Power forecast of overhead catenary islands in battery electric train operation.
--- Case Study of Pfalznetz ---

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Presentation Structure

1. Introduction
2. Approach & Methodology
3. OCI Model Results
4. Outlook

Introduction – Uprising BEMU Deployment

- BEMU Uprising Deployment:
  - Battery electric multiple units (BEMU) are increasingly replacing diesel units in regional services.
  - BEMU operation projected to reach 60 million train-kilometres annually in Germany by 2029.
  - EU-wide adoption is expected to grow significantly
- Overhead catenary islands
  - Limited BEMU range requires additional recharging
  - Overhead Catenary Islands (OCI) are commonly designed as charging infrastructure at remote stations.
- Challenges:
  - Frequent and high power demands during recharging can create peak loads in the power grid.
  - OCIs could be supplied by possibly weak rural electricity grids, not equipped for high peak loads.

Market-available BEMU

Talent 3 BEMU
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Civity BEMU
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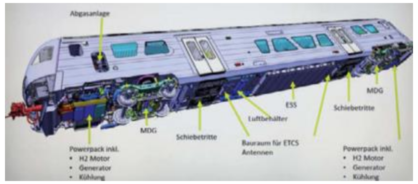
Flirt Akku
© Stadler

Coradia Continental
© Alstom AG

Mireo Plus B
© Siemens



RS Zero
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<u>Research Aim</u>:

Develop a **data-driven approach** to forecast **power demand** for **OCI** in regional **rail networks.**

Presentation Structure

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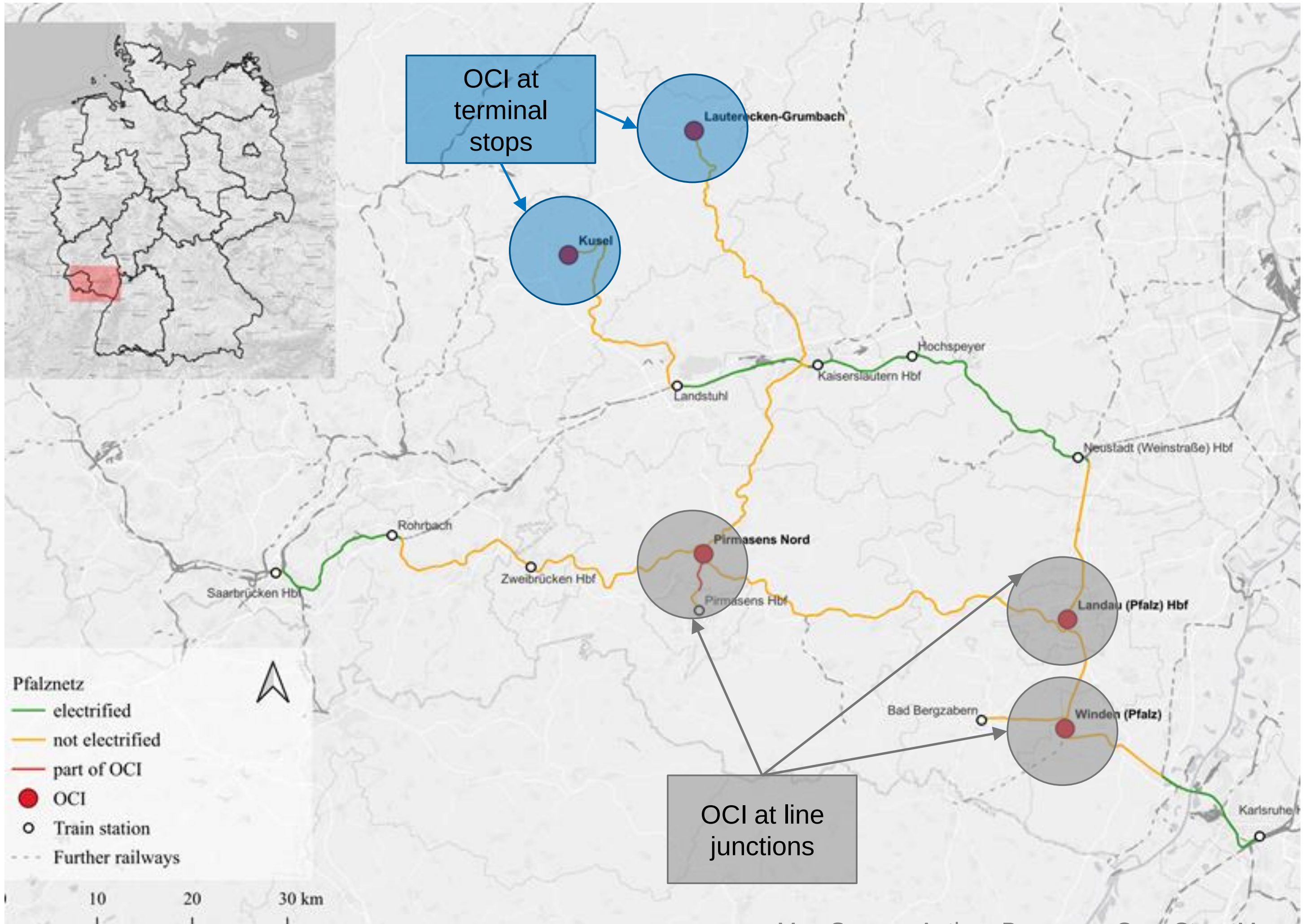
Case study: Pfalznetz - Regional Passenger Railway Network

