Demand and Generation in Distribution Grids: Future Challenges and Opportunities

Abhilash Bandam, Theresa Gross, Jochen Linssen, Detlef Stolten

a.bandam@fz-juelich.de

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IEK-3: Institute of Techno-economic Systems Analysis

Motivation

- Electricity generation from renewable energy sources to reduce greenhouse gas emissions.
- Adopting rooftop solar PV installations are rising due to government incentives, environment concerns, energy independence, and energy security.
- The employment of heat pump technology has gained traction as a viable substitute for conventional heating and cooling systems.
- Decarbonization goals are opening the paths towards CO_2 free transportation.
- Consumer demand for battery electric vehicles has increased and is continuing to rise.
- Integration of these distributed demand and generation is particularly observed in distribution grids.

Primary Focus is on Distribution Grids

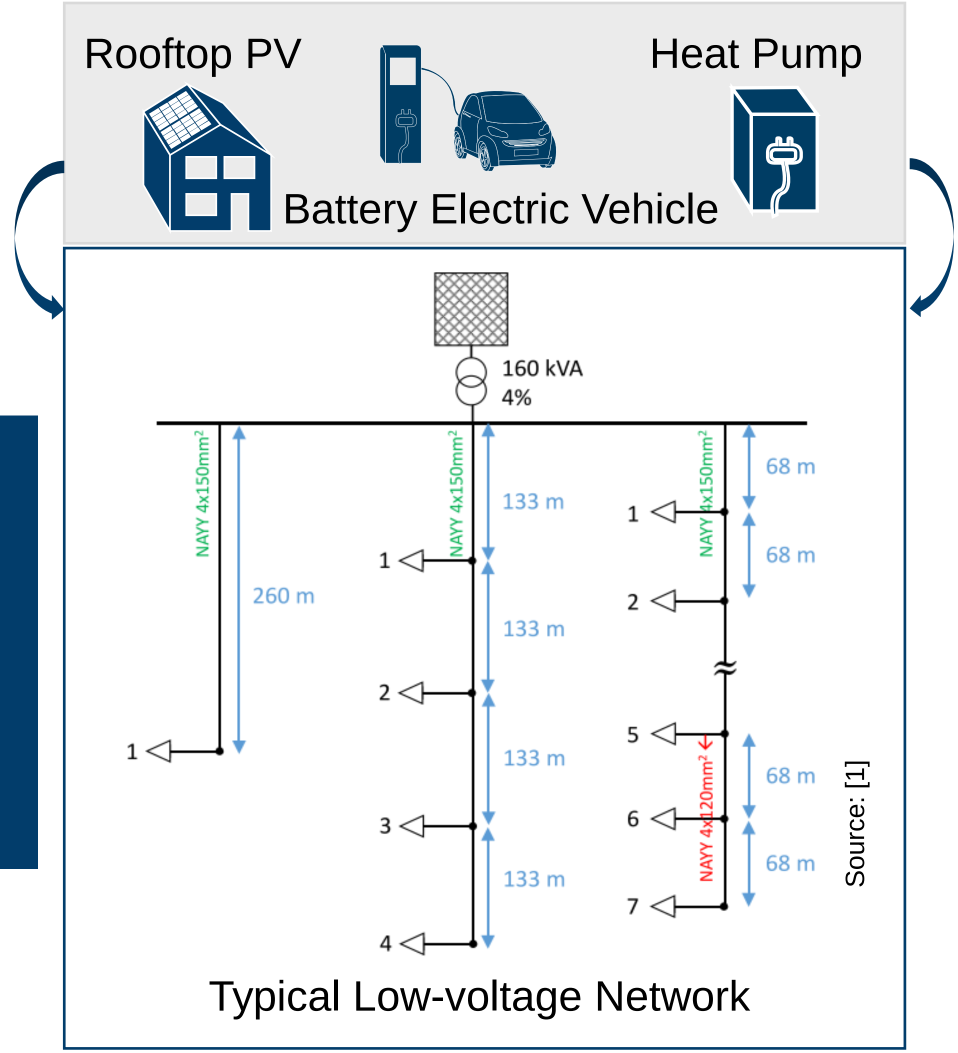
Motivation

- Lack of open real distribution grid topologies.
- Typical network topologies certainly do not resemble for the entire country.

Integration of Distributed Demand and Generation in the Future

Geo-referenced Synthetic Networks

Distributed Demand and Generation



[1]. Lindner, Marco, et al. "Aktuelle Musternetze zur Untersuchung von Spannungsproblemen in der Niederspannung." *14. Symposium Energieinnovation*. 2016.

