Flexibility Potential of Future EV-Fleets in Germany

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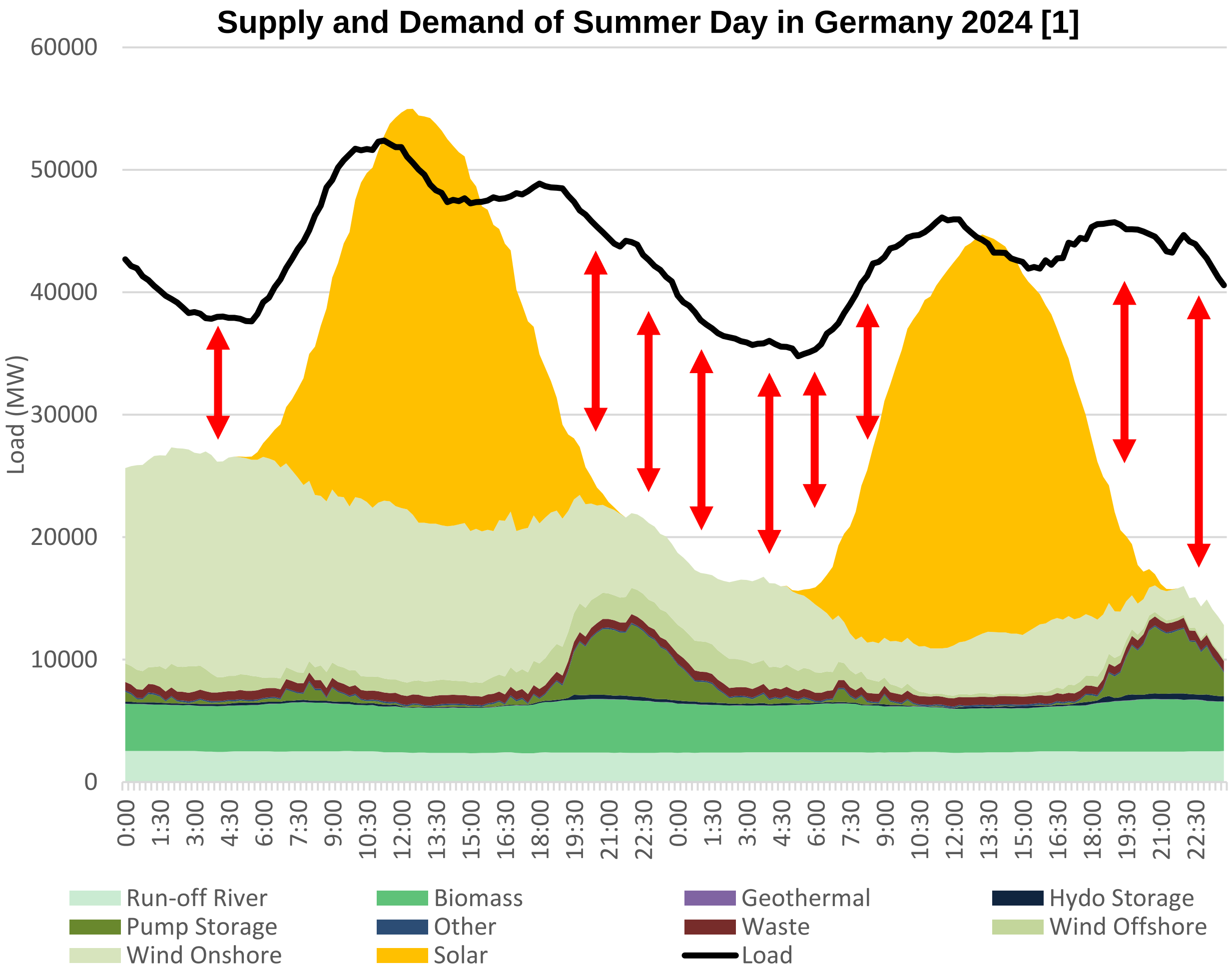
Motivation

Why do we need flexibility?



