Modelling flexibility from electric vehicles: where, when, why, and how

María Parajeles Herrera (ETHZ)
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sweet swiss energy research for the energy transition

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Lunch talk series V:
Flexibility provision from buildings and electromobility

1. Impacts of electric vehicles and heat pumps flexibility: European and Swiss perspectives
2. End-user flexibilities for electrical distribution grid planning
3. **Modelling flexibility from electric vehicles: where, when, why, and how**
4. Modelling flexibility from heat pumps: a bottom-up approach for Swiss buildings
5. Electrification, flexibility or both?
6. Emerging trends in recent Swiss and European policy
7. Operation and market mechanisms: from dynamic electricity tariffs to day-ahead and intraday auctions

Motivation

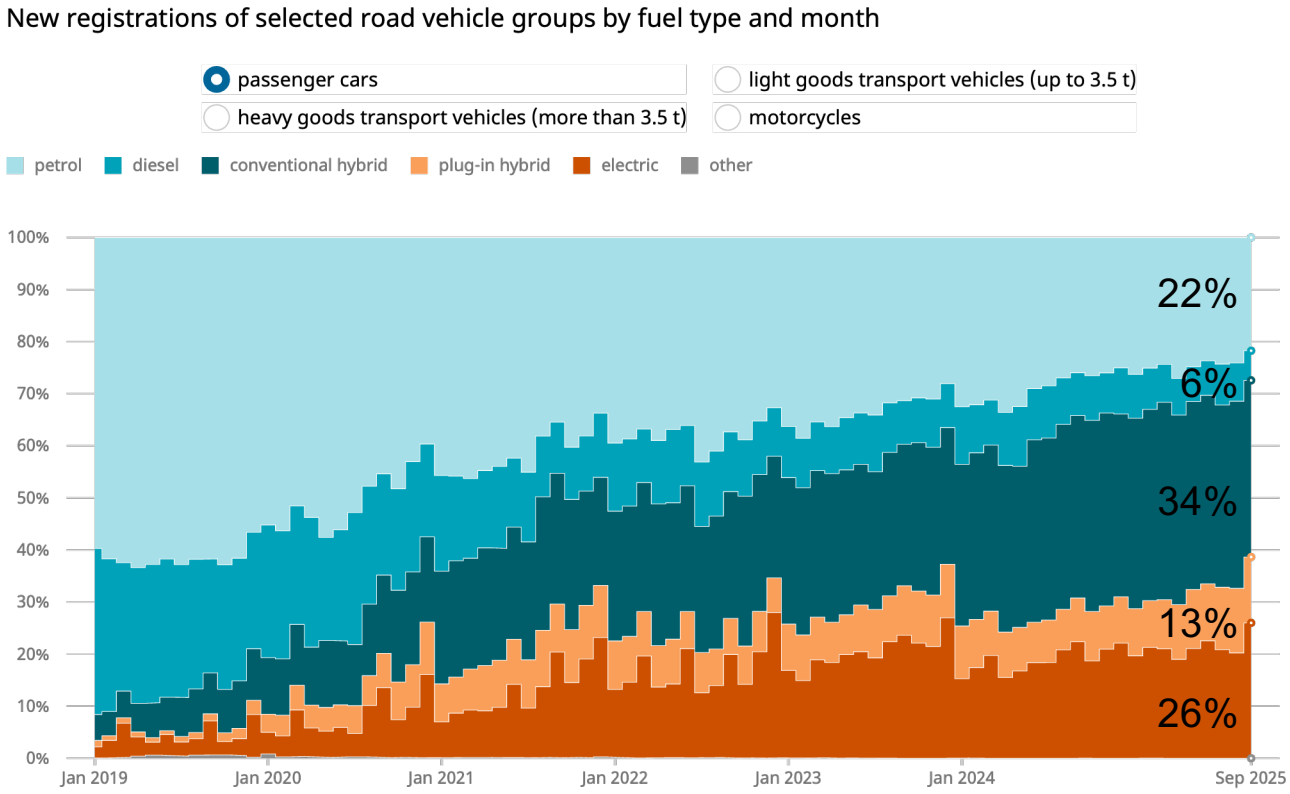
Why EVs?

