Optimization model for simultaneous controlled charging of electric vehicles in distribution grids in rural, suburban and urban areas

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Overview

- Motivation
- Low voltage distribution grids as predictors for future EV demand
- Parameterisation
- Clustering
- Results
- Summary and conclusion

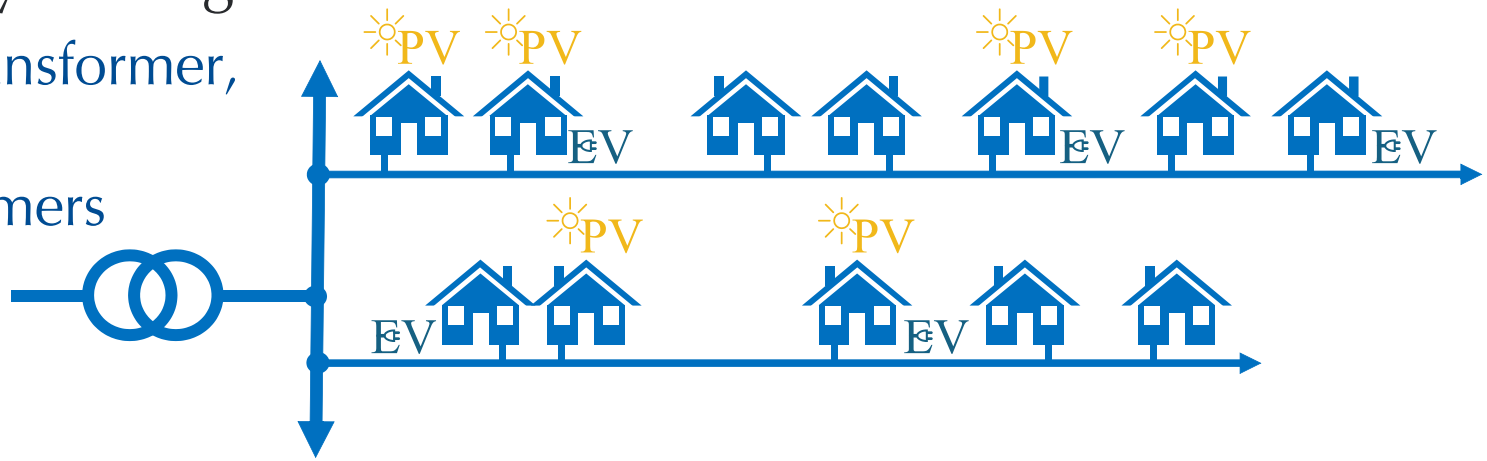
Heterogeneity of low voltage (LV) distribution grids

- Households and other small customers are connected to the LV electricity grid

  Total: more than 1.2 Mio km line length, more than 500.000 mostly radial branches
- Differences related to the settlement type (degree of urbanization):

  E.g., dense urban grids vs. sparse distribution of customers in rural areas;
- Heterogeneous topological layout of grids in a similar area:

  E.g., number of branches per transformer,
  line lengths,
  number and types of customers
  renewable infeed and
  configuration of branches



- No public database available

  Reasons: more than 800 grid operators, critical infrastructure and data privacy concerns…