- **Generation ≠ Demand**: Renewable energy is produced *when the sun shines or the wind blows* – not necessarily when demand is high.
- **Solar peaks at midday – demand peaks in the evening** → mismatch in timing.
- **Weather dependency** makes renewable generation hard to predict and plan.
- **Traditional flexibility** (e.g. gas, coal) is being phased out.
- The system needs **new flexibility sources**: 🔋 storage, 🏠 demand-side management, 🚘 electric vehicles.

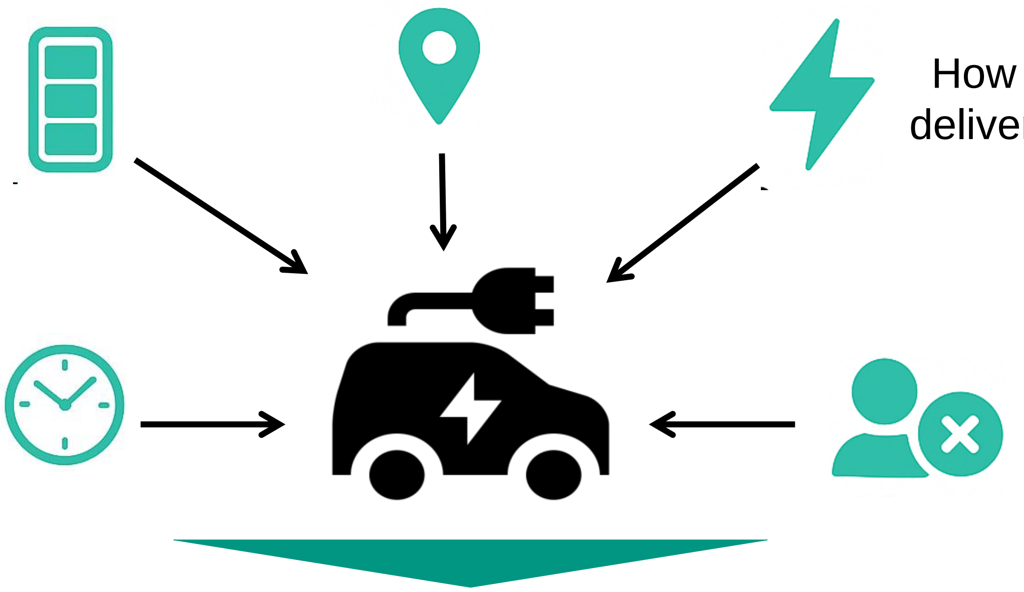
Research Scope

What determines the flexibility of EVs?

Spatial Availability
Where is the EV parked?

Energy Capacity
How much usable energy is stored in the battery?

Power
How much power can an EV deliver (charging/discharging)?



Temporal Availability
When and how long is the EV connected?

Further Constraints
Minimum State-of-Charge requirements, tariffs, …

<u>Objective</u>

Develop a **modeling framework** to quantify the **flexibility potential** of EV fleets, considering **capacity**, **power**, **availability in time and space**, and **user constraints**.

Method

Combining MiD data with BEV-specific parameters to compute flexibility metrics

Mobility profiles (24 hours)
MiD 2017 [2]

- Departure times
- Distances
- Locations

✚ EV data [3]

- Battery size
- Consumption

Consumption of each trip

Charging process simulation
Direct charging

- Modeling of plug-in times
- Concatenate vehicles over one week

SoC modeling for each vehicle

Flexibility estimation
Charge & discharge

- Compute flexibility metrics
- Consider reserved SoC

Vehicle scale

Weighting and extrapolation
Aggregate data

- Weighting and scaling factors

✚ Diffusion modeling

- Bass model
- 2025-2050

Fleet scale

PowerACE integration

Electricity market model

Scenario Assumptions for Flexibility Estimation

To estimate the system-level flexibility, we define the following scenario

Plug-in probabilites

- **Home: 70 %** (tenants) or **90 %** (owners)
- **Work: 50 %**

Charging parameters

- **Charging strategy:**
  - Direct charging (**11 kW**) at locations
  - Fast charging (**150 kW**) during long-distance trips
- **Charging limit** for all charging processes: **80 %**

Flexibility parameters

- **Reserved SoC** for all vehicles: **30 % [4]**
- Maximum **discharging rate** per vehicle: **11 kW**

