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# Big Data and Discrete Optimization for Electric Urban Bus Operations

TRBAM 22-00742

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## In a Nutshell

This paper proposes a framework for optimizing an electric urban bus network, based on data of an existing diesel bus fleet. Therefore, the required input data is described as well as the required steps to analyze and preprocess the data from the busses. With this aggregated data a mathematical model was formulated to optimize the cost of a future electric bus network. This is accomplished by choosing optimal battery sizes and charging station locations as well as charging powers.

### Challenges

- Collecting and processing of relevant data from the busses
- Formulation of a flexible optimization algorithm to incorporate real-world data

### Benefits

- Reliable results due to operational data from the existing diesel busses
- Highly adjustable to new urban bus networks
- With extensive real-world data logging, we could validate assumptions about energy demand, waiting times and different traffic situations during the day
- To use the data for the model implementation of a robust data pipeline including interpreting, preprocessing and aggregating the data, was necessary
- Based on the data of the diesel busses we simulated the electric busses energy demand
- The Integer Linear Programming model finds cost optimal solutions for charging infrastructure and batterie sizes
- The algorithm is very adjustable to specific needs of public transport operators and can generate optimal solutions in a short amount of time

## Acknowledgments

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## Contact Information

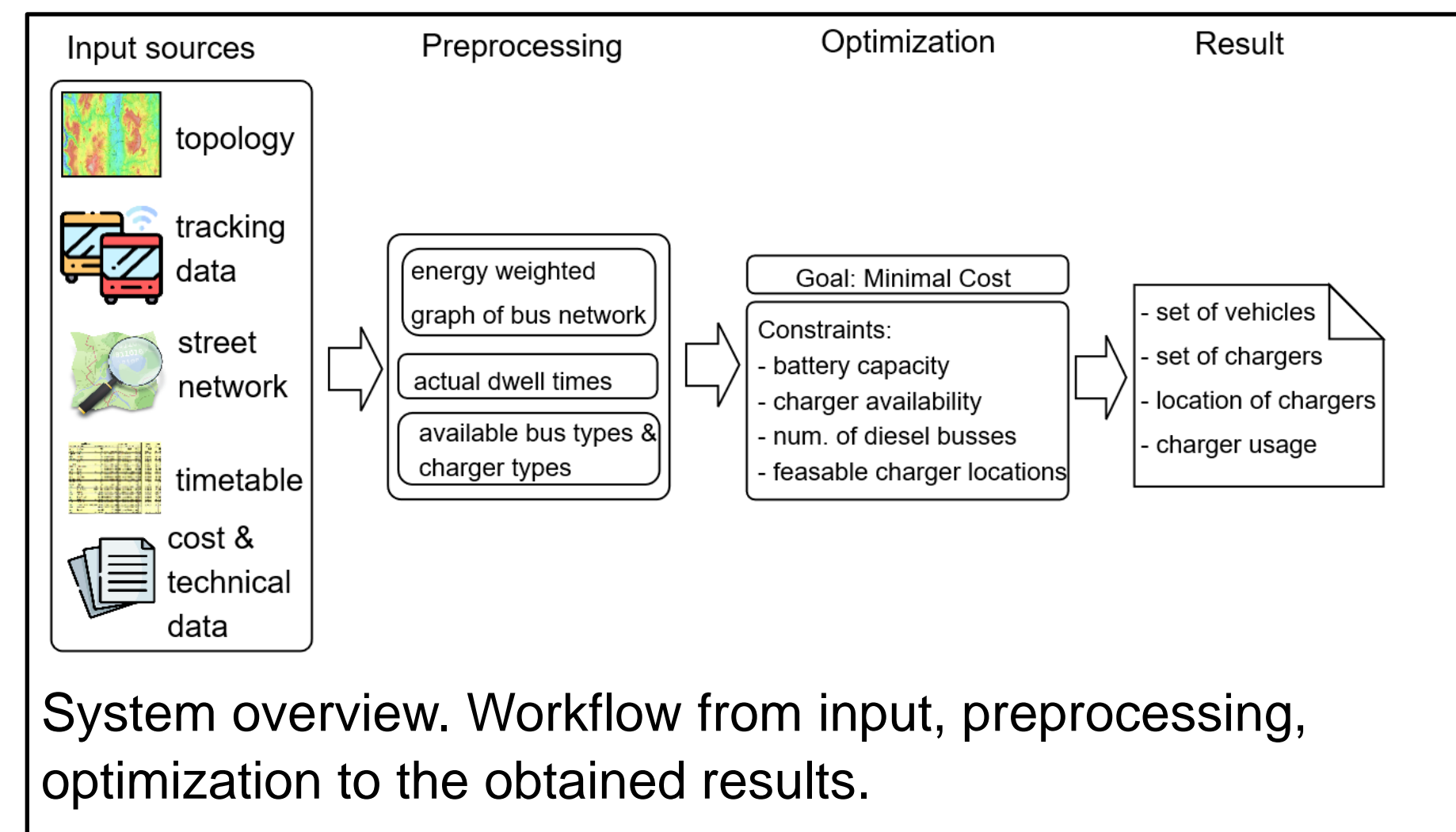
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## Framework