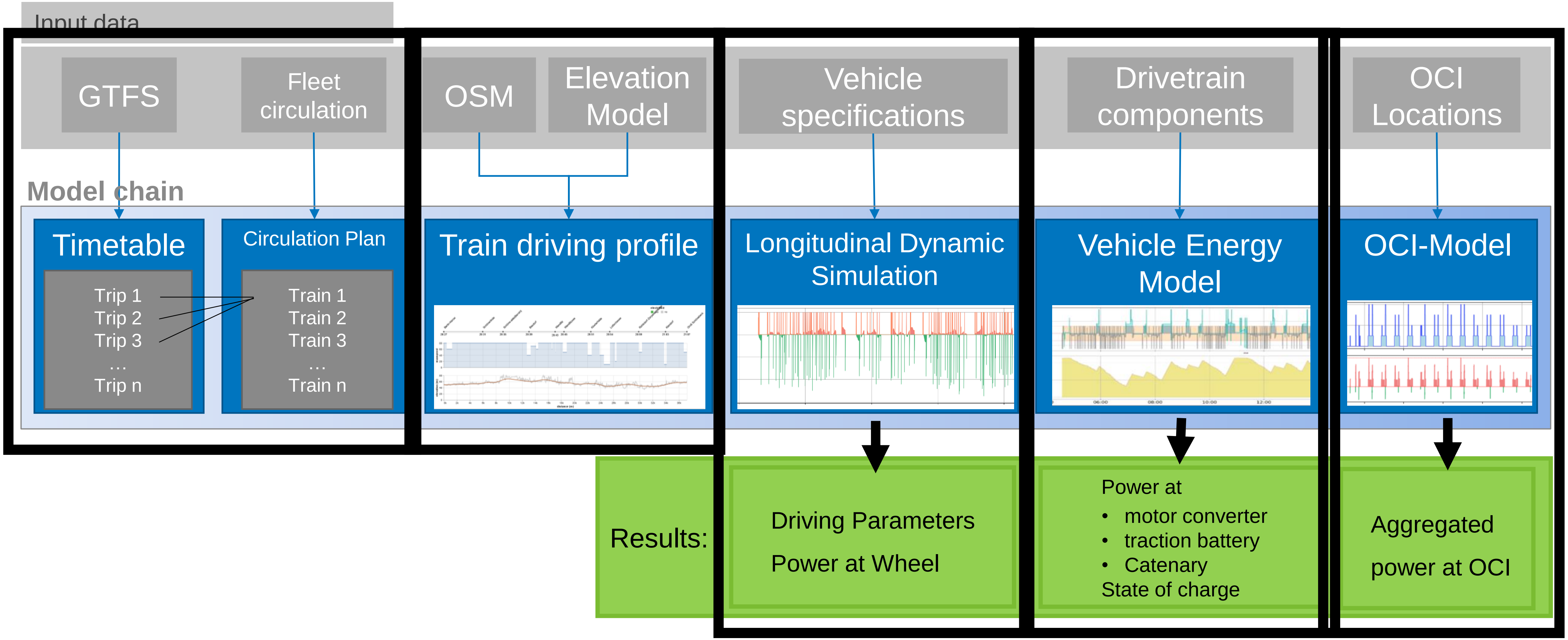
- From 2025: Stepwise integration of 44 BEMU

- Five OCIs are planned.
  - OCI at Lauterecken-Grumbach and Kusel are terminal stops.
  - Pirmasens Nord, Landau and Winden are junctions where several train lines intersect.
  - In Pirmasens Nord, an additional line electrification is required.



Map Source: Author; Basemap: OpenStreetMap

Data driven approach: Visualization of the model chain



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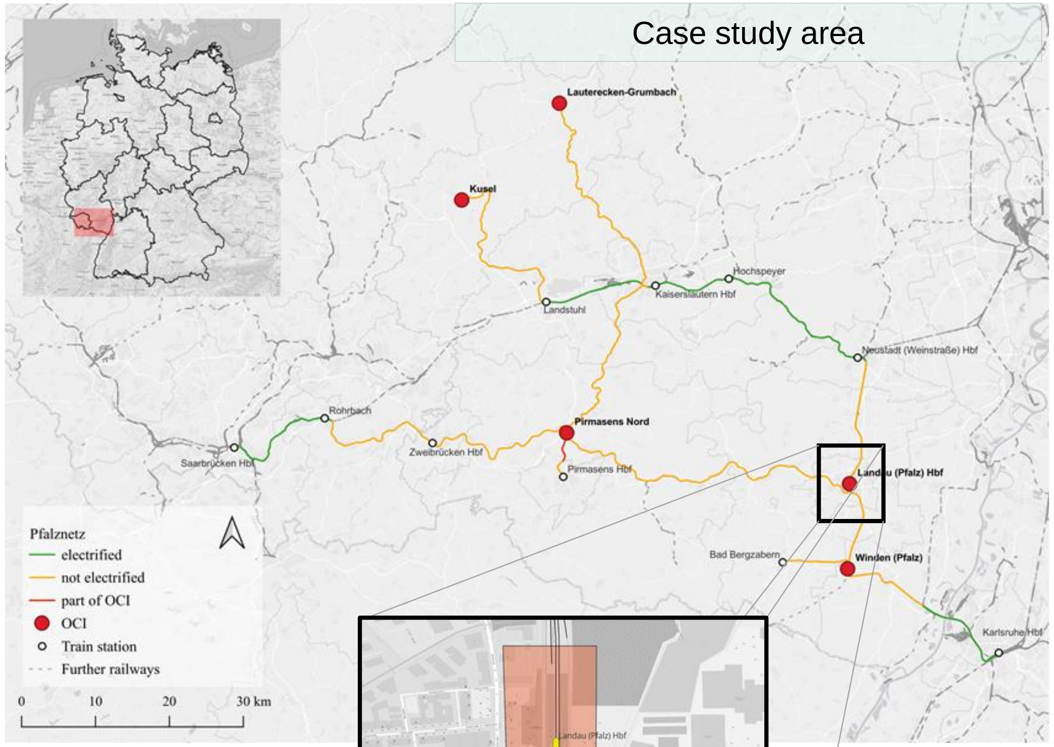
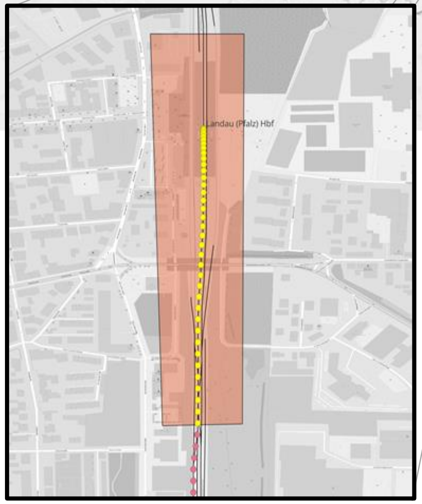
OCI-Model: Deriving requirements on BEMU recharging infrastructure