Bass diffusion

- **Uniform adoption probability**
- **Historic fleet data [5]**
- **2030 BEV prediction** (input value): **7.5 million**
- Diffusion of V2G-compatible **technology not modeled**

Note: Assumptions are changeable parameters in model. Work-in-progress, not based on empirical data

Installed Battery Capacity

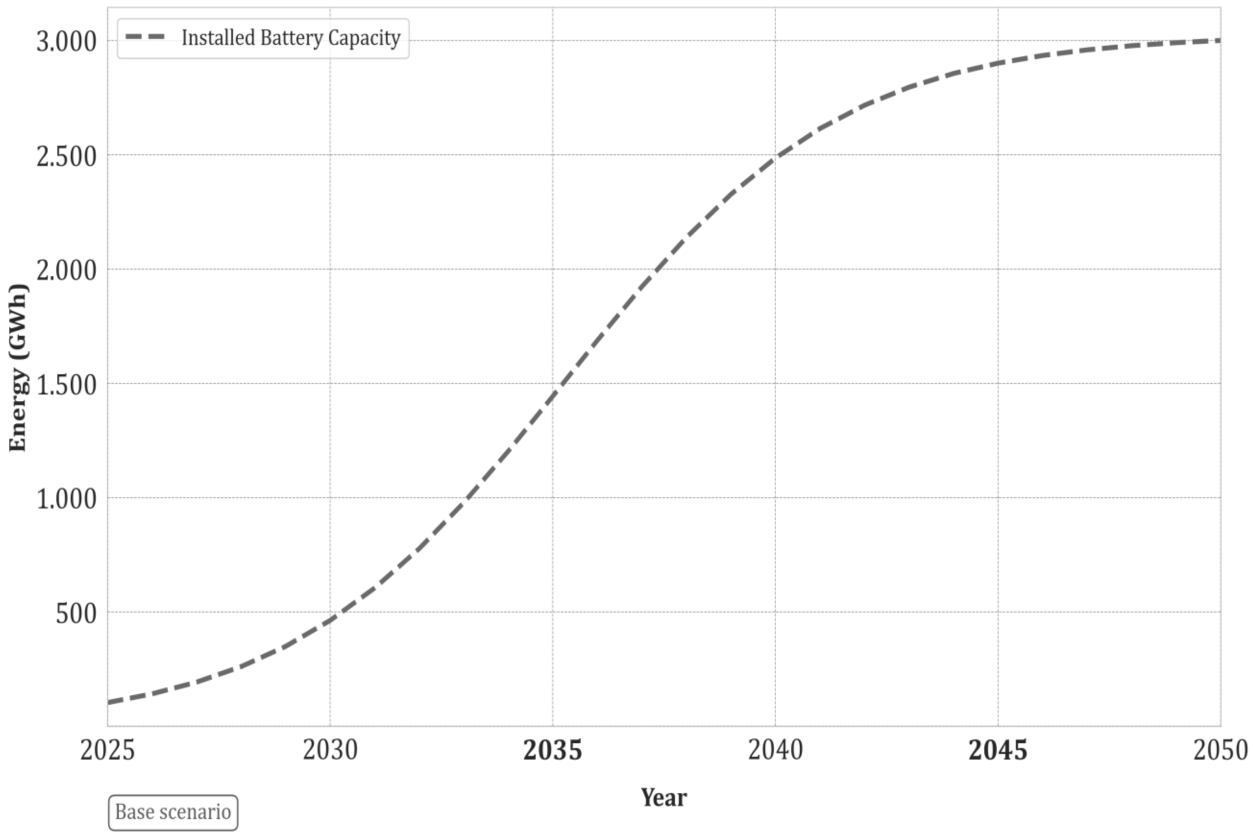
A growing technical storage potential – but not fully accessible

- **Installed battery capacity** in German EV fleets increases to:
  - **500 GWh by 2030**
  - **2500 GWh by 2040**
  - **3000 GWh by 2050**

  (For comparison: Pumped hydro ≈ 24 GWh in 2023 [4])