- EVs have >70% lower life-cycle emissions than petrol combustion engine vehicles in Switzerland (Knobloch, 2022)

What are EV targets?

- Fully electric + plug-in hybrids aim for 50% of new registrations by 2025

How is adoption going?



Note: provisional data for 2025, late additional registrations likely

Data as on: 03.10.2025
Source: FSO, FEDRO – New registrations of road vehicles (IVS)

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Knobloch, F., Hanssen, S. V., Lam, A., Pollitt, H., Salas, P., Chewpreecha, U., ... & Mercure, J. F. (2020). Net emission reductions from electric cars and heat pumps in 59 world regions over time. *Nature sustainability*, *3*(6), 437-447.

https://www.energieschweiz.ch/programme/roadmap-elektromobilitaet/

Primer on EV charging

Heterogeneous charging preferences for location, timing, and speed …

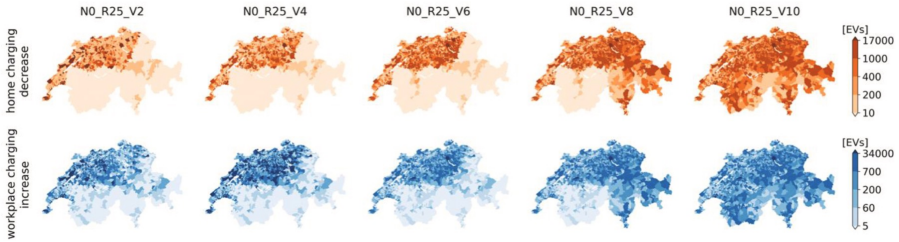
… impact electricity system operation and planning.

Key questions:

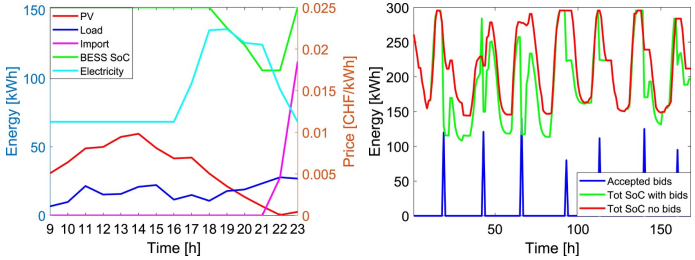
Where and when will charging occur?
How flexible is charging demand?
What is its flexibility useful for?
How can we use models to answer these questions?

More PATHFNDR Research Quantifying EV Charging is Led By…

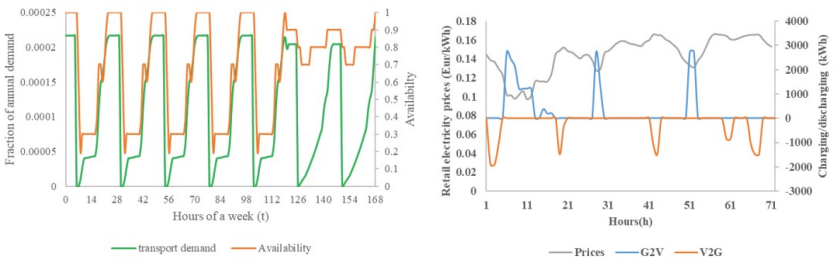
Dr. Zongfei Wang, UNIGE



Dr. Federica Bellizio, Empa



Dr. Binod Koirala, Empa



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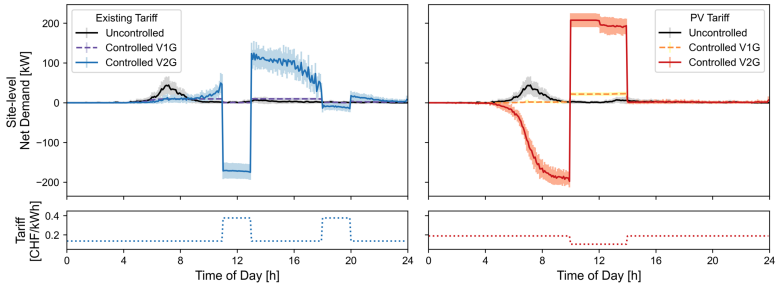

Wang, Z., Sasse, J. P., & Trutnevyte, E. (2025). Home or workplace charging? Spatio-temporal flexibility of electric vehicles within Swiss electricity system. *Energy, 320,* 135452.