Methods

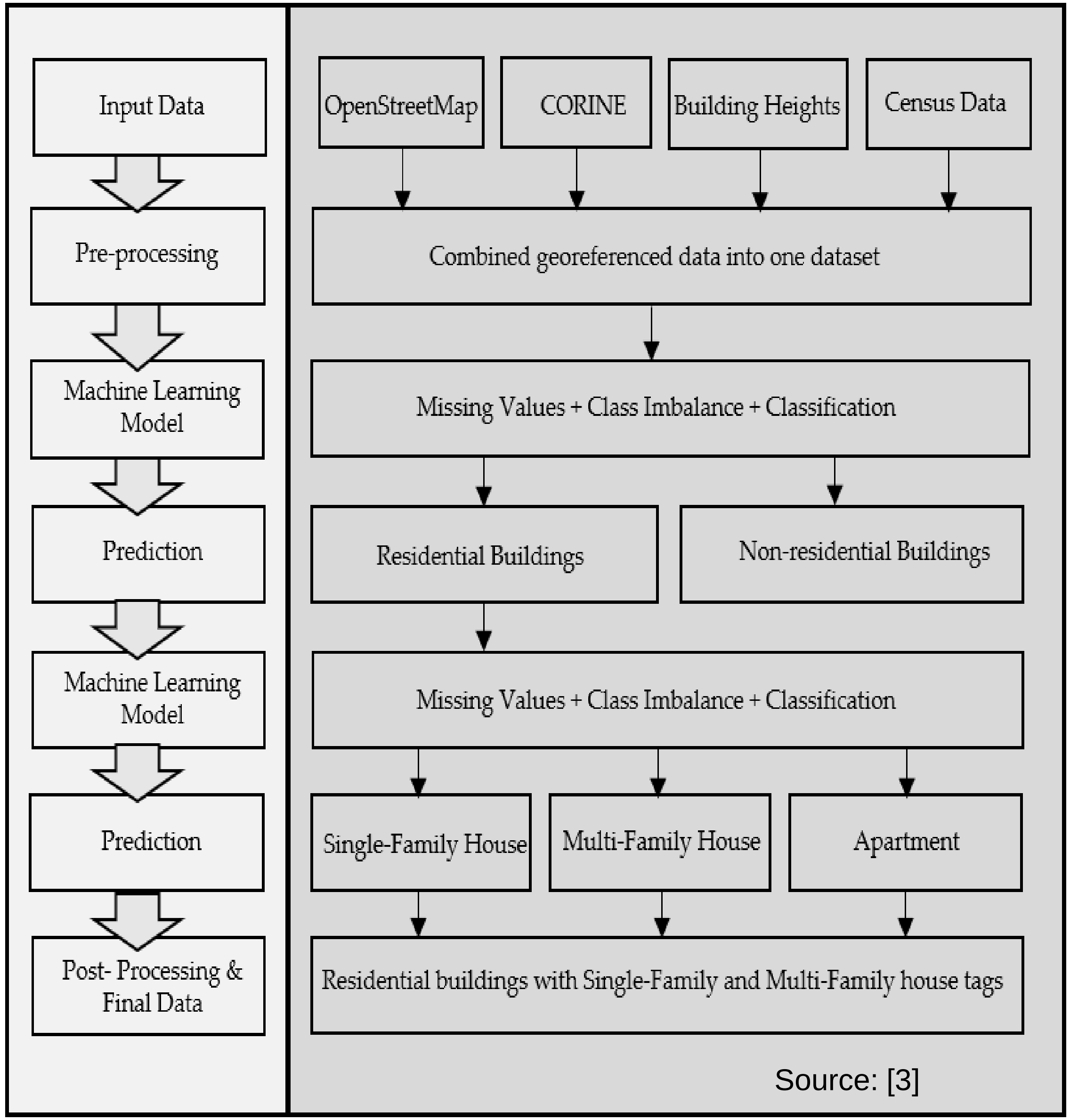
- Developing geo-referenced synthetic low-voltage networks necessitates the availability of open data pertaining to road infrastructures and buildings.
- Open data is typically regarded as authentic data that is unencumbered by restrictions or limitations.
- The most optimal data repository for extracting these elements is OpenStreetMap [1].
- The available data from OpenStreetMap about buildings comprise their geographical footprints and tags.
- Limited number of buildings hold comprehensive tags, as these tags are generated by users.
- Necessary to initially categorize buildings based on their structures, such as residential and non-residential buildings.

Open Data→ OSM → Building Type Classification → Synthetic Networks

[1]. OpenStreetMap contributors. (2017). Planet dump retrieved from https://planet.osm.org.

Methods: Classification of Building Types in Germany

- Various data sources are utilized to supplement the OpenStreetMap data, thereby enhancing its feature.
- The CORINE land cover data was utilized to analyze land use information [1].
- The Copernicus project's urban atlas offers information on building heights in select metropolitan areas [1].
- The 2011 census data presents insights into the demographic, socioeconomic, and occupational characteristics of the population residing in Germany [2].



Source: [3]

