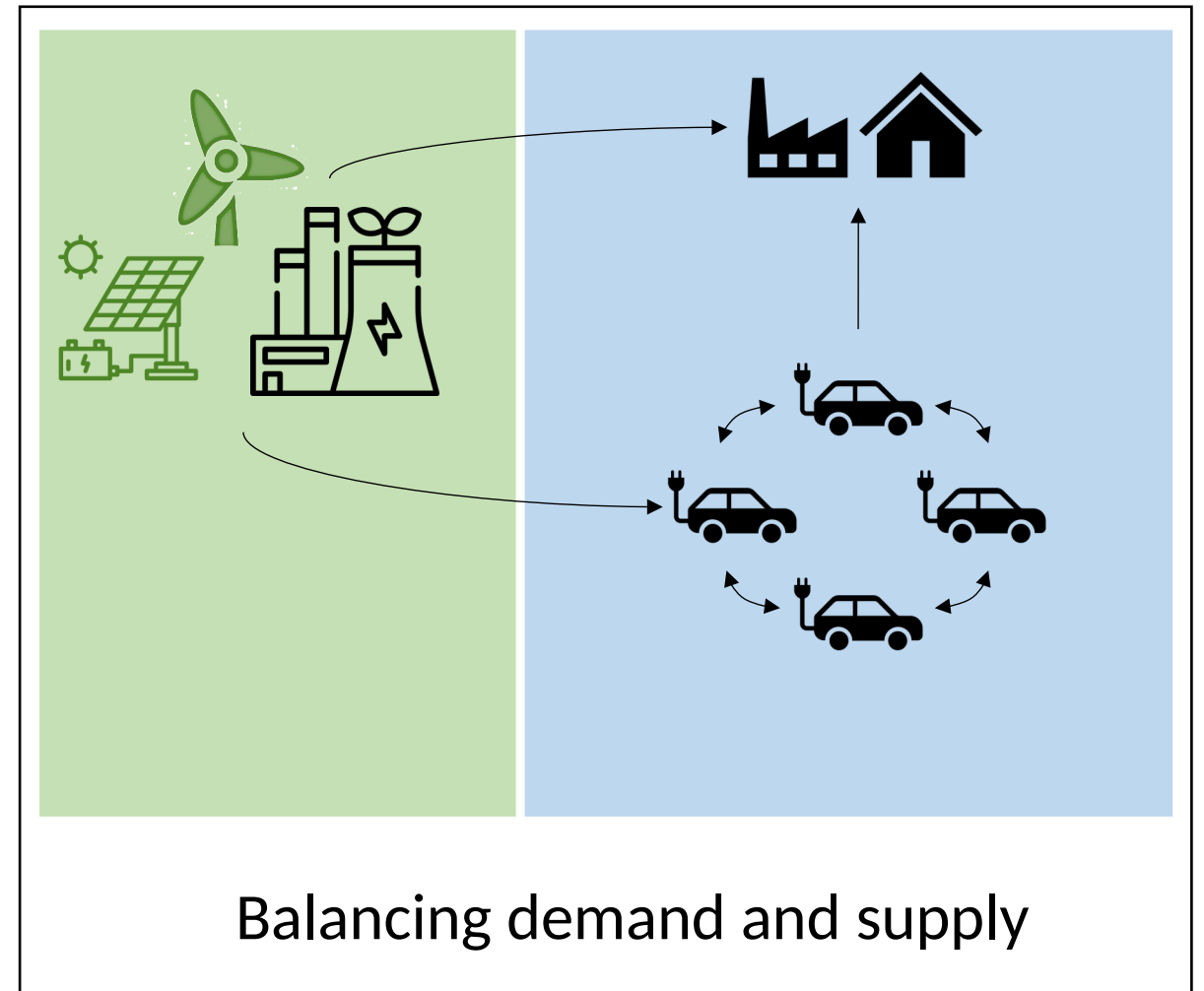


# Volatility and flexibility of electric vehicles

- integrating aggregated fleet profiles into energy system models



# Why do we need flexibility?

What is flexibility?

- No general definition - "potential to postpone and pull energy consumption forward or storing and discharging energy when required"
- EV-specific flexibility potentials: charging behavior<sup>1</sup> as idle times are above 90%<sup>2</sup>
  - Uncontrolled
  - Smart: Load-shifting
  - Bidirectional: Storage

Aim: Model the aggregated flexibility potential of a representative EV fleet

# How do we measure flexibility

What is the value of flexibility?

