ETH zürich | IVT Institut für Verkehrsplanung und Transportsysteme / Institute for Transport Planning and Systems | PSL Power Systems Laboratory

Results of the project **Rail Power:** **Power and energy for the future railways**

WP 1 until 3: Dipl.-Ing. Michael Nold
WP 4 and 5: Dr. Georgia Pierrou

Outline

- **Modeling the Electric Train Demand – Working Packages (WP) 1-3**
  - WP1: Simulate a complete network with several trains.
  - WP2: Probabilistic effects
  - WP3: Future influences and scenarios are taken into account.
  - Overview of research outcome/papers

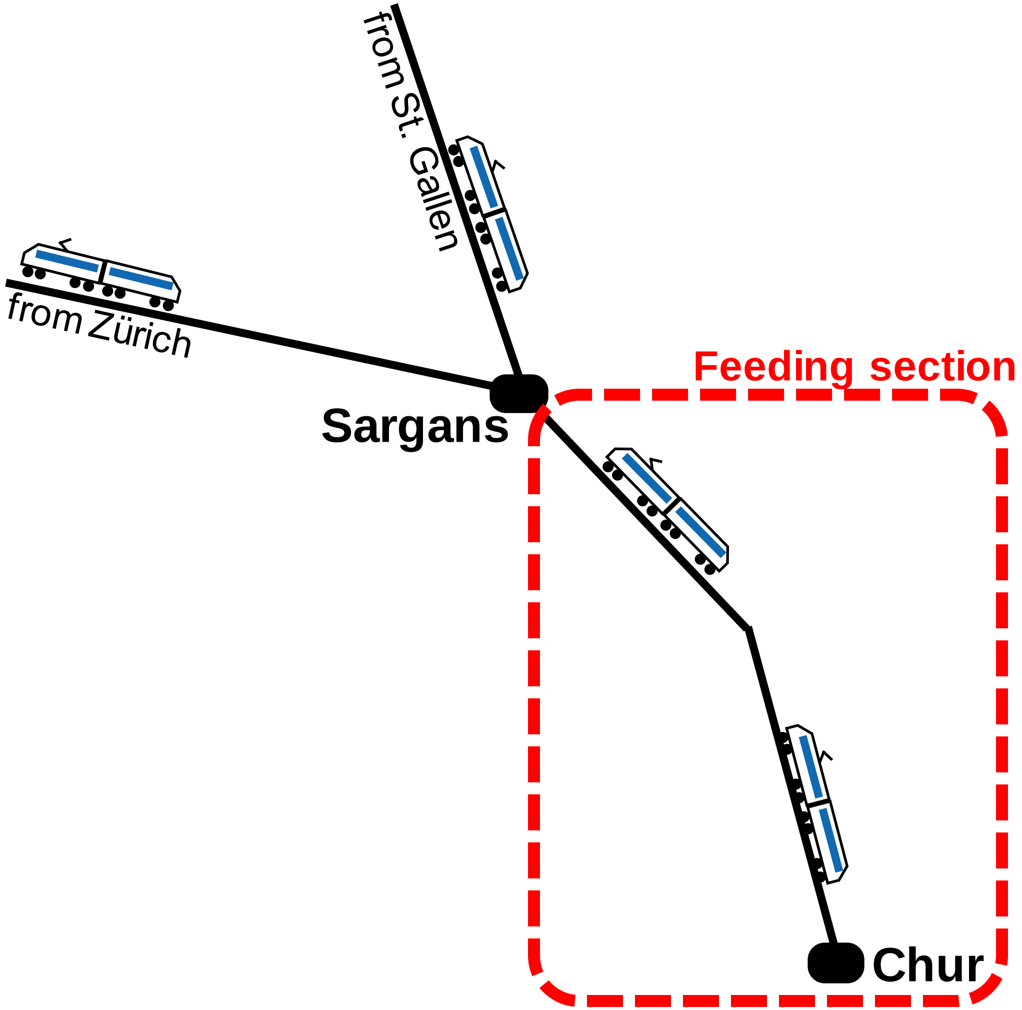
- **Designing the Electric Infrastructure – Working Packages (WP) 4-5**
  - WP4: Design AC/DC connections connecting PV and chargers to the 16.7Hz railway grid
  - WP5: Coordination of EV charging with PV output, train demand
  - Overview of research outcome/papers