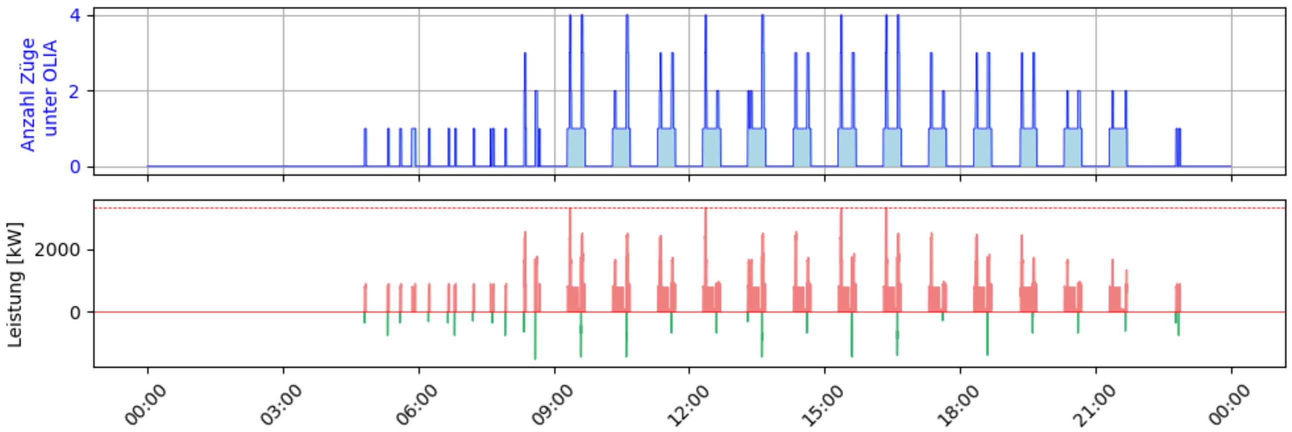
Case study area



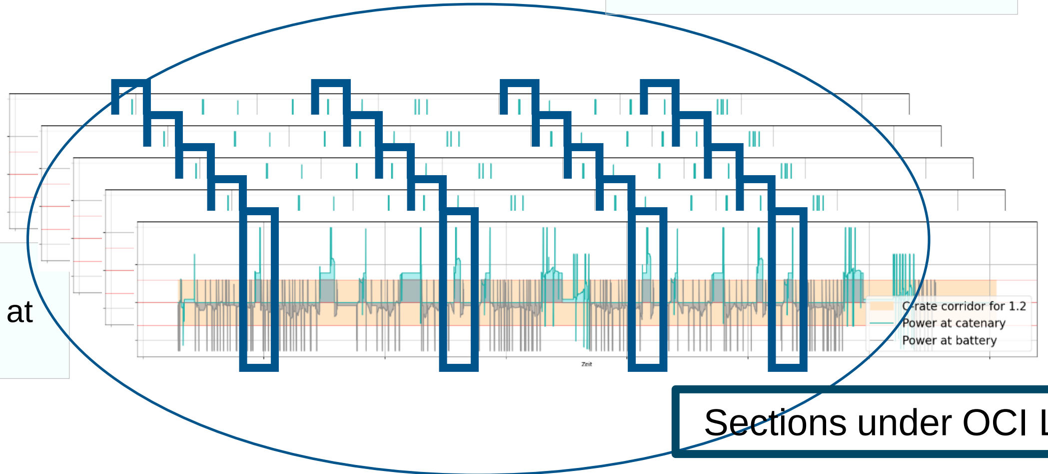


Representation of OCI as polygons in the geospatial data model

For each location: Query vehicle power consumption at catenary



Aggregation and time-matched for all trains in the circulation



Sections under OCI Landau

Presentation Structure

1 Introduction

2 Approach & Methodology

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Exemplary OLIA-demand profile

Key Observations:

- Power peaks occur when multiple trains recharge simultaneously under an OCI.
- Maximum power load observed at OCI Kusel is 2.6 MW.

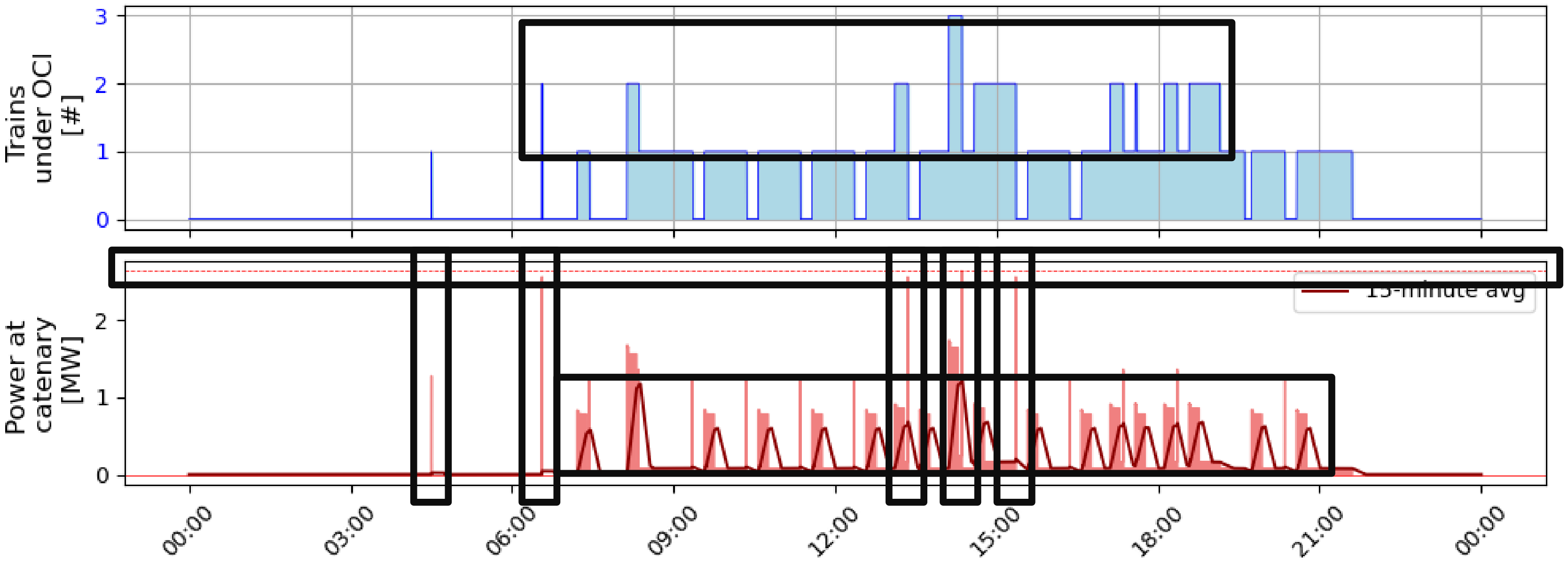
Peak Characteristics:

- Prominent peaks are short-lived, lasting above 30 seconds (from multiple acceleration)

Power Demand Smoothing:

- Averaging over a 15-minute window reduces peak power demand to 1.24 MW (marked by the dark red line).

