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Solutions for Clean Transportation

# Feasibility Studies for Bus Networks

## Planning Operations and Overhead Infrastructure

23/10/2024

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# Our Experience

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- R&D in the field of electric buses for more than 15 years
- Experts in battery and fuel cell technology and bus operations
- Many customers in Europe and beyond

IVB INNS' BRUCK
Mobilität Stadtwerke Offenbach
WIENER LINIEN
BVG
Foothill Transit
SALZBURG AG
wupsi
west VERKEHR
Mülheim an der Ruhr Stadt am Fluss
STADT ST. INGBERT
VOR DER VERKEHRSVERBUND
eLIPTIC electrification of public transport in cities
BVG
Transport for West Midlands
BREMEN ERLEBEN!
STIB MIVB .brussels
Birmingham City Council
Rheinbahn
VERKEHRSBETRIEBE KREIS PLÖN GMBH VKP
BVB
NVG Omnibus-Betriebsgesellschaft mbH
ZeEUS Zero Emission Urban Bus System


DSW21
ASEAG
BSAG
SWBC StadtWerkeBiberach
movia

...and many more.

- There are three mechanisms in the EU that will lead to the electrification of local public transport buses in Europe:
  - Clean Vehicles Directive (CVD) – Municipalities must procure clean and >32,5% emissions-free vehicles.
  - Emissions reduction quotas – From 2030 on, manufacturers must sell 90% emissions-free vehicles. (Fit for 55) From 2035 on, it is 100%.
  - Emissions trading system (EU ETS) – Certificates necessary to emit $CO_2$. Less and less certificates will be issued, which will increase prices of fuel and gas.
- Only buses with electric drivetrain are a viable option to fulfill all these requirements.
- Bus manufacturers are now switching their production lines from conventional to electric drivetrains. Already now, some manufacturers do not offer conventional buses anymore, but only emissions-free buses.
  - Electrification might very well become mandatory for the entire fleet earlier than 2030.

**At the end of the day, there is no way around an entirely electrified bus fleet.** (only very few and small exceptions)

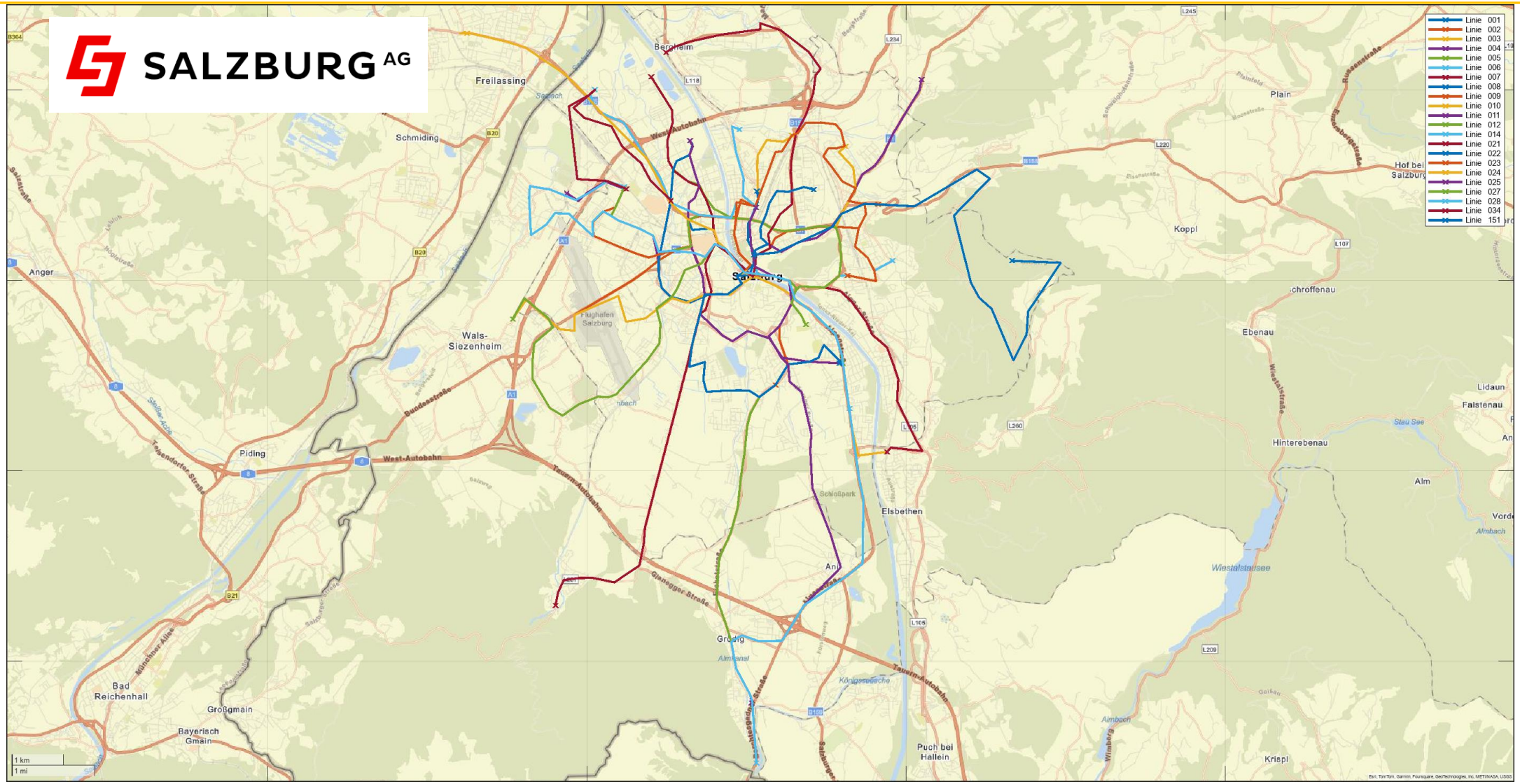
- Every city with a trolley bus network also has a certain number of conventionally fuelled buses.
  - Some more, some less.
  - There will always be bus routes / itineraries that do not justify overhead infrastructure.
- In future, this conventionally fuelled portion will need to be electrified, too.