Koirala, B., Mutschler, R., Bartolini, A., Bollinger, A., & Orehounig, K. (2022, June). Flexibility assessment of e-mobility in multi-energy districts. In *CIRED Porto Workshop 2022: E-mobility and power distribution systems* (Vol. 2022, pp. 824-828). IET.

Bellizio, F., Guo, Y., & Heer, P. (2025). Sector-coupled vehicle-to-everything operation of EV fleets for demand-side flexibility provision. *Energy,* 138508.

Andersen, D., & Powell, S. (2025). Policy and pricing tools to incentivize distributed electric vehicle-to-grid charging control. *Energy Policy, 198,* 114496.

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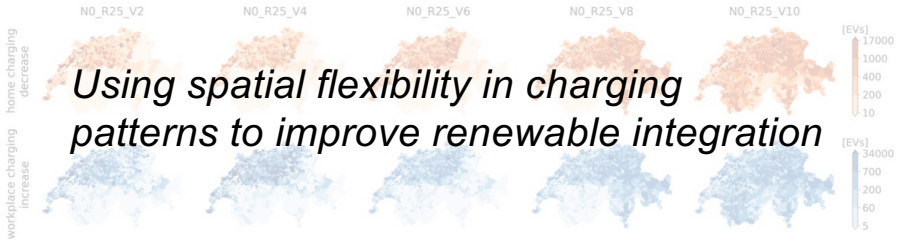
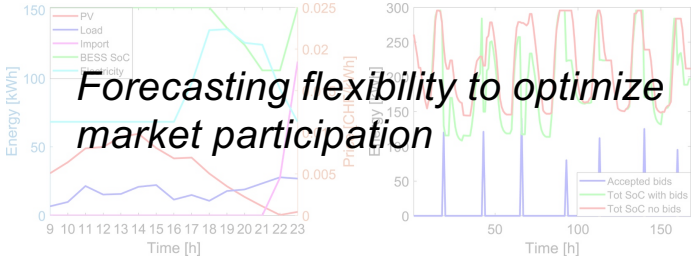


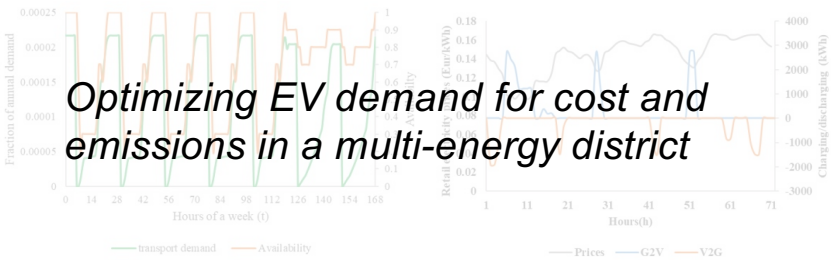
Using spatial flexibility in charging patterns to improve renewable integration

Dr. Federica Bellizio, Empa



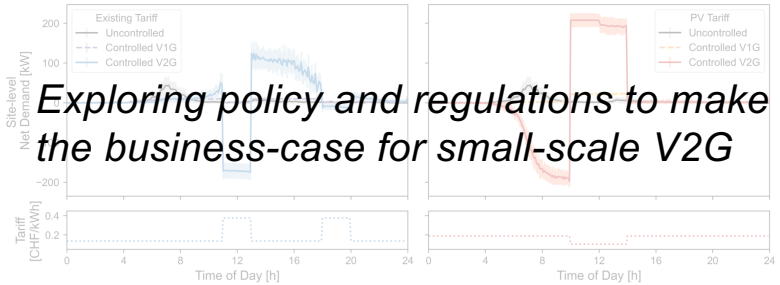
Forecasting flexibility to optimize market participation