Power load curve of overhead catenary island Kusel



OCI Location Impact

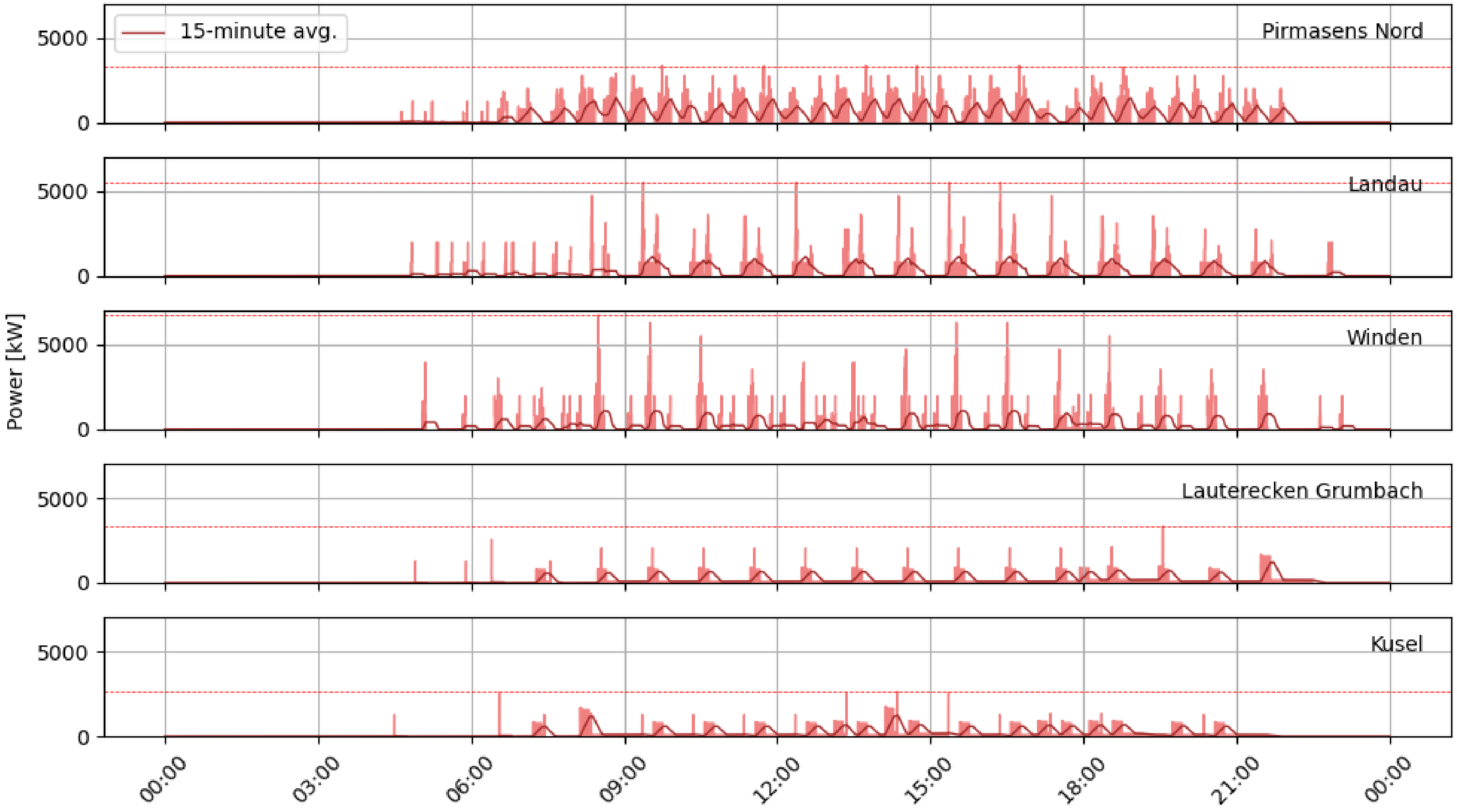
Power load curves of OCI in the railway network

OCI at line junctions

- Characteristics:
  - Short and dense recharging periods.
  - Increased frequency of power peaks.

OCI at Terminal Stops

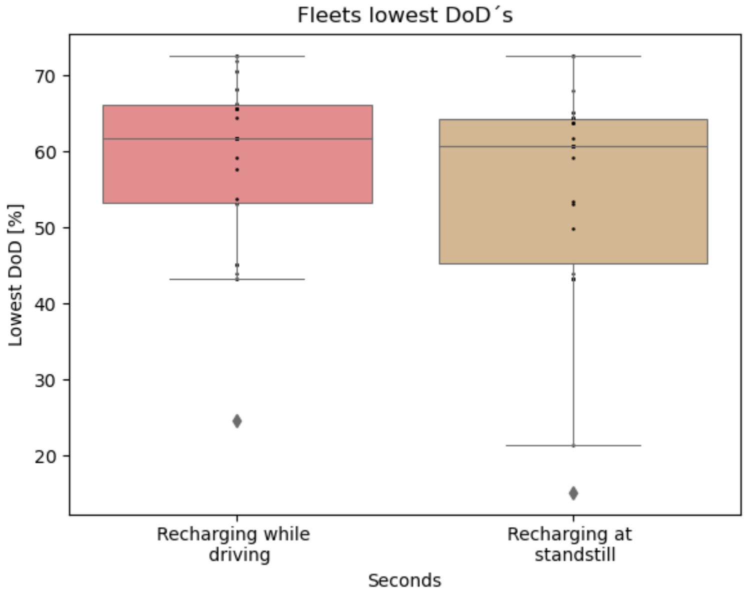
- Characteristics:
  - Continuous and consistent recharging.
  - Homogeneous & even load patterns.
  - Modest power peaks.



The location of an OCI within the network significantly influences the power load curve shape.

Operational peak-shaving

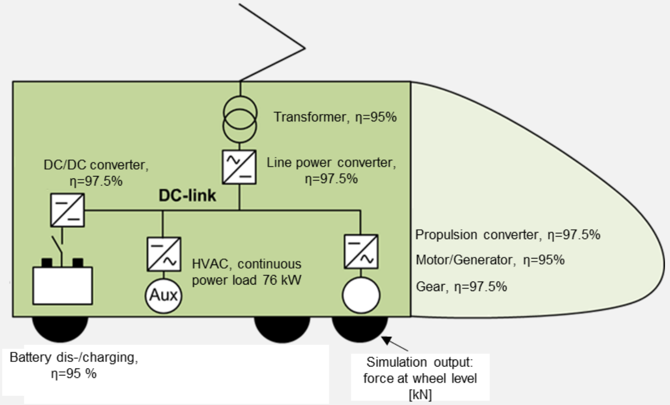
OCI supplies power for:	Power peaks during acceleration occur in:
Traction, auxiliaries and recharging during driving	The grid
Auxiliaries and recharging at standstill	The traction battery