**What portion of the conventional bus services can be electrified using existing overhead infrastructure?**

**Where does it make sense to reinforce the existing overhead infrastructure? Where to extend?**

**How to best electrify the rest of the bus services?**

# Example for a Study for the Entire Bus System
## Trolley Bus Routes and Conventional Bus Routes (Autobus)



# Individual Operation Concepts and Infrastructure Concepts
## Simulation and Vehicle Scheduling with Software *eplan*

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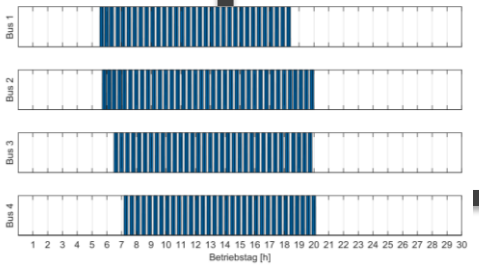
Services
(all route trips)




Route parameters and environmental conditions (e.g. HVAC)

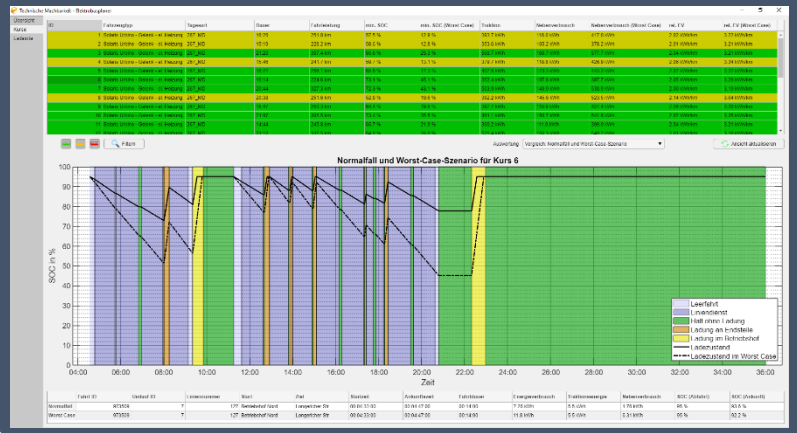
Vehicle and infrastructure parameters

EBUSCO® Electric Buses & Components
SOLARIS
MAN
BYD
Irizar lighting the road
HESS since 1882
rampini
VDL BUS & COACH
...


Operational requirements

eplan

Simulation
Analyses
Optimisation




Integrated operation concept + infrastructure concept

# Evaluation of Technical Feasibility of Bus Routes with Trolley Hybrids (In-motion charging, IMC) using Existing Overhead Lines

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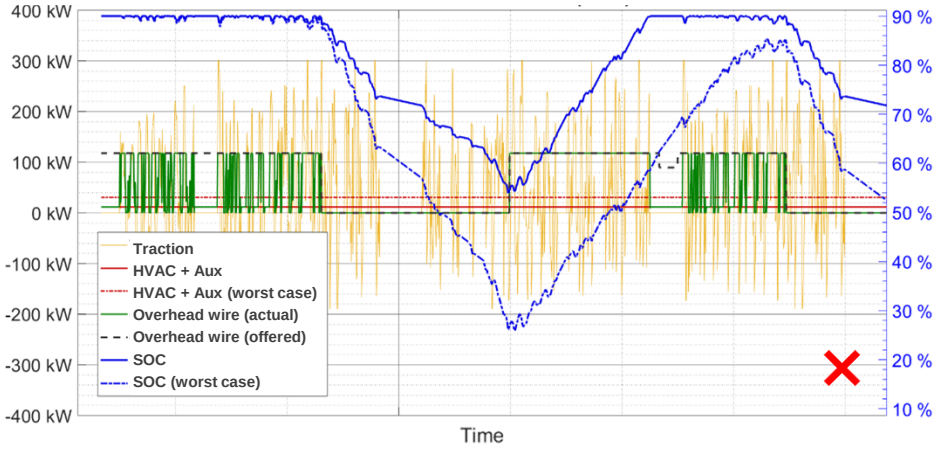
| Bus Route | Percentage covered by existing overhead lines | Energetic feasibility |
|---|---|---|
| *** | 36% | ✓ |
| *** | 50% | ✓ |
| *** | 13% | ✗ |
| *** | 31% | ✓ |
| *** | - | Not feasible for other reason |
| *** | 61% | ✓ |
| *** | 45% | ✓ |
| *** | 48% | ✓ |
| *** | - | Not feasible for other reason |
| *** | 28% | |
| *** | 43% | |
| *** | 35% | |