Dr. Binod Koirala, Empa



Optimizing EV demand for cost and emissions in a multi-energy district

Dr. Siobhan Powell, ETHZ



Exploring policy and regulations to make the business-case for small-scale V2G

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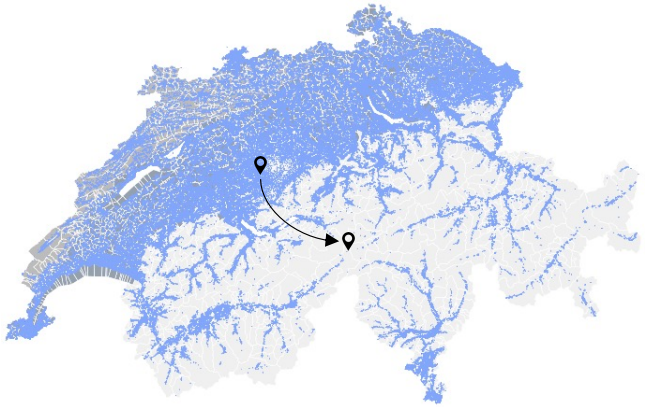
Deep Dive

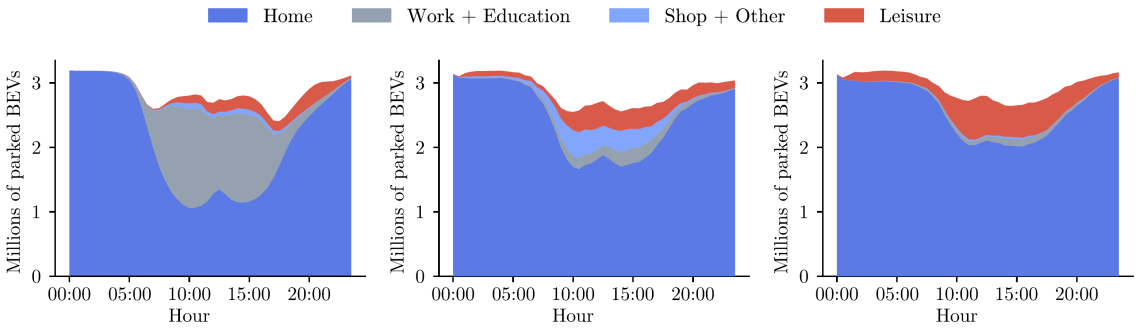
Looking into modeling EV charging demand and flexibility with bottom-up models:
where, when, why, and how

Mobility choices drive charging energy needs

Passenger car usage model:
A georeferenced, population-wide choice model shows when, where, and how people travel.



Charging timing:
Charging times inferred from spatiotemporal travel and parking patterns

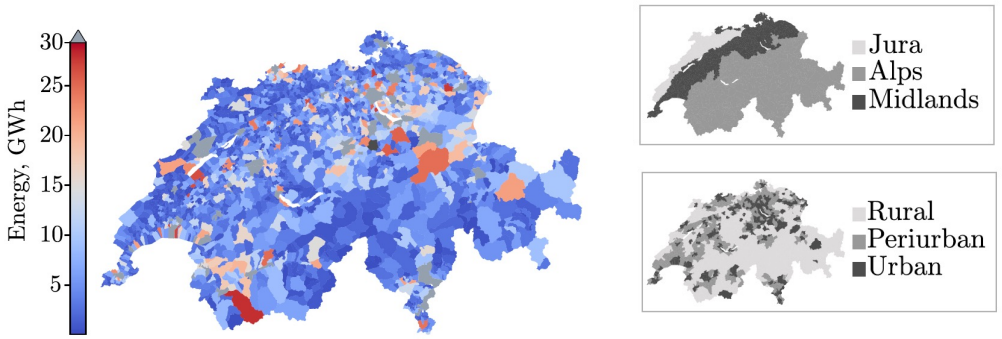


Distribution of vehicles parking times per type of location

Parajeles Herrera, et al. (2024). Spatio-Temporal Modeling of Large-Scale BEV Fleets' Charging Energy Needs and Flexibility. *2024 International Conference on Smart Energy Systems and Technologies*, 1–6.610.1109/SEST61601.2024.10694497