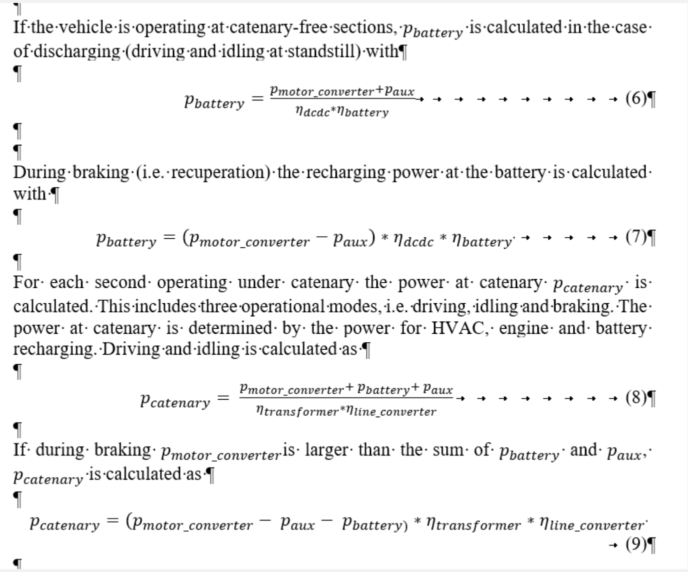
Presentation Structure

What else you will find in our conference paper

- Vehicle specifications



- A thorough description of the vehicle energy model



If the vehicle is operating at catenary-free sections, $p_{battery}$ is calculated in the case of discharging (driving and idling at standstill) with

$$p_{battery} = \frac{p_{motor\_converter} + p_{aux}}{\eta_{dcdc} * \eta_{battery}} \quad (6)$$

During braking (i.e. recuperation) the recharging power at the battery is calculated with

$$p_{battery} = (p_{motor\_converter} - p_{aux}) * \eta_{dcdc} * \eta_{battery} \quad (7)$$

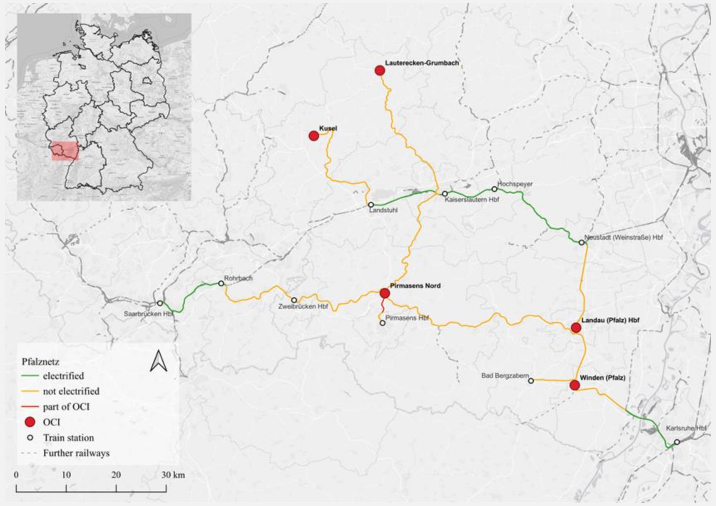
For each second operating under catenary the power at catenary $p_{catenary}$ is calculated. This includes three operational modes, i.e. driving, idling and braking. The power at catenary is determined by the power for HVAC, engine and battery recharging. Driving and idling is calculated as

$$p_{catenary} = \frac{p_{motor\_converter} + p_{battery} + p_{aux}}{\eta_{transformer} * \eta_{line\_converter}} \quad (8)$$

If during braking $p_{motor\_converter}$ is larger than the sum of $p_{battery}$ and p_{aux}, $p_{catenary}$ is calculated as

$$p_{catenary} = (p_{motor\_converter} - p_{aux} - p_{battery}) * \eta_{transformer} * \eta_{line\_converter} \quad (9)$$

- A deeper description of the study area



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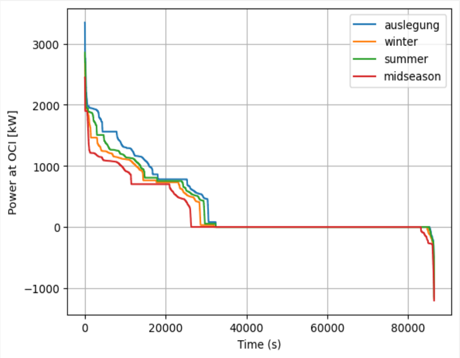
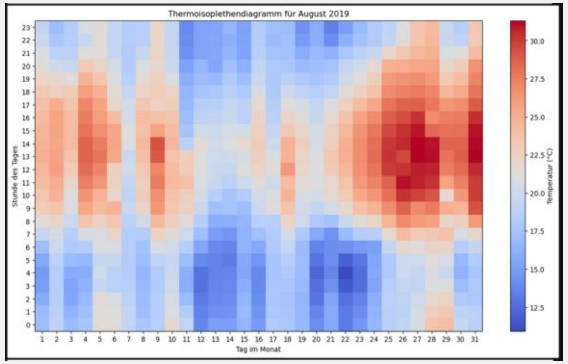
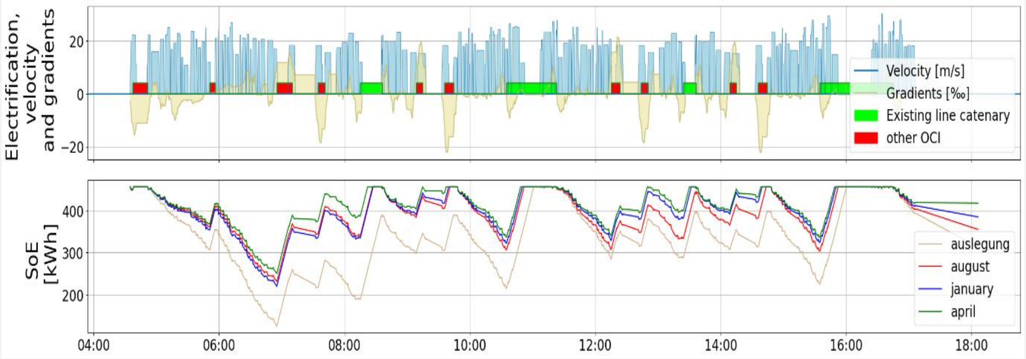
In our future publications