- $\Delta$ system costs, in comparison to an energy system without the flexibility [€/a]
- $\Delta$ electricity price [€/kWh]

What is the unit of flexibility?

- Avoided uncontrolled charging [kWh<sub>uncontrolled</sub>]

Which data is required for modeling?

- Charging data

# Charging data is essential for modeling EV's flexibility potential

Empirical data is:

- Scarce
- Potentially not representative for current or future behavior<sup>3</sup>

Alternative: driving-data-driven simulation of charging profiles

- Consumption
- Power availability (grid availability & connection)
- Strategy (e.g., SoC-constraints)



Solution space for potential charging profiles

# Different approaches: an overview

	Description	Modeling scope	Some differences	Some limitations
<b>emobpy</b> <sup>4</sup>		Very detailed <ul style="list-style-type: none"> <li>- Trip &amp; driver type</li> <li>- Abstract locations</li> <li>- Heat insulation</li> <li>- Slope of</li> </ul> Implicit SoC constraints	Sampling of individual EVs	It only uses distances but has no real spatial resolution
<b>RAMP – mobility</b> <sup>5</sup>	EV electricity load generator: mobility statistics □ charging time series	European mobility statistics Explicit SoC rules for sampling	Sampling with assumptions different to emobpy	Mobility time series are simulated irrespective of the charging strategy but negative SoCs are avoided
<b>VencoPy</b> <sup>6</sup>		Explicit SoC constraints	Aggregated and normalized empirical fleet profiles	Ignores vehicle sizes because travel data is not allocated to specific vehicles

<sup>4</sup>Gaete Morales et al. (2020), <sup>5</sup> Lombardi et al. (2020), <sup>6</sup>Wulf et al. (2021)

# Open issues considering the generation of charging profiles

## Mathematical aspect:

- Aggregation of individual charging profiles  $\square$  overstimating flexibility potentials
- Convergence problem, when using representative days

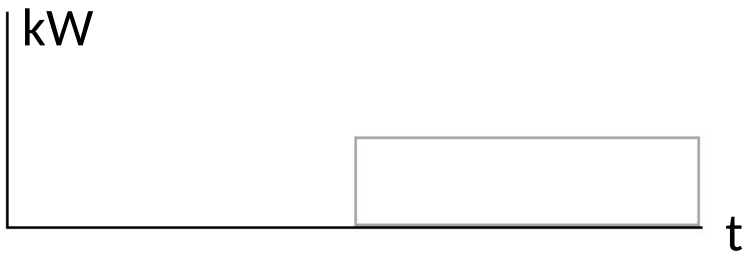
## Behavioral aspects / system dimension:

- Account for human's decision to actually plug-in the vehicle
  - Is modeling the plug-in probability as a function of the SoC too simple?
- Account for human's preferences (SoC-constraints)
- Modeling regulatory framework (especially for V2G)

## Technical aspects

- Battery degradation
- Seasonal effects on drain profiles
- Specifics of regional charging infrastructure, that affect the probabilities for grid connection

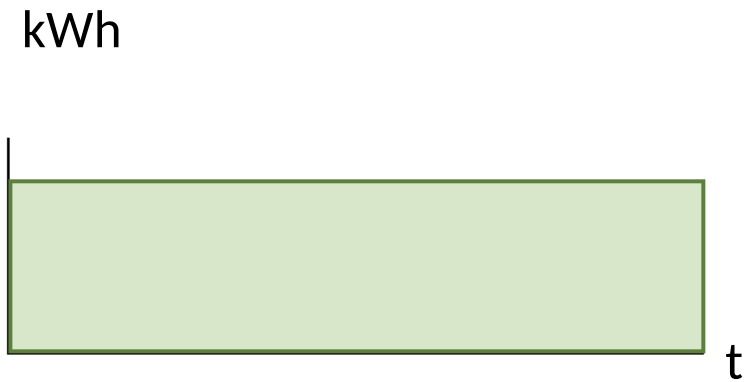
# Overestimating flexibility - the aggregation problem