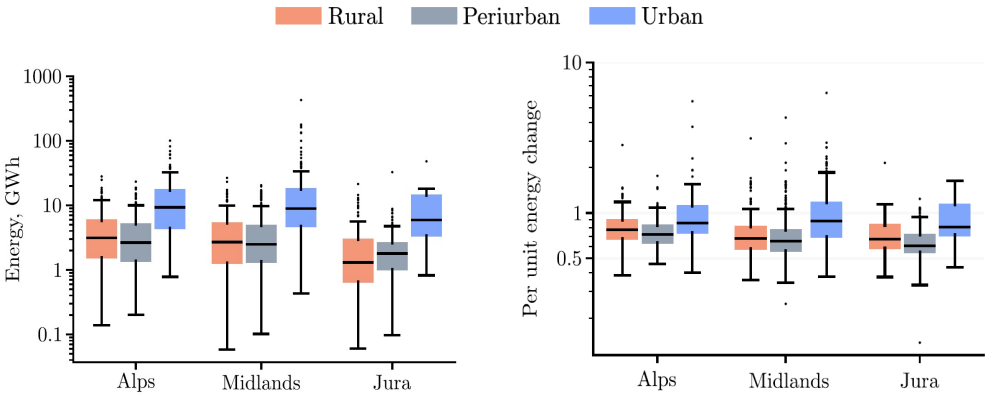
Charging energy needs vary both in time and space

Home charging:
Night-time demand clusters in the urban Midlands.



Home-based charging energy needs across Switzerland

Workplace charging:
Demand shifts from rural/peri-urban to urban areas and daytime hours.



Home-based charging

Shift to workplace charging

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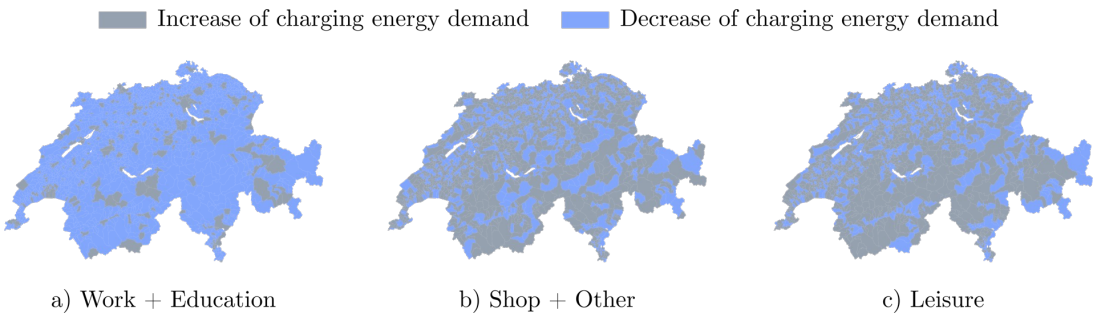
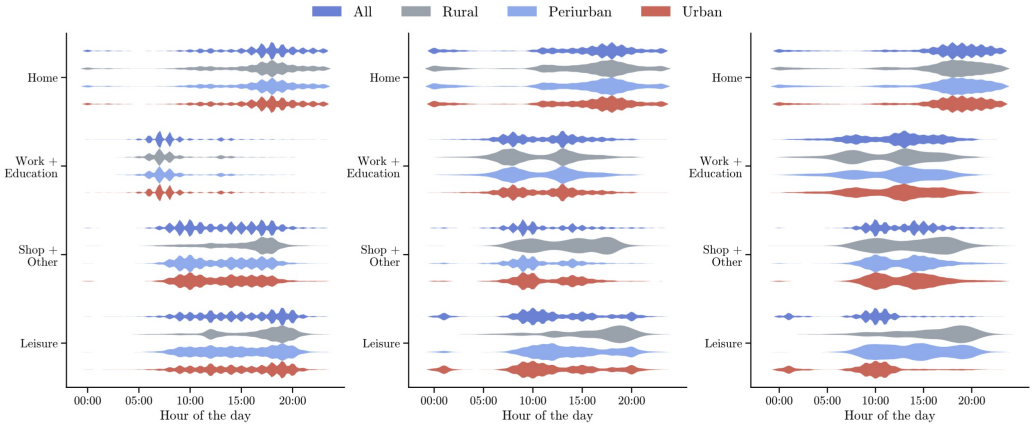
Charging demand varies by region and time, depending on location

Regional concentration:
Workplace charging concentrates demand (13% of municipalities); other locations disperse.