WP 1:
Background

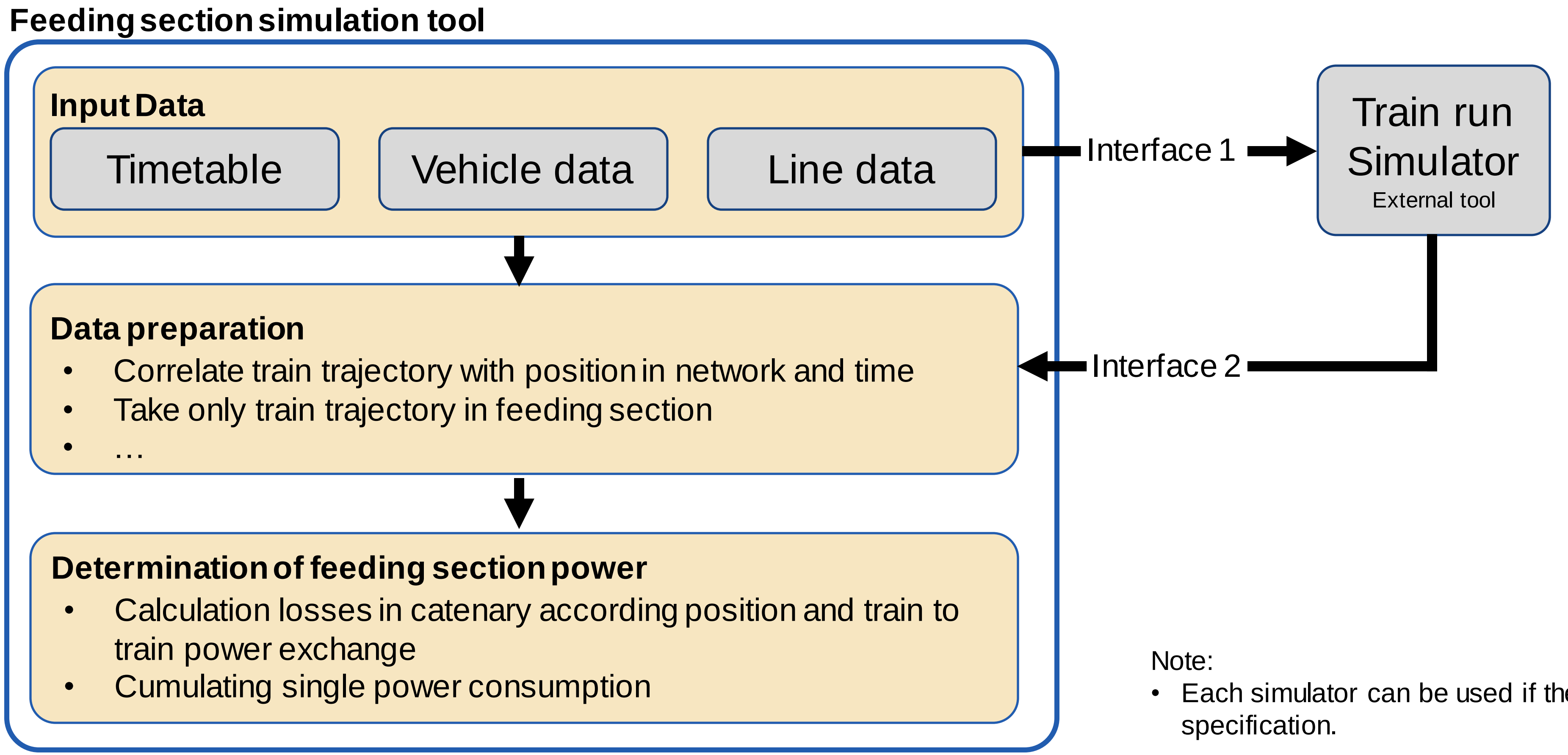
- The railway power supply is divided into different feeding-sections.
- A feeding section can be a single line or a network.
- A train journey usually crosses different feeding-sections
- The number of trains in each feeding section varies over time.
- In each feeding section, there can be interactions between multiple trains.

Goal:

- Develop a simulating tool to simulate a network with several trains.



WP1
Development / tool architecture



Note:
- Each simulator can be used if the train run simulation fulfils the specification.

WP1
Verifying results and calibrating

2-Step-Approach by using power measurement data

1. Using single train runs

- The train run simulator with the model is given, but input parameters can be adapted (e.g., driving resistance, efficiency).
- ➢ Two calibration approaches were developed to determine the parameters.
- ➢ As the critical could be identified:
  - If the simulator describes the physics in a not detailed enough (→ Changing the simulator is with system architecture easy).

2. Feed section measurement

- The single trajectories and power output is given and calibrated in Step 1.
- ➢ The cumulation of the power consumption was compared and verified.
- ➢ Sources of error have been removed.
- ➢ As the critical could be identified:
  - Mismatches in train position (e.g., is the train at time X inside or outside the feeding section).
  - Probabilistic effects which part of WP2.

WP1
Output & Results

1. Tool & Quantification for the **power demand over time** of the feed sections.

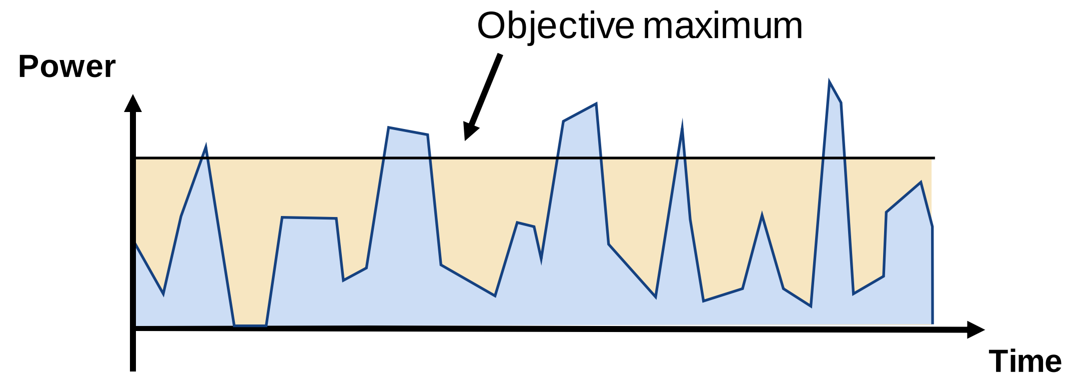
   Usage for:
   - Dimensioning of the power supply→ SBB
   - Optimization, e.g. peak reduction → WP 2
   - Electro vehicle charging → WP 4 & 5

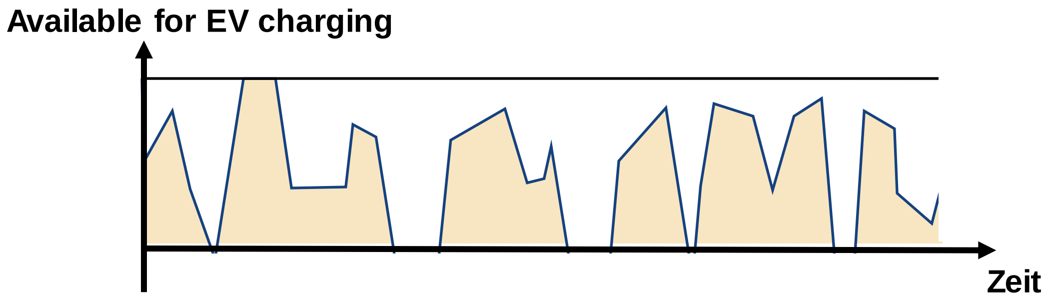
2. Development of new calibration approaches.