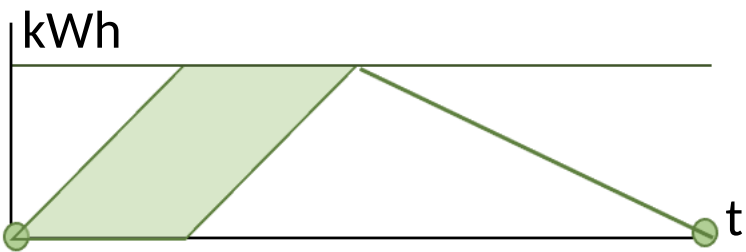
Consumption



Power constraint

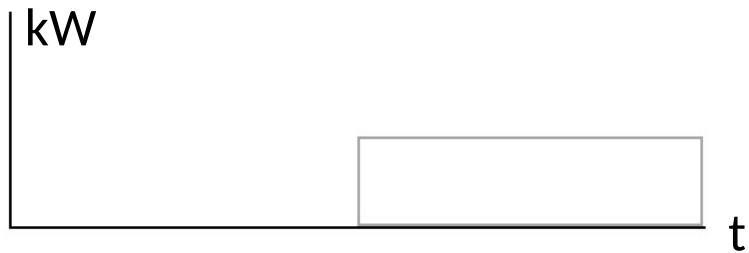


Energy constraint

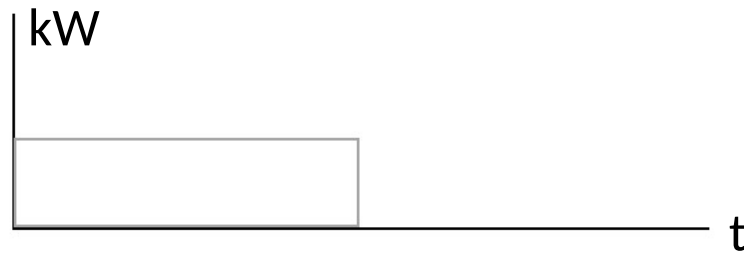


Battery level solution space [kWh]





