Karlsruher Institut für Technologie

Institut für Industriebetriebslehre und Industrielle Produktion

Aggregating load shifting potentials of electric vehicles for energy system models

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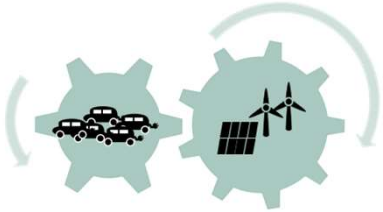
Agenda

- Introduction & motivation
- Methods for modelling EVs
  - Single charging events
  - Time series for single EVs
  - Approximation of EV fleets
  - Exact consideration of EV fleets by aggregating polytopes
- Summary

Electric vehicles (EVs) in energy system models

- Use EVs' flexibility for renewables' integration



But: **EVs are not stationary storages.**

They differ in:

- Mobility behaviour and charging demand
- Charging power and plug-in times
- User requirements for battery state-of-charge (SoC) before next trip

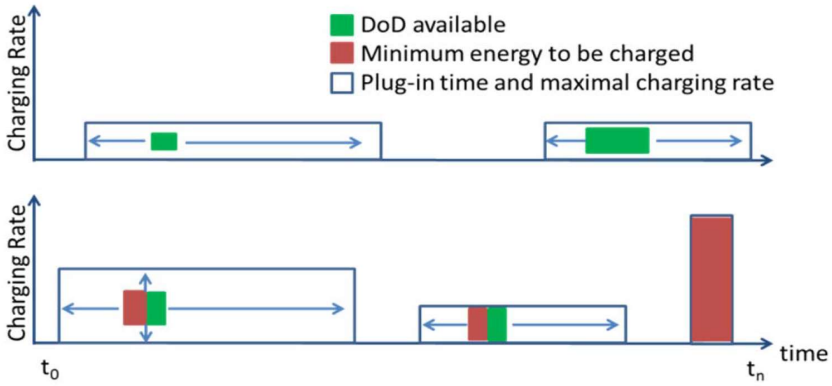


Figure 1. Outline of the challenging aggregation of EVs' load flexibilities with unidirectional charging. (Own illustration)

Research Questions:

- How to consider flexibility of thousands of EVs in energy system models?
- Which methodologies are used for aggregating EVs‘ load shifting potentials?

Single charging events

Application field of this approach

- Used for small, decentralized systems

For implementation, modelers need

- Charging data
- SoC before and after charging event
- Efficiencies for battery and electronics
- Charging power curves

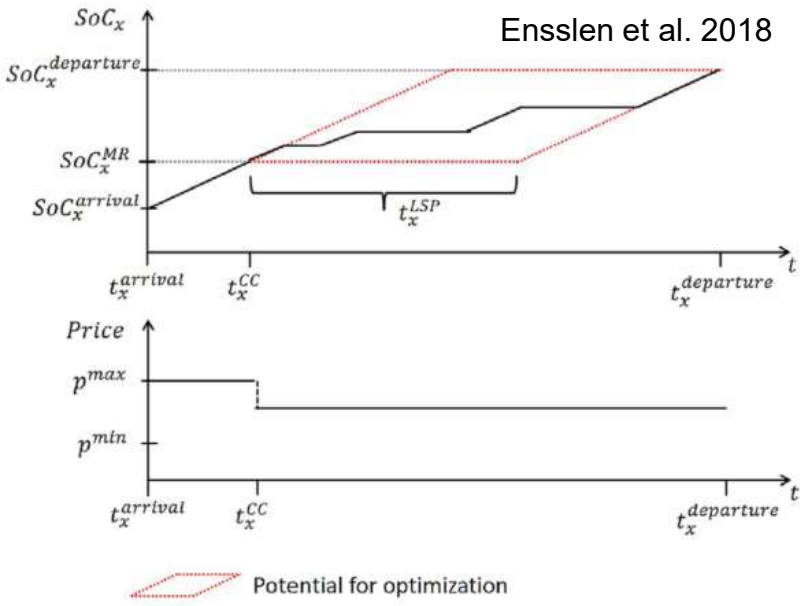


Figure 2. Load shifting potential of a single charging process. [26]

Advantage:

- Simple mathematical formulation

Challenge:

- Possibly non-linearities due to technical constraints which require simplification
- Computation time too long for large system

Literature examples: Jochem et al. 2015, Seddig et al. 2019, Hanh et al. 2013, Wang et al. 2020, Ensslen et al. 2018

Time series for single EVs

Application field of this approach

- Regionally limited systems: e.g. households, communities, micro-grids, optimization models

For implementation, modelers need time series of

- Individual driving and parking patterns
- Extreme scenarios for SoC
- Connection to a charging point and available power