Regional change in energy demand when shifting away from home charging

Temporal variation:
Home and workplace show clear charging times; other locations disperse in time and space.



Comparison of the distribution of parking arrival/ charging start times

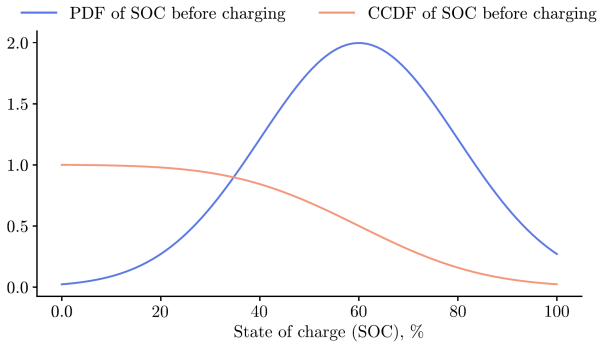
Parajeles Herrera, et al. (2024). Spatio-Temporal Modeling of Large-Scale BEV Fleets' Charging Energy Needs and Flexibility. *2024 International Conference on Smart Energy Systems and Technologies*, 1–6.610.1109/SEST61601.2024.10694497

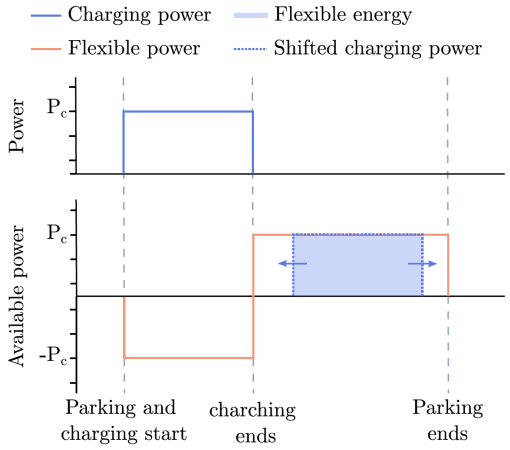
Quantifying flexibility as a deviation from baseline charging

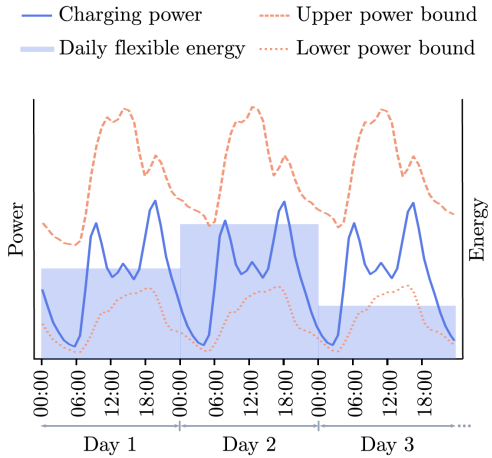
Probabilistic charging decision-making:
Meeting mobility needs within battery range comfort

Bottom-up flexibility quantification:
Idle parking enables power and energy flexibility

Baseline charging profiles and flexible energy:
Upper and lower power bounds and daily flexible energy







