# Grid Integration Studies for eMobility Scenarios with Comparison of Probabilistic Charging Models to Simultaneity Factors

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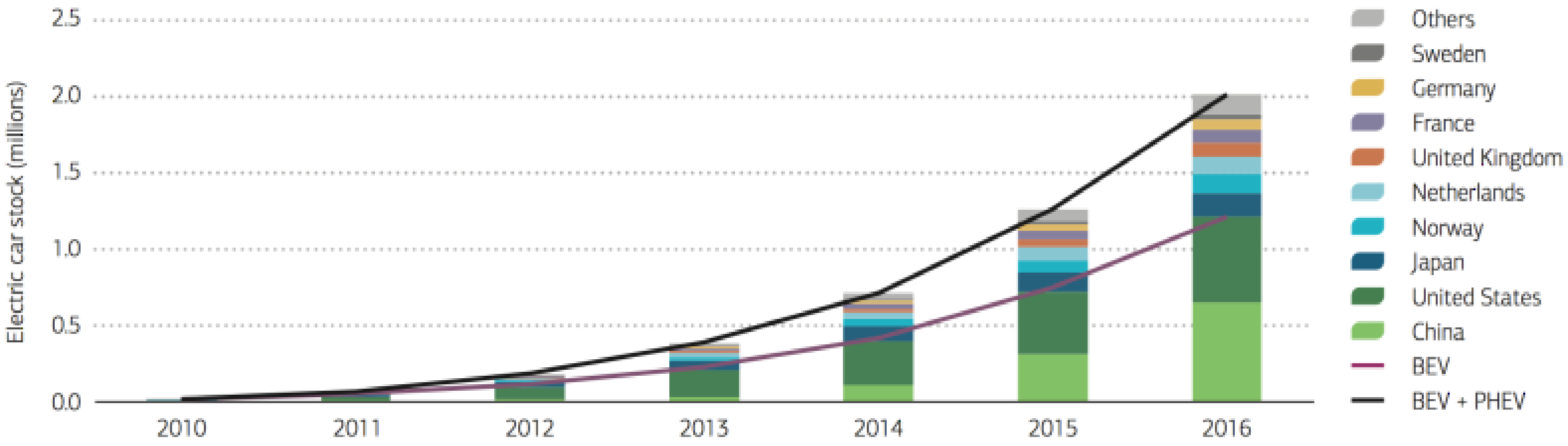
# Motivation
## Transition to Battery Electric Vehicles (BEVs)

- In the upcoming decades in many countries a **transition to battery electric vehicles** (BEVs) is expected
- The additional power consumption puts stress on electric grids, this could lead to **overloadings** and **voltage band violations**

**Grid integration studies** are important in order to assess:

- The hosting capacity for (additional) charging stations
- Necessary reinforcement and expansion measures + investment cost

Evolution of the global electric car stock, 2010-16[1]







[1] IEA analysis based on EVI country submissions, complemented by EAFO (2017a), IHS Polk (2016), MarkLines (2017), ACEA (2017a, 2017b) and EEA (2017).

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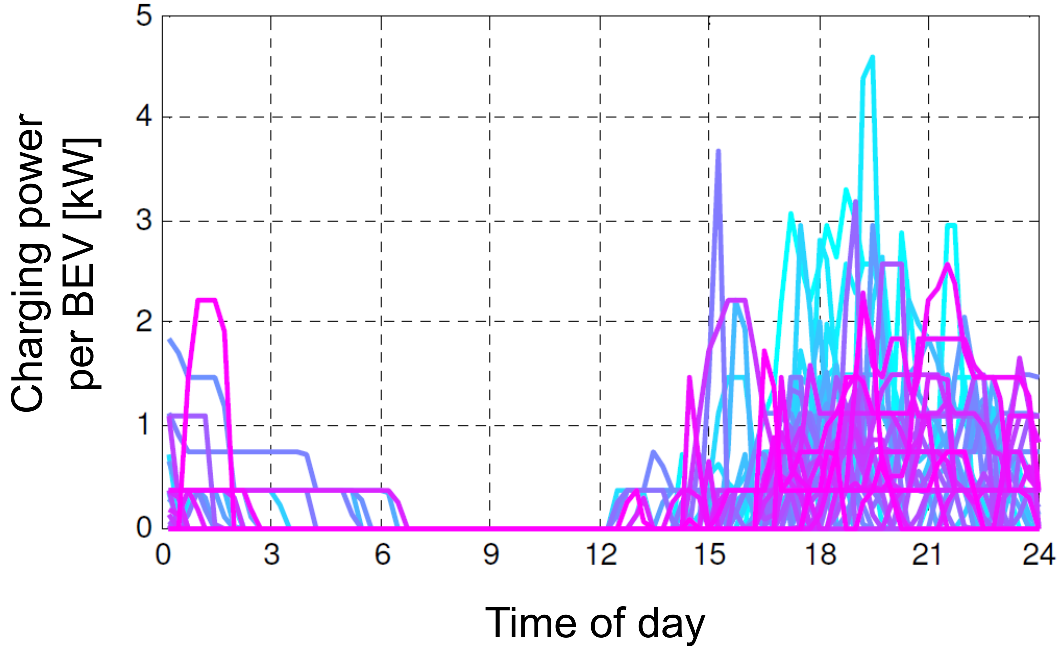
# Motivation
## Simultaneity Factors for BEV Charging

- In the absence of market induced effects it is very unlikely that all BEVs in a grid **charge at the same time** with their rated power

- Common method: usage of **simultaneity factors** in order to **scale down** power consumption per BEV according to the number of simultaneously charging vehicles