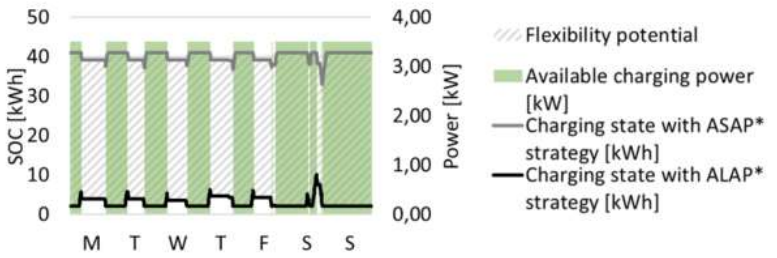


Figure 3. Flexibility of one EV over the course of a week, charging only at home, 3.5 kW, ASAP: as soon as possible, ALAP: as late as possible. (Own illustration)

Advantage:

- Exactly formulation of each EV's load shifting potential
- Resulting time series can be used as input for optimizing energy system models

Challenge:

- More effort on generating the time series input data
- Complexity increases with numbers of EVs and time horizon

Literature examples: Kaschub 2017, Fachrizal et al. 2020, Cai et al. 2018, Wu et al. 2018, Heinz 2018

Approximation of EV fleets

Application field of this approach

- Optimizing energy system model on central level
- Aggregation on spatial basis of EVs to fleets

For implementation, modelers use “one battery” per system or regional subsystem

- Min. and max. SoC of the fleet
- Total discharging energy due to driving
- Total available charging power

Advantage:

- Low complexity

Challenge:

- Depending on aggregation approach flexibility might be overestimated

Literature examples: Babrowski et al. 2014, Heinrichs 2013, Wulff et al. 2020, Weinand et al. 2020

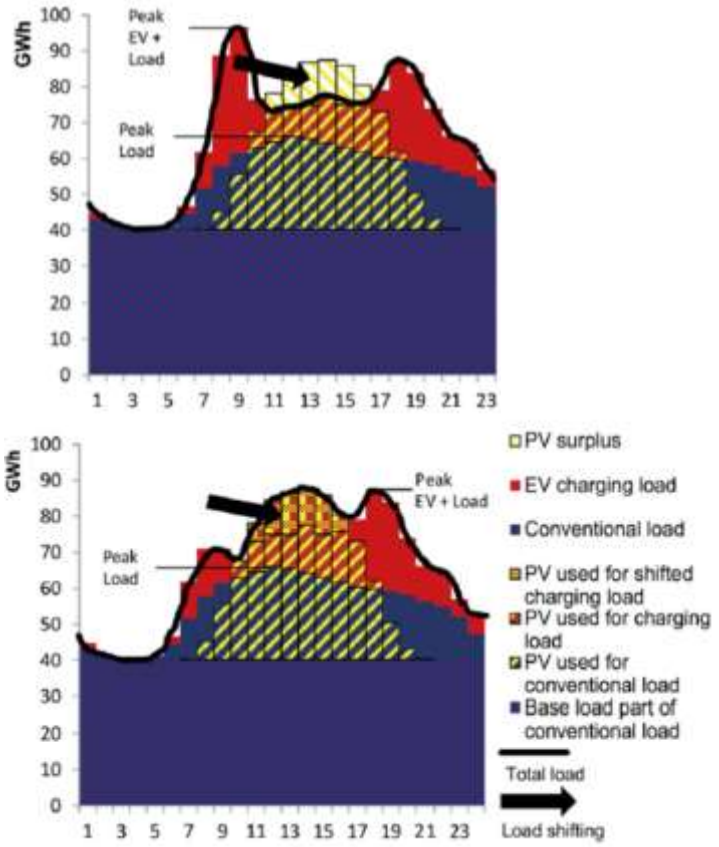


Figure 4. EV fleet’s load shifting (right) for solar integration in Germany, results of a European energy system model. [2]

Exact consideration of EV fleets by aggregating polytopes (1/2)

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1. Model flexibility of one EV:

Construct system of (in)equations (=solution set = polytope) for charging and discharging behavior of an EV over timeframe T:

$$\begin{bmatrix} I \\ -I \\ L \\ -L \end{bmatrix} \cdot [x] \leq \begin{bmatrix} P^{max}(t) \\ -P^{min}(t) \\ SoC^{max}(t) - SoC(0) \\ -\left(SoC^{min}(t) - SoC(0)\right) \end{bmatrix}$$

