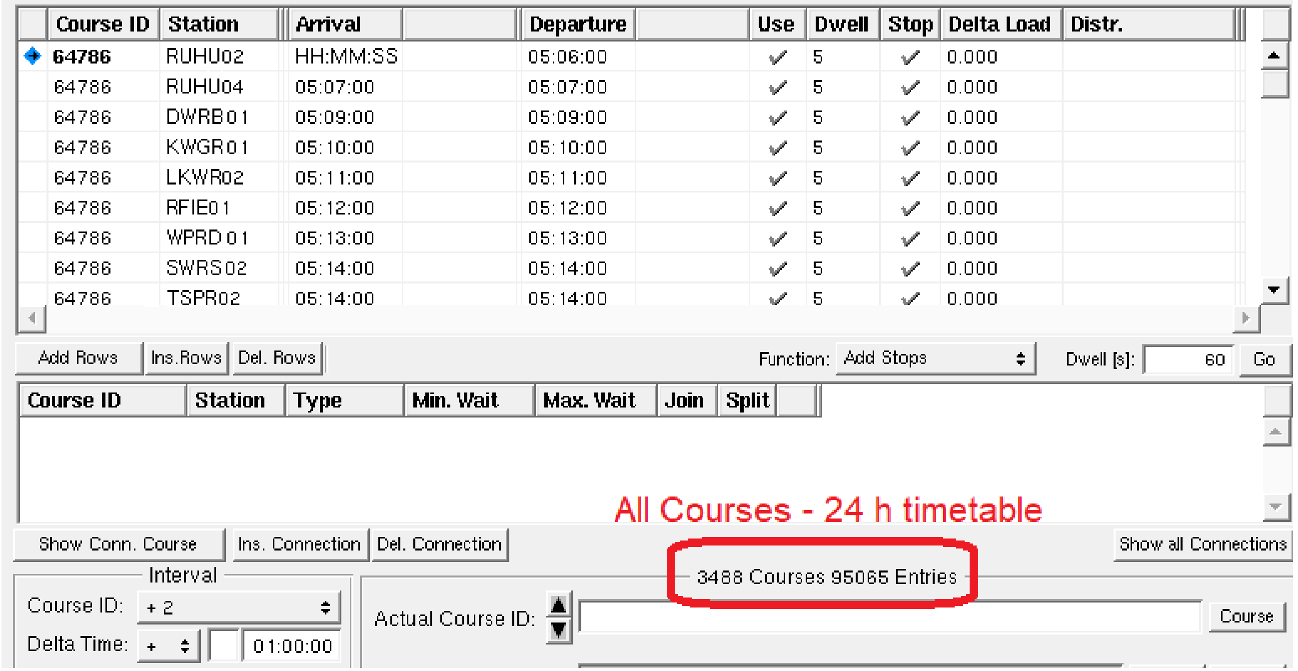
Articulated trolley bus, Eberswalde (DE)

Double-articulated trolley bus, Zürich (CH)