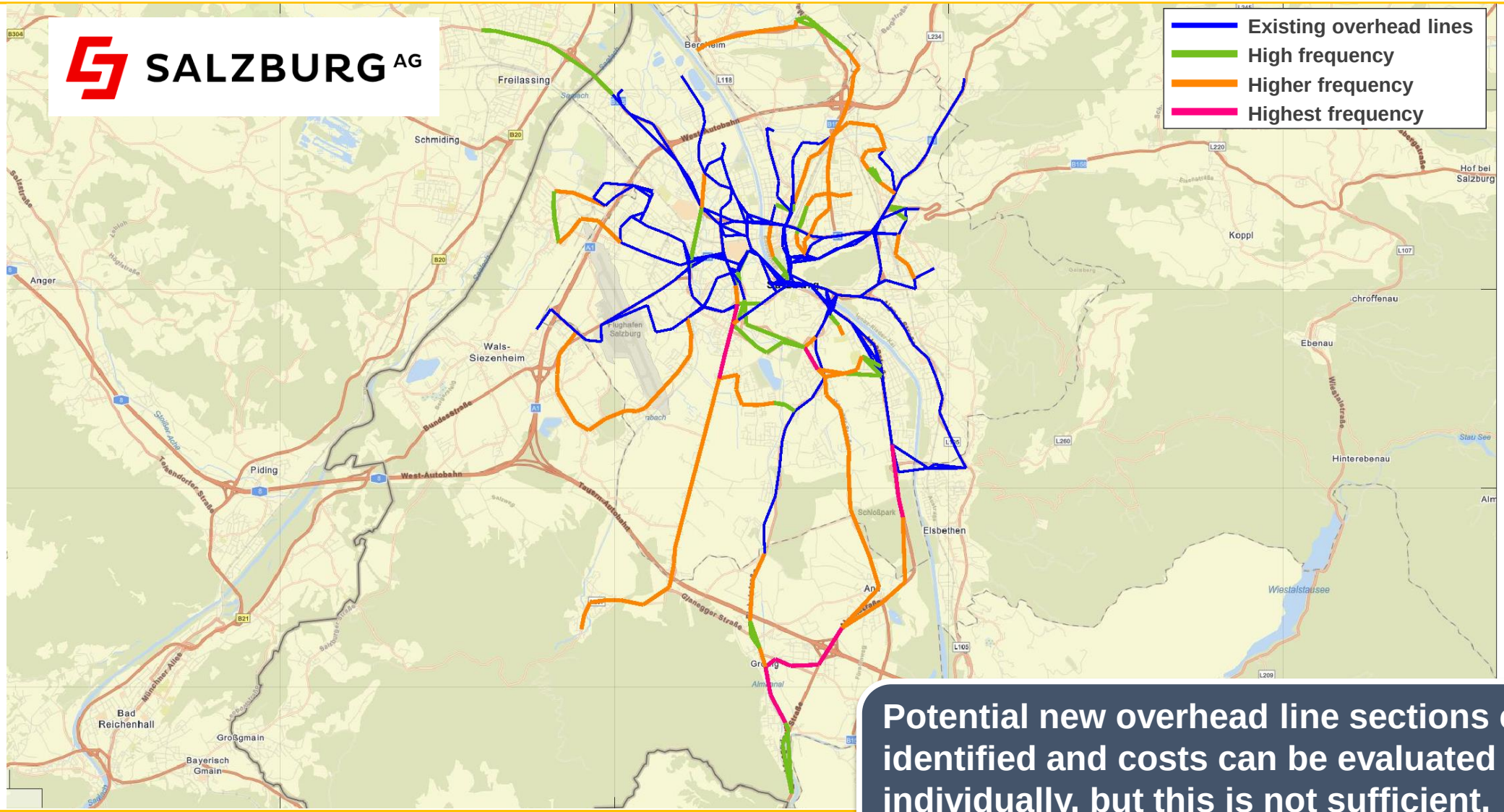



Example for not feasible bus route

**Where to reinforce existing substations to feed the buses for the ✓ bus routes?**

**How to electrify the non-feasible ✗ bus routes?**
1. **Extend overhead lines (new sections), or**
2. **Switch to battery electric buses (BEB) or fuel cell buses (FCB) ?**

# Option 1.: Extend Overhead Lines
## Initial Identification of Potential Extensions to the Existing Grid




**Potential new overhead line sections can be identified and costs can be evaluated individually, but this is not sufficient.**
**→ Overall systemic perspective required.**