- Suitability for small numbers of vehicles is **questionable**

**Charging profiles of 10 BEVs [2]**







[2] reprinted [translated] from: A. Probst, Auswirkungen von Elektromobilität auf Energieversorgungsnetze analysiert auf Basis probabilistischer Netzplanung

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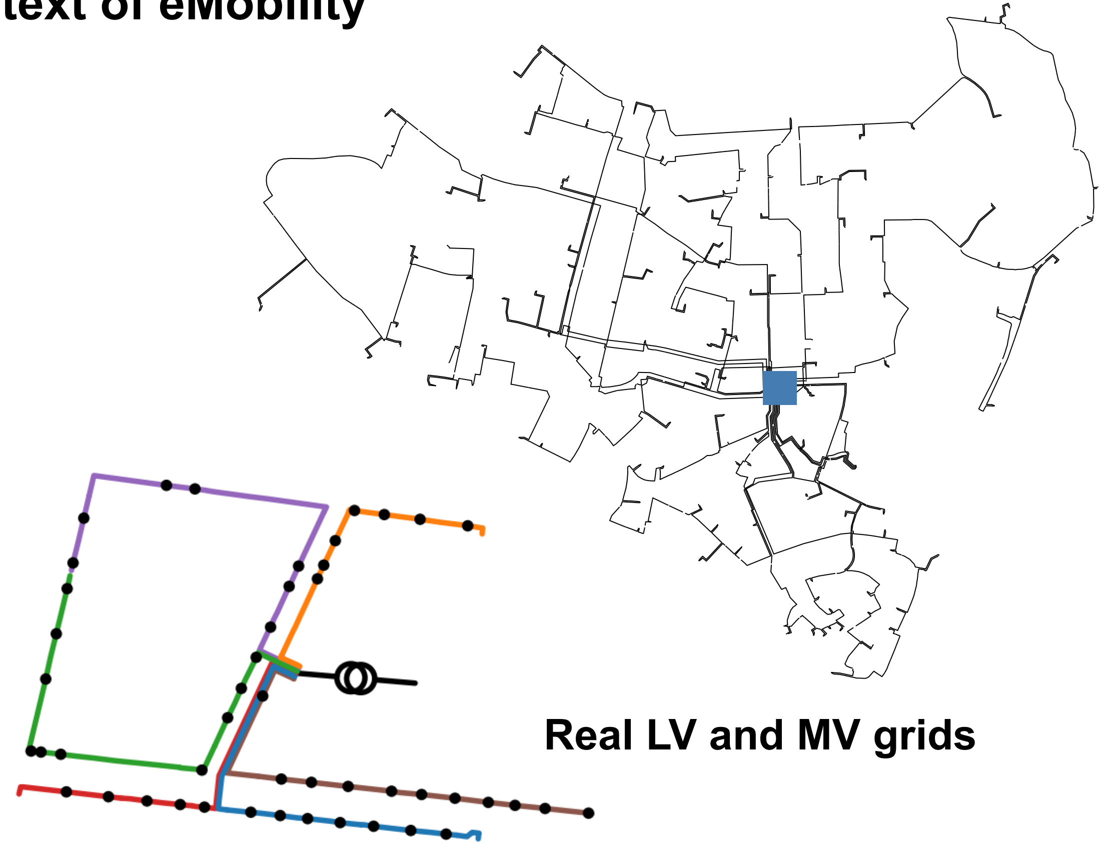
# Agenda
## Contents of the Paper

**Method for conducting grid integration studies in the context of eMobility**

- Detailed comparison of **simultaneity factors** vs. a **probabilistic distribution approach** based on BEV charging profiles
- Application on **real medium- and low-voltage grids** provided by the German DSO Stadtwerke Kiel
- Demonstration of different BEV **charging infrastructure concepts**
- Evaluation of grid integration cost with an **automated grid reinforcement and expansion approach**



**Real LV and MV grids**





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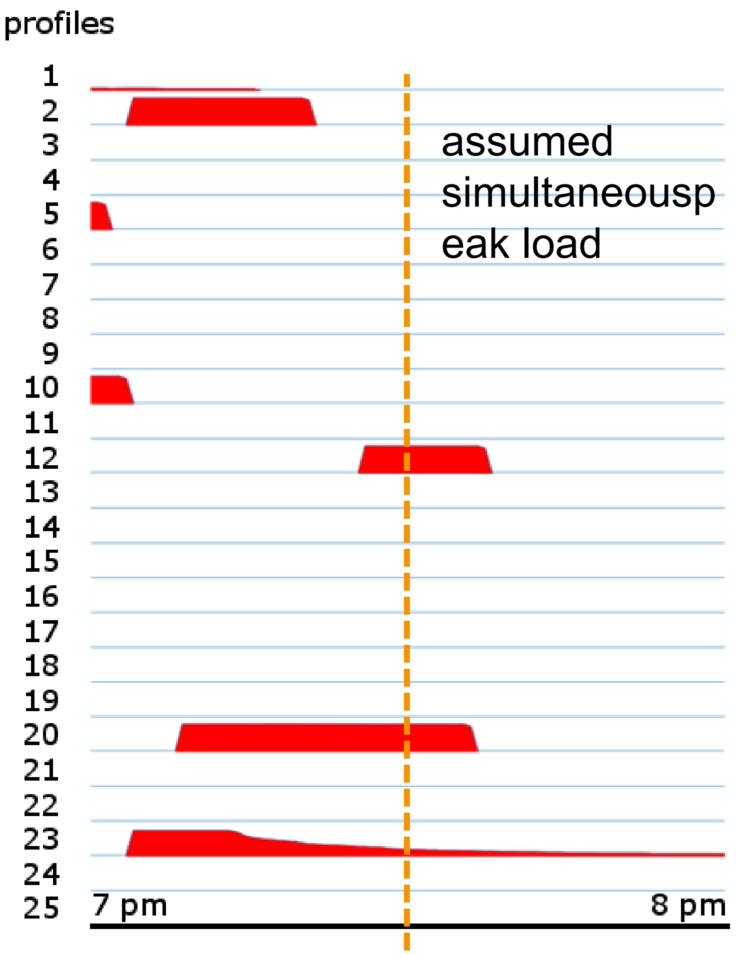
# Modelling of BEV Charging
## BEV Charging Profiles