LV distribution grid as limiting factor for controlled EV charging

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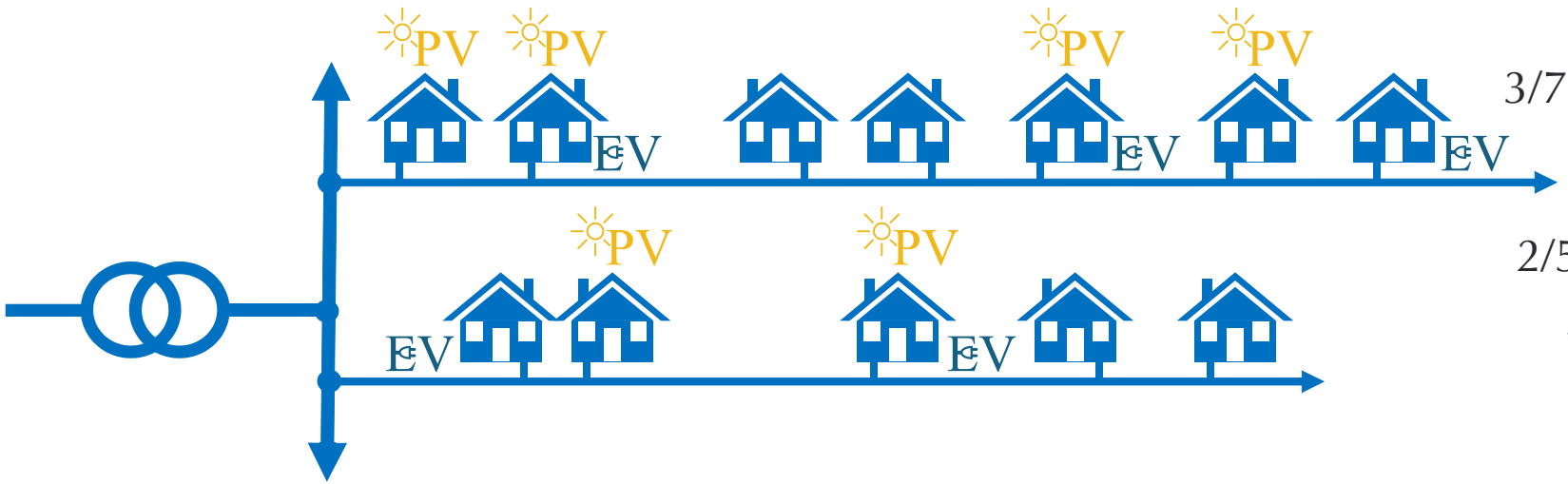
Low voltage distribution grids as predictors for future EV demand

- Germany in 2030: Government goal 15 million EV
- Number of households in Germany (2030): 41.7–42.3 million*)

$p \approx 0.36$ (15/41)



3/7 ≈ 0.43

2/5 ≈ 0.4

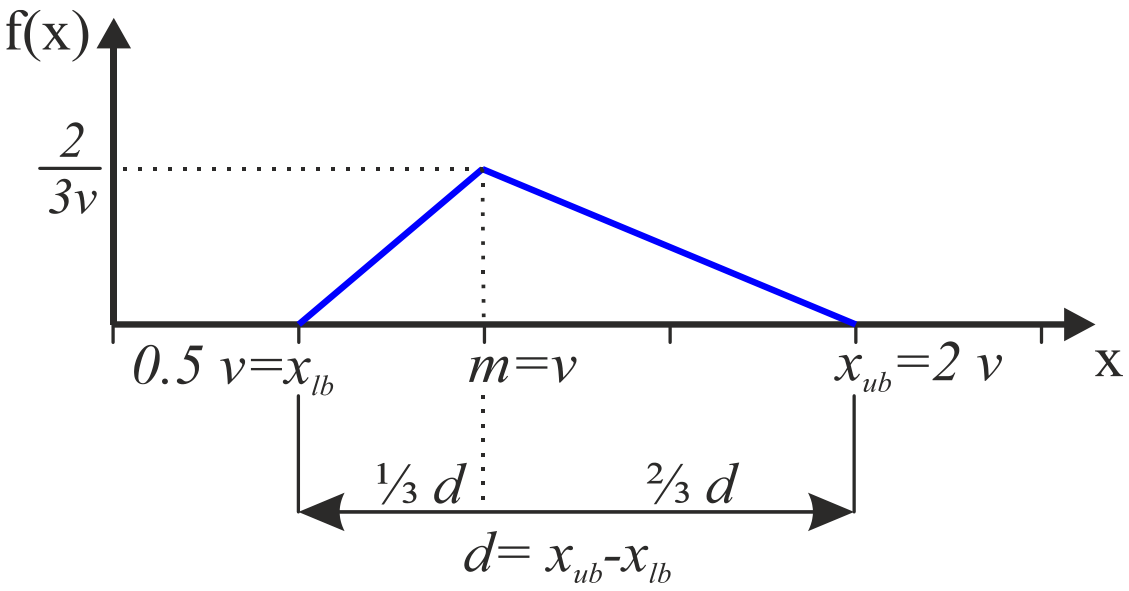
EV ownership: "binomial lottery" for households in grid branch

- Charging possibilities depend on
  - size of the transformer,
  - other electrical loads in branches, PV infeed …

*)Destatis: Table 12421-0100. Vorausberechnete Privathaushalte. https://www-genesis.destatis.de/genesis/ online, checked on 08/16/2024.