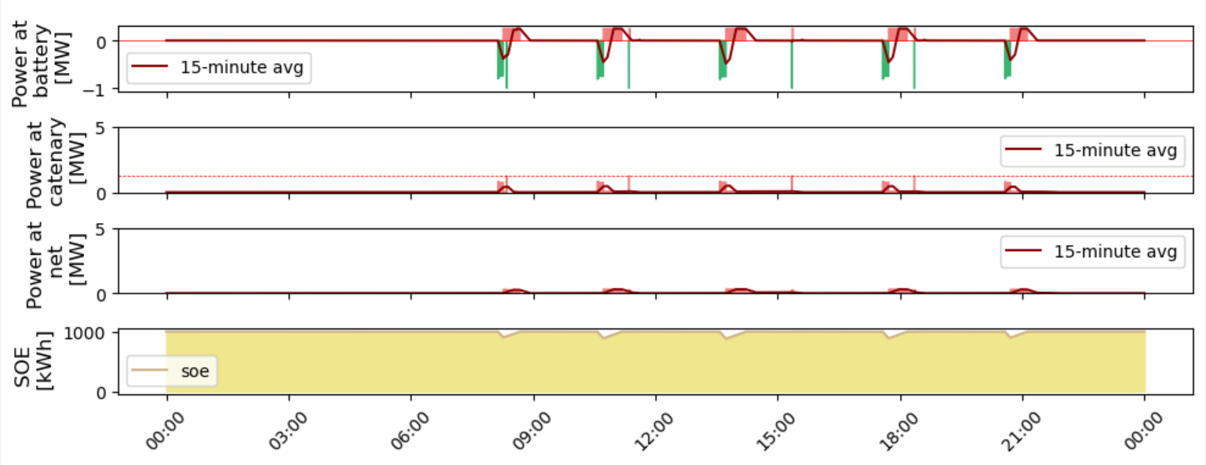
- Implementation of seasonal weather effects on hvac







- An additional model implementing a stationary buffer storage for technical peak-shaving



Thank your for your attention.

Selected Publications, Institute of Vehicle Concepts, DLR

1. Sebastian Herwartz-Polster, Mathias Böhm, Sebastian Stickel, Christoph Streuling, Benedikt Hertel, and Johannes Pagenkopf (2024) Rail vehicles: Fuel cells and batteries. In: Encyclopedia of Electrochemical Power Sources 2nd Edition Encyclopedia of Electrochemical Power Sources. (in Press).

2. Streuling, Christoph und Arens, Stefan und Schenker, Moritz und Pagenkopf, Johannes (2023) Potentialanalyse der BEMU-Nachladung mittels Direktstromnutzung aus EEA. Elektrische Bahnen, 121 (9), Seiten 310-321. https://elib.dlr.de/198284/

3. Hertel, Benedikt und Pagenkopf, Johannes und König, Jens (2023) Challenges in the (Re-)Connection of Peripheral Areas to the Rail Network from a Rolling Stock Perspective: The Case of Germany. Vehicles, Seiten 1138-1148. https://elib.dlr.de/197286/

4. Zerhusen, Jan und Böhm, Mathias und Landinger, Hubert und Pagenkopf, Johannes und Astono, Yanni und Heckert, Florian (2023) H2-Infrastruktur für Nutzfahrzeuge im Fernverkehr - Aktueller Entwicklungsstand und Perspektiven: Ergebnisbroschüre. https://elib.dlr.de/194633/

5. Dittus, Holger und Pagenkopf, Johannes (2022) Alternative Antriebe für Rangierlokomotiven. In: EIK 2023 - Eisenbahn Ingenieur Kompendium Eisenbahn Ingenieur Kompendium. https://elib.dlr.de/191904/

6. Böhm, Mathias und Fernandez del Rey, Abraham und Pagenkopf, Johannes und Maider, Varela und Herwartz, Sebastian und Nieto Calderón, Beatriz (2022) Review and comparison of worldwide hydrogen activities in the rail sector with special focus on on-board storage and refueling technologies. International Journal of Hydrogen Energy. https://elib.dlr.de/188112/

7. Pagenkopf, Johannes und Böhm, Mathias und Jäger, Victoria Carolin und Konrad, Marcel (2022) Einsatzpotenziale alternativer Antriebe in Rangierlokomotiven. bahn manager. https://elib.dlr.de/187184/

8. Streuling, Christoph und Pagenkopf, Johannes und Schenker, Moritz und Lakeit, Kim Malin (2021) Techno-Economic Assessment of Battery Electric Trains and Recharging Infrastructure Alternatives Integrating Adjacent Renewable Energy Sources. Sustainability, 13 (15), Seite 8234. https://elib.dlr.de/143453/

9. Teske, Sven und Pregger, Thomas und Simon, Sonja und Naegler, Tobias und Pagenkopf, Johannes und Deniz, Özcan und van den Adel, Bent und Dooley, Kate und Meinshausen, Malte (2021) It Is Still Possible to Achieve the Paris Climate Agreement: Regional, Sectoral, and Land-Use Pathways. Energies, 14 (8), Seite 2103. https://elib.dlr.de/142923/

10. Herwartz, Sebastian und Pagenkopf, Johannes und Streuling, Christoph (2021) Sector coupling potential of wind-based hydrogen production and fuel cell train operation in regional rail transport in berlin and brandenburg. International Journal of Hydrogen Energy, 46 (57), Seiten 29597-29615. https://elib.dlr.de/140358/