**Simulated BEV charging profiles with consideration of:**

- Usage behaviour of BEV owners (time of day, time spans, travelled distance, …)
- Technical specifications of common BEV models (battery capacity, energy consumption per km, …)
- BEV market shares in Germany
- Charging behaviour of lithium-ion batteries (charging speed dependence on state of charge)

**→ 10.000 BEV charging profiles generated**

**→ In this paper all charging points have an assumed rated power of 22 kW (other rated powers are possible)**



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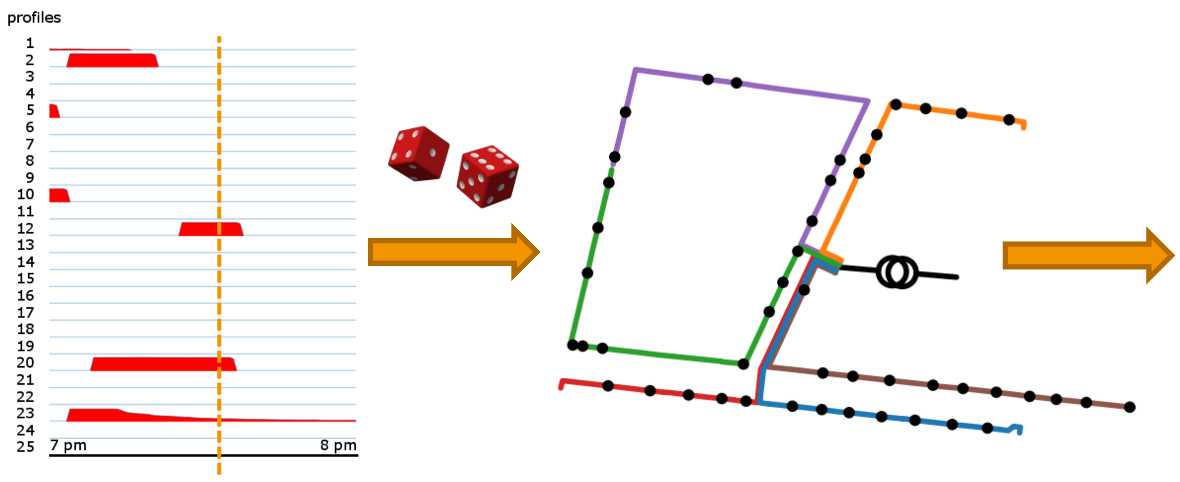
# Modelling of BEV Charging
## Probabilistic Distribution Approach




- **max. line + transformer loading**
- **min. bus voltage**

100.000 iterations

1) randomly chosen charging profile for every charging point in the grid (positions of charging points are fixed)
2) Power flow calculation with pandapower[3]
3) Analyses of line/transformer loading and bus voltages