# Option 2.: Switch to Battery or Fuel Cell Buses
## Individual Operation Concepts for all Scenarios

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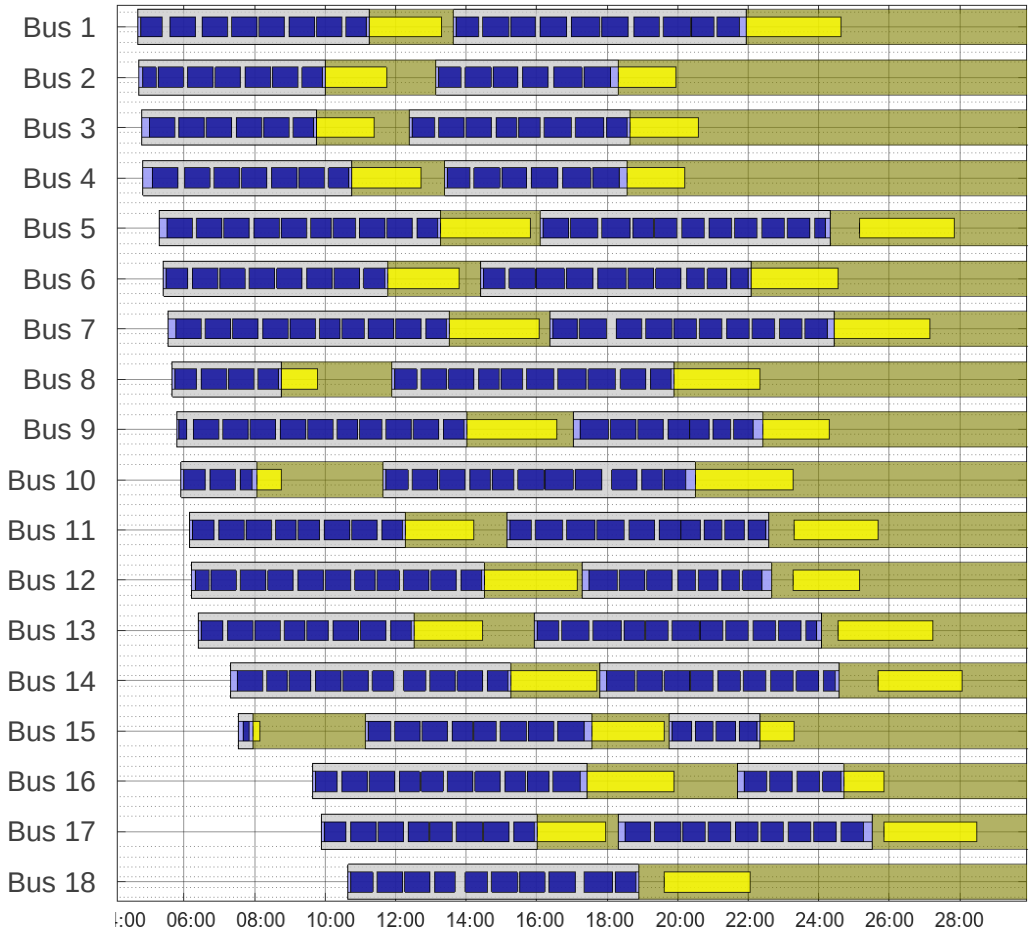
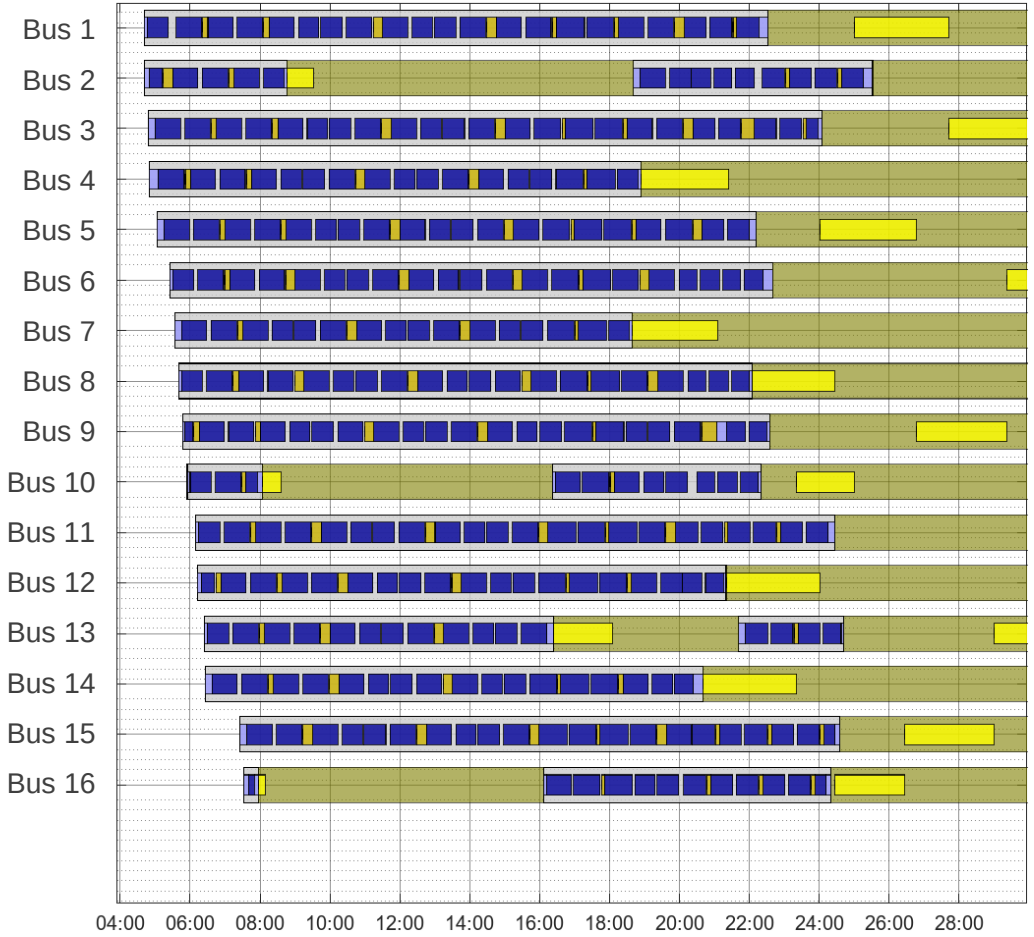
### Depot charging