Approximation of other distribution grid characteristics: Triangular probability density function

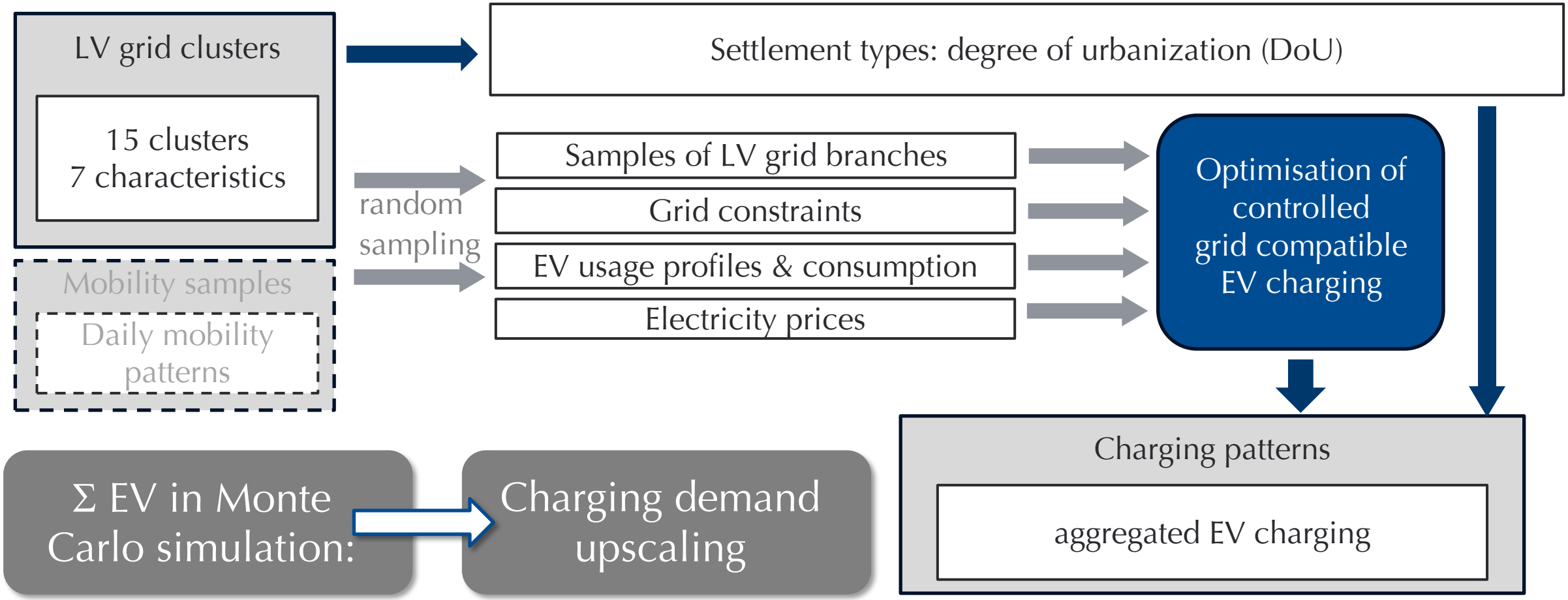
Parameterisation



- Number of house connections to the grid,
- residences per house connection,
- LV transformer power per house connection,
- installed PV power per house connection,
- (Effective) length of the distribution network branch,
- Number of branches.

Simulation approach

Low voltage distribution grids as predictors for future EV demand



Objective: Minimised cost for aggregator

Clustering of LV distribution grids

Clustering

Cluster	Degree of Urbanisation
Scattered settlement mixed-use area	100 %
Low-density residential area A	100 %
Low-density residential area B	100 %
Low-density mixed-use area	50 % / 50 %
Medium-density residential area A	100 %
Medium-density residential area B	100 %
Medium-density mixed-use area	50 % / 50 %
High-density residential area	50 % / 50 %
High-density mixed-use area	50 % / 50 %
Low-density multifamily residential area	50 % / 50 %
Medium-density multifamily residential area A	50 % / 50 %
Medium-density multifamily residential area B	50 % / 50 %
High-density multifamily residential area	100 %
Urban multifamily residential residential area	100 %
High rise area	100 %

Municipality areas:

rural

sub-urban

urban

Cluster and DoU categorisation defined in: Springmann, E.; Weiß, A.; Hecker, M. (2023): Meta-Cluster. Niederspannungsnetze. FfE. München. https://www.ffe.de/wp-content/uploads/ 2023/07/Steckbriefe-Meta-Cluster.pdf. checked on 12/16/2023.

Computed population parameters

- Application of official statistics:
  - Categorization of 10,990 German municipalities into settlement types (DoU),
  - Clustering of communities into data matrix in dependence of size classes and DoU,
  - Number of households for all communities´ size classes in dependence on the number of persons per household (1–5+ persons).