**→ worst-case scenario based on 100.000 charging profile distributions**




[3] http://www.pandapower.org/

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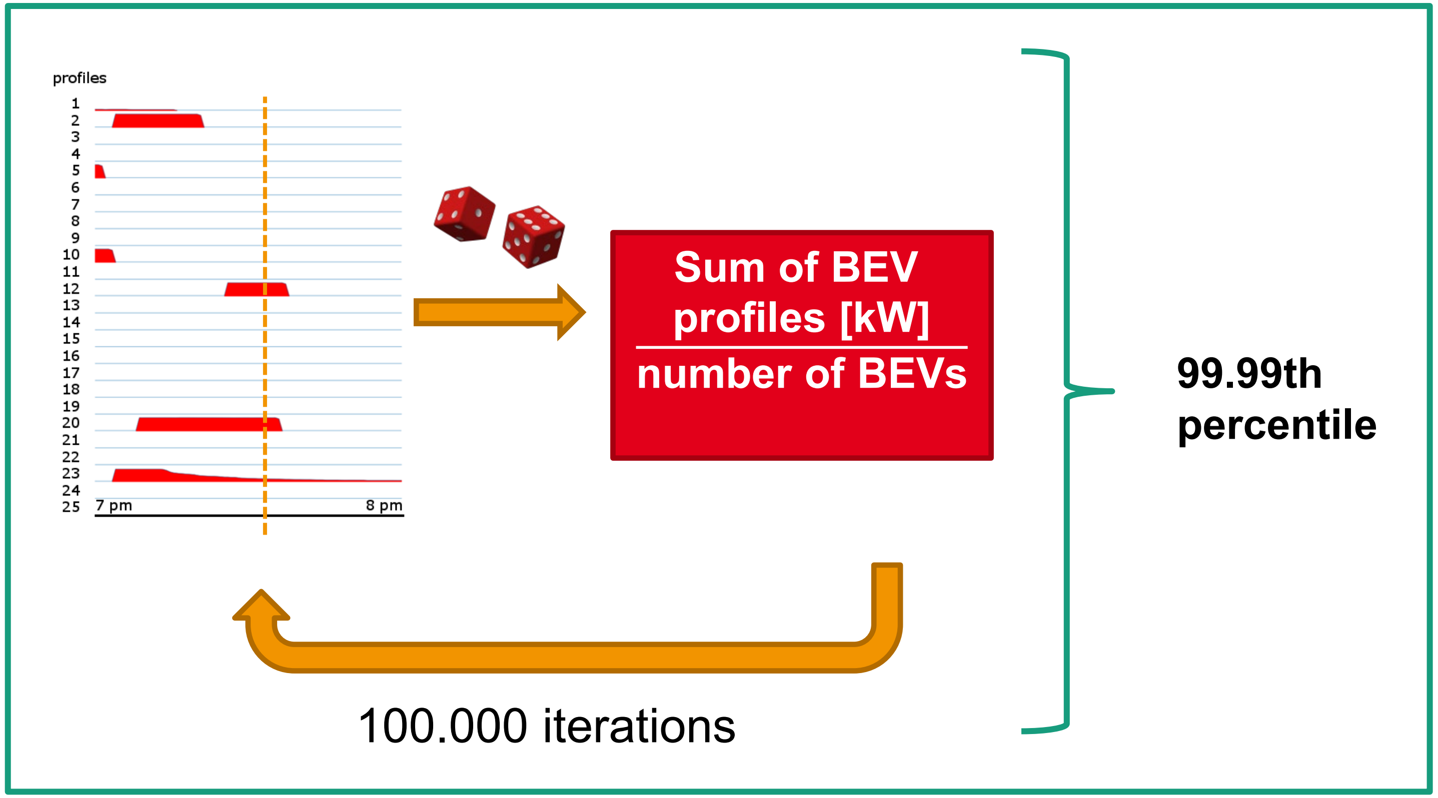
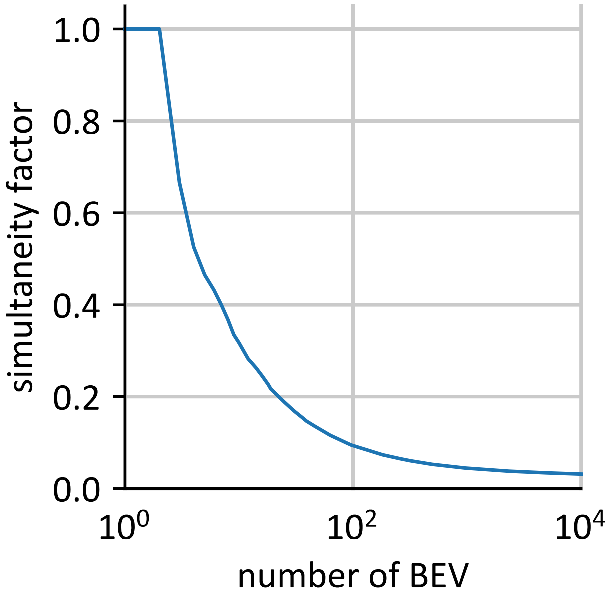
# Modelling of BEV Charging
## Simultaneity Factors

**for 1 to 10.000 BEVs**




**Simultaneity curve**



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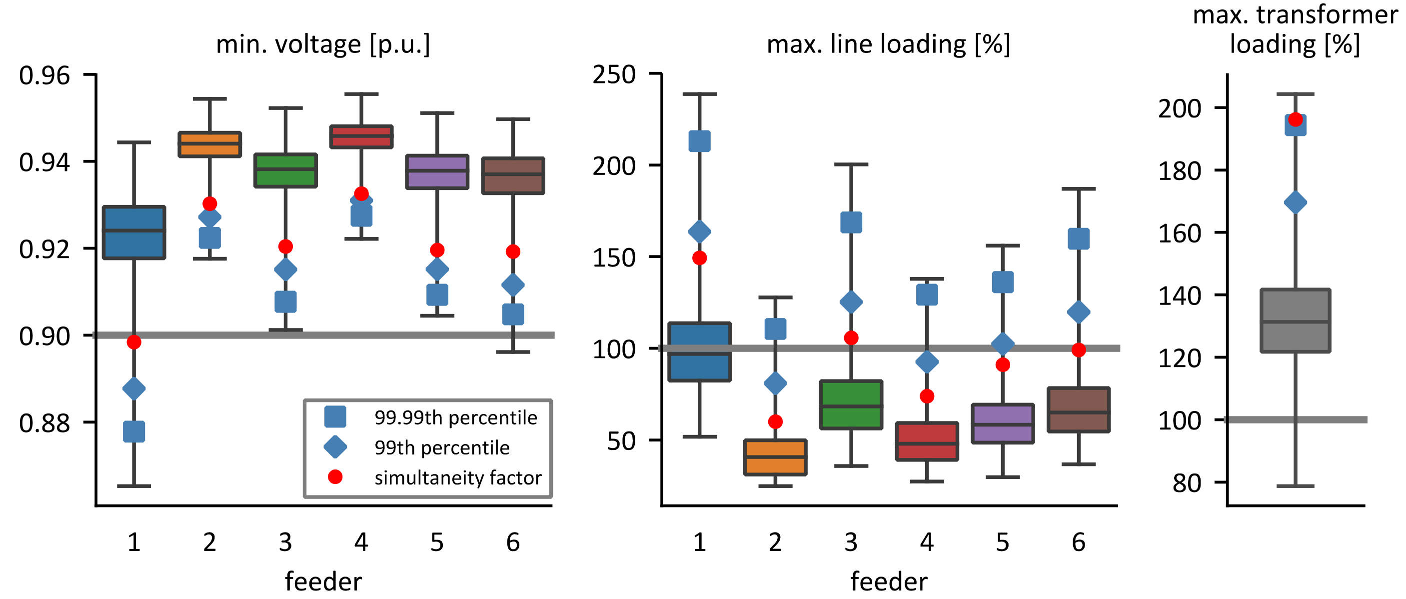
# Probabilistic Distribution Approach vs. Simultaneity Factors
## Application and Comparison in Real Grids