### Depot- and terminal stop charging

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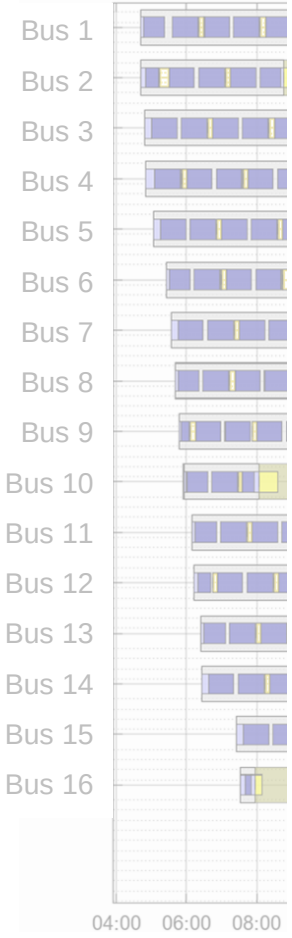
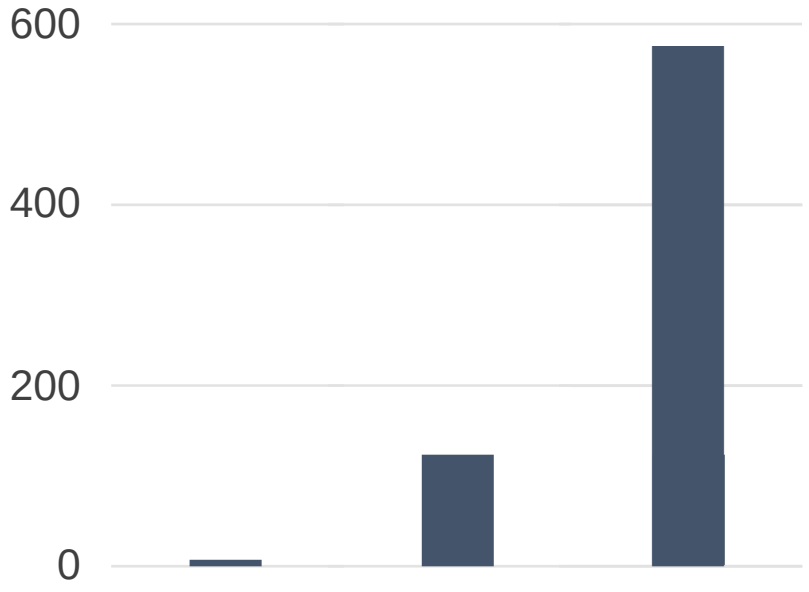


# Many Different Options Possible

- Solution:
  - Develop concrete, specific operation + infrastructure concepts
  - Evaluate consequences for operations and TCO

- Solution space grows rapidly with the options considered
  - 24 bus routes
  - x 6 vehicle types (trolley hybrid, depot charging, opportunity charging; different battery capacities)
  - x 4 infrastructure options for each vehicle type (different overhead line extensions, different charging locations)
  - = 576 scenarios (20 per bus route)



# Detailed Results for Each Bus Route

- For each bus route, there is a catalogue of possible operating concepts and their consequences for operations and infrastructure

**Bus route 27**

Term

Scer

Troll
Troll
Troll
Troll
Depo
Depo
Oppo
Oppo
Oppo
Oppo
Oppo
Oppo
...

**Bus route 24**

Term

Scer

Troll
Troll
Troll
Troll
Depo
Depo
Oppo
Oppo
Oppo
Oppo
Oppo
...