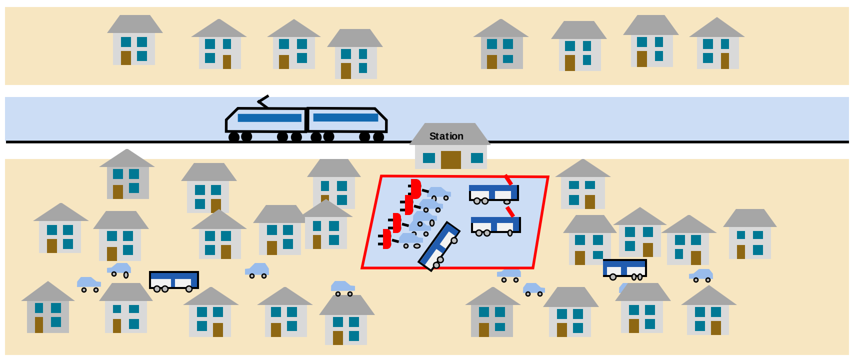
   Usage for:
   - Calibration of further simulations and vehicles
   - Further Research

3. Determining of vehicles parameters.

   Usage for:
   - Further Simulations & Digital Twin
   - WP 2 & 3







WP2
Including probabilistic effects

The simulation of the train runs is influenced from:

- probabilistic effects and/or
- systematically technical effects.

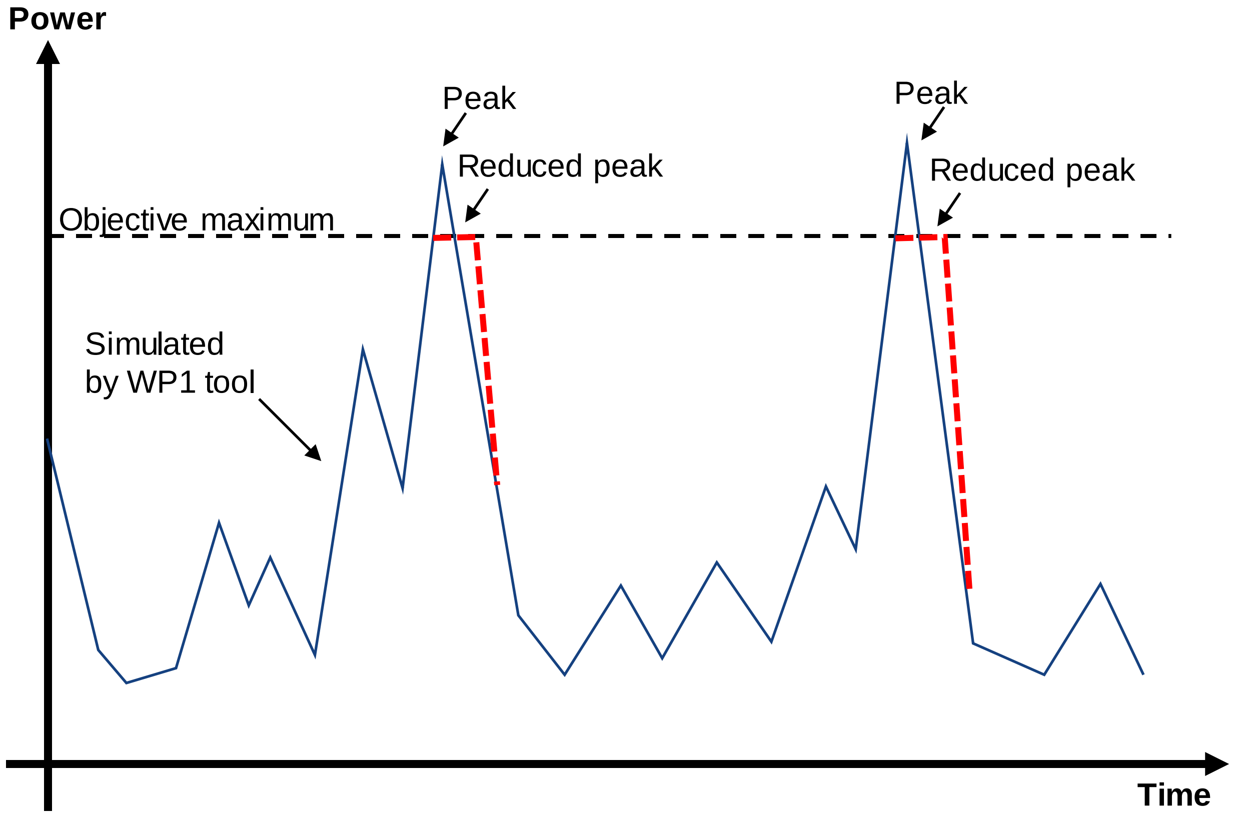
Both can more or less influence power consumption and peaks.

In this WP, it was examined, e.g.:

- Acceleration and declaration depending on train type and station
- Power Peaks and approaches for reducing them
- Dynamic efficiency and the impact on the energy consumption
- Temperature and their impact
- Data analyses to determine correlations

WP 2
Power Peaks

1. Quantifying power peaks
2. Reduction of power peaks by influencing the train runs (and comparing) of:
   - shift in departure
   - reduced power vehicle consumption



Results

- Short-term power reduction can significantly reduce the peaks with fewer delays as departure shifts.