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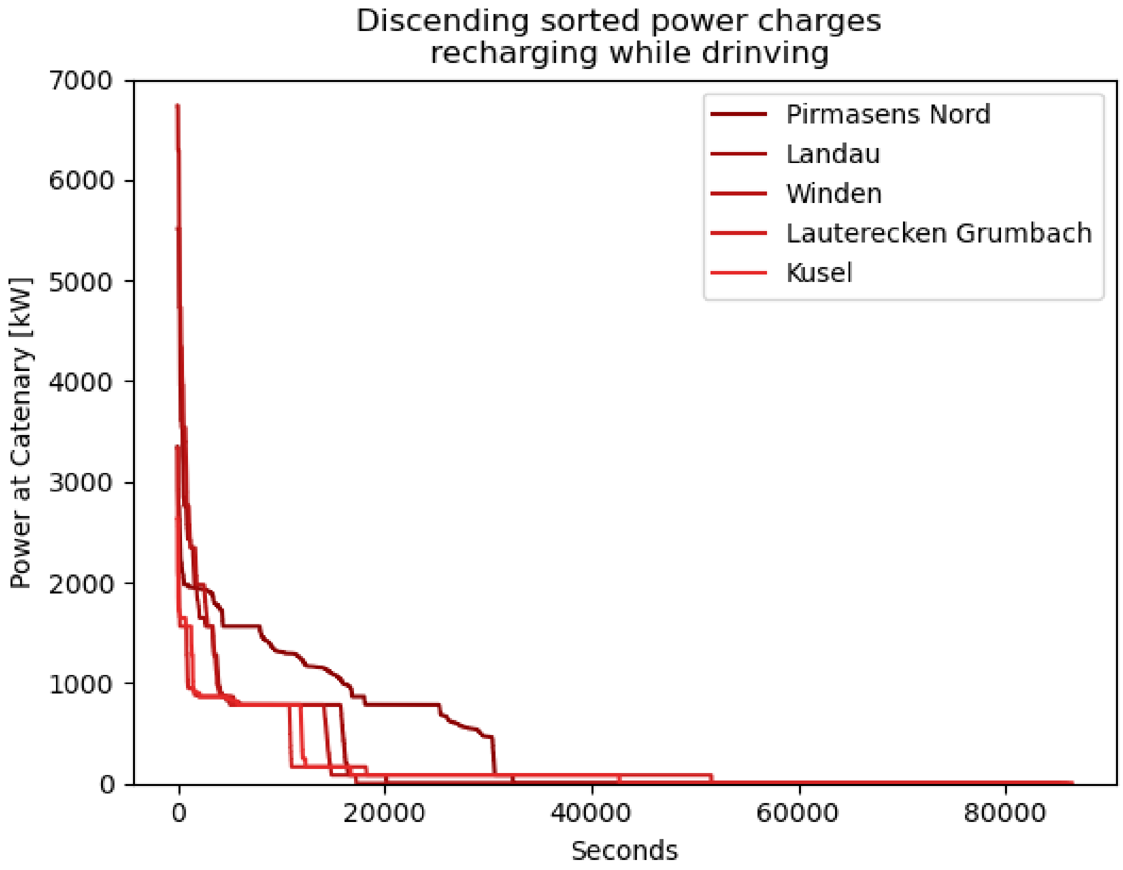
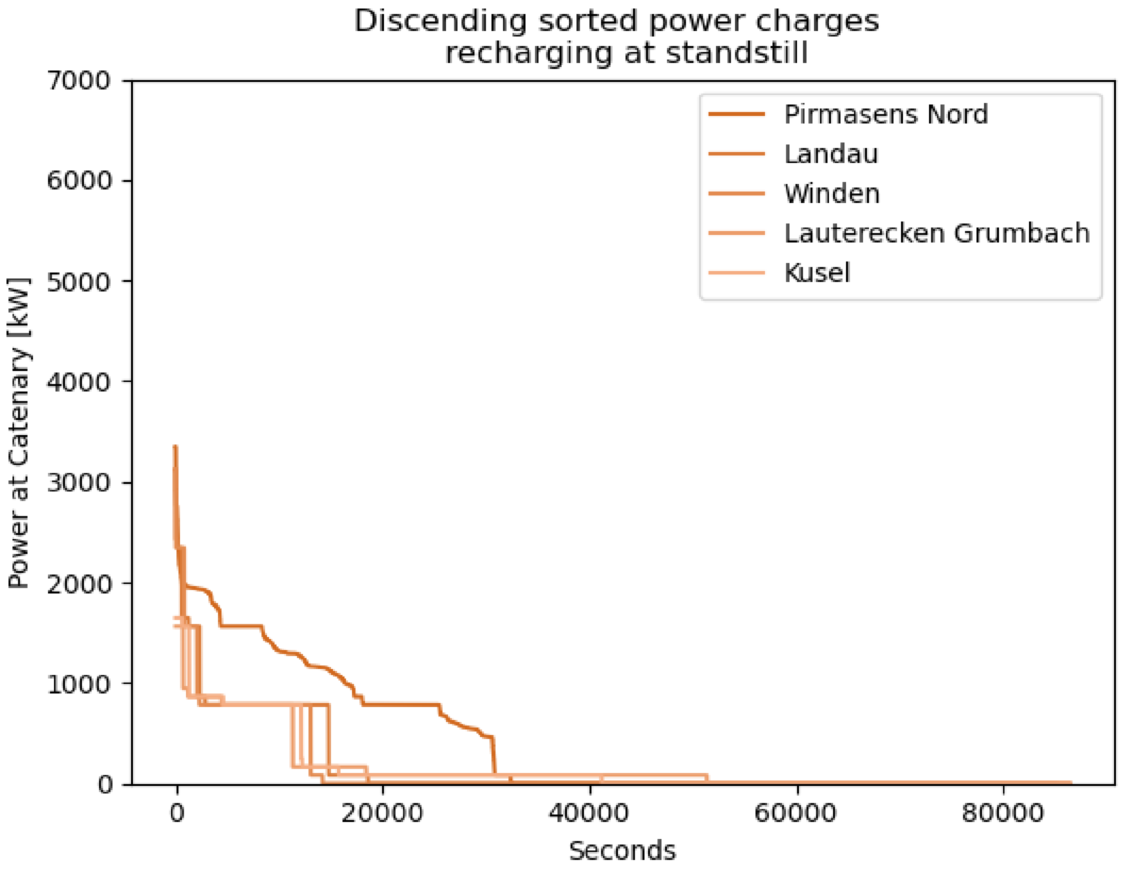
Operational peak-shaving