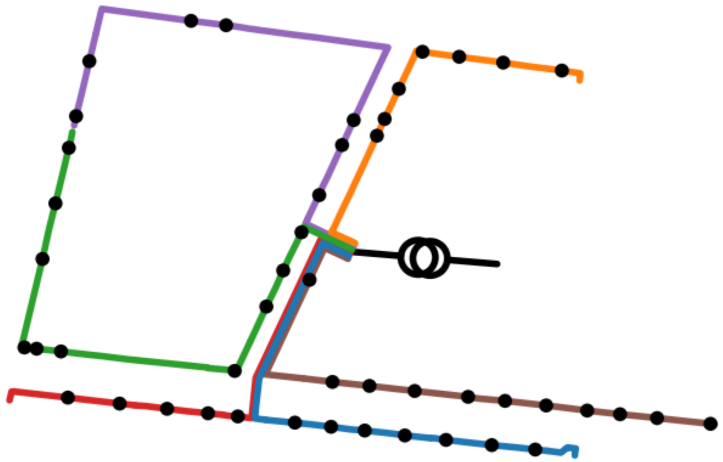
**LV grid - min. voltages/ max. loadings in 100.000 BEV distributions**




- Simultaneity factor approach underestimates min. bus voltages / max. line loadings in all six feeders compared to 99.99th and 99th percentile
- Max. transformer loading: Simultaneity factor value matches the 99.99th percentile value

### Exemplary LV grid

- Urban area
- Supplies ~500 households
- Six feeders
- 48 to 116 BEVs per feeder





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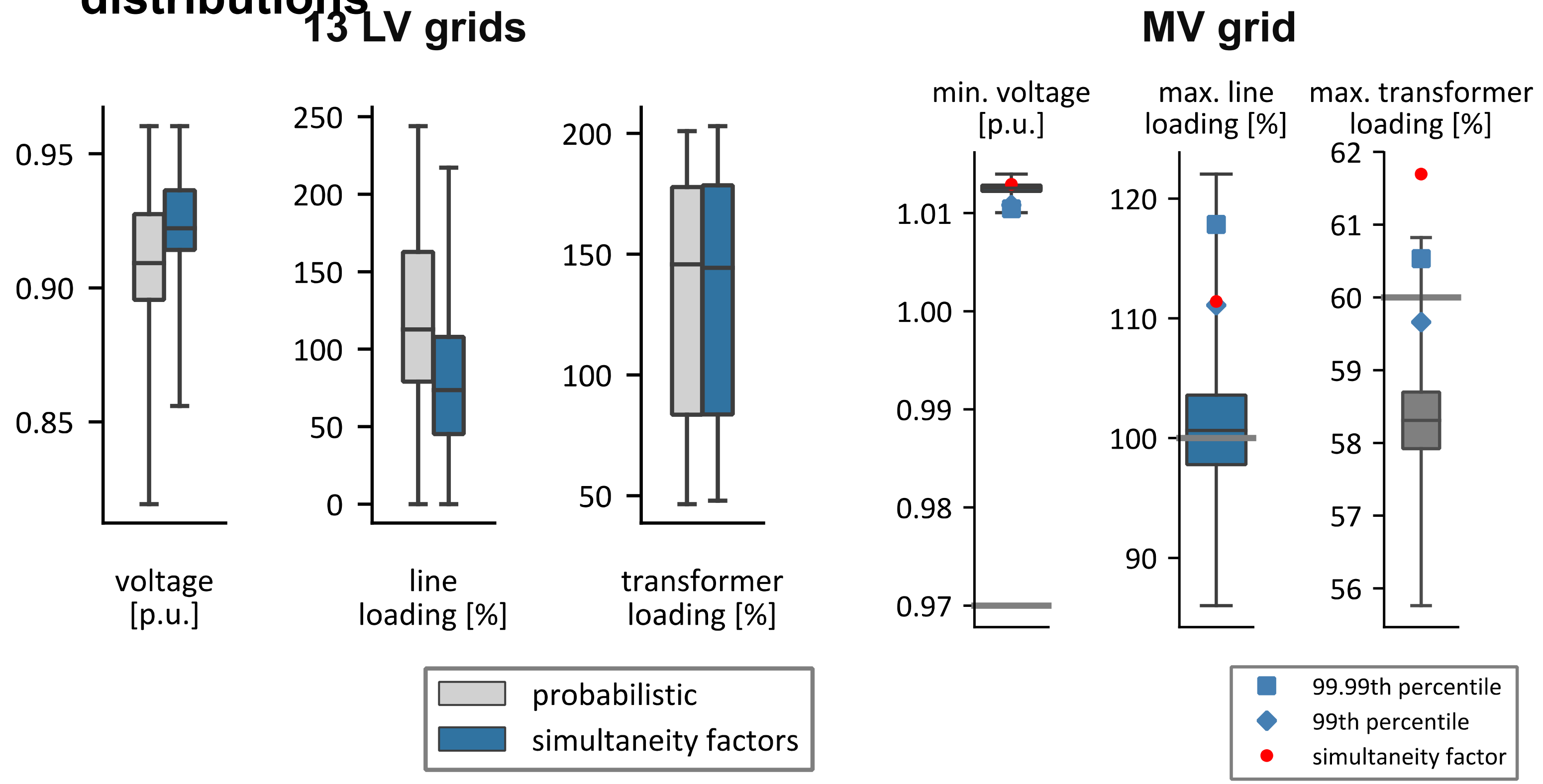
# Probabilistic Distribution Approach vs. Simultaneity Factors

## Application and Comparison in Real Grids

**Min. voltages/ max. loadings for 100.000 BEV distributions**




**13 LV grids -** Regarding the median:

- Min. voltages are 0.01 p.u. higher
- Max. line loadings are 40 percentage points lower,
- Transformer loadings hardly deviate

when using simultaneity factors compared to the probabilistic approach.