- Represents the **technical storage potential** of the fleet

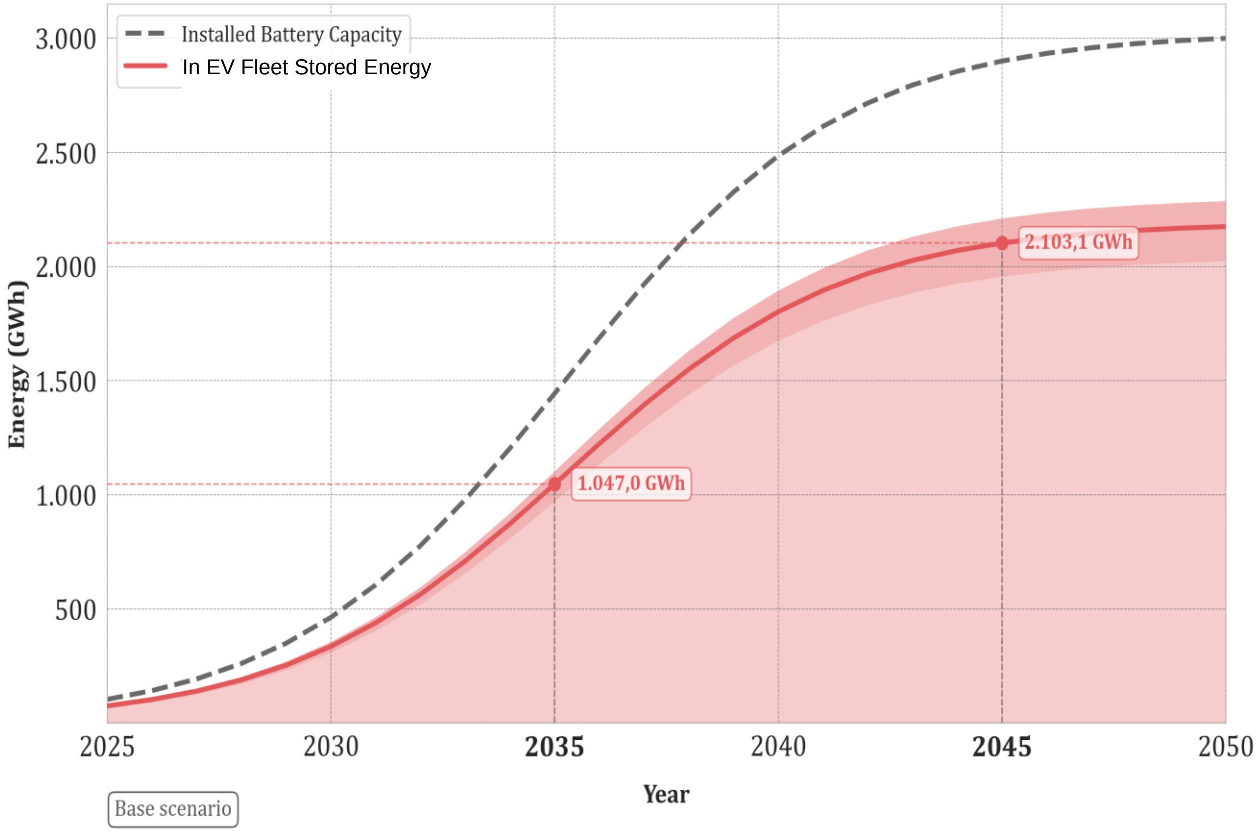
- But: This is a **theoretical upper bound** - not all of it is accessible for flexibility



Usable Capacity

State-of-charge reduces usable storage

- We assume EVs typically charge up to **80% SoC**
  - **Battery aging**
  - **Charging speed**
  - **Preset by OEM**
- As a result, **stored energy (red area)** is well below total capacity
- **Daily fluctuations** (darker red) reflect usage patterns
- **Most stored energy remains unused for driving**
  - ➢ Potential flexibility remains untapped