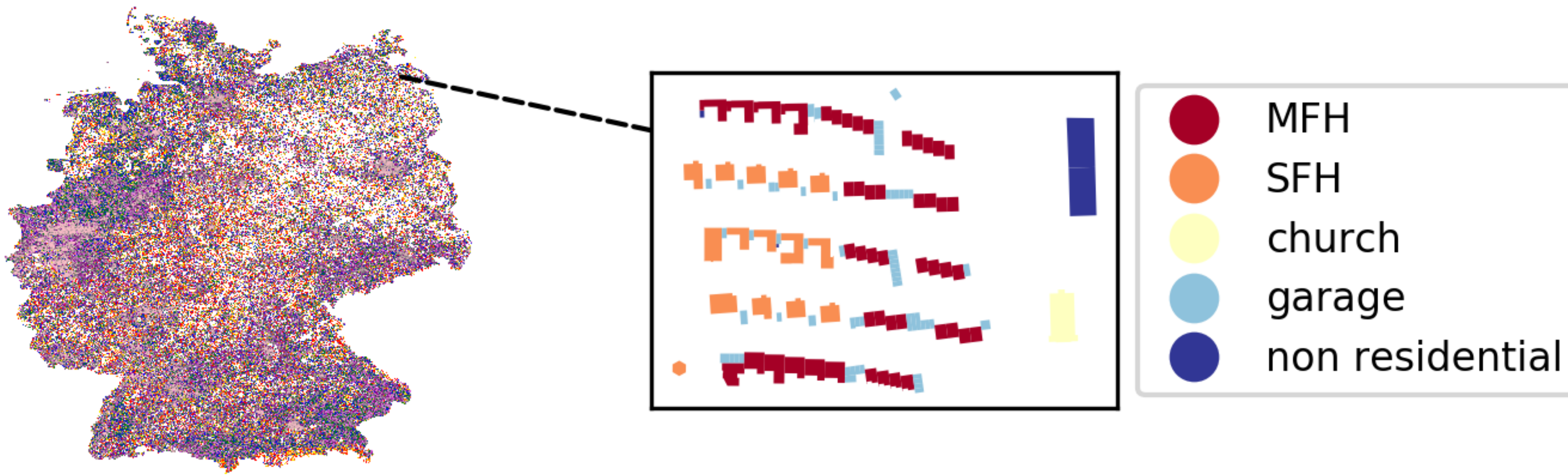
[1]. "Copernicus Land Monitoring Service," *Copernicus Land Monitoring Service*. https://land.copernicus.eu/

[2]. "ZENSUS2011 - Bevölkerungs- und Wohnungszählung 2011," *ZENSUS2011 - Bevölkerungs- und Wohnungszählung 2011*, Feb. 03, 2018. https://www.zensus2011.de/

[3]. A. Bandam, E. Busari, C. Syranidou, J. Linssen, and D. Stolten, "Classification of Building Types in Germany: A Data-Driven Modeling Approach," *Data*, vol. 7, no. 4, p. 45, Apr. 2022, doi: 10.3390/data7040045.

Methods: Classification of Building Types in Germany

- Building types were classified using machine learning algorithms
- The algorithms addressed the issues of missing values and class imbalance in the dataset.
  - Residential buildings: 19,747,802 (3.6% error)
  - Single-family houses (SFH): 14,378,638
  - Multi-family houses (MFH): 5,369,164



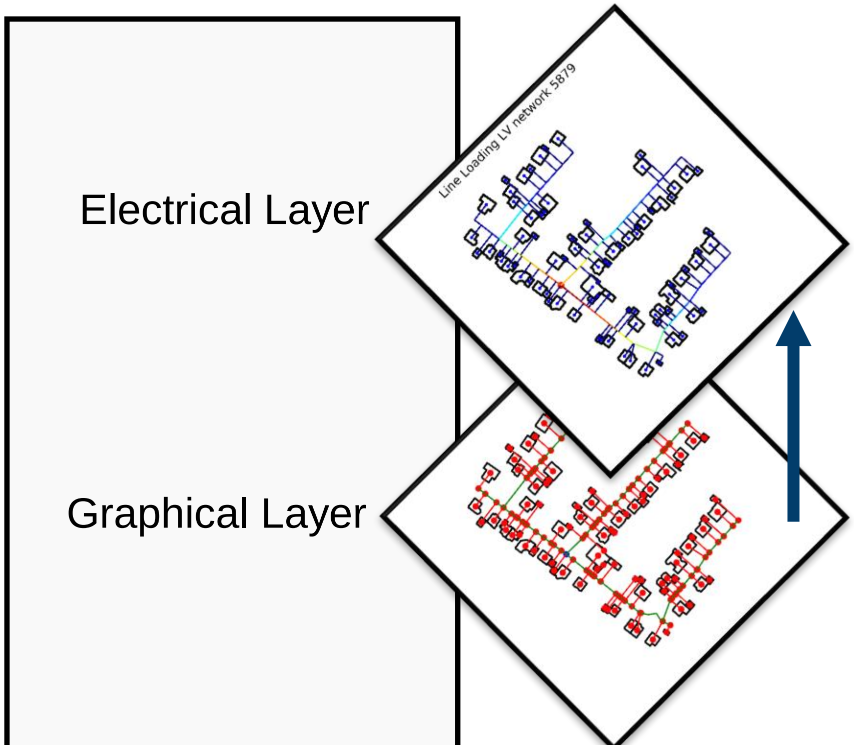
Source: [1]

