Evaluating policy instruments for the balancing of renewable energies using electric vehicles:

On the interplay between distribution and transmission grids

Anya Heider

(Together with Stephanie Halbrügge, Alexandra Märtz, & Martin Weibelzahl)

Motivation

Fighting climate change calls for an increasing **integration of renewable energy sources** (RES) into energy systems, worldwide.

Decarbonizing the mobility sector, the **electrification of the mobility sector** – mainly by promoting the use of electric vehicels (EVs) – promises significant emission reductions.

System integration through smart charging

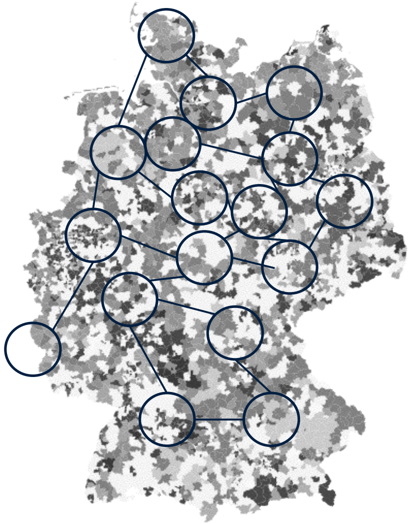
Model Framework

- Connected and directed graph $G = (N, L)$
  with a set of network nodes N
  and a set of transmission lines L

- We assume one transmission network node for each Federal State of Germany
  $N = |16|$
  $= \{BB, BE, BW, BY, HB, HE, HH, MV, NI, NRW, RP, SH, SL, SN, ST, TH\}$

Players at different network nodes

- Set of given conventional generation facilities, demand and RES infeed at each transmission network node
- Prosumage household at each distribution network node
  - Electricity purchase on the market
  - Demand: charging process of EV
  - PV generation



Model Formulation

Objective Function: Single-level cost minimization

$$\sum_{t \epsilon T} \left(\sum_{n \epsilon N} 0.5 \cdot g_{n,t}^2 \cdot C_{n,t}^{GEN} + \left(lol_{n,t}^{PRS} + lol_{n,t}^{TSO} \right) \cdot VOLL + \bar{f}_n^{DSO} \cdot MC^{DSO} \cdot |\tau| \right) \qquad \forall t \in T, n \in \mathrm{N}$$

Constraints

(1) An household's own demand can be satisfied by its supply from PV generation, from EVs that possibly discharge, or from the market; own generation must be consumed, charged, or sold to the market

(2) For each point in time, PV feed-in must be balanced by self-consumption, sales to the market, EV charging, or curtailment

(3) The state of charge (SoC) of electric vehicles is determined by the initial state of charge plus the amount that is charged during the charging process

(4) The SoC can not exceed the vehicle's battery capacity

(5) The SoC at the end of a charging process respects a guaranteed minimum SoC

(6) The charging power provided can not exceed the vehicle's maximum charging speed

(7) The (dis-)charging process takes place within the considered period in time

(8) Each TSO-node‘s demand, loss of load, generation, RES infeed, curtailment, in- and outflow have to be balanced

(9) Generators in the transmission network are constrained by the available generation capacity

(10) Balancing of flows by the TSO in the TSO network (following Kirchhoff's Laws)

(11) Line capacities

Model Calibration

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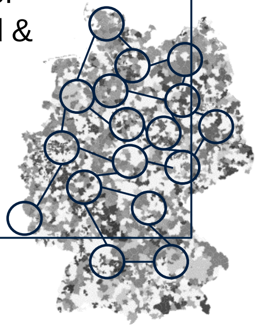
Power System

- **Transmission and generation data** from (Neetzow et al. 2019)
    - Cost function of generation
    - Availabilities of generators
    - Investment costs for DSO links
    - Transmission capacities of TSO lines
- Prediction of **PV and wind infeed** for 2020, 2030 and 2040 from (ForWind & Öko-Institut, 2016 a,b,c)



EV fleets

- **Prediction of EV until 2050** based on (Destatis 2020, KBA 2020, NPM 2020), Assumptions:
    - Degree of motorization stays constant
    - Percentage of EV of all vehicles assumed to follow s-curve
    - Regionalization following current numbers of EV penetration
    - No H2-vehicles for personal use

Case Study

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Basic setup

- Investigations for **exemplary summer and winter day** in the years 2020, 2030 and 2040
- Conventional generation park stays constant

- **Charging groups and charging demand** based on (Nobis and Kuhnimhof 2018, Elia Group 2020) and previous work
  - 65% home-charging, 15% work-charging, 20% other
  - Medium size vehicles
    - Battery capacity: 100 kWh
    - Charging capacity: 11 kW
    - Efficiency: 0.9
- **Only home- and work-charging** considered, Charging periods:
  - Work: 7:00 – 17:00
  - Home: 18:00 – 06:00

Case Study

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Application of three different **charging strategies** in order to consider their impact on total system costs

1 **“network-friendly":** TSO wants to minimize system costs and can use EVs for charging/discharging activities

2 **"full security":** charge as early as possible up to the maximum battery capacity

3 **"constant charging":** charge with limited capacity for the entire time that is available for charging

Case Study

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Application of three different **policies** in order to evaluate their impact on different charging strategies and total system costs

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a **“maximum charging limit":** restrict maximum charging by $\alpha = 0.1$ and $\alpha = 0.2$, such that $x_{c,t}^{charge} \leq \alpha * \overline{p}_c$

b **“loss of load EV":** allow for loss of load of EV fleets

c **“promote work charging":** adapt share of work- and home-charging such that equal amount of both take place