**MV grid -** Only minor deviations between both approaches.

→ **Simultaneity factors are not well suited for small numbers of charging vehicles (e.g. LV feeders)**

→ **For larger numbers of BEVs (e.g. in MV grids) simultaneity factors are a good approximation**



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# Comparison of different Charging Infrastructure Concepts
## Alternatives to Residential Charging

**Residential charging**

- Areal distribution of 22 kW charging points in proportion to residential loads
- Total number of BEVs corresponds to total number of households supplied by the grid

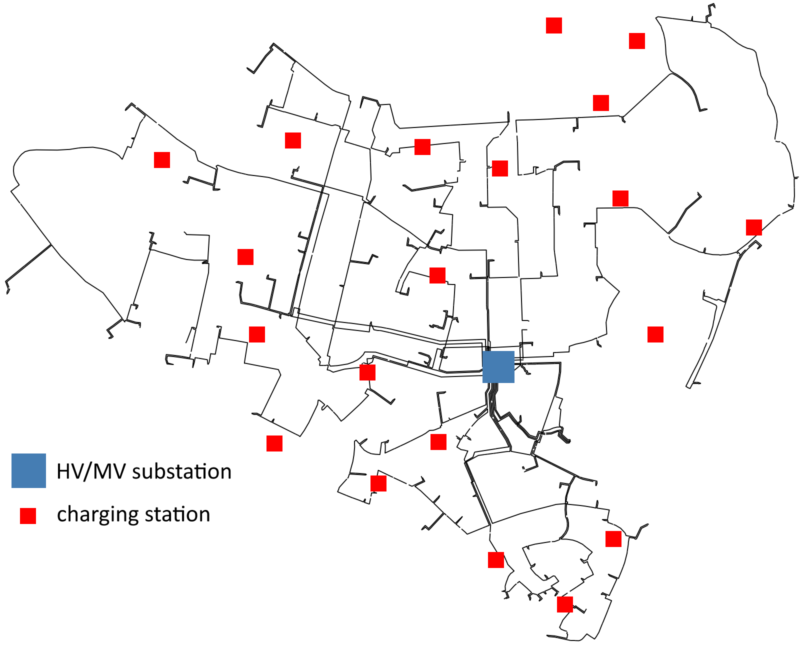
**Autonomous driving**

- Like residential charging but BEVs are capable of autonomously driving to charging stations located near the HV/MV substation

**Fast charging**

- 20 fast charging stations with six 350 kW charging points each
- Randomly distributed in the MV grid (min. distance of 300 meters)
- Two variants: 1) integration into the existing MV grid and 2) dedicated MV feeders
- Dedicated feeders allows for individually adapted planning principles like no (n-1) security, lower min. voltage limit

**MV grid with fast charging stations**



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# Reinforcement and Expansion Cost

## Integrated LV/MV Grid Model with probabilistic BEV Integration Scenarios

### Grid model

- 1 real MV grid and 13 real LV grids provided by the German DSO Stadtwerke Kiel
- Urban MV grid, that supplies 86 LV grids with ~23,000 households
- Not all original LV grids were available → missing LV grids are substituted with the most similar of the 13 available LV grids (with respect to number of households, rated transformer power…)

### Spatial variation of BEV charging point positions

- BEV charging points are randomly distributed according to the number of households per connection point
- Probabilistic approach: 10 variations of the spatial charging point distribution



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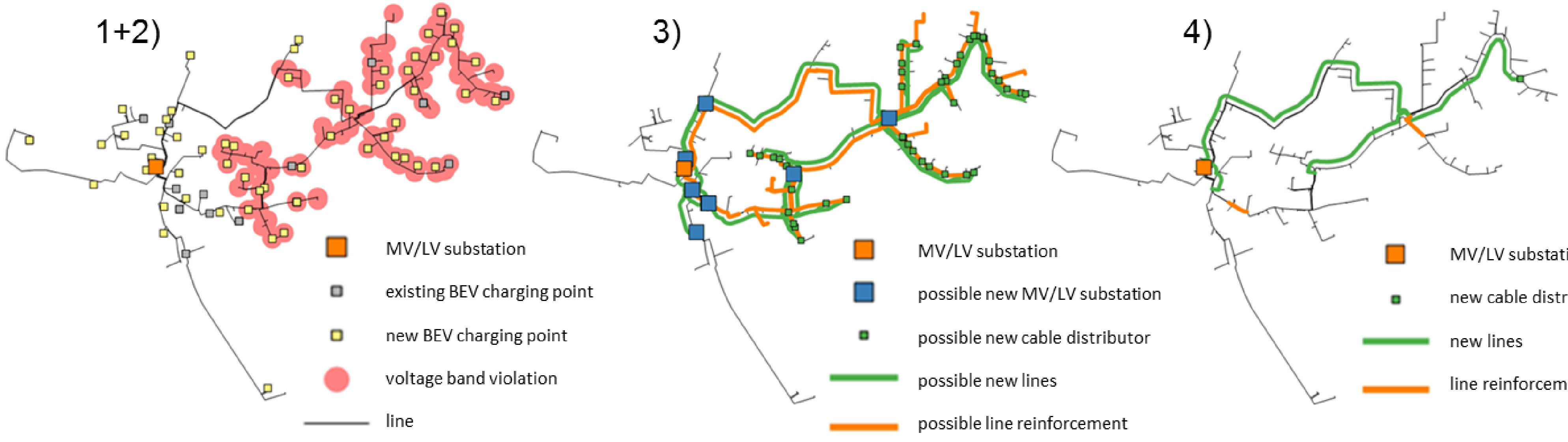
# Reinforcement and Expansion Cost
## Automated Grid Planning