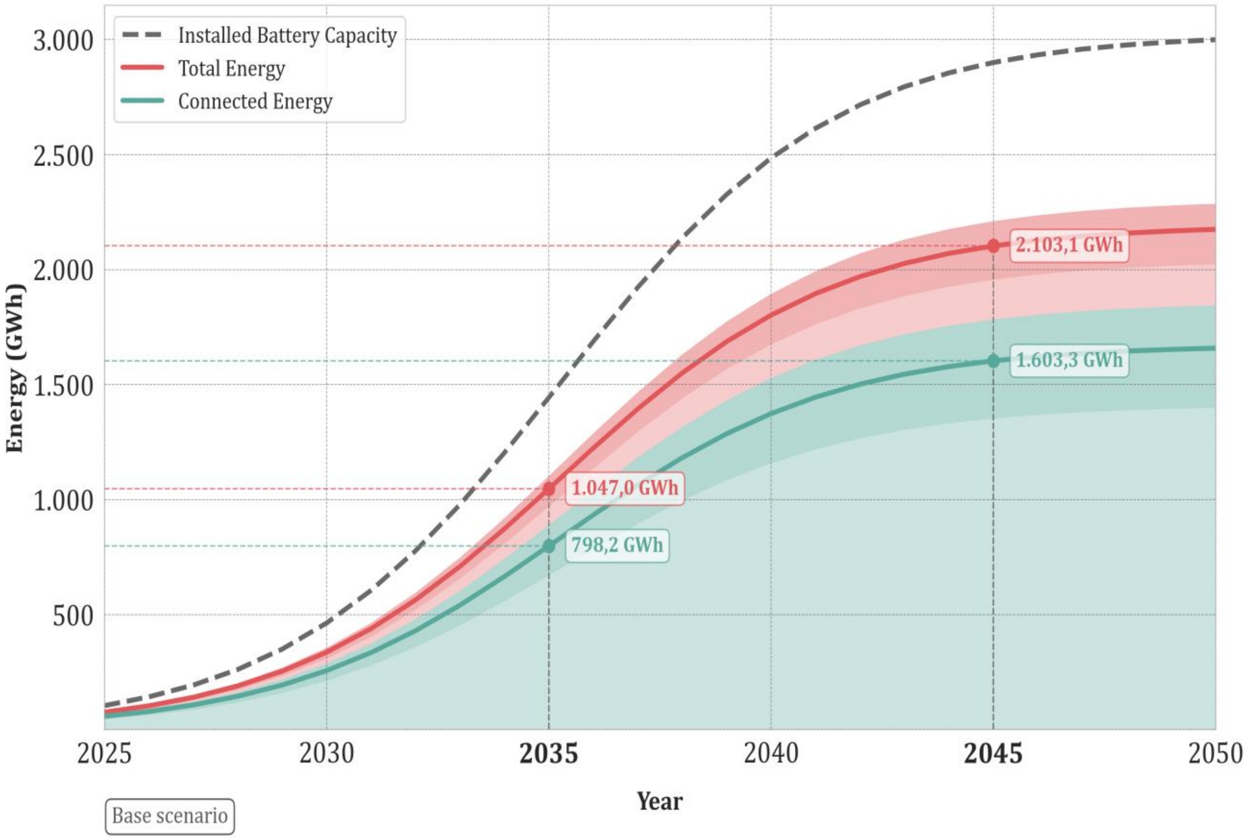


Accessible Capacity

Plug-in behavior determines how much storage can be used

- Even if batteries contain energy, **not all vehicles are plugged in**
- **Green area** shows energy that is both stored and connected
- Plug-in behavior varies **by time of day, weekday, and location**
- This behavioral availability is a key constraint unique to EVs