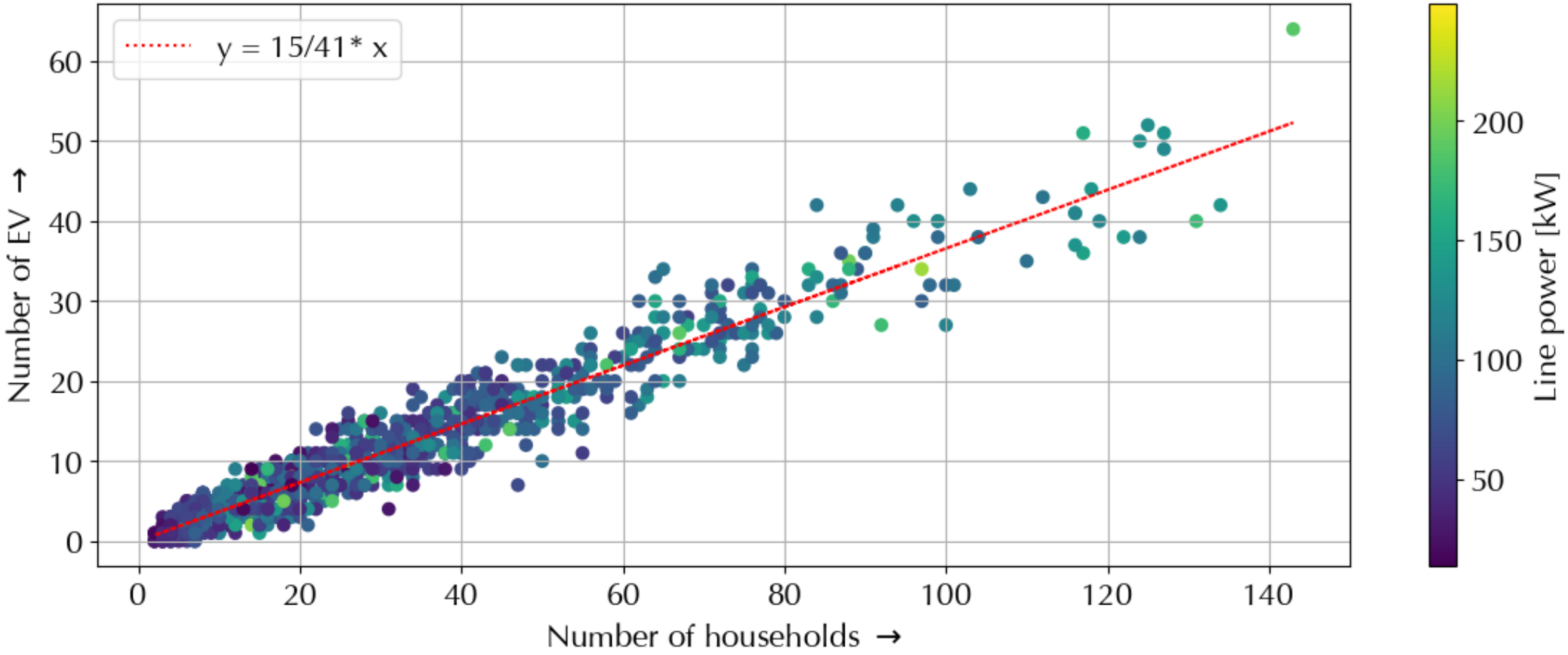
DoU:	rural	sub-urban	urban
Inhabitants GER*)	19.01	34.86	30.50
% of population	22.53%	41.32%	36.15%
Persons per household	2.16	2.12	1.88
Total household*)	8.81	16.48	16.20
% of total households	21.23%	39.72%	39.05%

*) in millions

> Bundesinstitut für Bau-, Stadt- und Raumforschung: Raumgliederungen Referenztabellen Deutschland. Gebietsstand 31.12.2022. https://www.bbsr.bund.de/BBSR/DE/forschung/raumbeobachtung/downloads/download-referenzen, checked on 03/07/2024.
> Destatis: Table 12211-9023. Privathaushalte: Deutschland, Jahre (bis 2019), Haushaltsgröße, Gemeindegrößenklassen. https://www-genesis.destatis.de/genesis/online, checked on 03/07/2024.