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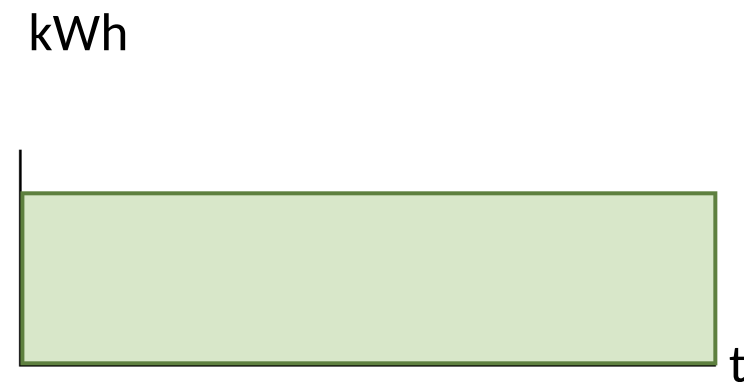
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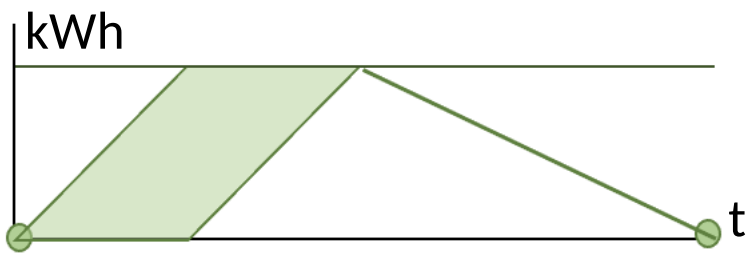
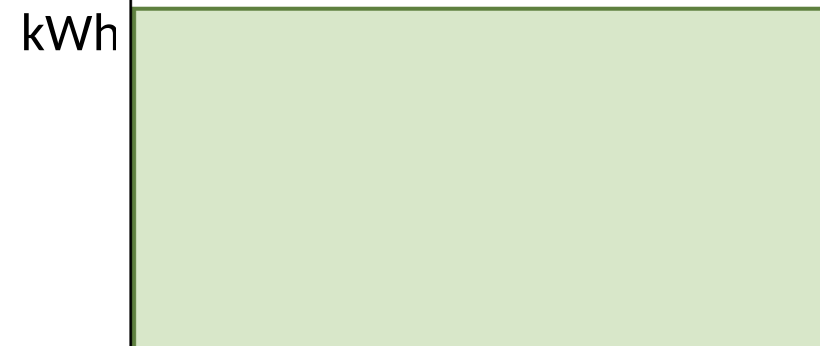
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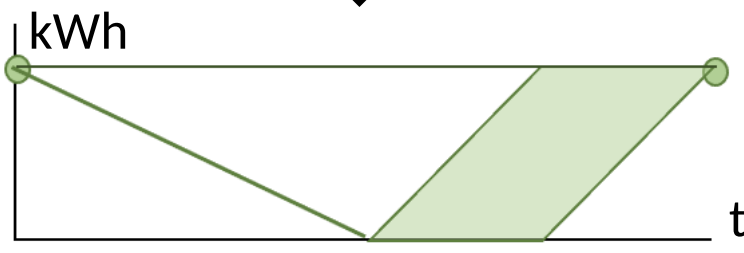
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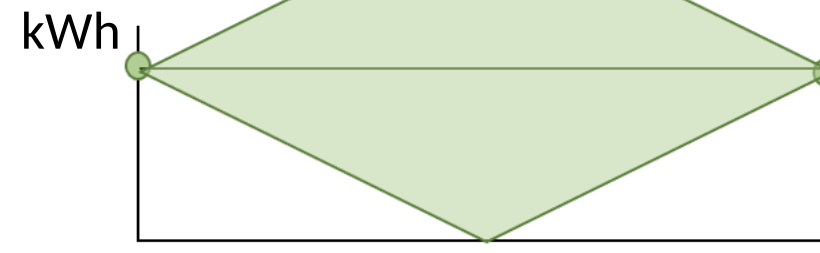
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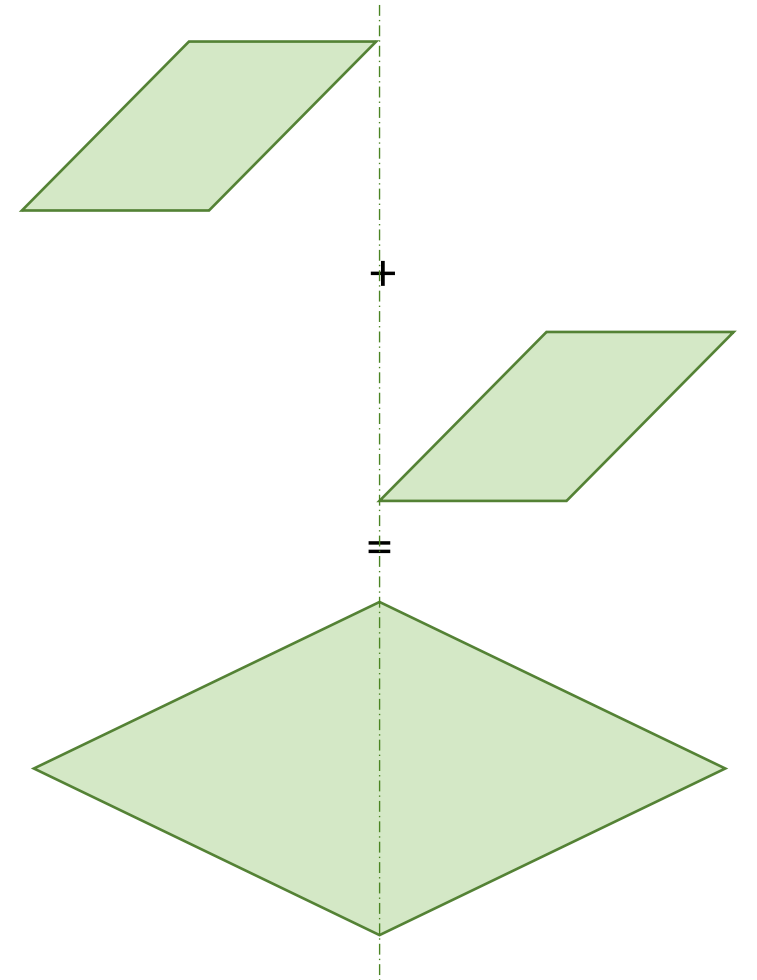
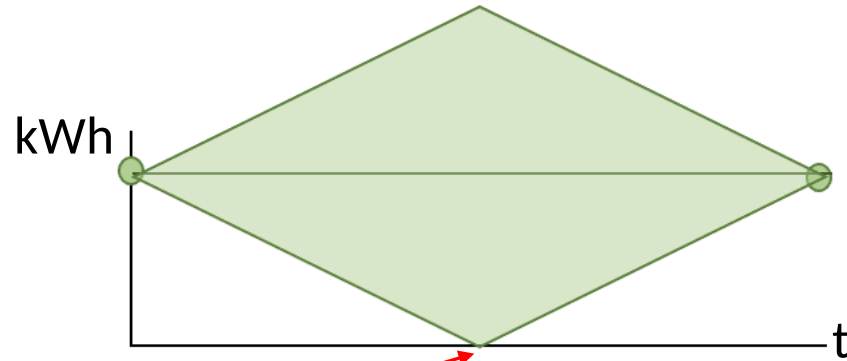
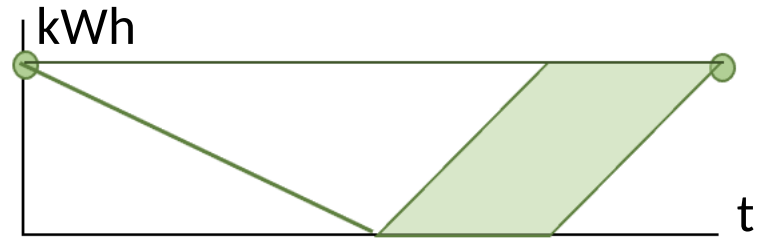
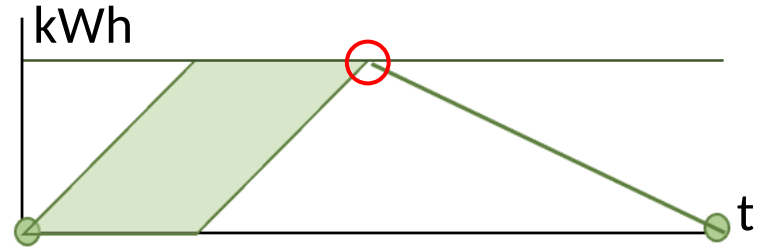