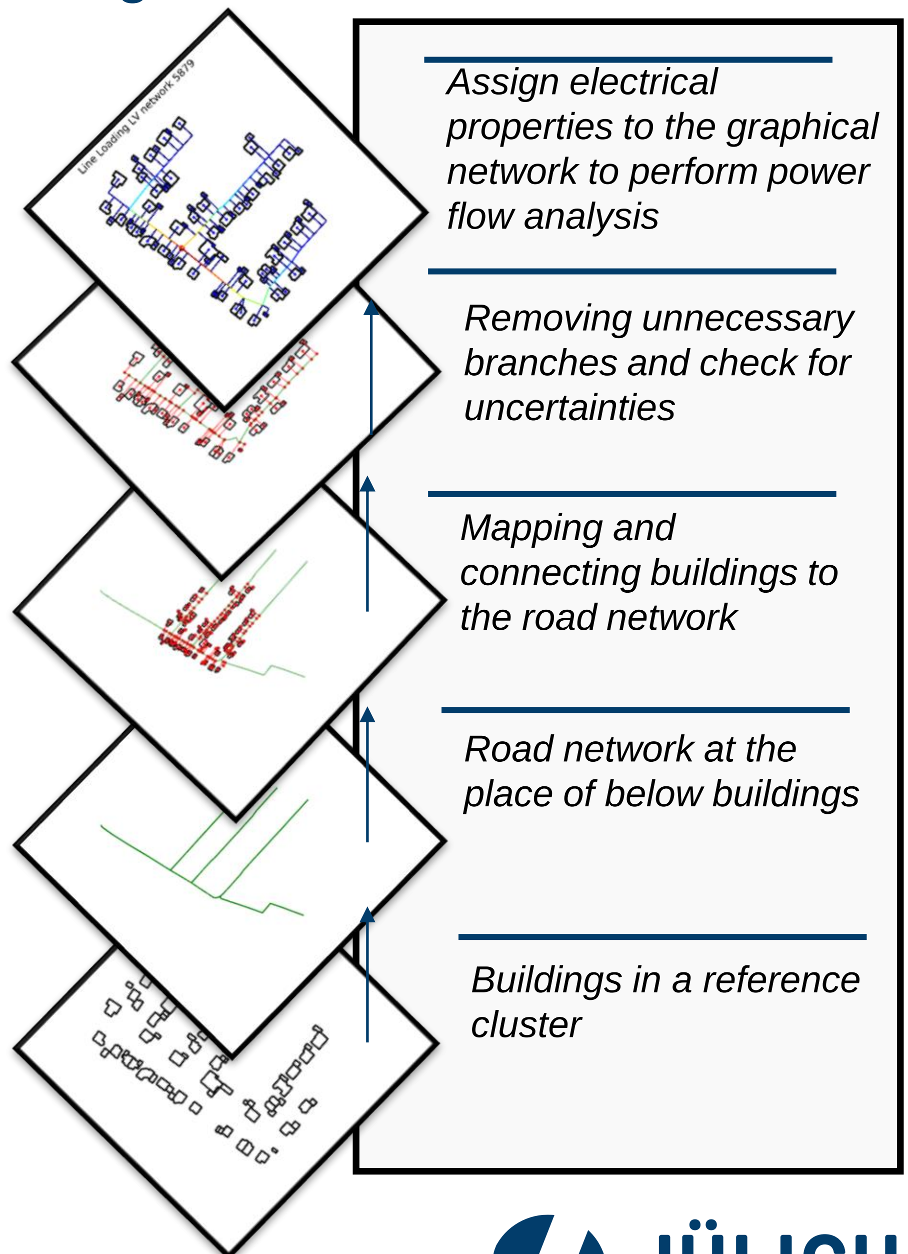
[1]. A. Bandam, E. Busari, C. Syranidou, J. Linssen, and D. Stolten, "Classification of Building Types in Germany: A Data-Driven Modeling Approach," *Data*, vol. 7, no. 4, p. 45, Apr. 2022, doi: 10.3390/data7040045.

Methods: Geo-referenced Synthetic Low-voltage Networks

Known Data

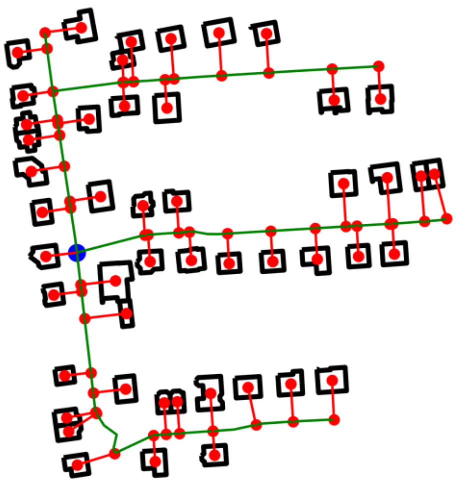
- Buildings and their locations
- Street networks
- Low-voltage transformers count (500,000)