Exemplary LV grid parameter set for 10^3 runs

Exemplary results



Cumulated charging power for 10 EV

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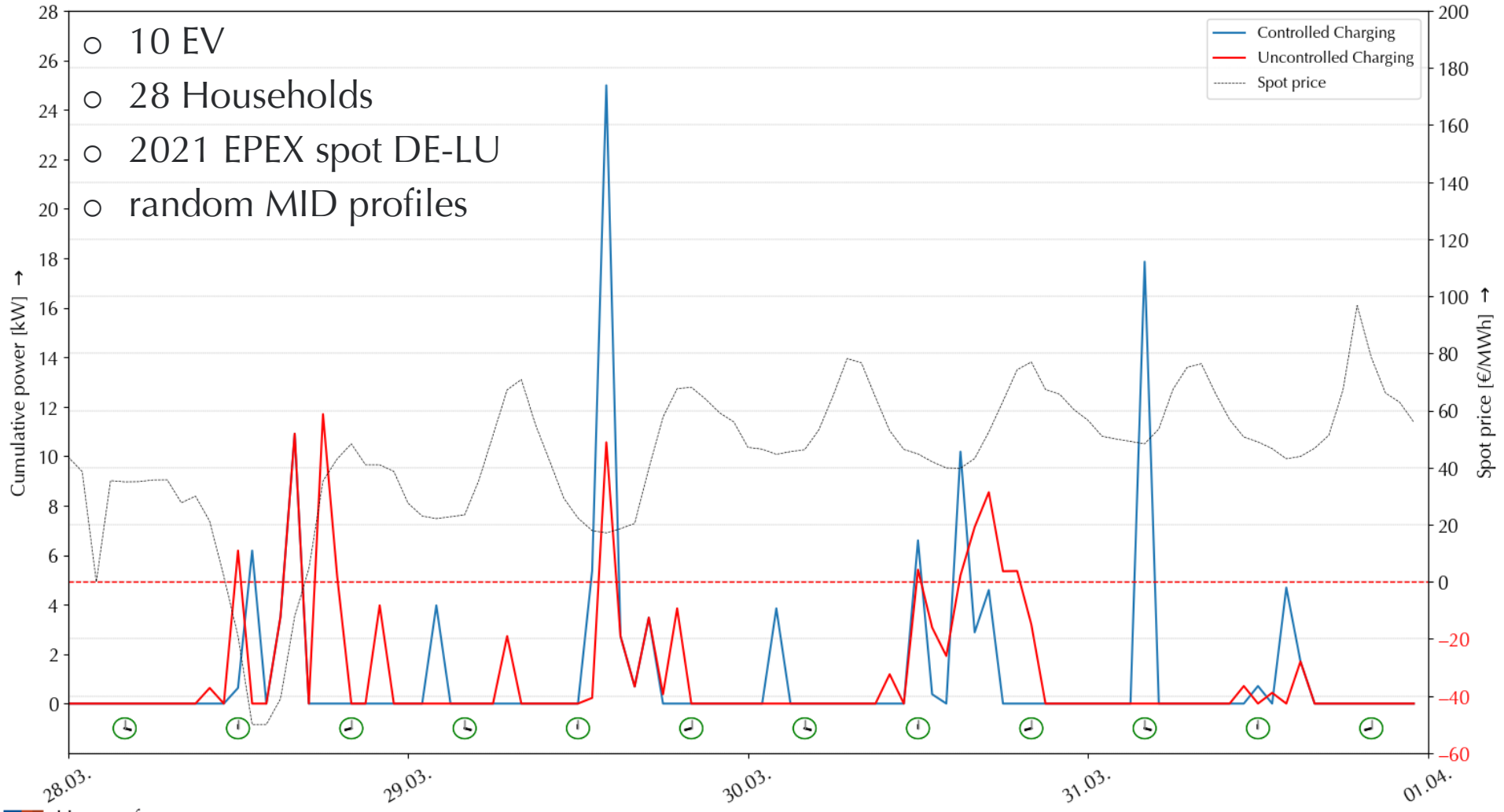
Exemplary results



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Summary and conclusion

- Model Setup: Flexible approach for analysing German low voltage grids using Monte Carlo simulations
- Grid Branches: Modelled through 15 distinct clusters, each with specific parameter values
- Randomisation: Selects clusters/parameters from predefined ranges for adaptability
- Efficiency: simulation of 10^3 branches (hourly resolution, 1 year) in under 45 minutes
- Value: Suitable for large-scale analysis and assessing EV charging flexibility

Thank you very much for your attention!