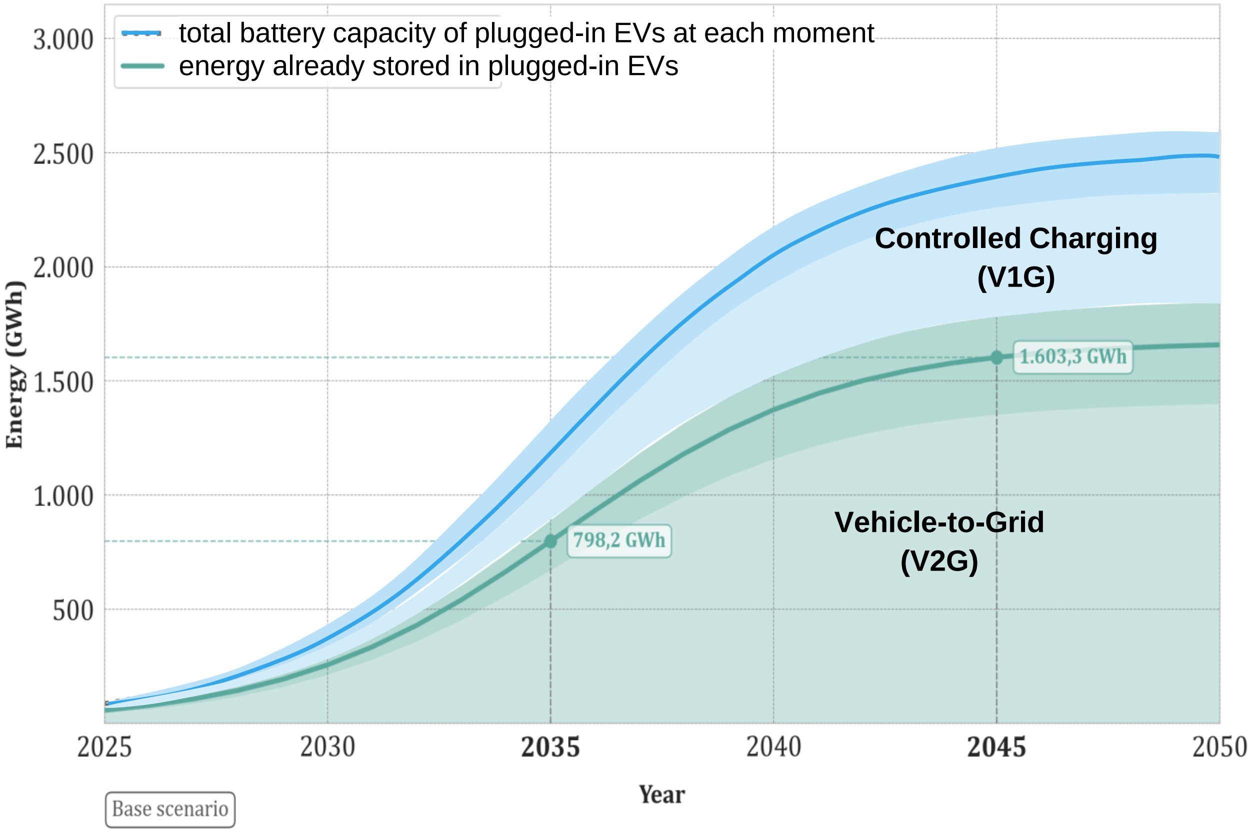
➢ **Incentivizing plug-in behavior** is essential to make EV flexibility accessible



EV Flexibility in Practice

From smart charging to vehicle-to-grid

- **Unidirectional charging potential** (V1G):
  - Unused battery space that can be filled by **adjusting the timing and speed of charging**
- **Bidirectional charging potential** (V2G):
  - Stored energy in plugged-in vehicles that can be **fed back into the grid**
- **V1G is easier to implement** – requires only smart charging infrastructure and user incentives
- **V2G unlocks full flexibility**, but requires bidirectional chargers and enabling regulations