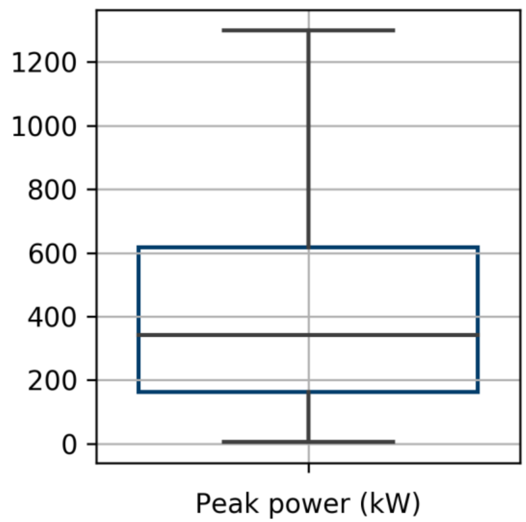


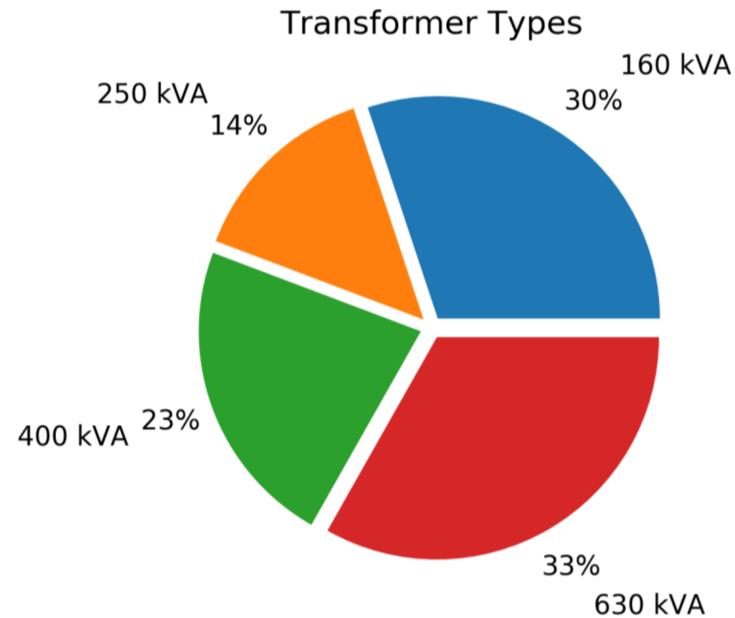


Methods: Geo-referenced Synthetic Low-voltage Networks

Low voltage network (1/500,000)







- Household load profiles are assigned to the buildings based on the building type.
- Cumulative peak of all buildings is extracted from the peak load of each building.
- Transformer type for each network was chosen based on the peak load.
- Four standard secondary transformers were distributed to modeled 500,000 synthetic LV networks.

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Results: Scenario Calculations on Low-Voltage Networks

- Given information [1]:
  - 62.7 GW solar rooftop photovoltaics (PV) in Germany by 2050
  - Battery electric vehicles (BEV): 26% of total vehicles by 2050
  - Hybrid: 5% of total vehicles by 2050
  - Gasoline Hybrid: 6% of total vehicles by 2050
  - Heat pumps (HP): 82.9% of total buildings living area

Total vehicles: 42.7 million
37% of total vehicles

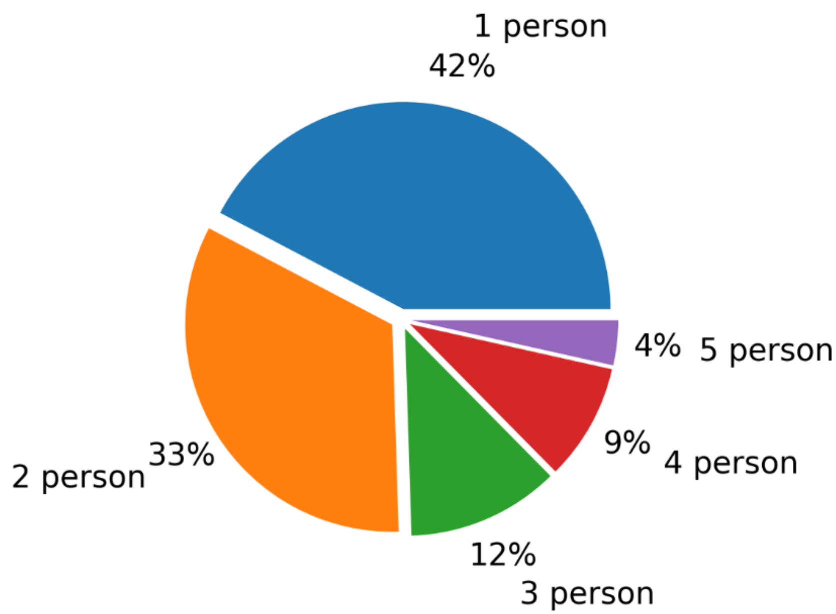
- Scenario ES2050
  - PV: 6kW for each building, 52.9 % of total buildings
  - BEV:
    - 1 BEV for each building → 80% of buildings
  - HP: 82.9% of total buildings

[1]. M. Robinius *et al.*, *Wege für die Energiewende: kosteneffiziente und klimagerechte Transformationsstrategien für das deutsche Energiesystem bis zum Jahr 2050*. Forschungszentrum Jülich GmbH Zentralbibliothek, Verlag, 2020

Results: Scenario Calculations on Low-voltage Networks

Assumptions:

- 500,000 geo-referenced synthetic low-voltage networks.
- Nodes in the low-voltage networks are buildings which are classified into single-family houses, multi-family houses, and apartment buildings.
- Single-family house has one dwelling.
- Multi-family house holds five dwellings.
- Apartment building holds an average of 15 dwellings.
- Household demand is distributed randomly with a probability of 0.42, 0.33, 0.11, 0.1, and 0.04 for all dwellings corresponding to 1 to 5 persons per household.
- PV: 6 kW for each building, 52.9% of buildings
- BEV: 1 Vehicle per building, 80% of buildings



Results

- Performed simulations for mentioned scenarios for weekdays and weekends for four seasons.
- Three important components in the networks are analyzed for violations.
- Transformer, Lines, and Nodes.