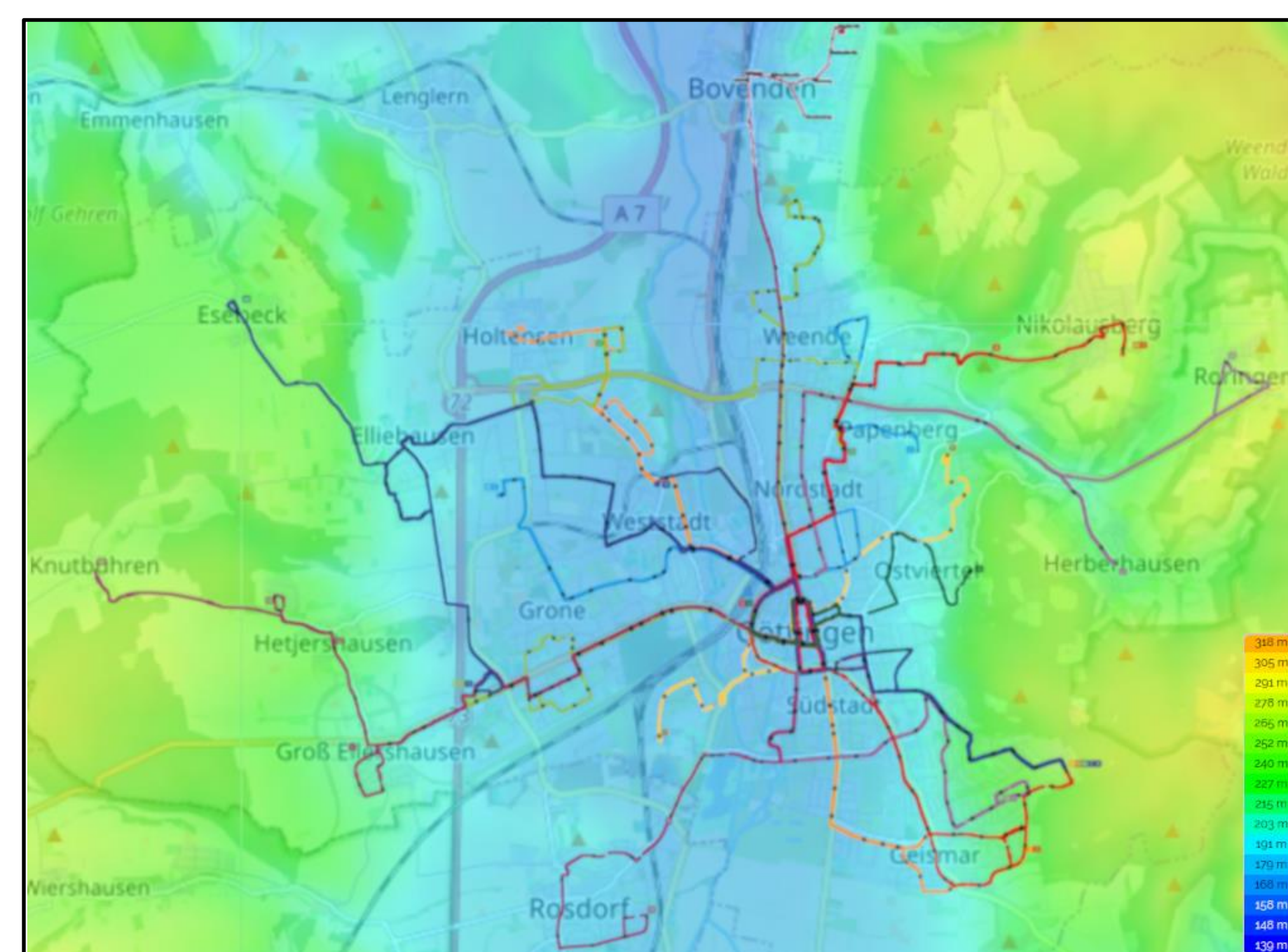
The process consists of three distinct steps.