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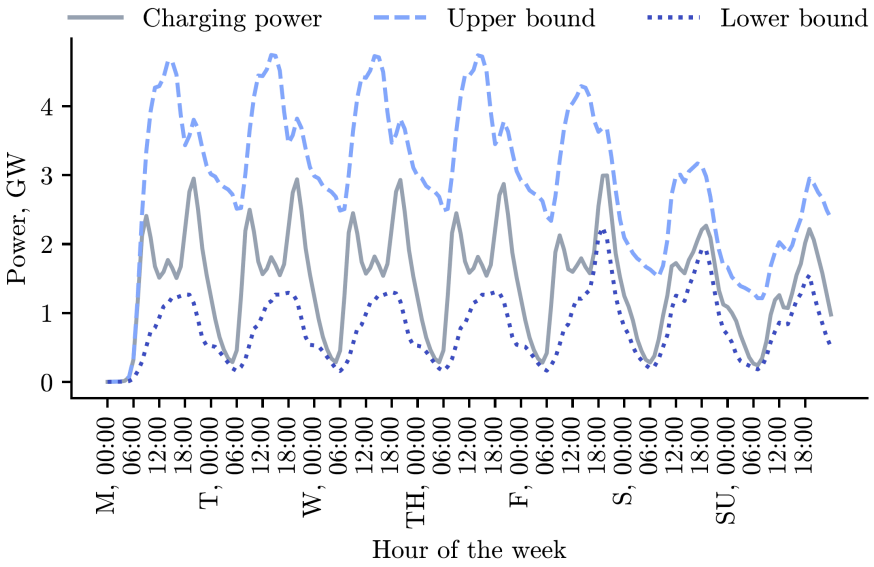
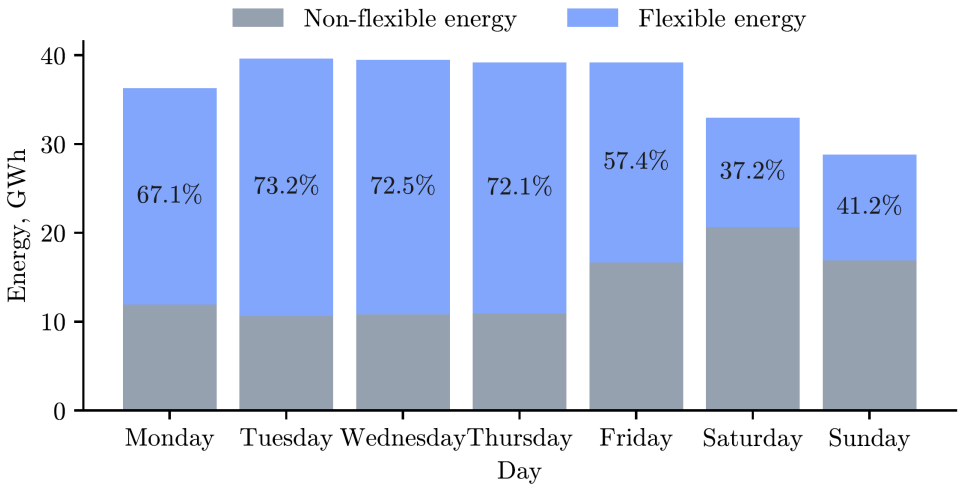
60% of the entire future Swiss EV fleet's charging energy is flexible



Non-symmetrical lower and upper bounds:
Shorter charging times at high power are common



Weekends show less charging flexibility:
Less mobility during the weekends and long plug-in periods are considered unrealistic

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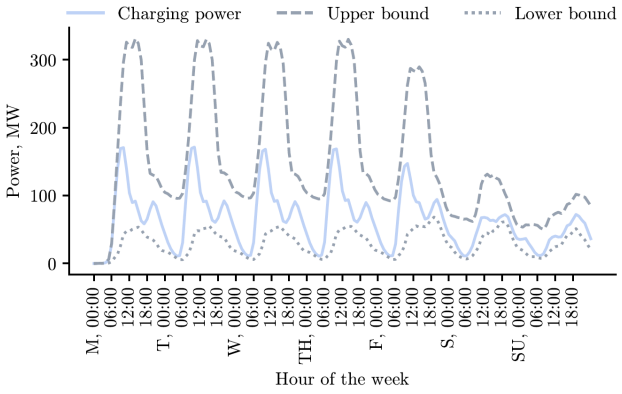
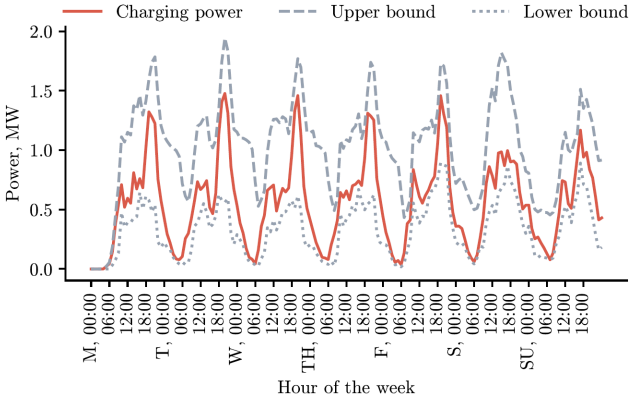
Urbanization level and geo-location shape charging and flexibility