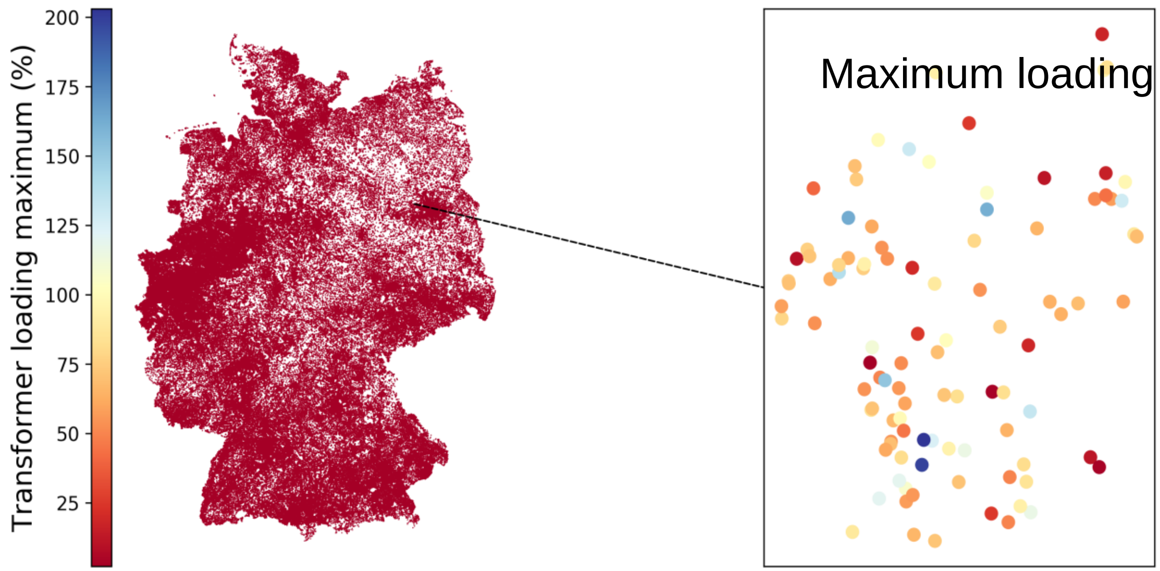
Grid component	Limits
Transformer	$> 100\%$ of rated capacity
Overhead line	$> 100\%$ of rated capacity
Underground cable	$> 100\%$ of rated capacity

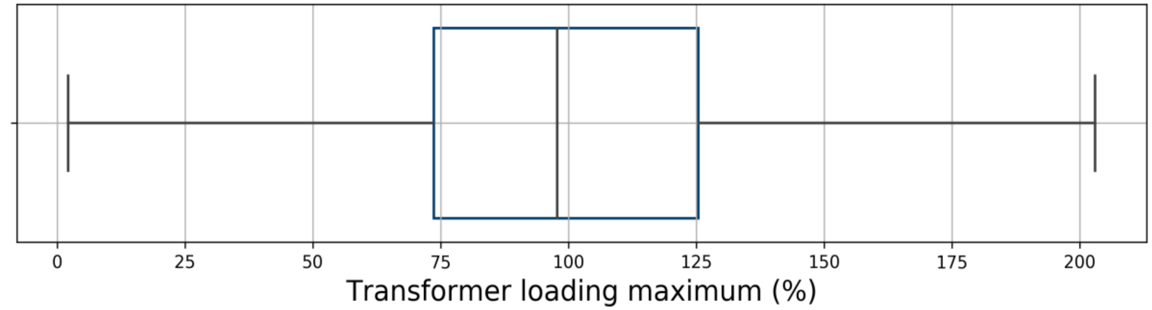
Voltage constraint	Limits
Voltage magnitude	$\pm 10\%$ of the V_n for 95% of data measured in a week and $+10\%$ and -15% of V_n for total time.

99.9% of the 500,000 Networks Converged in Power Flow Analysis

Results: Transformer Violations

- The maximum loading of the transformer throughout the simulated time snapshots.
- 50% of the networks exhibit utilization levels exceeding their maximum capacity.
- 25% of the entire networks are experiencing critical violations.
- It is essential to examine the frequency of instances in which transformers are experiencing violations in their operational capacity.