Input Data – Courses and Timetable

OpenPowerNet





3488 Courses within the 24 h timetable

Example screenshot of the courses and timetable data in OpenTrack

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Exemplary results

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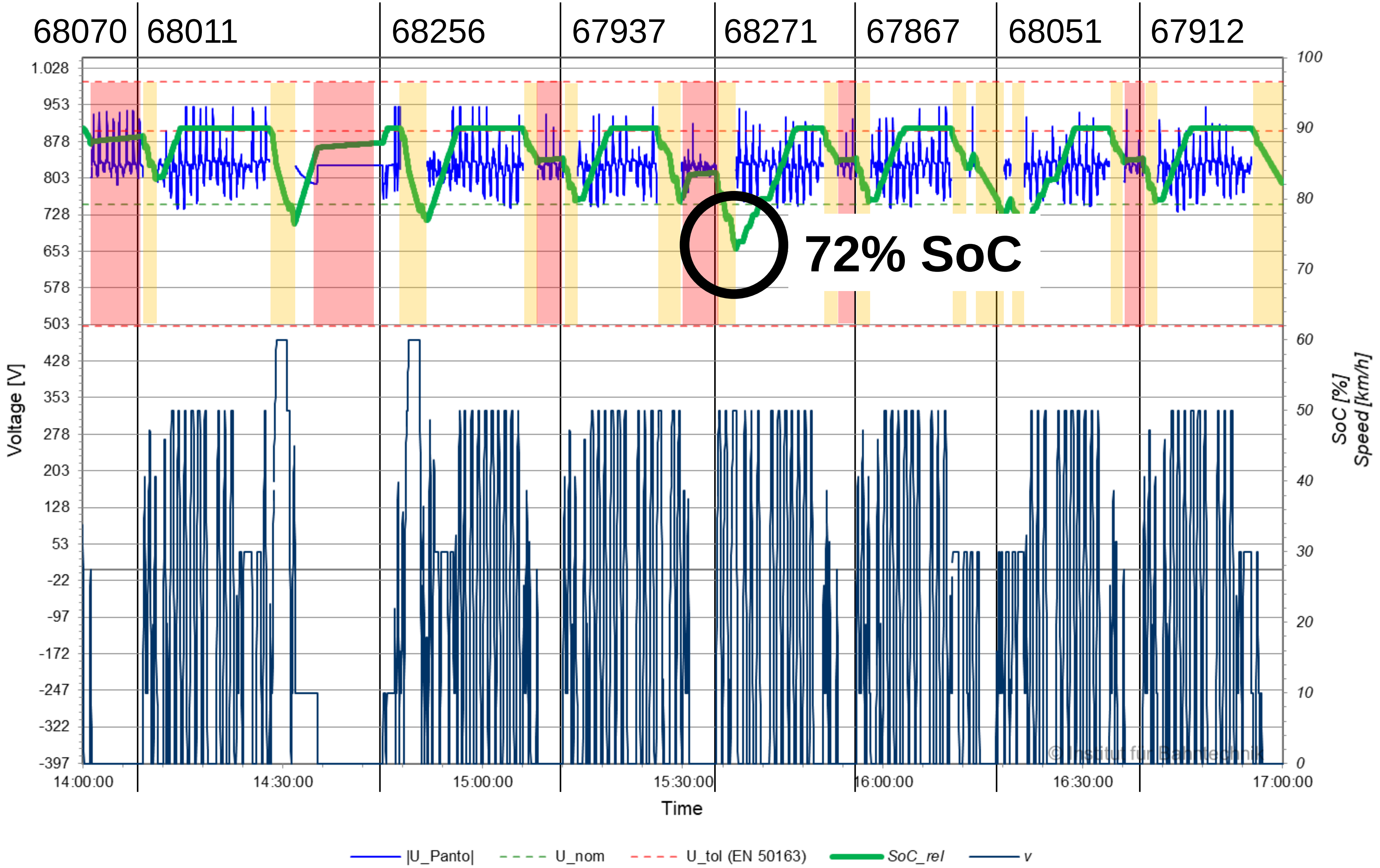