**Bus route 21**

Terminal stops: Fürstenbrunn, Bergheim S-Bahn

| Scenario name | Bus type | New overhead line extensions | Charging locations | No. of vehicles required | Empty mileage (km) | Driver time (h) | No. of chargers required |
|---|---|---|---|---|---|---|---|
| Trolley hybrid (IMC) 1 | IMC - 70 kWh | Section "North 1" | Depot | | | | |
| Trolley hybrid (IMC) 2 | IMC - 70 kWh | Section "North 2" | Depot | | | | |
| Trolley hybrid (IMC) 3 | IMC - 70 kWh | Section "North 1" | - | | | | |
| Trolley hybrid (IMC) 4 | IMC - 70 kWh | Section "North 2" | - | | | | |
| Depot charging 1 | BEB - 500 kWh | - | Depot | | | | |
| Depot charging 2 | BEB - 650 kWh | - | Depot | | | | |
| Opportunity charging 1 | BEB - 500 kWh | - | Depot, Fürstenbrunn | | | | |
| Opportunity charging 2 | BEB - 500 kWh | - | Depot, Bergheim S-Bahn | | | | |
| Opportunity charging 3 | BEB - 500 kWh | - | Depot, Fürstenbrunn, Bergheim S-Bahn | | | | |
| Opportunity charging 4 | BEB - 650 kWh | - | Depot, Fürstenbrunn | | | | |
| Opportunity charging 5 | BEB - 650 kWh | - | Depot, Bergheim S-Bahn | | | | |
| Opportunity charging 6 | BEB - 650 kWh | - | Depot, Fürstenbrunn, Bergheim S-Bahn | | | | |
| ... | ... | ... | ... | | | | |

Each line in these lists is an individual scenario

# Detailed Results for Each Bus Route

- For each bus route, there is a catalogue of possible operating concepts and their consequences for operations and infrastructure

Bus route 27

| Bus route | Vehicle size | Additional vehicles required (compared to conventional buses) | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Battery buses - depot charging | | | Battery buses - opportunity charging | | | Fuel cell buses | |
| | | Small battery | | Large battery | Small battery | | Large battery | FC REX | FC Hybrid |
| | | 150 kW | 300 kW | 150 kW | 150 kW | 300 kW | 150 kW | | |
| *** | Solo | + 2 | + 1 | + 1 | + 1 | + 1 | + 1 | + 0 | + 0 |
| *** | Solo | + 4 | + 3 | + 3 | + 2 | + 0 | + 0 | + 0 | + 0 |
| *** | Solo | + 2 | + 1 | + 2 | - | - | - | + 0 | + 0 |
| *** | Midi | + 0 | + 0 | + 0 | - | - | - | - | - |
| *** | Solo | + 1 | + 0 | + 0 | - | - | - | + 0 | + 0 |
| *** | Solo | + 0 | + 0 | + 0 | - | - | - | + 0 | + 0 |
| *** | Articulated | + 3 | + 3 | + 2 | - | - | - | + 1 | + 0 |
| *** | Articulated | + 3 | + 3 | + 2 | + 2 | + 2 | + 1 | + 1 | + 1 |
| ... | ... | ... | ... | ... | ... | ... | ... | ... | ... |

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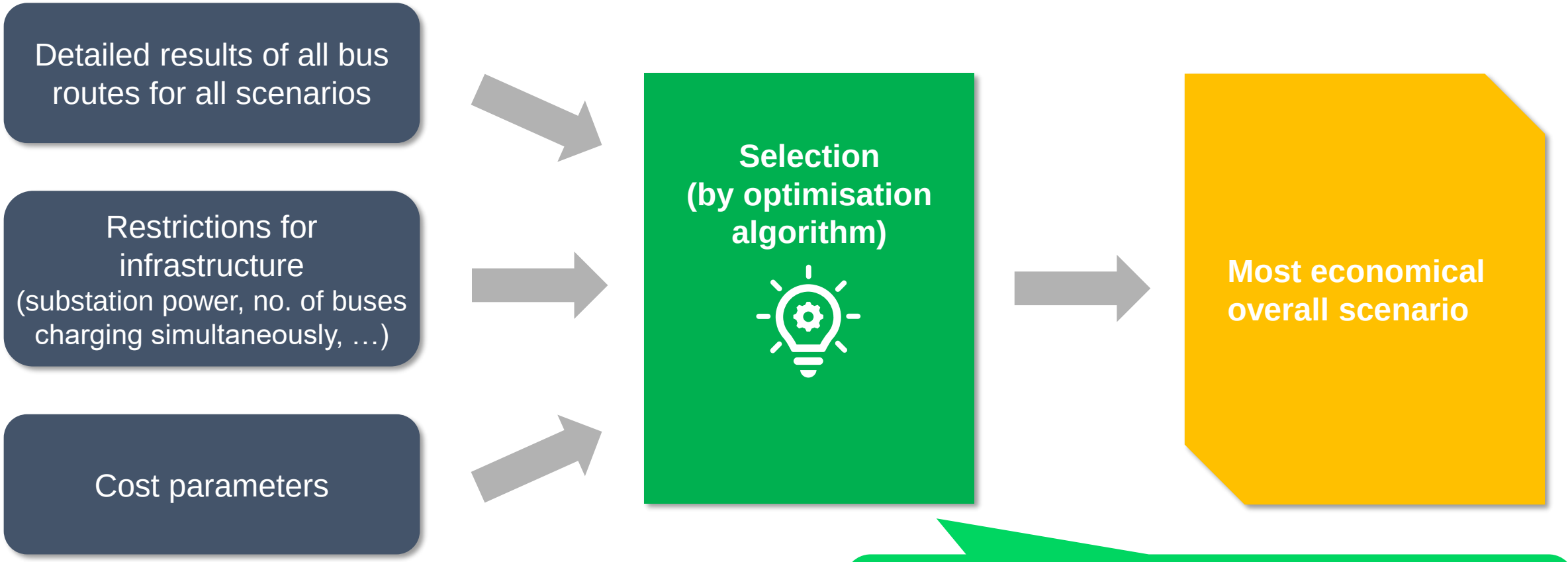
No. of chargers required