Automated grid planning with a heuristic optimization approach:

1) **Scenario implementation**: Additional loads are added to the grid model
2) **Analysis of possible violations**: Load flow calculations to identify voltage band violations, line and transformer overloading
3) **Identification of possible reinforcement and expansion measures**
4) **Heuristic optimization**: Search for the optimal subset of measures, that solves all violations with the least possible cost



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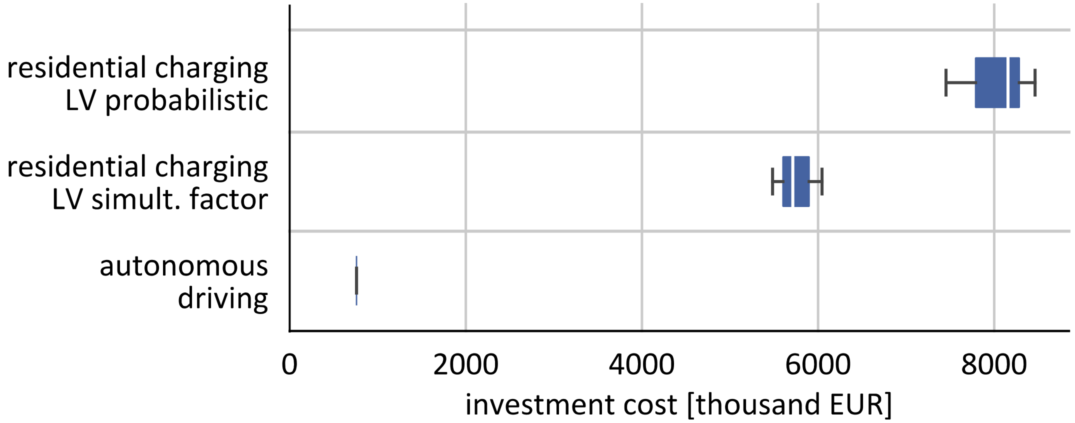
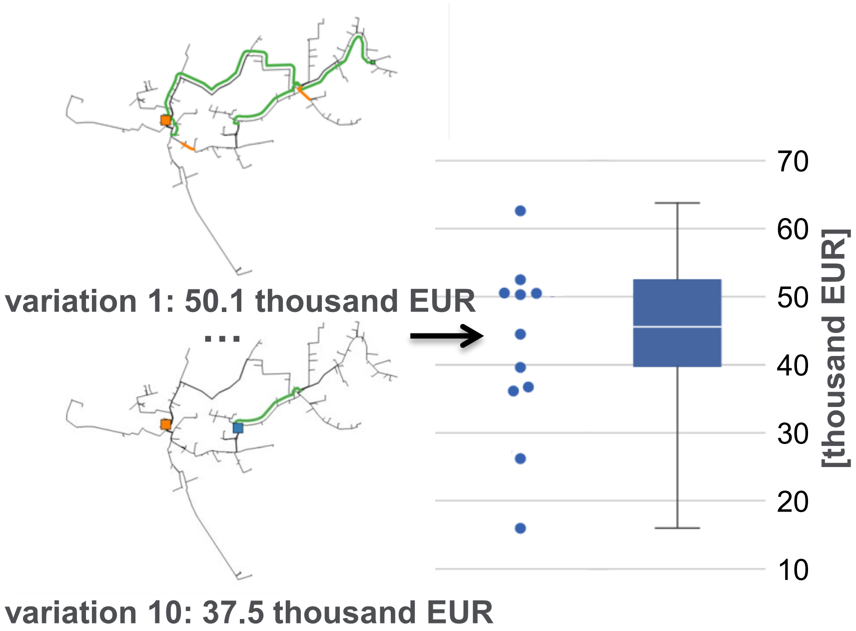
# Reinforcement and Expansion Cost

## Residential Charging and Autonomous Driving

- 10 spatial distribution variations of BEV charging points result in a distribution of reinforcement and expansion cost
- Distribution width indicates the amount of uncertainty regarding expected investment cost




### Residential charging

- Median cost are 2.5 million EUR lower when using simultaneity factors and the spread of cost decreases
- Simultaneity factors underestimate violations which directly translates into undererstimating cost

### Autonomous driving

- Investment cost around 800,000 EUR
- No variation (only HV/MV transformer replacement)
- Additional costs (coordination of vehicles, mileage, …) are not considered