25% of the Networks are in Critical Condition Without Reinforcement

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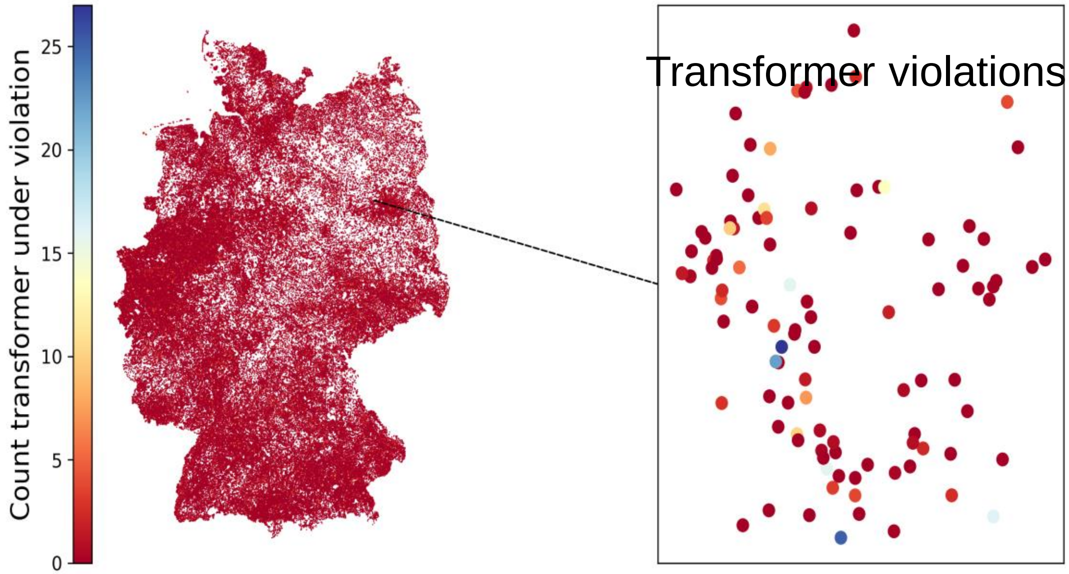
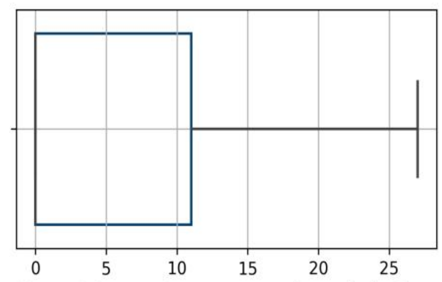
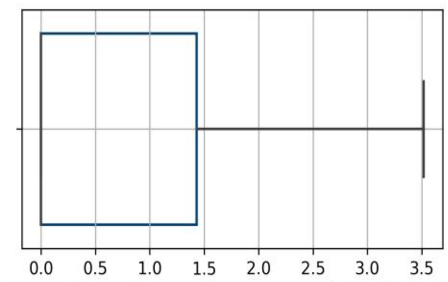
Results: Transformer violations

- When a transformer exceeds its operational limitations, it is considered to be in violation.
- According to the data, 75% of the transformers analyzed experienced violations for less than 10-time snapshots during the simulated period.
- This implies that a 25% of the transformers are presently in a critical state, necessitating the exploration of potential solutions such as reinforcement or other measures to ensure that the transformers operate within their capacity during such occurrences.







25% of the Networks are in Critical Condition Without Reinforcement

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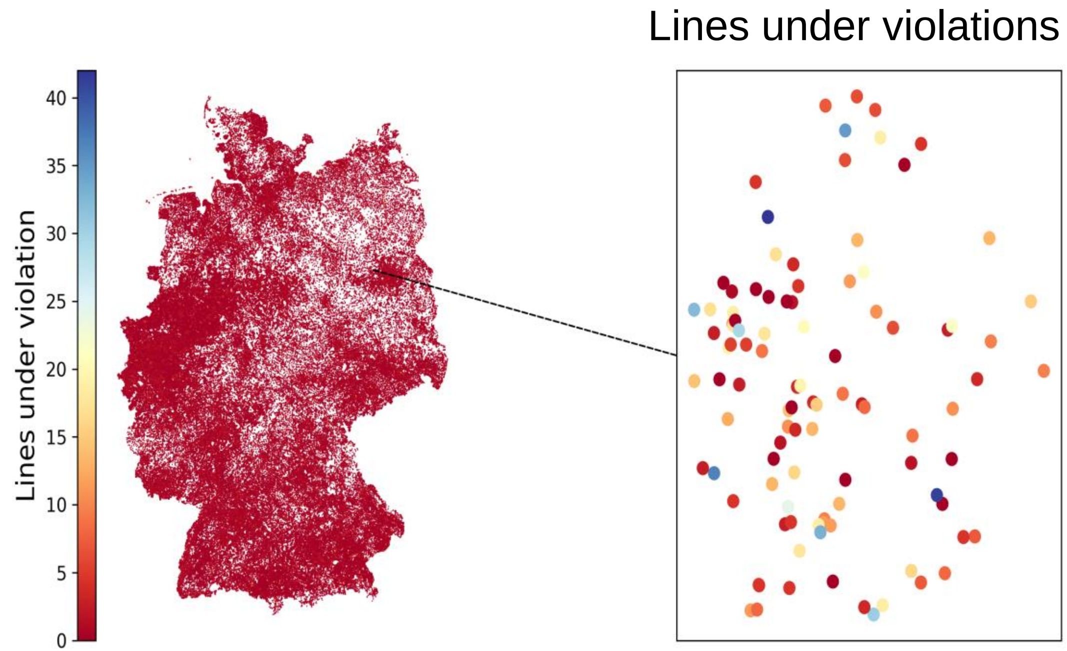
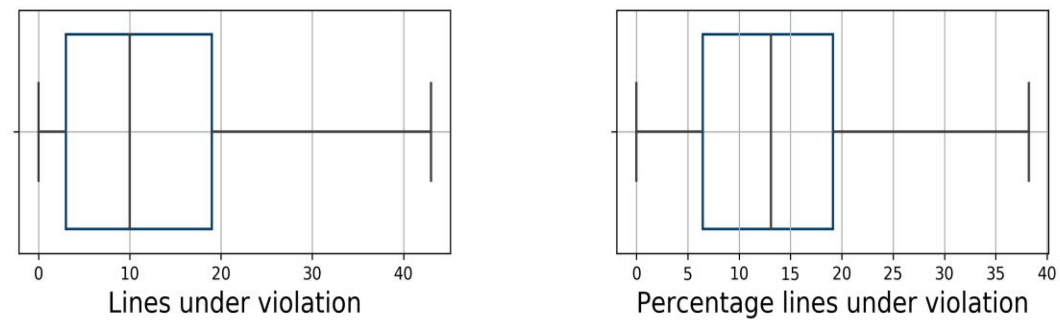
Results: Power Line Violations