Voltage, Speed, and Battery State of Charge

One vehicle, 3 hours, different destinations

Catenary free section

Charging at standstill

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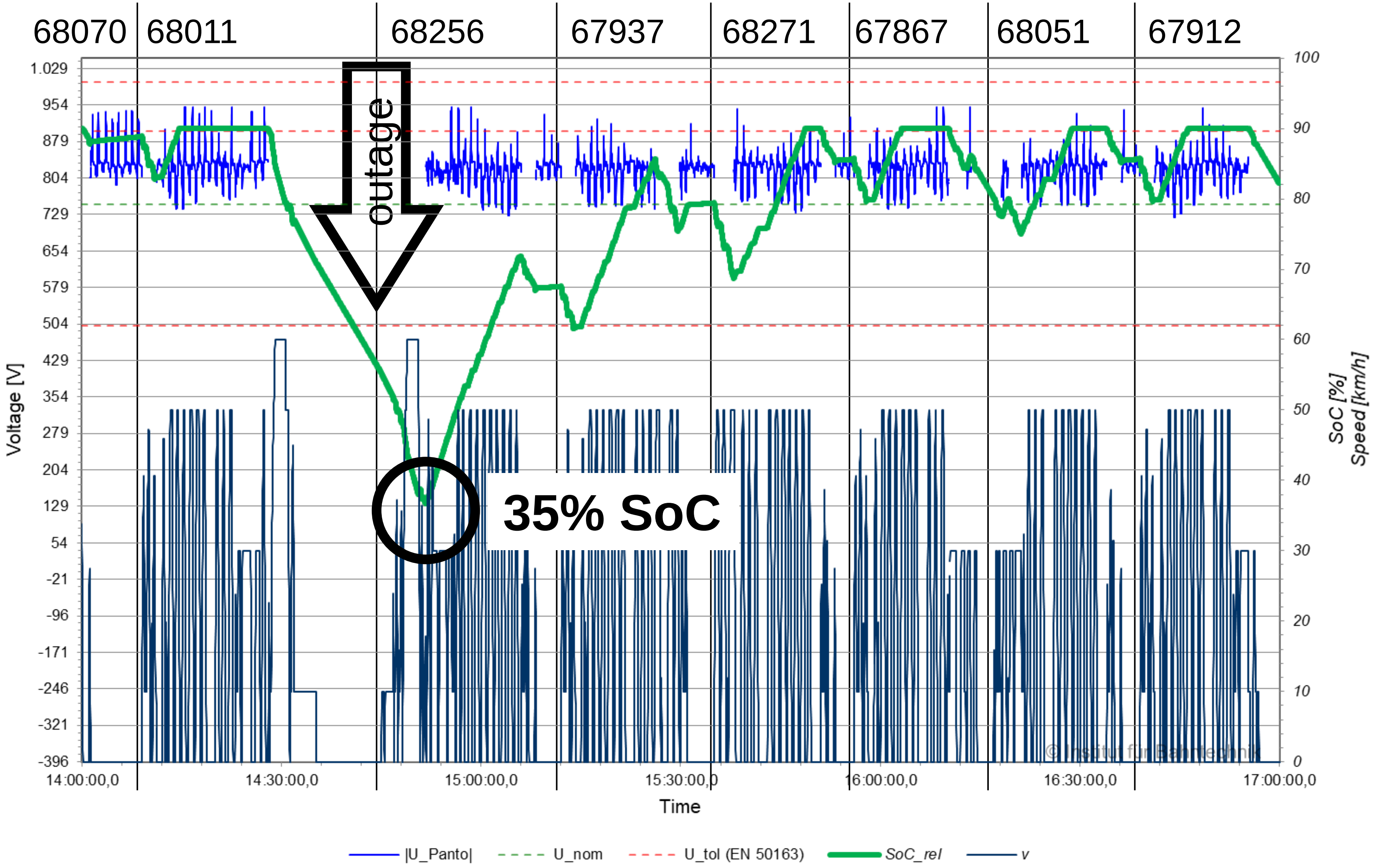
Exemplary results

OpenPowerNet



Voltage, Speed, and Battery State of Charge

One vehicle, 3 hours, different destinations

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Energy Consumption for different Scenarios