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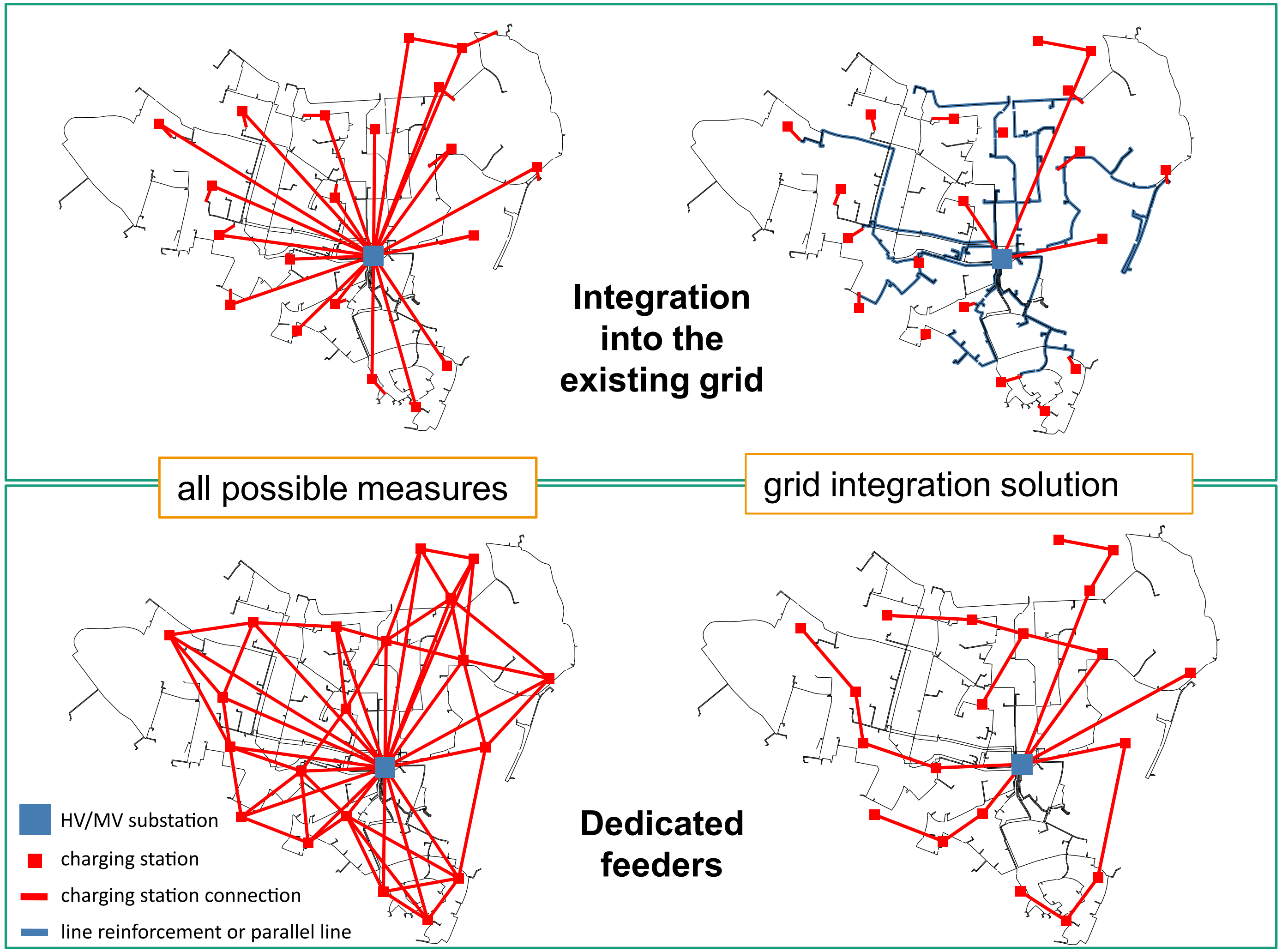
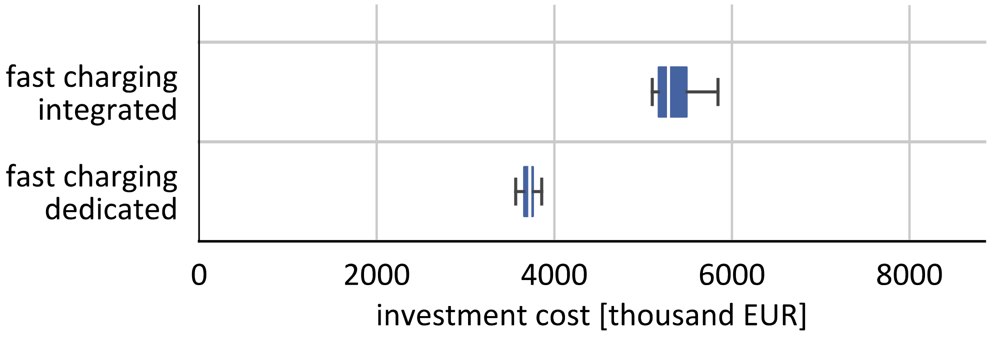
# Reinforcement and Expansion Cost

## Fast Charging Stations




- Integrating the fast charging stations into the existing grid leads to 1.6 million EUR higher median cost compared to dedicated feeders
- Investment cost for dedicated charging station feeders are more predictable and do not depend as much on the spatial distribution of the charging stations





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# Summary and Conclusion

**Comparison of a probabilistic distribution approach to simultaneity factors**

- The usage of simultaneity factors leads to an **underestimation** of power demand, violations and **grid integration cost** when applied on **small numbers** of BEVs (e.g. in LV feeders)
- Simultaneity factors seem to be **well suited** for application in **MV grids** or for assessing MV/LV transformer loading

**Comparison of charging infrastructure concepts**

- The **autonomous driving** scenario shows cost saving potential compared to **residential charging** (note: only costs from a grid integration perspective are considered)
- Dedicated feeders for fast charging stations result in **more predictable and overall lower** cost

**Outlook and possible further studies**

- Grid integrations studies with **combinations of different charging infrastructure concepts** and/or more grids
- More comprehensive assumptions for autonomous driving
- Quantification: What is the **limit** (number of BEVs) **for the application of simultaneity factors**?

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