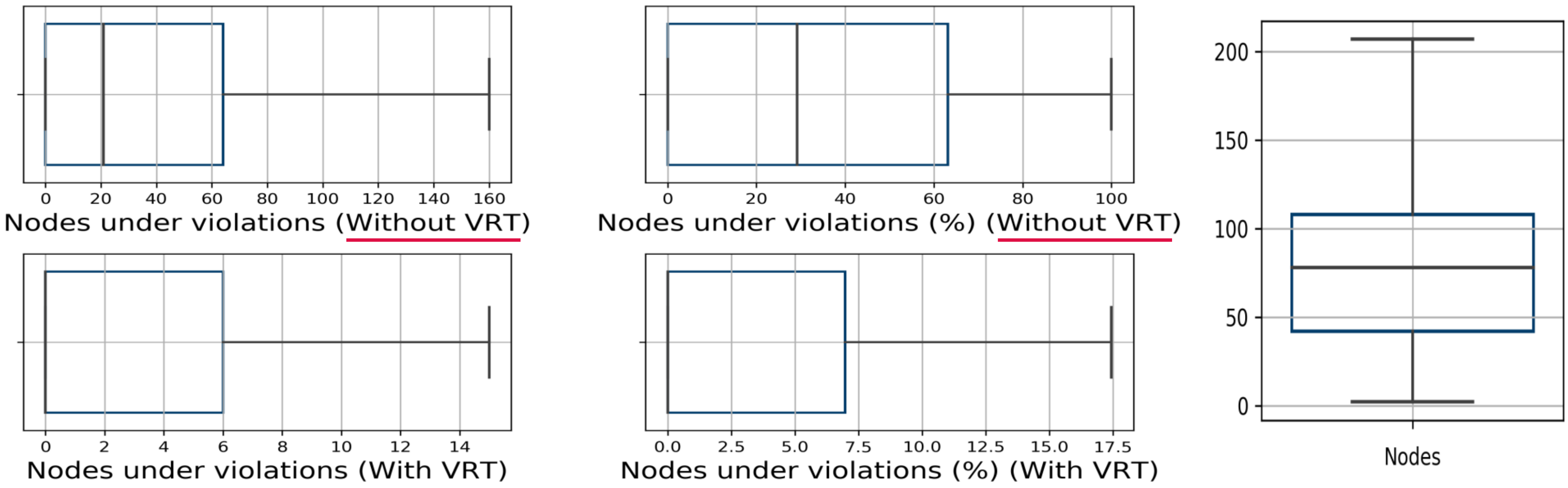
- Lines under violations at least once.
- Lines in the networks ranges from 1 to ~200.
- 50% of the networks shows more than 10 lines under violations at least once in the total time steps simulated.
- Percentage lines under violations are less than 20% for 75% of the networks.
- Upon consideration of all 500,000 networks, it has been determined that an average of 11% of the lines experience overloading and necessitate reinforcement.





11% of the Lines Need Reinforcement

Results: Under-voltage Violations



- Higher load and low power generation cause bus voltage to drop.
- Voltage regulating transformer helps regulate the voltage in the network.
- Nodes in the generated networks ranges from 1 to approx. 200.
- Nodes under violations at least once without voltage regulating transformer are higher than with voltage regulating transformer.
- There were no instances of overvoltage violations observed in the simulated networks.

34% of the Network's Nodes Need Attention Due to Under-voltage Violations

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Key findings

- More than 99.9% of the developed geo-referenced synthetic low-voltage networks converged in the power flow analysis.
- Quantification of network violations by systematic power flow analysis of 500,000 synthetic distribution networks for German energy system scenario 2050.
- A quarter of the low-voltage transformers are considered critical as a result of being overloaded.
- Power flow analysis reveals that an average of 11% of the lines exhibit overloading and necessitate reinforcement.
- It has been observed that, around 34% of the nodes present in networks require attention in order to rectify voltage violations.

Thank you for your attention!

For further questions, please contact:

Abhilash Bandam
+49(0)0261 61 9155
a.bandam@fz-juelich.de

Prof. Dr. Detlef Stolten
+49(0)2461 61 5147
d.stolten@fz-juelich.de

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