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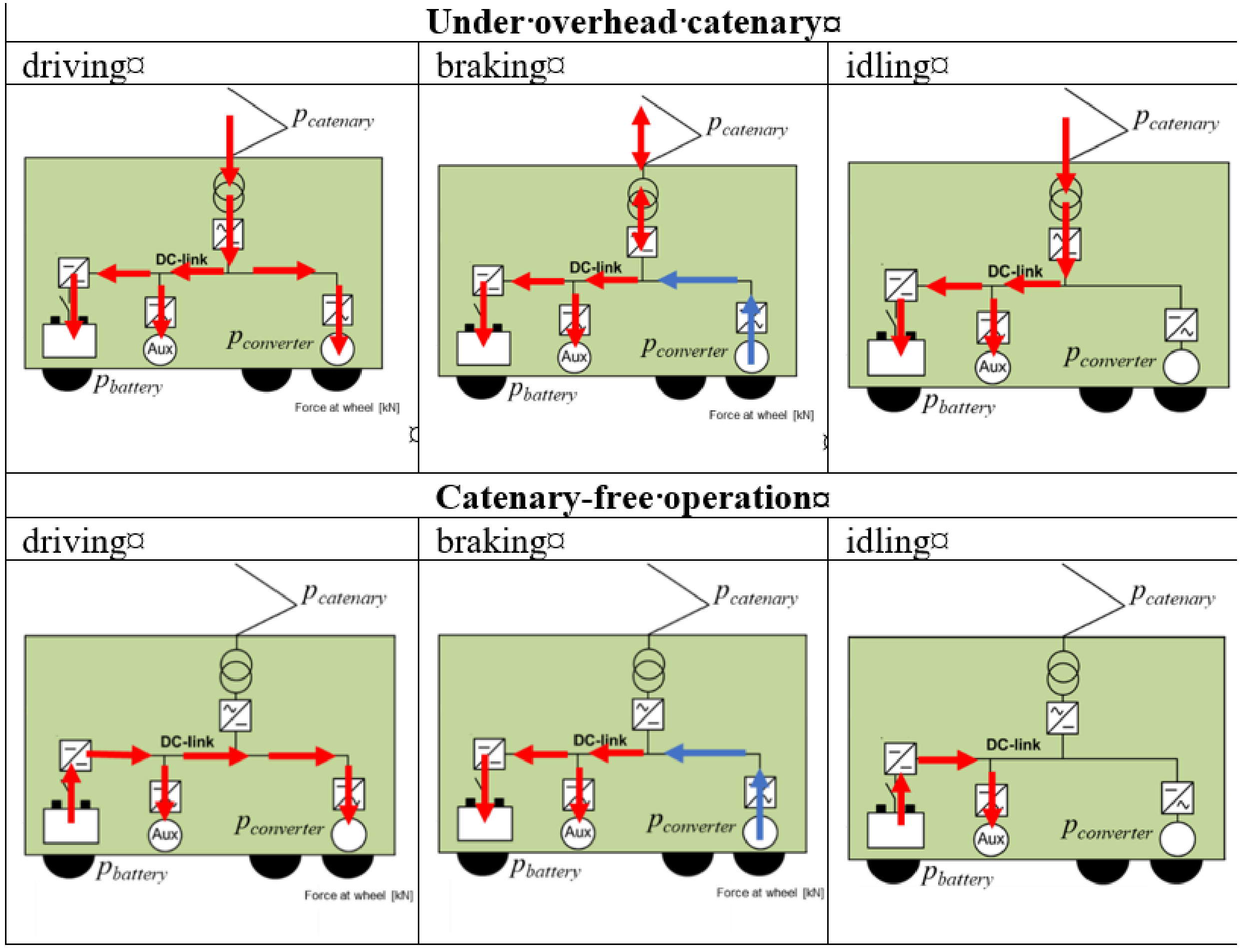
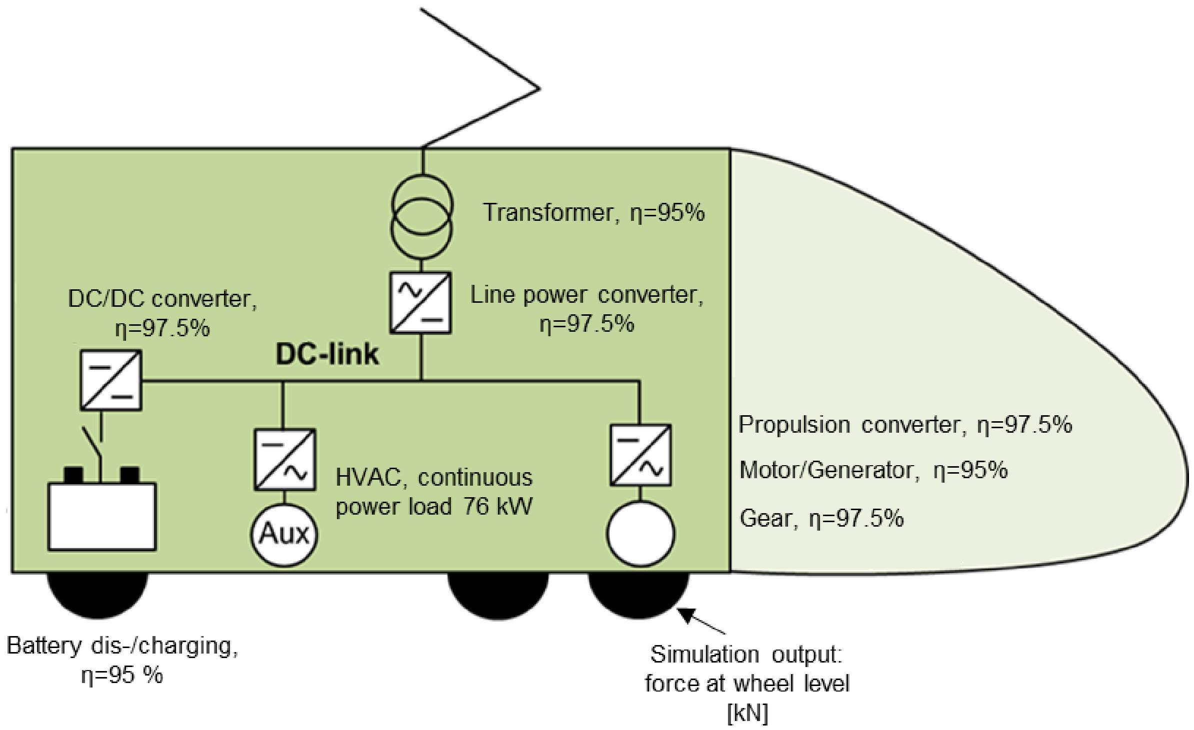
Vehicle Energy Model



Generic Vehicle Specifications

- **Vehicle for longitudinal simulation: generic 2-car BEMU**

Length	42 m
Mass (seated)	97.5 t
Passenger seats	120
Maximum velocity	140 km/h
Max. de-/acceleration	1 m/s²
Max. power at wheels	1000 kW
Davis coefficients A,B,C	1956 N, 17.6 N/ms^{-1}, 2.59 N/ms^{-2}
Maximal power rating of line power AC/DC converter	2000 kW
Maximal power rating of propulsion converter	1400 kW
Maximum force of electro-dynamic brake	60 kN
Battery: installed energy	500 kWh
Maximum c-rate during recharging	1.2



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Vehicle Energy Model: Exemplary Trajectory

Trajectory of a demanding circulation day:

- Daily mileage: 487 km
- Operating time: 13.5 hours
- Stations called: 127
- Average station distance: 3.8 km
- Energy consumed: 2329 kWh
- Highest power peak at catenary: 900 kW
- Recuperated energy for onboard usage: 600 kWh
- Lowest DoD: 25.1 %
- Equivalent full cycles: 3.93