Night-time vs day-time charging flexibility:
Stable upward urban flexibility - faster workplace and public charging
Limited rural downward flexibility - home-based, longer charging

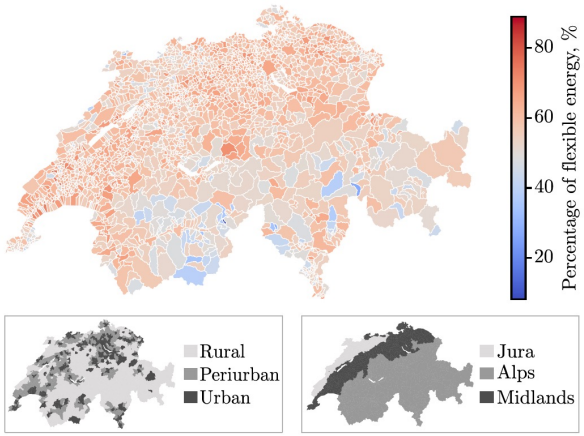


Charging and flexibility bounds in Municipality Zürich (Urban)



Charging and flexibility bounds in Municipality Fischenthal (Rural)

Geo-dependent flexibility:
High-energy trips in Alpine areas reduce charging flexibility



Comparison of % of flexible energy of the total charged energy

Parajeles Herrera, M., & Hug, G. (2025). Modeling Charging Demand and Quantifying Flexibility Bounds for Large-Scale BEV Fleets. *Accepted in 2025 IEEE Kiel PowerTech*, 1–6. 10.48550/arXiv.2504.03633

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Key Takeaways

Understanding demand patterns

1. A significant new load:

National charging peak is ~⅓ of today's Swiss power demand; baseline peak around 18:00 and a secondary morning peak.[1]

2. Charging varies in time and space, and timing follows location:

Home charging clusters at night in cities (especially the Midlands).[1] Home and workplace charging occur in predictable day periods; other locations disperse charging both spatially and temporally.[1]

3. Geography matters:

Urban areas (faster public/work charging) → shorter sessions and steady daytime flexibility.[2] Rural areas (home charging) → evening peaks and lower flexibility.[2] Alpine regions show the least flexibility.[2]

Flexibility

1. Flexibility is large but uneven:

Weekday energy is >60% flexible; weekends drop to ~30%.[2] Flexibility bounds are asymmetric, with greater upward potential.[2]

2. Benefits of a shift to workplace charging:

Shifting to workplace charging moves demand to daytime and concentrates it in ~13% of municipalities.[1] Shifting to workplace charging can support the integration of PV and reduce electricity system costs.[3]

3. Benefits of automated V1G and V2G:

Flexibility can be used at the site level to minimize electricity costs and maximize alignment with renewable generation.[4,5,6]

4. Forecasting EV flexibility:

Forecasting flexibility potential is important for real-time implementation, forecasts can be improved by considering user specific behaviours and local conditions.[7]

[1] Parajeles Herrera & Hug, 2024; [2] Parajeles Herrera & Hug, 2025; [3] Wang et al., 2025; [4] Koirala et al., 2022; [5] Andersen and Powell, 2025; [6] Bellizio et al. 2025; [7] Bellizio et al. 2023

Main Recommendations

To leverage both spatial and temporal flexibility from EVs:

Federal, cantonal, and municipal governments should

- Support the deployment of widespread charging infrastructure, including at workplaces and other daytime parking locations.
- Use regulations to ensure new charging infrastructure is flexibility-ready.

The TSO, DSOs, aggregators and energy suppliers should

- Support/adopt mechanisms for aggregating and signaling EV flexibility *(more on this in later talks!)*

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