Power Capacity

EVs can provide high power – but not for long

- EVs could deliver **185 GW** of power for **30 minutes in 2035**

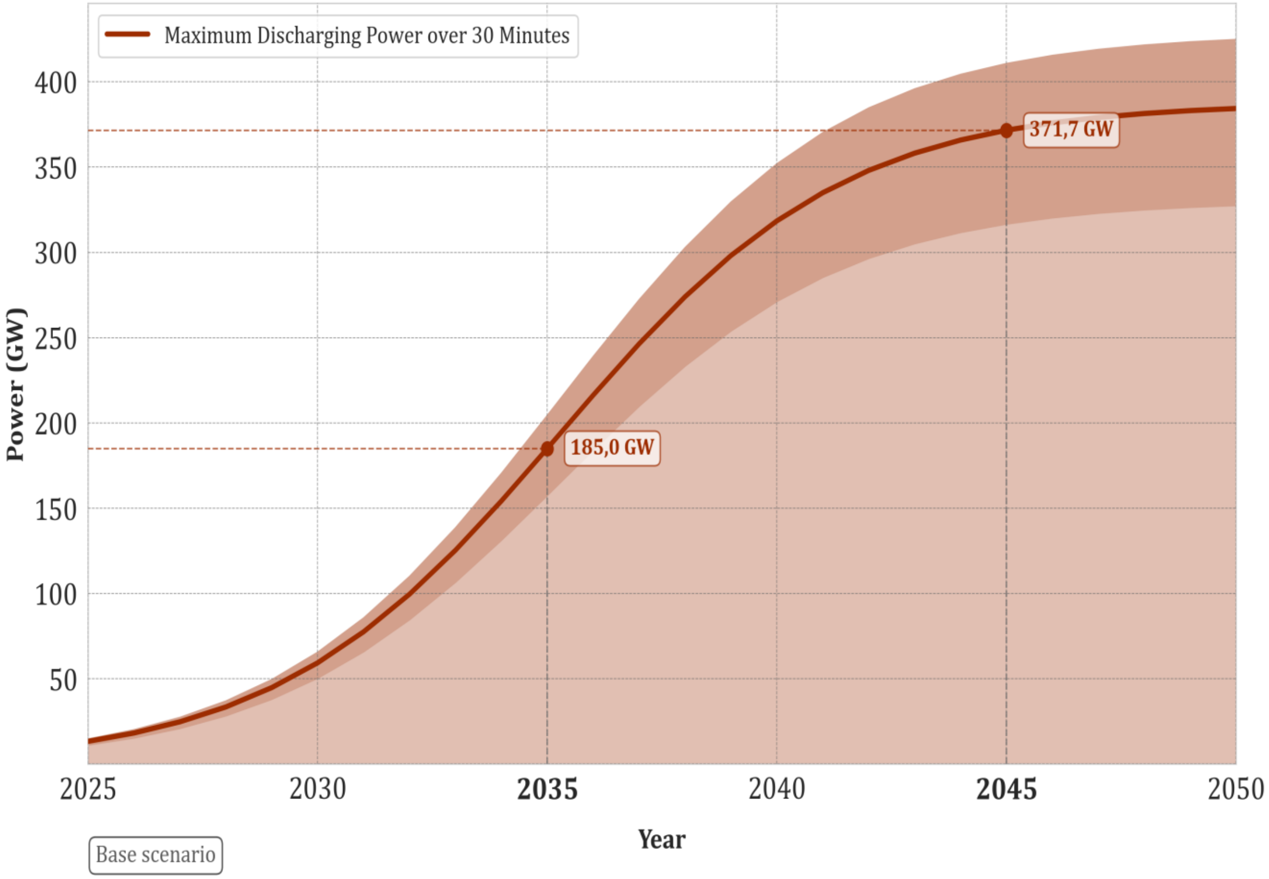
➢ Equals > 200 % of German peak load [3]

Power potential depends on:

- Plug-in rate
- Discharging power
- Sufficient state of charge

- Charging infrastructure enables **high power output**
- Battery capacity limits duration

➢ EVs are well-suited for **short-term storage or grid support**, not long-term energy delivery