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Charging-while-driving possibility  $\square$  the battery-level does not allow for the consumption of car1 (red-circle).  
Violated constraint:

$$\text{level}(t_{\text{consumption\_start}}) \geq P_{\text{consumtion}} * (t_{\text{consumntion\_end}} - t_{\text{consumntion\_start}})$$

**Overestimation of flexibility**

# How do I use emobpy?

i) mobility\_ts

[generic location, distance to location](t)

ii) electricity consumption for driving

[kWh](t)

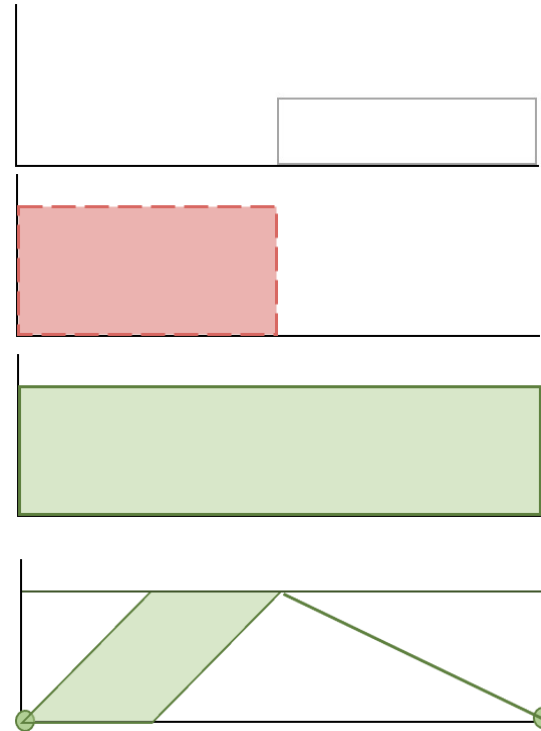
iii) power availability at location

[probability for kW-rating at location]

iv) SoC constraints / battery size of simulated evs

□ Deriving at individual charging solution spaces

□ Develop aggregation method



# Solutions and final thoughts

- Potential in agent-based modeling<sup>7</sup>
- Mathematically exact Minkowski sums<sup>6</sup>
  - Exponentially increasing calculations times
- How big does a fleet has to be?
  - Gaete Morales (2021)<sup>4</sup>: 200
  - Kern (2020) on V2G<sup>8</sup>: 50 profiles for commuters (consumption patterns are more regular), 75 for non-commuters
  - Expectation: saturation characteristics with increasing N

# Discussion

- How significant is the aggregation problem in reality?
- How much runtime does it actually take to simulate EVs individually?
- How big should a representative fleet be?