- Collection of required data.
- Evaluating and preprocessing the data for the optimization.
- Definition of the task as a mathematical optimization model which will produce the needed result set.



## Use Case

- Medium sized city in Germany (Göttingen)
- Varied topology on almost every bus line
- 20 bus lines during the day and eight lines at night with varying frequency between every 15 to every 60 minutes.
- Weekly mileage of around 26,000 km.
- served currently by 90 combustion engine vehicles and 10 hybrid vehicles

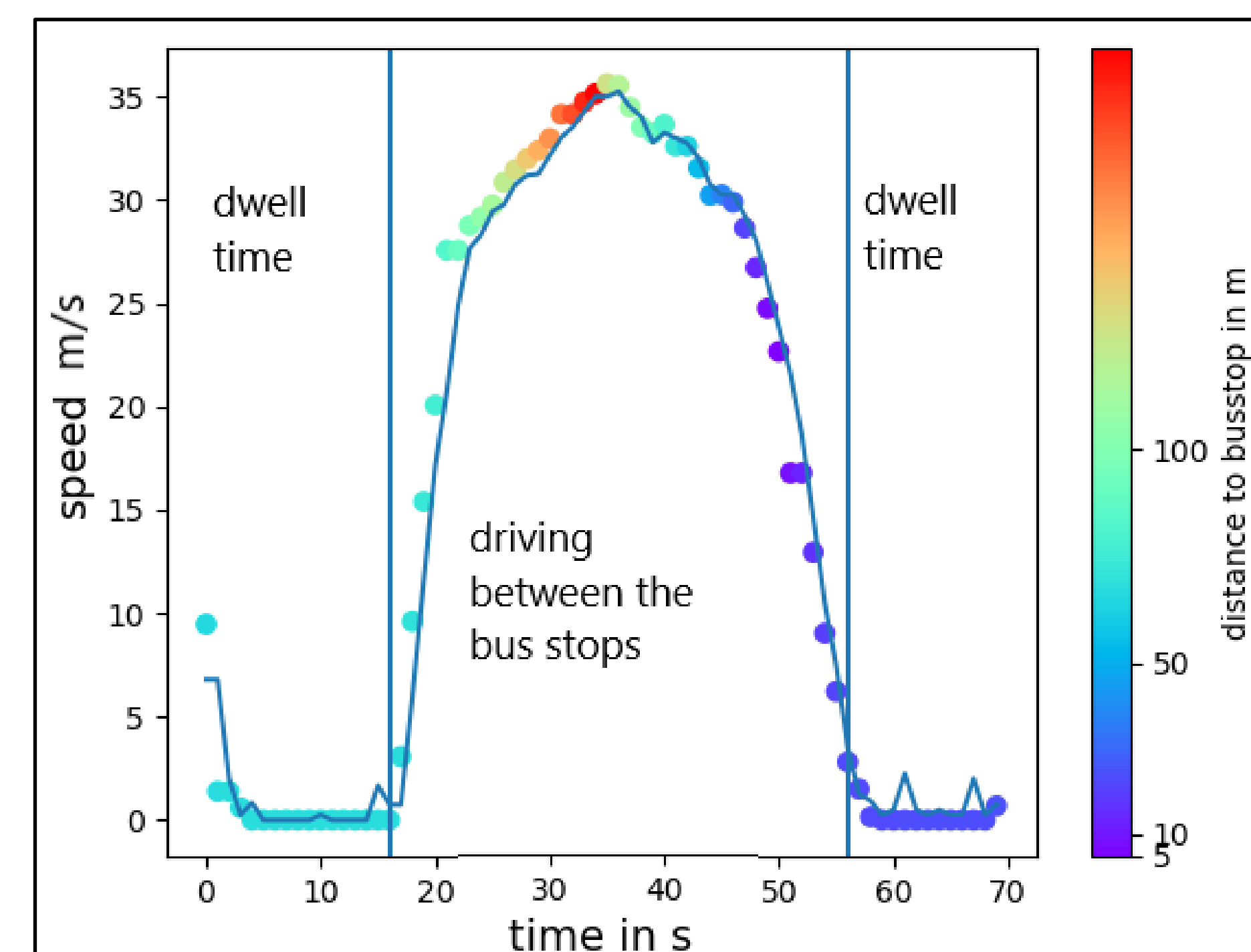


The whole bus network of Göttingen as an overlay over a topographic map (right).

- 50 of those vehicles with data loggers which track all necessary data and sent it via mobile communication to our servers.
- 200 million datapoints sent daily and 60-100GB of interpreted values every day on our servers,
- A robust and reliable data pipeline is needed

## Data

- tracking data from the vehicles which consists of GPS data and data from the CAN-Bus, such as vehicle weight, open/close-door status, and ambient temperature.
- Technical data of the vehicles like battery size, engine power, efficiency and vehicle cost. Data from the charging infrastructure are cost of a charging station and charging power
- Operational data in form of the timetables
- Map data in form of the street network, bus stop locations and topology



Visualization of a bus trip between two stops. The colors show the distance to the nearest bus stop and the y-axis the speed of the vehicle. Those are the main criteria to calculate the dwell times of the vehicles (left).

- In order to use the tracking data for the optimization algorithms it must be preprocessed first:
- Detection of the driven line, since every vehicle drives on a different line everyday
  - Calculation of the actual dwell times, by cutting the trips at the bus stops and validating with the door status
  - Enrich the trips with temperature and vehicle weight data

- Calculating the energy demand for each sub trip
- Calculating the 10<sup>th</sup>-percentile of waiting time
- Calculating the 90<sup>th</sup>-percentile of energy demand for each sub trip
- Construct the data structures for the optimization model