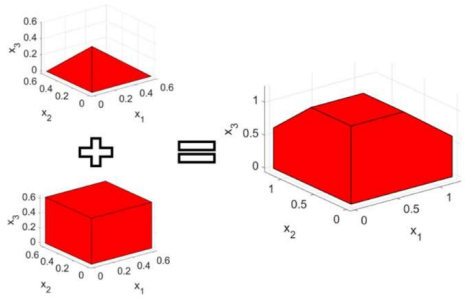
upper bound of the potential energy flow

lower bound of the potential energy flow

upper bound for SoC

lower bound for SoC

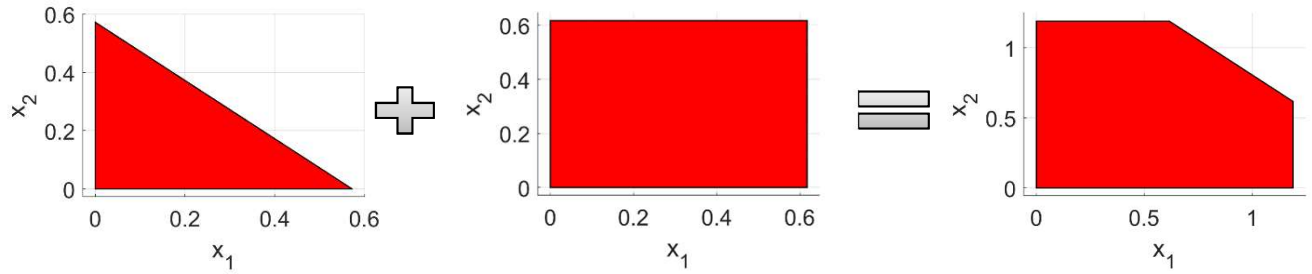
I: identity matrix, L: lower triangular matrix.



2. Aggregate the load shifting potential (LSP) of a fleet:

Minkowski sum = sum of individual polytopes

Minkowski sum for 2 EVs and 2 time slots



x_1: Energy flow to/from battery in time t=1

x_2: Energy flow to/from battery in time t=2

Literature example: Barot 2017

Exact consideration of EV fleets by aggregating polytopes (2/2)

Minkowski approach – challenge:

- Computing the exact Minkowski sum is an NP-hard problem (Tiwary 2008)
- Exponential increase in computation time with polytope dimension (t)

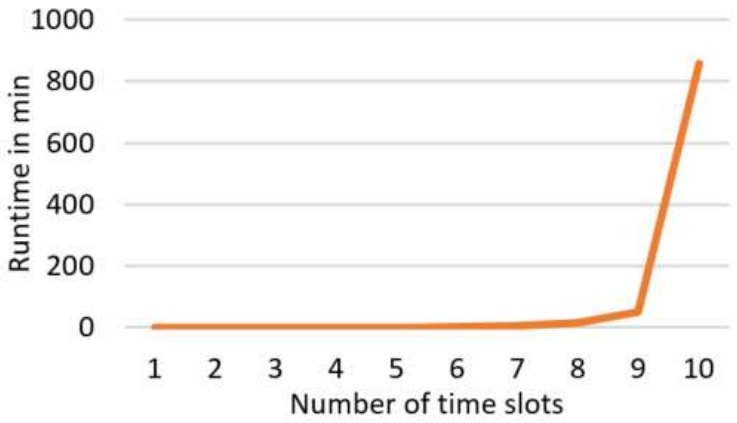
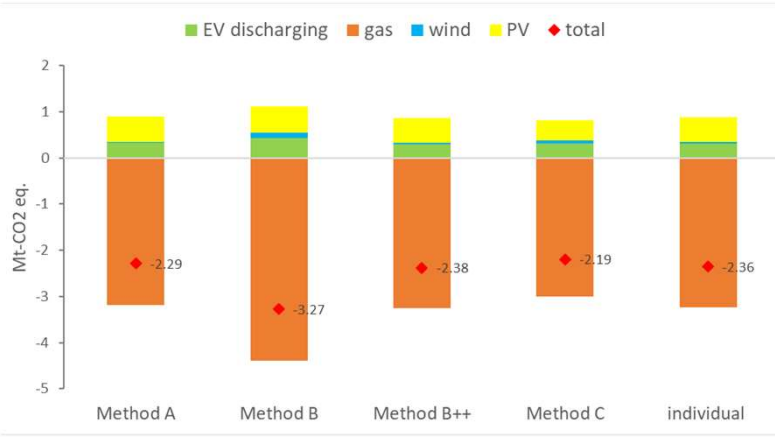


Figure 7. Computational time for calculating the Minkowski sum. (Own illustration)

- Need for approximation methods (e.g. outer and inner approximation of Minkowski sum by Barot 2017, Mueller 2018)
- However, they are not exact (cf. Wang et al. coming forward)



Summary

Approaches of aggregating EV LSP:

Mathematically exact ⟷ **Approximation**

- For distributed energy systems with low number of time steps, few EVs
- When technical aspects shall be considered

- For energy system models with a wider regional scope, >10 time steps and large EV fleets

Future research

- In future also for large energy system models by new Minkowski approximation methods?
- Imprecisions by simplification?

Please consider our paper: Ried, S.; Dengiz, T.; Soldner, S.; Jochem, P. (2020): Aggregating load shift potentials of electric vehicles for energy system models, European Energy Markets, Stockholm, doi: 10.1109/EEM49802.2020.9221974.

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