Usage for

- Stabilization of the power supply
- Further research

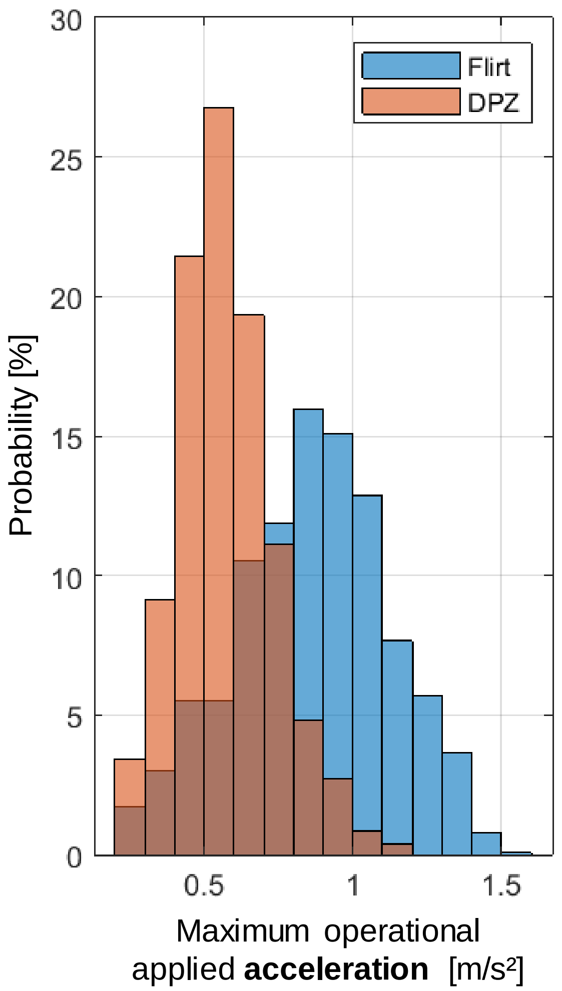
WP 2
Determining of acceleration

Results

- The acceleration can vary significantly
- Its depends from
  - the technical feasibility of the vehicle,
  - the driver behavior,
  - the railway line (e.g. slope) and
  - further aspects (e.g. weather, delay).
- Have an impact on Power peaks

Usage for

- Energy simulations
- Timetables
- Vehicle comparison and allocation
- Digital Twin
- Research



WP 3
Future influences and scenarios

1. Overview of more future influences of railway and power consumption

   → Report which considers +50 fields, identified according +190 references

   Results:
   - Several technical and social aspects will have an impact on the future railway power consumption and supply.

2. Determining of the impact of energy models for on the power consumption and energy efficient train control (EETC). At EETC, the usual applied simplified modelling of energy

   Results:
   - overestimate energy saving,
   - determines not the most energy efficient trajectory.

Usage for:

- Further scenarios
- Further energy simulation and research
- Dimensioning of the power supply

Conclusion & Impact from the WP 1 until 3

The project and its results can influence various aspects of the railway and energy supply sectors, e.g.:

- Determination and dimensioning of the future power supply.
- Power peaks determination and reduction for stabilization of the power supply.
- Electro vehicle charging via the railway grid.

- Development of new calibration approaches.
- Determination of Parameters for Simulations, Timetables, and Digital Twin.

- Further research.

References
& Overview of research outcome

Publications which are directly or partially related to the WP 1-3:

- Nold, M., & Corman, F. (2024). Fast calibration of dynamic and energy parameters of railway vehicles using acceleration sensors. 24rd Swiss Transport Research Conference (STRC 2024), Ascona, Switzerland
- Nold, M., & Corman, F. (2024). Increasing realism in modelling energy losses in railway vehicles and their impact to energy-efficient train control. *Railway Engineering Science*. doi:10.3929/ethz-b-000650828
- Nold, M., & Corman, F. (2023). RailPower - Power and energy for the future railways. Calibrated simulation of railway networks. doi:10.3929/ethz-b-000615323
- Nold, M., & Corman, F. (2023). A simulation-based approach for determination of the traction chain efficiency for multiple train trajectories. 23rd Swiss Transport Research Conference (STRC 2023), Ascona, Switzerland
- Trepat Borecka, J., Regueiro Sánchez, D., Nold, M., Bešinovic, N., & Corman, F. (2023). Real-time mitigation of power peaks in railway networks using train control measures. RailBelgrade 2023. Belgrade: University of Belgrade, The Faculty of Transport and Traffic Engineering.
- Nold, M., Pierrou, G., Strietzel, R., Schäfer, R., Bühlmann, P., Zimmermann, M., Corman, F., Hug, G. (2022). *RailPower. Power and energy for the future railways*. doi:10.3929/ethz-b-000546007
- Nold, M., & Corman, F. (2022). Modelling realistic energy losses from variable efficiency and vehicle systems, in determining energy efficient train control . 22rd Swiss Transport Research Conference (STRC 2022), Ascona, Switzerland
- Regueiro Sánchez, D. (2021). Quantification and reduction of power peaks in railway networks. A simulation-based approach (ETH Zurich, Zurich). doi:10.3929/ethz-b-000502365

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Outline

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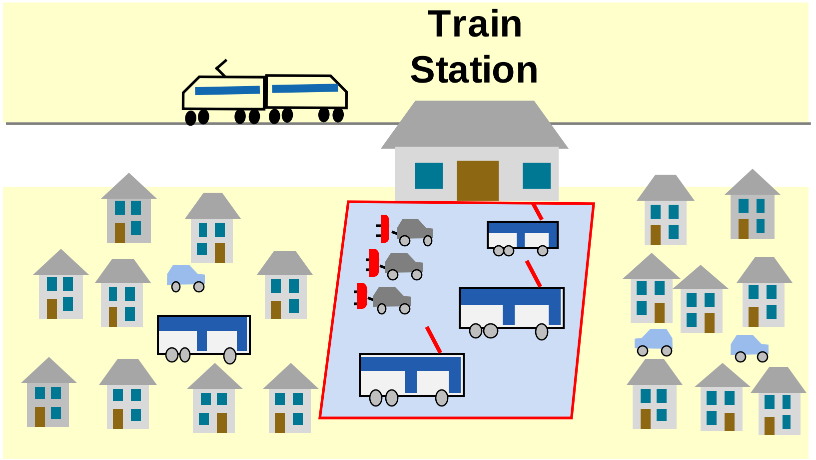
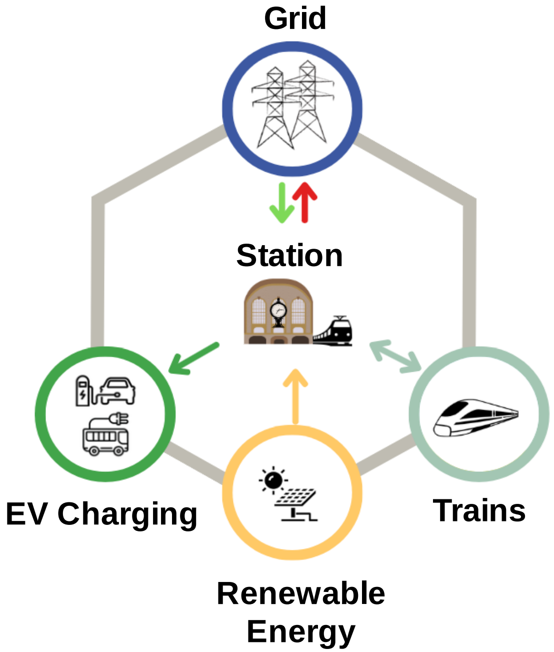
Electric railway stations as EV charging hubs