Plugged-in Battery Capacity

Home is the hub of EV flexibility

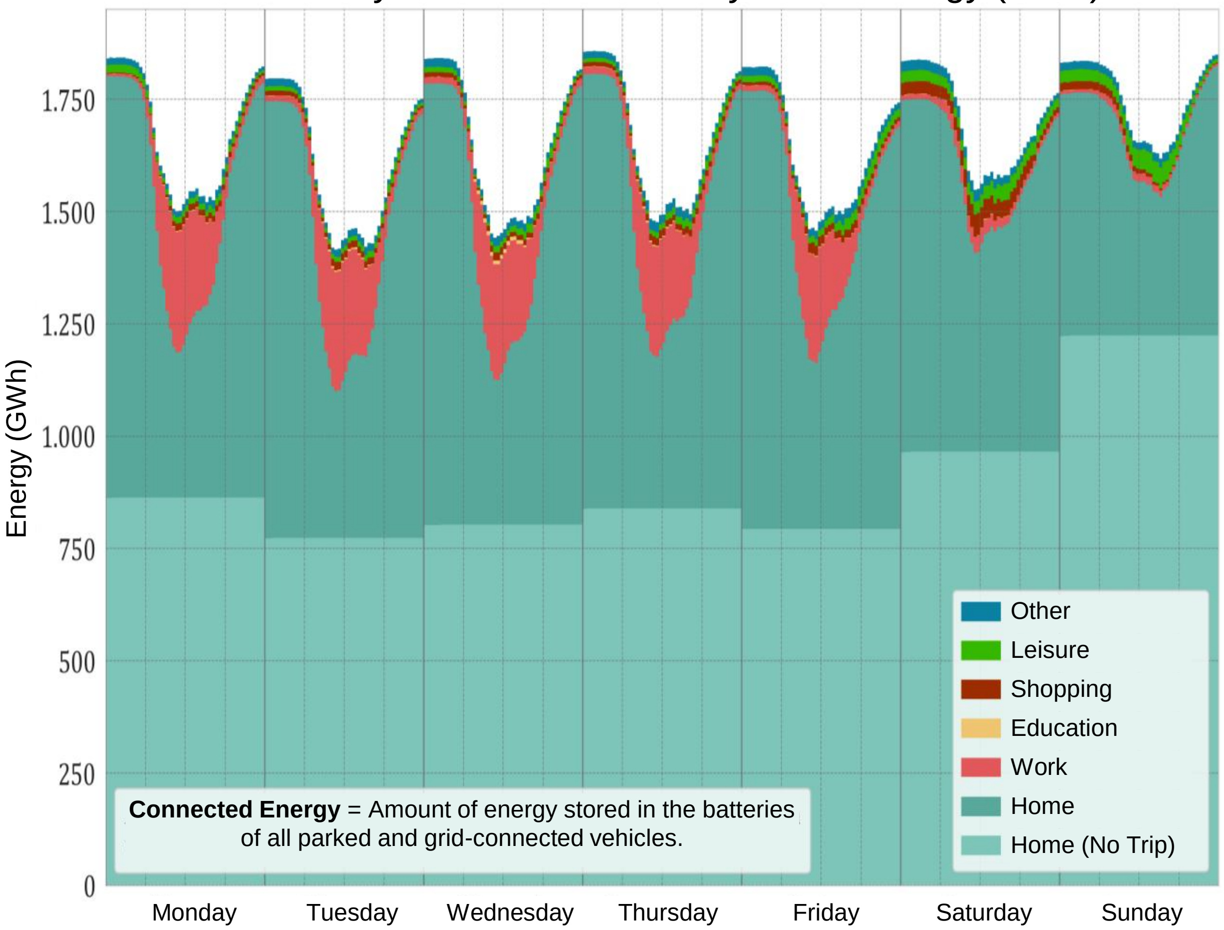
- EV flexibility follows a **clear weekly pattern**: higher availability overnight and on weekends.
- **Most stored energy is located at home** – especially outside working hours.
- Around **half of all EVs are not moved daily**

➢ high stationary potential.

- **Workplace and public locations** contribute less to available flexibility.

➢ Focus should be on **residential charging** to unlock EV potential.

Weekly variation of in battery stored energy (2050)



Conclusion and Outlook

Model enhancement:
- Integrate additional data and behavioral parameters to refine flexibility estimates.
- Providing open-source version of model

Smart charging & price signals:
State-of-charge depends on charging strategy and electricity prices
→ Price-driven charging could shift battery content and flexibility timing
→ Future work: Coupling with a market model for analysis of electricity market interactions

Grid-aware flexibility:
EVs are connected to capacity-limited low-voltage grids, but widely distributed.
→ Smart control necessary that enables flexibility without overloading the grid
→ Future work: Highly spatially resolved EV diffusion, to know where peaks occur

EVs as short-term storage:
High rollout anyway → tapping flexibility avoids costly parallel investments in stationary storage

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