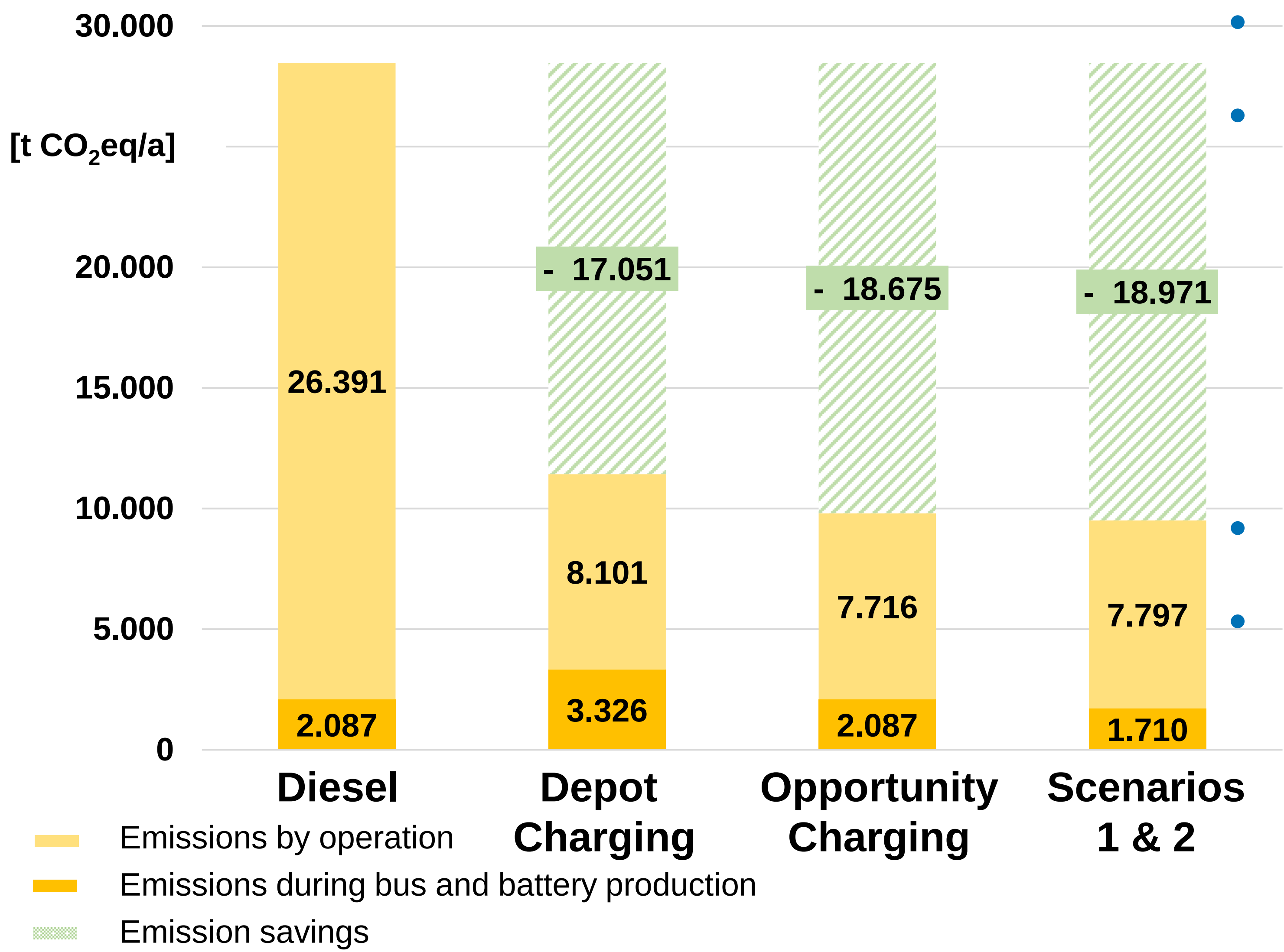
OpenPowerNet

Parameter	Scenario 1 All services / high percentage of electrification	Scenario 2 All services / reduced percentage of electrification	Scenario 3 Limited Services / reduced percentage of electrification
Performed kilometers	41.339 km	41.339 km	30.938 km
Daily energy consumption @ 33 % auxiliary power	84 MWh	84 MWh	54 MWh
Daily energy consumption @ 75 % auxiliary power	130 MWh	130 MWh	89 MWh
Annual energy consumption	38 GWh	38 GWh	25 GWh
Specific energy demand per bus	2,5 kWh / km	2,5 kWh / km	2,2 kWh / km

Comparison of energy consumption

Environmental Effects

OpenPowerNet



- **High CO_2 savings**
- **Additional advantages compared to diesel buses:**
  - Advantages of air pollution control (reduction of NO_x)
  - Reduction of noise pollution
- **Assumption: power mix 2030**
- **CO_2 emissions not taken into account for infrastructure production**