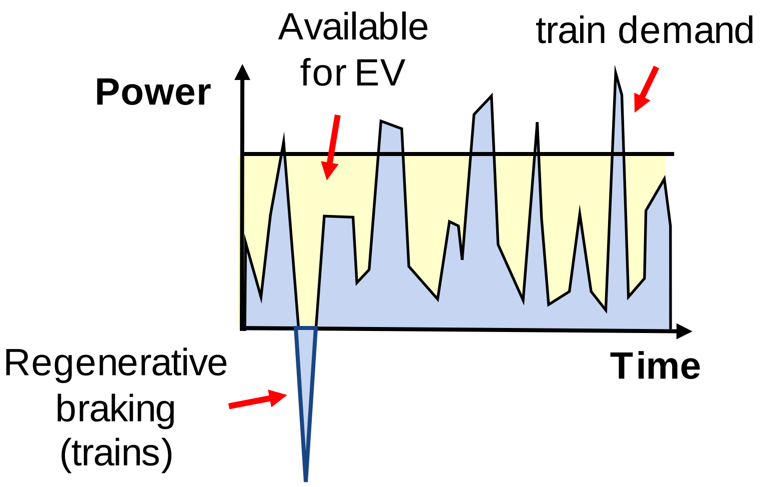
Motivation:

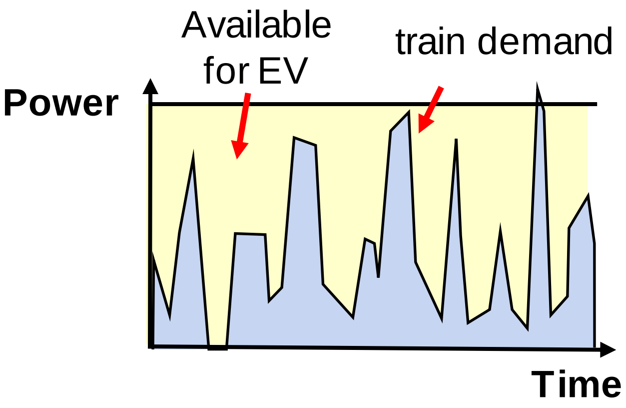
Leverage existing **electric railway** infrastructure to satisfy **electric vehicle (EV) charging** requirements.

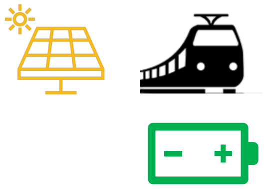
Train Station: Energy Hub



Challenges in integrated EV-railway operation

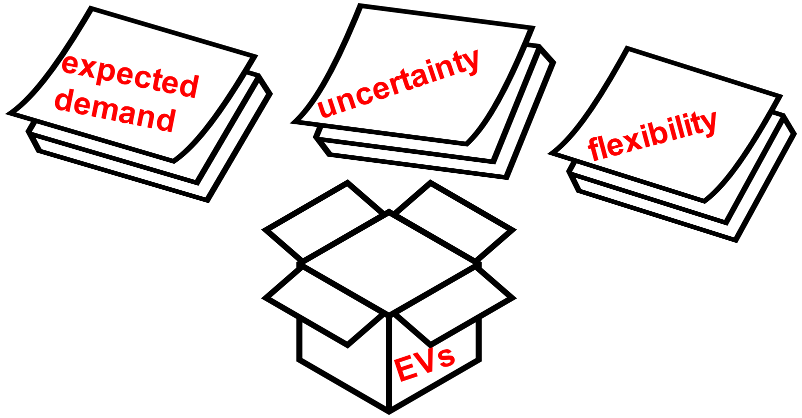




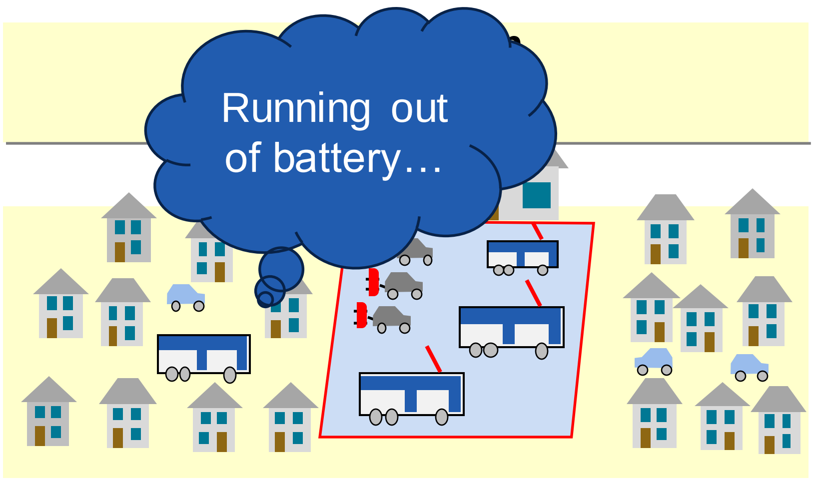


Train load profile:

- **Peaks** occur only for a **short** period of time (<1 min)
- Power rates are **high**: +- 25 MW/s
- 50% of maximum load within 15 min



Goal: Flexible EV charging scheduling

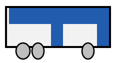


Goals:

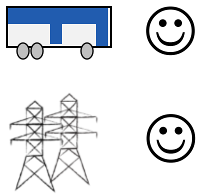
How to integrate EV charging **without overloading** the railway grid?

How to leverage EV **flexibility**?