Opportunity charging 3 BEB - 500 kWh - Depot, Fürstenbrunn
Opportunity charging 4 BEB - 650 kWh - Depot, Fürstenbrunn
Opportunity charging 5 BEB - 650 kWh - Depot, Bergheim S-E
Opportunity charging 6 BEB - 650 kWh - Depot, Fürstenbrunn

**Each scenario can be quantified and assessed economically, but this is not sufficient.**
**→ Overall systemic perspective required.**

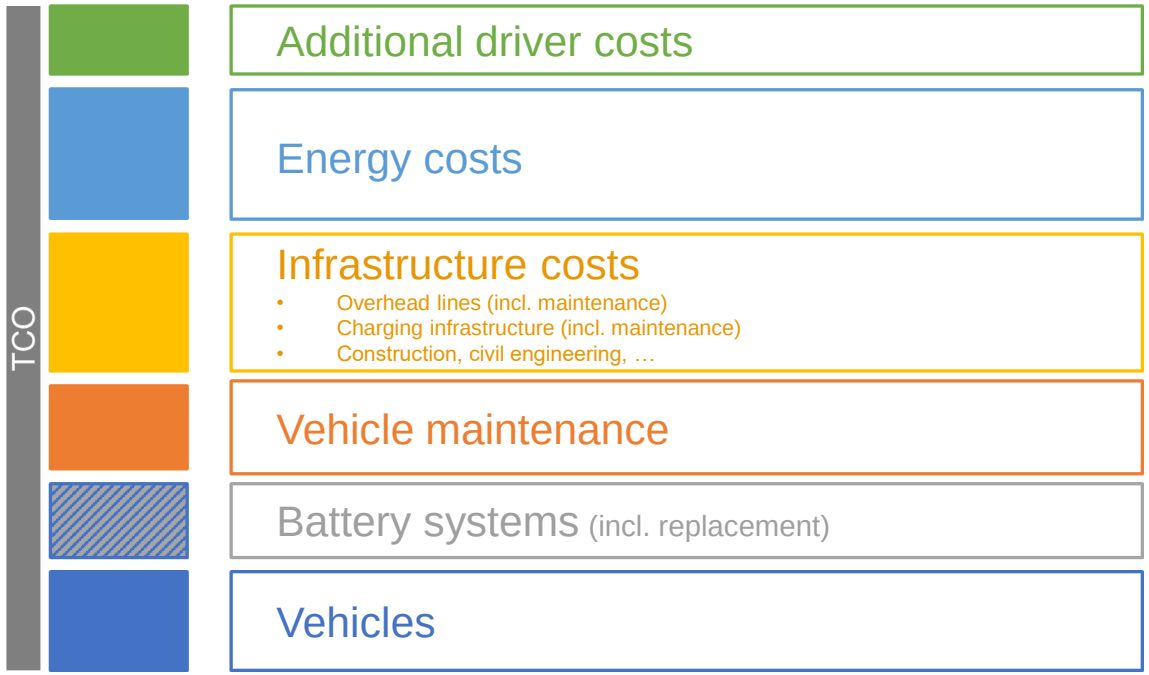
# Optimised Selection of Detailed Results