## Mathematical Model

The model is formulated to minimize overall capital expenditure,

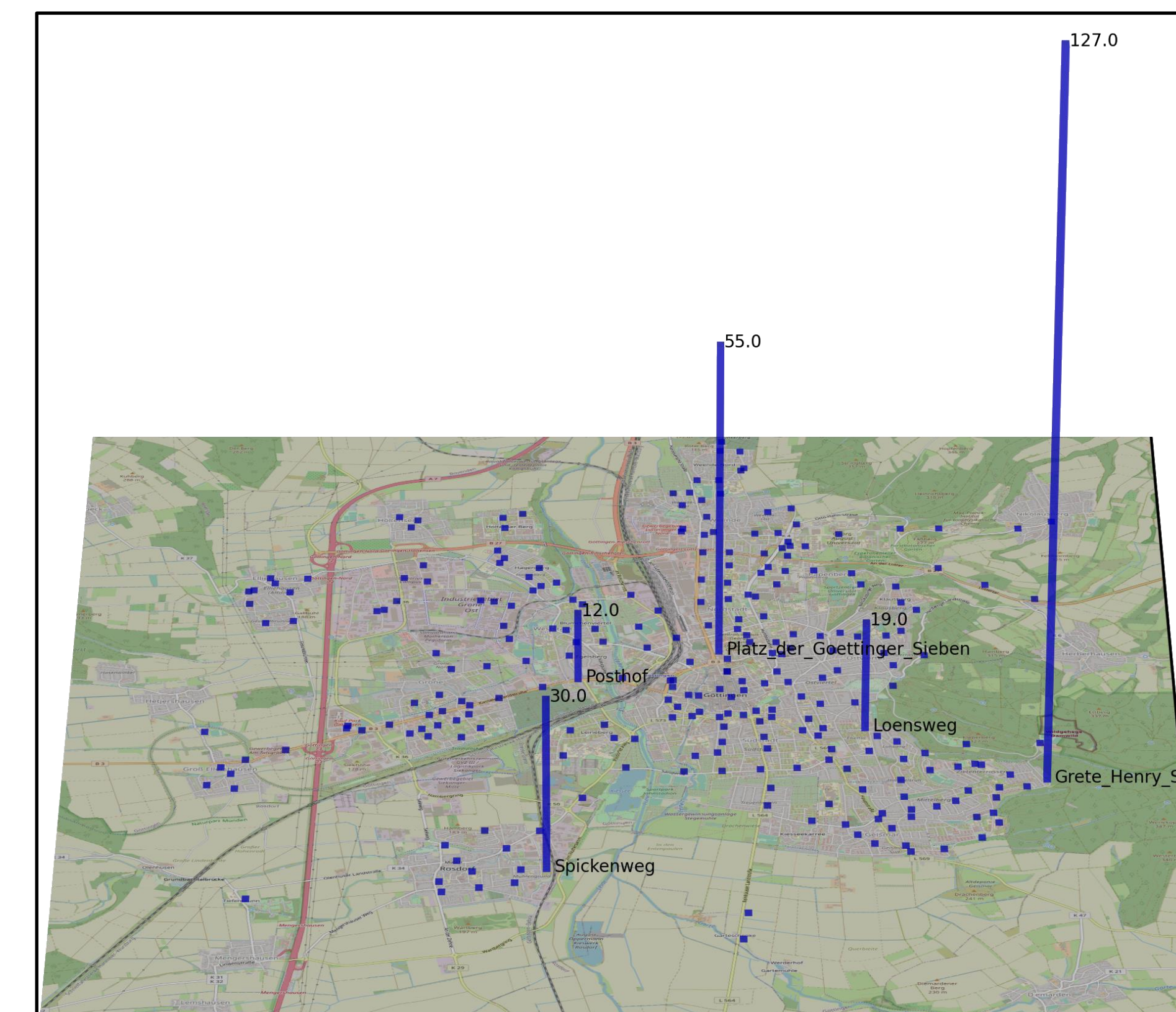
$$\min \sum_{i=1}^{bs} \sum_{j=1}^c (\alpha_{ij} * CC_j) + \sum_{i=1}^b \sum_{j=1}^i (\beta_{ij} * BC_i) \quad (1)$$

while ensuring energetical feasible bus trips by placing charging infrastructure and choosing appropriacy sized batteries for the vehicles:

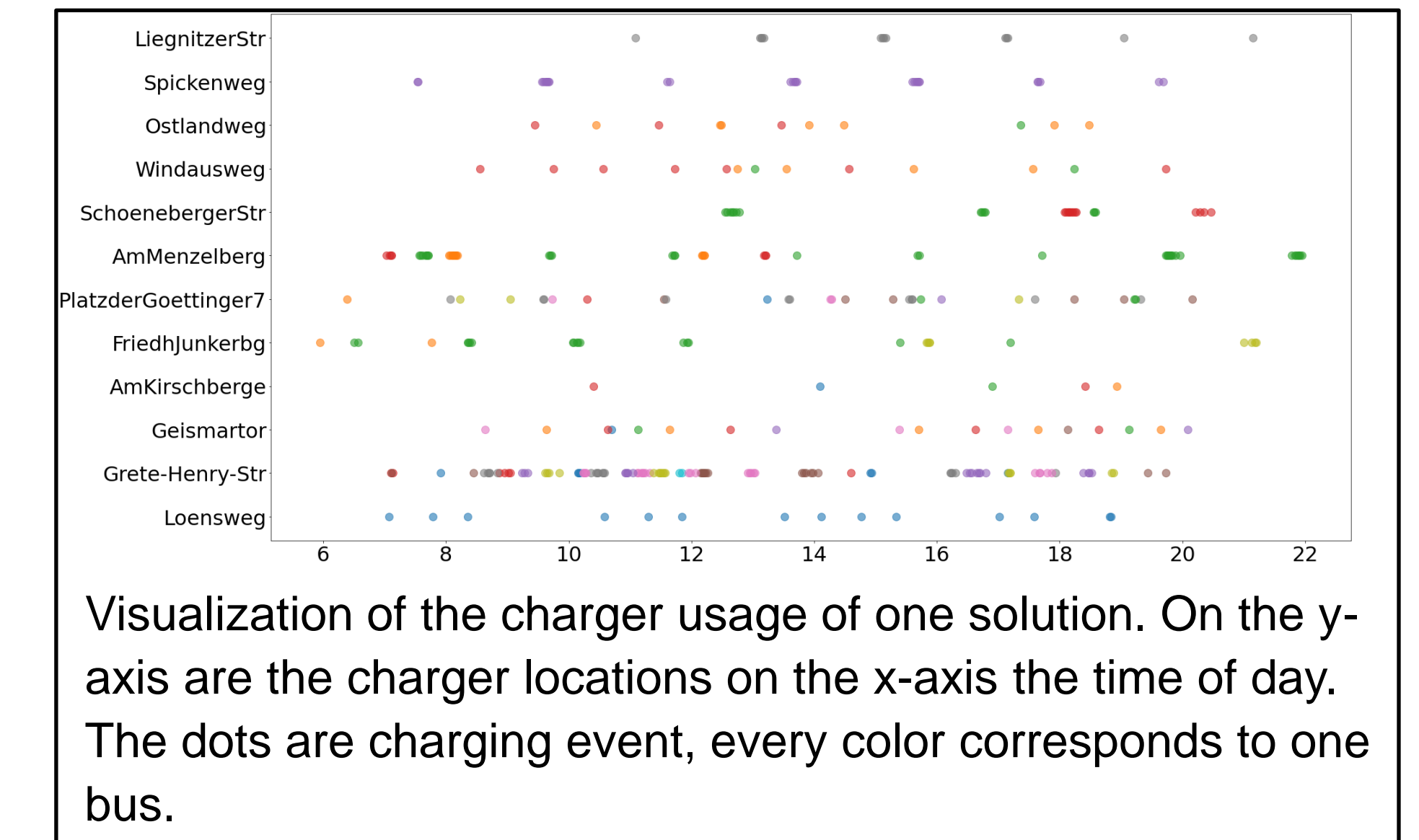
$$\sum_{j=1}^i (d_{jj-1} - \sum_{k=1}^c \sum_{o \in \{s_{m,s}\}} (\gamma_{miko} * \alpha_{jk} * RC_k)) \leq \sum_{l=1}^b (\beta_{lm} * RB_l), \quad \forall m \in \{0, \dots, r\}, i \in \{bs_m\} \quad (2)$$

## Results

- List of vehicles with battery size for the solution
- List of chargers to be used
- The location of the chargers
- The usage of each charger during one day