Charging demand → **Optimization models** → **EV charging scheduling**



Arrival	09:30
Departure	10:00
Energy	100 kWh



Related work

Offline tools:

- Day ahead optimization [Pierrou et al., PESGM23, PSCC2024]

Online tools:

- Receding horizon control [Pierrou, Hug PowerTech23]

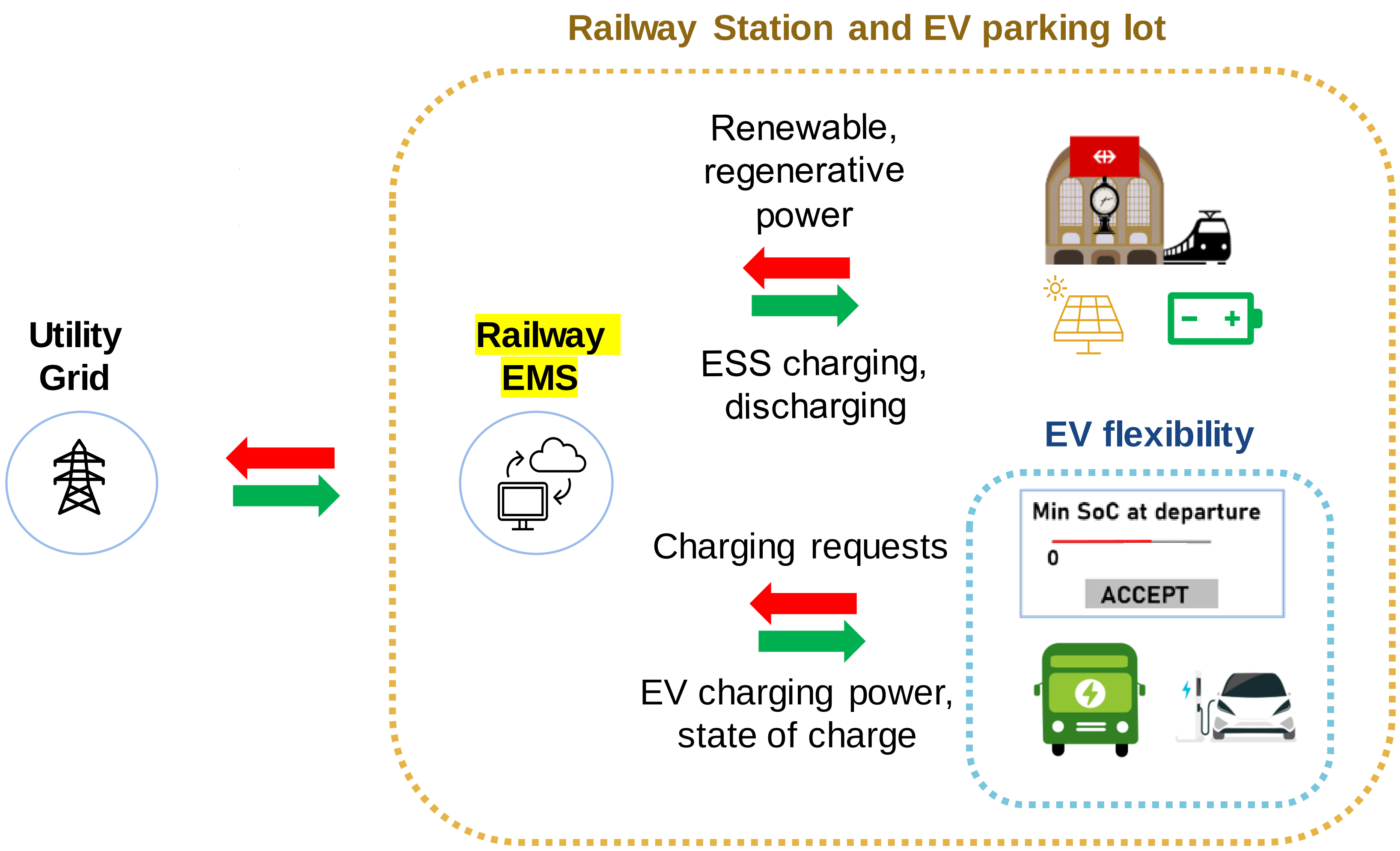
Proposed methods:

✓ **Flexible end-user EV scheduling** in electric railway systems

✓ **Additional elements** (renewables, storage, regenerative braking capabilities)

✓ **Robustness** against **uncertainty** in the available power for EV charging

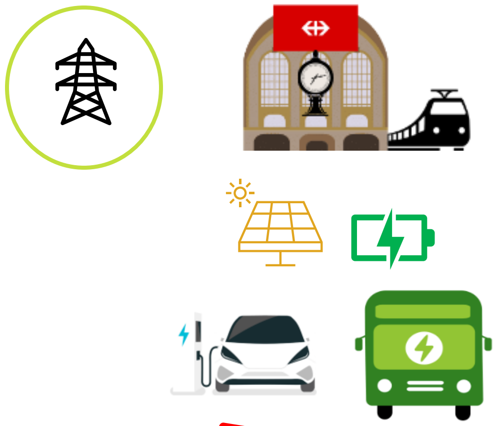
Integrated EV-railway operation set-up



Offline integrated EV-railway energy management

[Pierrou, Hug PESGM ’23, EPSR/PSCC ’24]

Railway EMS



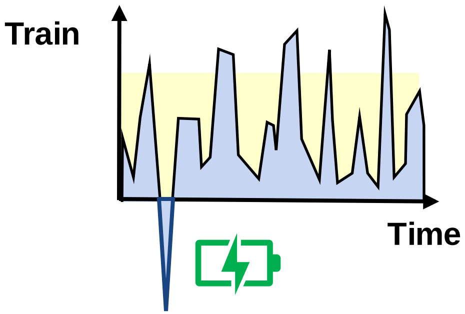
Assumes perfect knowledge of information

Objective: Minimize daily operating costs

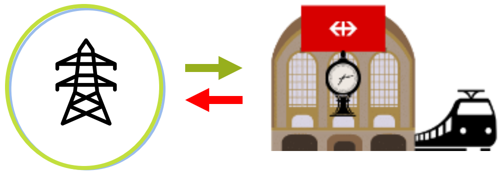
Subject to:

- Power Balance

- Energy Storage



- Grid Power Exchange



Online EV charging optimization

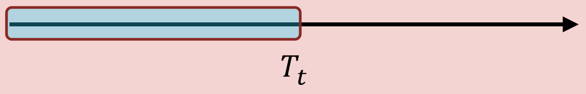
[Pierrou, Hug PowerTech ’23, ’24]

EV Parking Lot Operator

Optimizing EV charging schedules

Objective: EV peak power

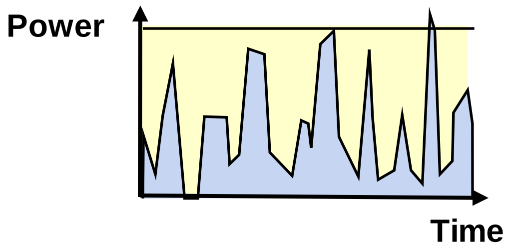
Moving Optimization Horizon



Subject to

- **Uncertainty**
- Customer satisfaction

Available power for EV:
Pmax + PV + Regenerative Braking



Solar radiation

Train demand

RB power

→ Scenario ξ_i →

Available power for EV charging

$P_a(\xi_i) = P_{max} + P_{PV}(\xi_i) + P_{RBE}(\xi_i) - P_D(\xi_i)$

EV power <= $P_a(\xi_i)$ with high probability!

Online EV charging optimization

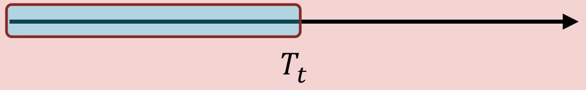
[Pierrou, Hug PowerTech ’23, ’24]

EV Parking Lot Operator

Optimizing EV charging schedules

Objective: EV peak power

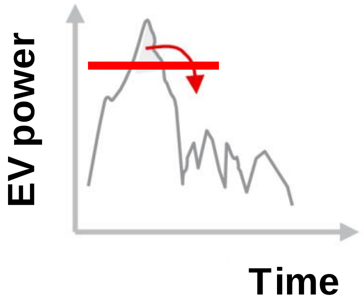
Moving Optimization Horizon

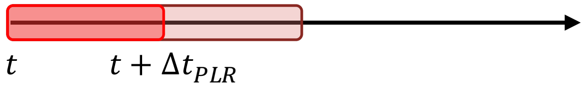


Subject to

- Uncertainty
- **Customer satisfaction**

Flexible state of charge under request for load reduction





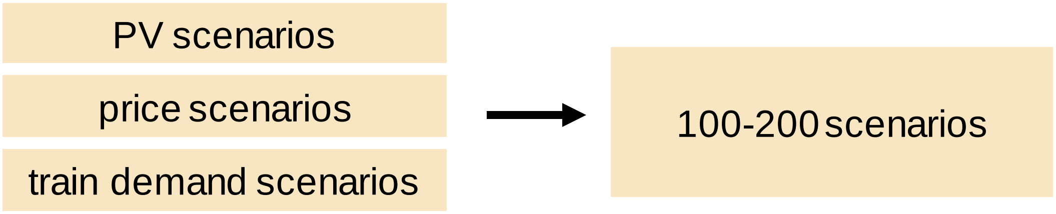
- Equivalent to skipping charging cycles
- Suitable for buses due to larger batteries

EV flexibility

Case study

- Route from Sargans to Chur (Switzerland)

- Chur as the main train station with PV generation, ESS, and EV charging facilities
- Railway Demand: historical data with 10-min resolution
- Solar Generation: 1000kW (~20% of peak load)
- Uncertainty modeling



Case study

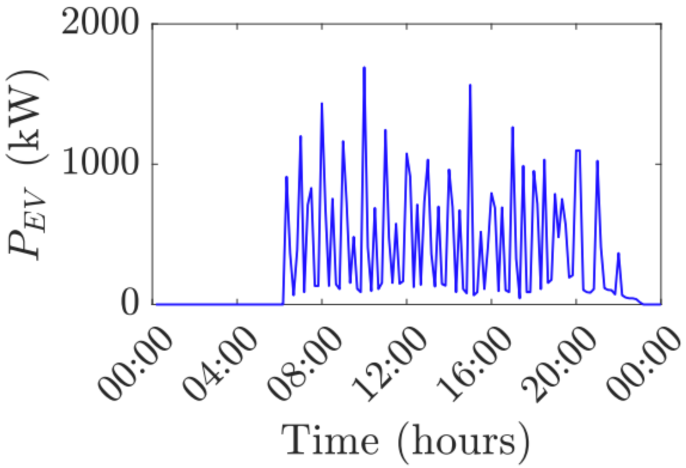
- EV arrival

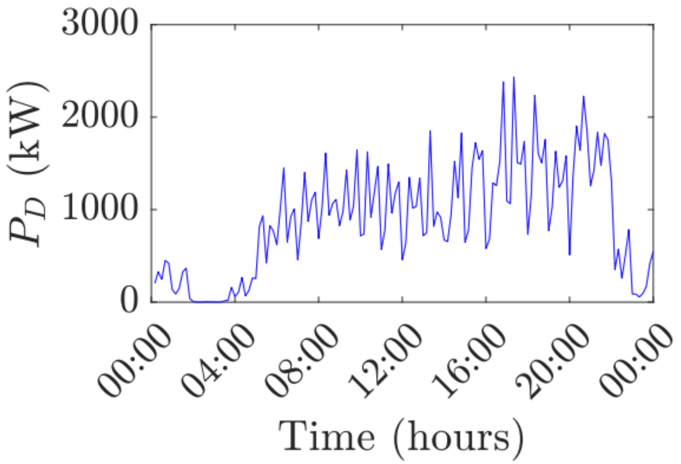
Electric cars:

4 cars/hour
Nominal charging rate 11kW
Maximum charging rate 22 kW
Requests [10,50] kWh
Any departure time

Electric buses:

Departure times according to official timetable
Arrival times 10-60min before departure
Nominal, Maximum charging rates 300kW
Requests [100,300] kWh





EV demand compared to train demand?