Results – Charging demands

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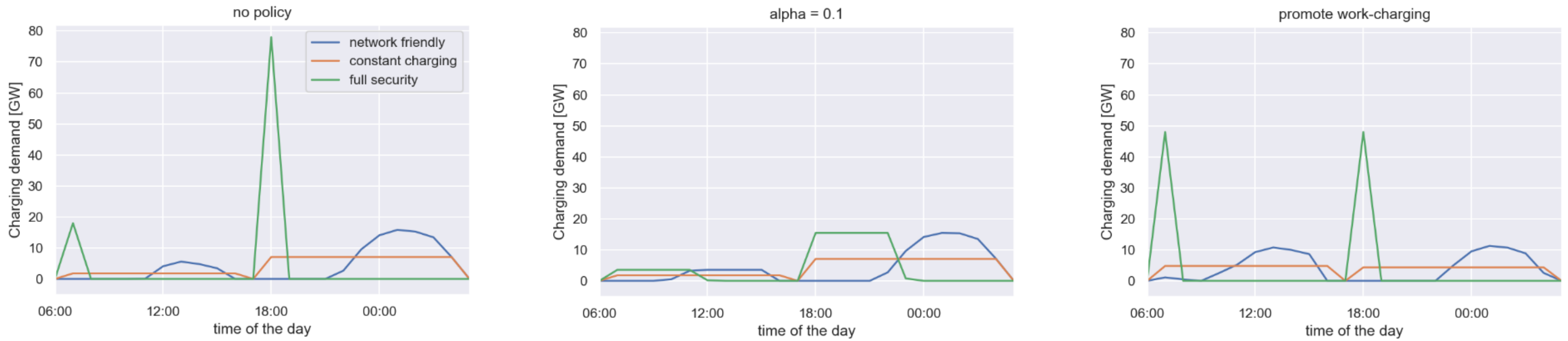
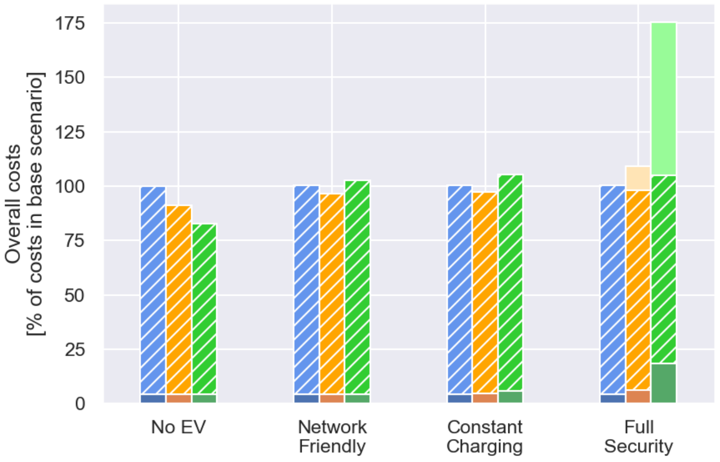


Comparison of the three charging strategies and policies for the year 2030

→ Full security leads to high peak in load
→ Constant charging and network friendly show flatter consumption curve
→ Policies can limit the peak introduced by full security charging

Results – Charging Strategies



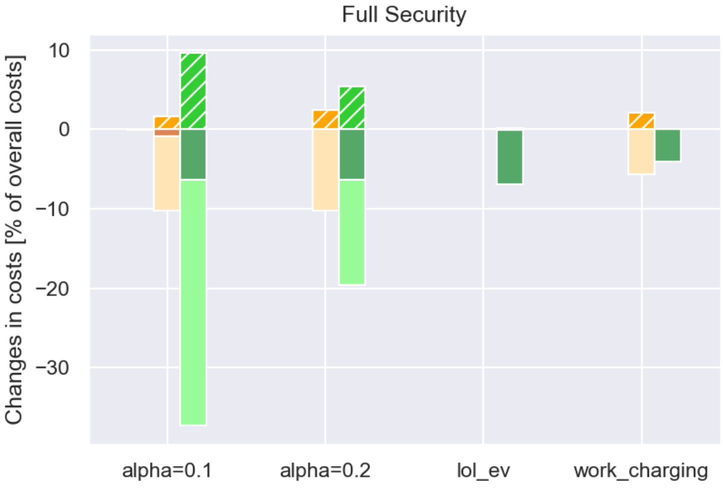
Comparison of the development of system costs on a winter day: System costs (left) and relative change in costs (right)

→ Growing generation cost due to additional demand

→ Constant charging slightly higher generation and investment costs than network friendly

→ Full security leads to high increase of investment and loss of load

Results - Policies



Comparison of the influence of different charging scenarios on system costs

→ All policies can help to reduce the costs for full security charging strategy, small α seems to be most effective

→ Most policies have no influence on network-friendly charging, however promoting charging at work can increase system costs

Summary

First insights

- **Charging behavior** has high influence on predicted costs of EV integration
- Charging with **full security** can lead to high peak and therefore **increase in system costs**
  - Realistic simultaneity factors are likely to lower the influence
  - Different policies can limit the negative impact
- Promoting charging at work has positive influence on full-security charging strategy, but raises costs for network-friendly charging strategy
  - Distribution of charging strategies will determine **optimal policy**

Conclusion & Outlook

Contributions

- Evaluation of different charging strategies and policy instruments in terms of balancing RES and EV charging in the German power system
- Providing a basis for further evaluations on this relevant topic

Further Research

- Evaluate compensation for lost comfort for coordinated charging
- Implementation of further charging strategies and additional charging/EV “types”
- Modelling of phase-out of power plants
- Include more progressive transport transition scenario
- Detailed analysis of transformation processes and “dynamic” investments

Thank you for your attention!

Anya Heider

Tel: +49 30 1208 434 90

E-Mail: anya.heider@rl-institut.de

Web: https://www.reiner-lemoine-institut.de

Twitter: @RL_Kolleg

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