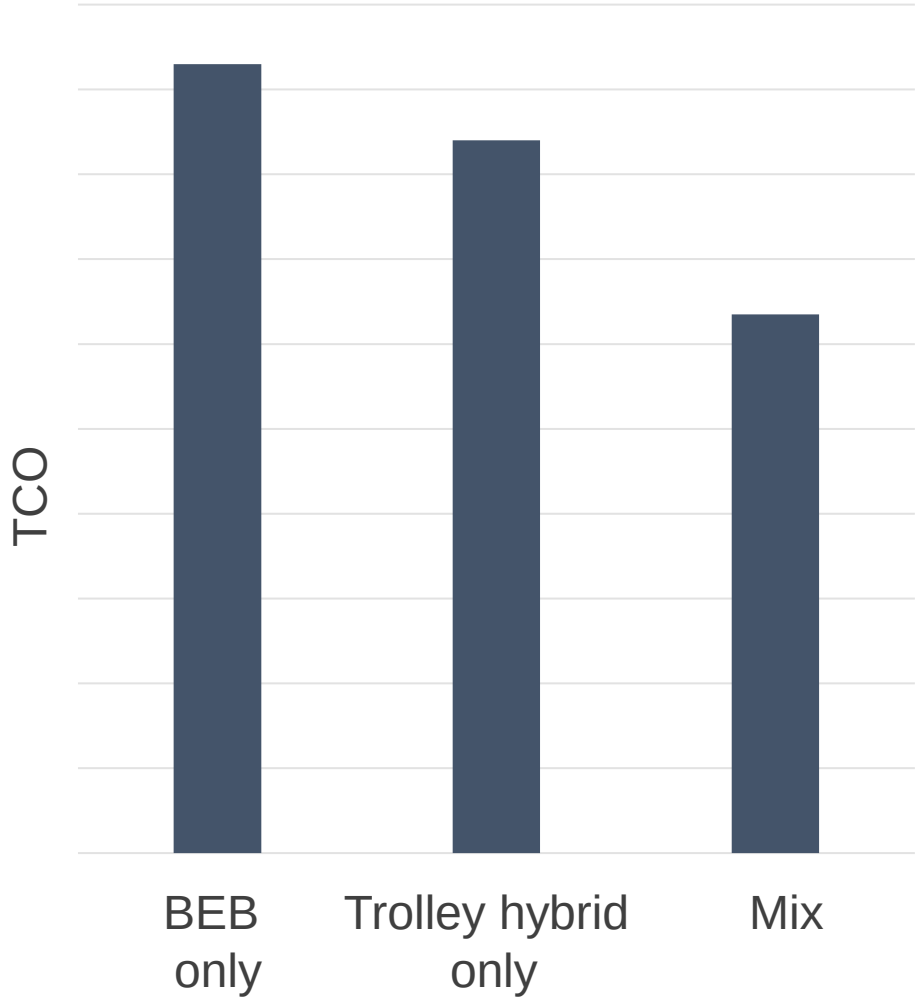



Considers potential synergies between the bus routes (e.g. using the same new overhead line section, using the same terminal stops for charging, …)

# Economic efficiency as a Basis for Planning and Decision-Making

- Holistic evaluation of the various options requires a total cost of ownership calculation (TCO)



# Conclusion

- It is foreseeable that local public bus fleets will have to be electrified entirely.
  - Also cities with already existing trolley bus networks need to plan the electrification of their non-trolley bus routes.
- Many technical solutions are possible, each with different effects on operations and with different costs for vehicles, for infrastructure and for operational (in)efficiency.
  - For each bus route on its own, a different technical solution may be the best solution.
- Software helps to understand the problem and the complexity, and it provides reliable key figures that enable an economic evaluation.
  - Not only for single bus routes, but for the entire bus network, while exploiting synergies.
- The resulting scenarios for the entire bus network offer holistic and technically feasible solutions, including their economic consequences, and form a basis for sustainable decisions.

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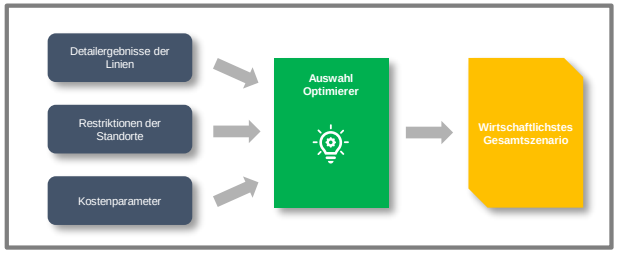
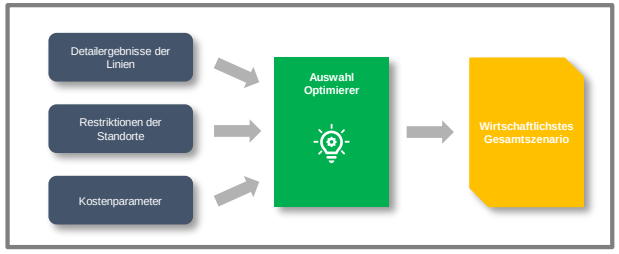
# Dynamic Adaptation of the Planning to Changing Framework Conditions



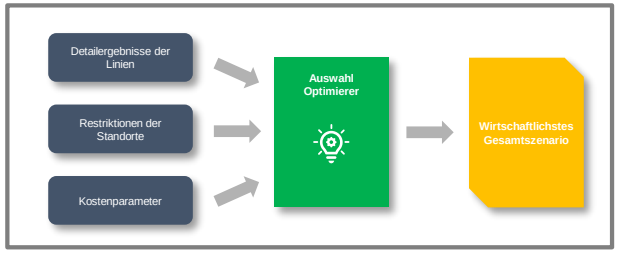

First planning and system design

Variation of parameters: e.g. 2 additional new overhead line sections cannot be installed




First planning and system design for decision-making in the city‘s committees

Variation of parameters: infrastructure was ordered (tender call completed)




Concretisation of the planning and system design for the procurement of buses