Case study – Operating costs

1. The proposed approach achieves savings in daily operating costs.

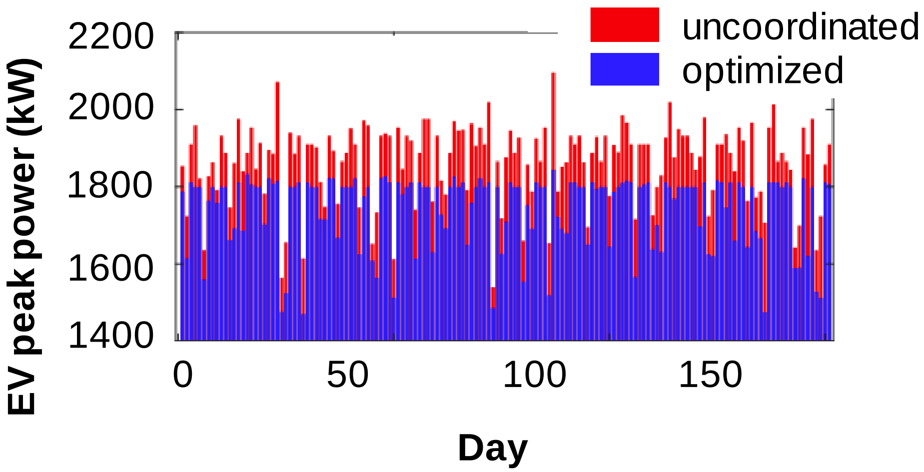
	Train	EV	PV	ESS
Base	✓	-	-	-
Proposed	✓	✓	✓	✓

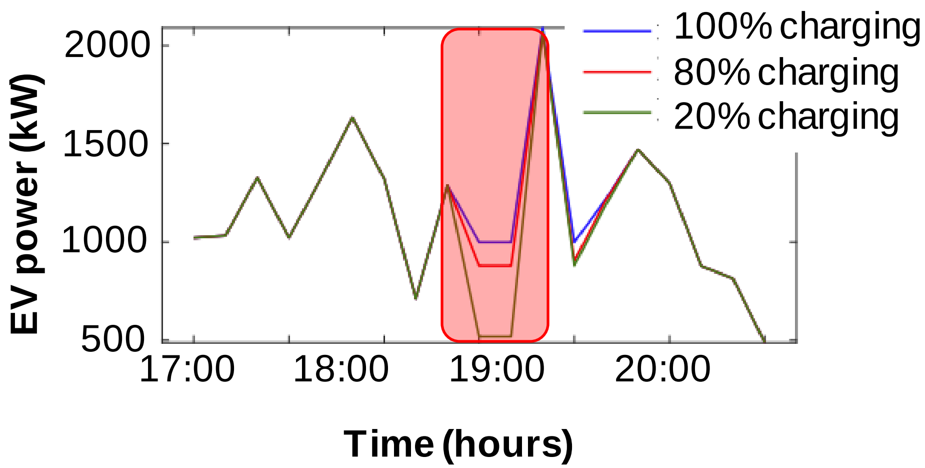
Operating cost savings

of up to 17%

Case study – EV power

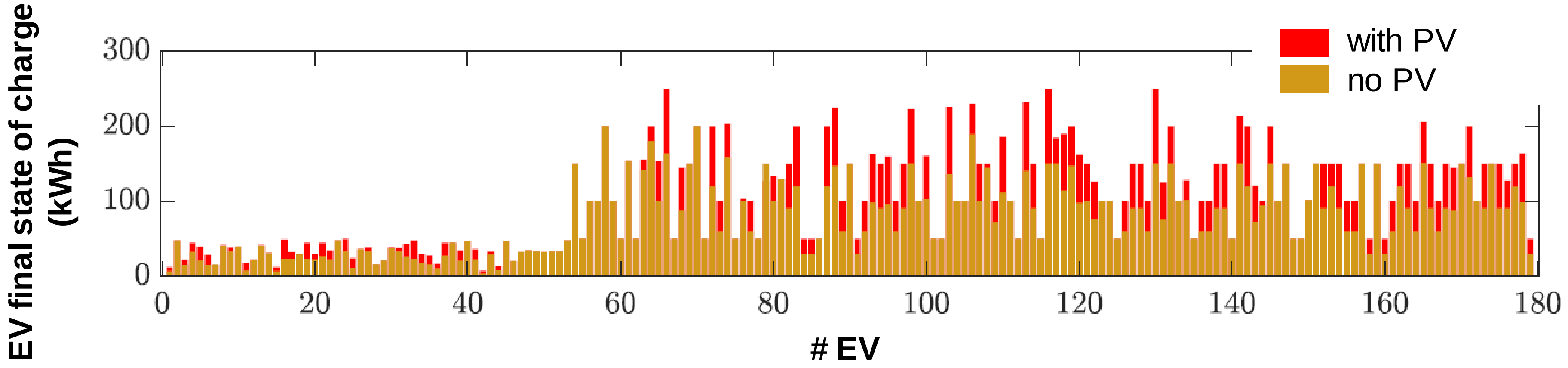
2. The proposed approach minimizes daily EV peak power.





Case study – PV impact

- Example: weekday with highest amount of PV generation
- Up to 40% increase in the state of charge upon departure (vehicle 116)



Summary

- Successfully integrating flexible EV charging in electric railways along with renewable generation, ESS and regenerative braking

- PV and ESS may significantly improve EV customer satisfaction

- Future work

- incentives and user acceptance

References

1. G. Pierrou, C. Valero-De la Flor and G. Hug, “Optimal EV Charging Scheduling at Electric Railway Stations Under Peak Load Constraints,” to appear in Electric Power Systems Research, 2024.
2. G. Pierrou, Y. Zwirner, and G. Hug, “An Optimal Energy Management Algorithm Considering Regenerative Braking and Renewable Energy for EV Charging in Railway Stations,” in IEEE PES General Meeting, Orlando, FL, USA, 2023.
3. G. Pierrou and G. Hug, “Integrating Optimal EV Charging in the Energy Management of Electric Railway Stations,” in IEEE PowerTech, Belgrade, Serbia, 2023.

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Project Team

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- **Main Project & Lead:**
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- **Partially involved:**
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Project team SBB

- **Lead:**
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- **Main Project:**
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