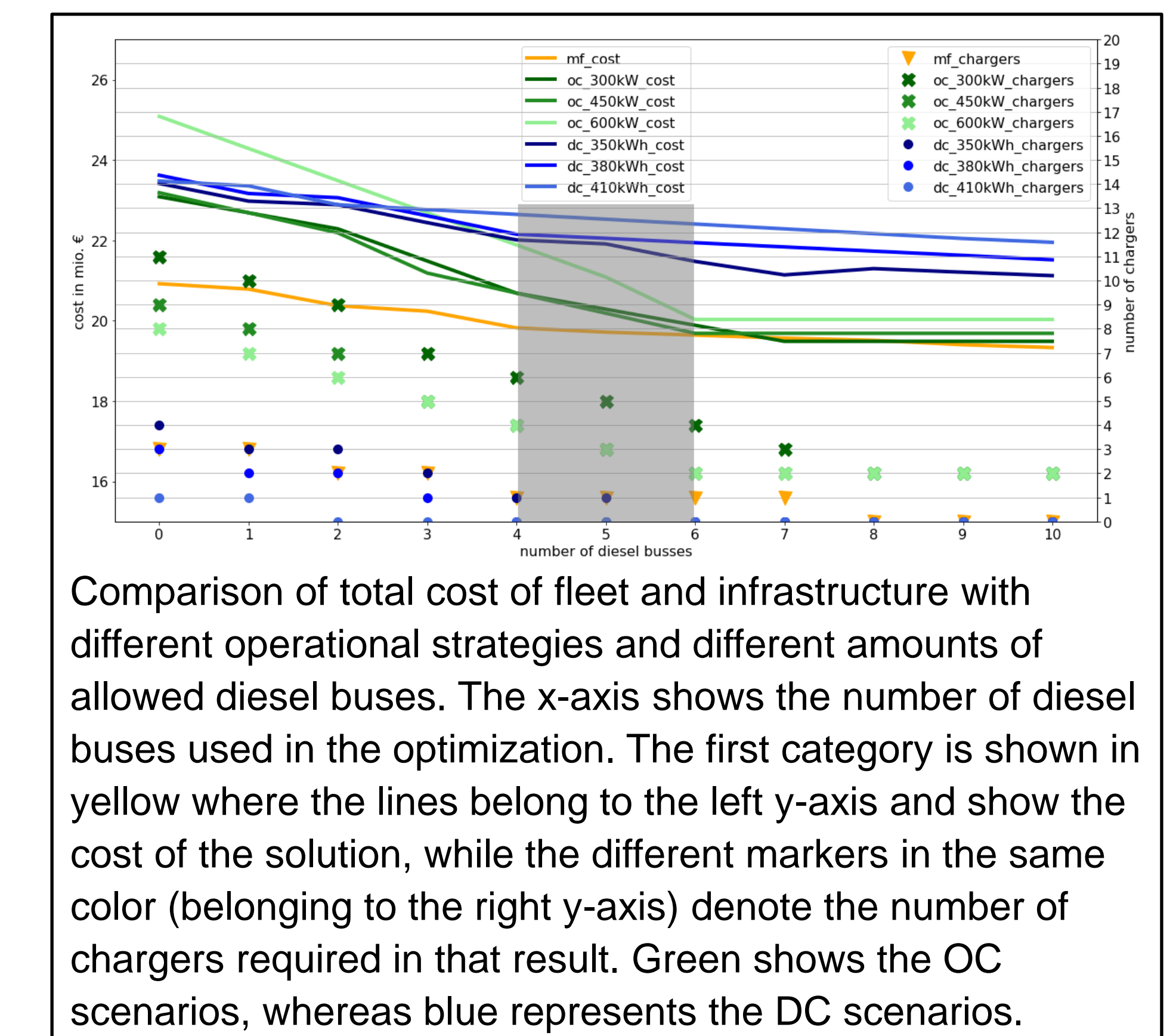


The blue squares denote potential charging station locations; the blue bars are chargers in the current solution. The height of the bar shows the usage per day in minutes.



Visualization of the charger usage of one solution. On the y-axis are the charger locations on the x-axis the time of day. The dots are charging event, every color corresponds to one bus.

- To analyze the behavior of the algorithm we did set up different scenarios for different operational strategies, considering decreasing numbers of diesel busses in the solution to simulate a gradual electrification strategy.



Comparison of total cost of fleet and infrastructure with different operational strategies and different amounts of allowed diesel buses. The x-axis shows the number of diesel buses used in the optimization. The first category is shown in yellow where the lines belong to the left y-axis and show the cost of the solution, while the different markers in the same color (belonging to the right y-axis) denote the number of chargers required in that result. Green shows the OC scenarios, whereas blue represents the DC scenarios.

## Conclusion

- General framework to optimize the transition of a diesel bus fleet to electric vehicles
- Real-world tracking data helps to understand and quantify the influence of driving behavior, traffic, passenger load, topology and dwell times on the overall solution
- Many simplifying assumptions about dwell times and energy demand can be avoided
- With the flexible constraint-based formulation it can be adjusted to the needs of the PTO