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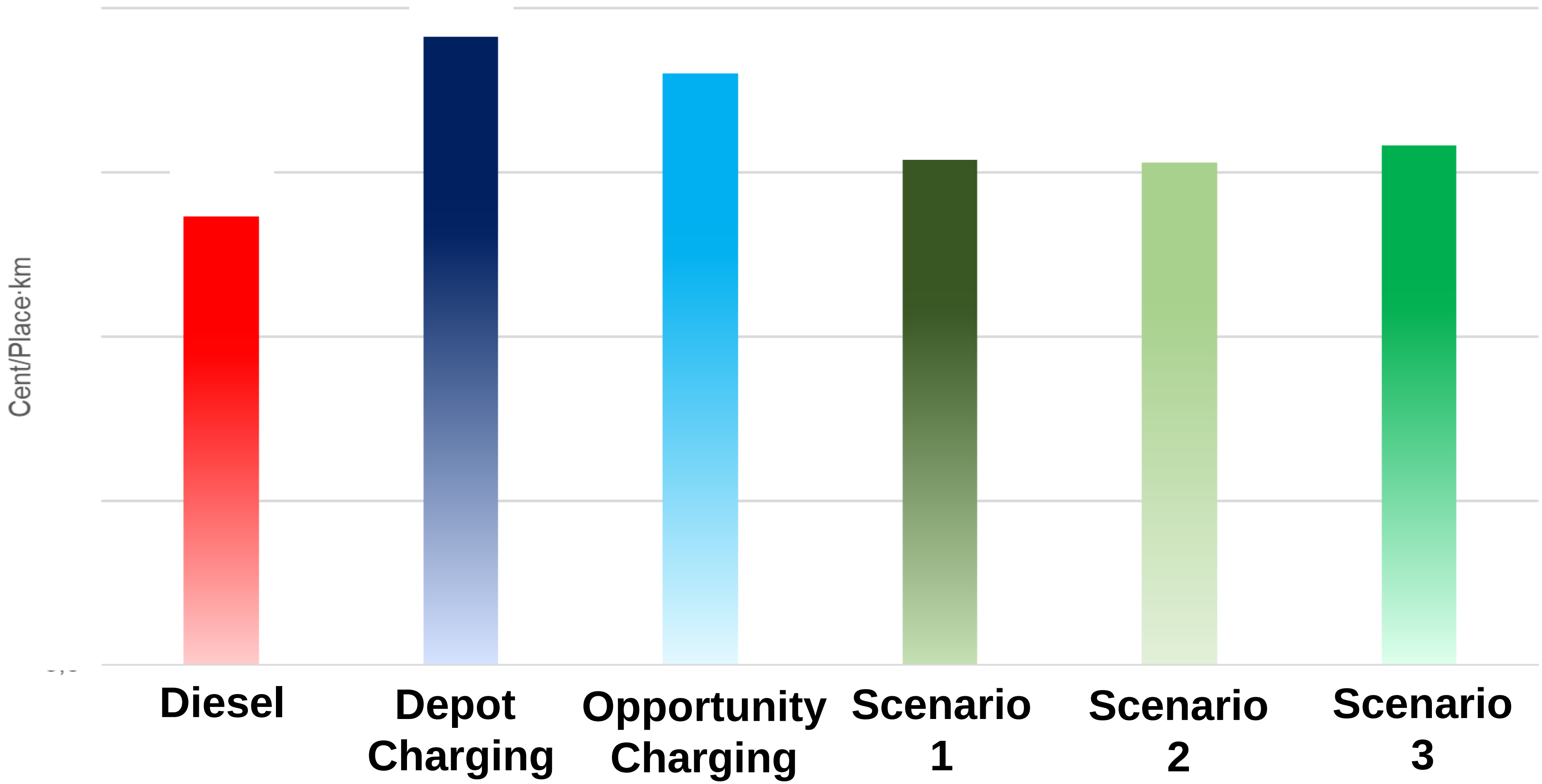
Economic efficiency comparison

Comparison of specific annuities

OpenPowerNet



At the specific annuity, the profitability of the Hybrid-Trolleybusses is 10-20% higher than the other variants.

Summary of results

OpenPowerNet

- **Hybrid - trolleybus system for the chosen city is technically and economically feasible.**
- A hybrid - trolleybus is especially advantageous where bus lines are concentrated and characterised by **high passenger numbers** and **long trip lengths.**
- Hybrid-trolleybuses combine trusted, proven, and reliable technology of conventional trolleybuses with modern battery storage technology → this allows **high-performant and reliable operation.**
- With an on-board energy storage, turns, crossings and other sections where electrification is complicated and expensive or unwanted for aesthetic reasons can be realised catenary-free → **Broadened flexibility for the best technical realisation of urban electrical infrastructure.**
- From economic point of view, the hybrid - trolleybus is an alternative to other electric bus technologies, with the additional possibility to operate bigger vehicles (e.g. double-articulated buses).
- **The comparison of specific annuities shows that it is worth in general to invest in electrical infrastructure for continuous storage loading and operating a bus system in case of dense headways and a high transportation quantity.**

Thank you for your attention!

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