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Integrating electric vehicles and stationary electricity storages into decentralized energy systems with photovoltaic generation

Patrick Jochem, Katrin Seddig, Johannes Schäuble and Wolf Fichtner

Chair of Energy Economics (Prof. Fichtner)

Agenda

1. Introduction
2. Methodology and model structure
3. Results
4. Conclusion and Outlook

Motivation

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Situation

The ongoing energy transition leads to
- build-up of photovoltaic (PV) systems
- **growing share of electric vehicles (EV)**
- declining battery costs

Challenge

- Fluctuation of power generation through RES
- An increasing number of EV cause
  - increase of energy consumption of a representative household
  - influence of the grid load (i.e. peak power)
- Local stationary or mobile storages might solve this challenge

Objective

- Use of different fleets of EVs as controllable loads
  - integration of PV power through smart charging
  - evaluation of uncertainties of PV generation and energy demand

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Energy Policy

journal homepage: www.elsevier.com/locate/enpol

ELSEVIER

On the influence of jurisdiction on the profitability of residential photovoltaic-storage systems: A multi-national case study

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Energy Policy 98 (2016) 520–532

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ELSEVIER

ENERGY POLICY

Solar energy storage in German households: profitability, load changes and flexibility

CrossMark

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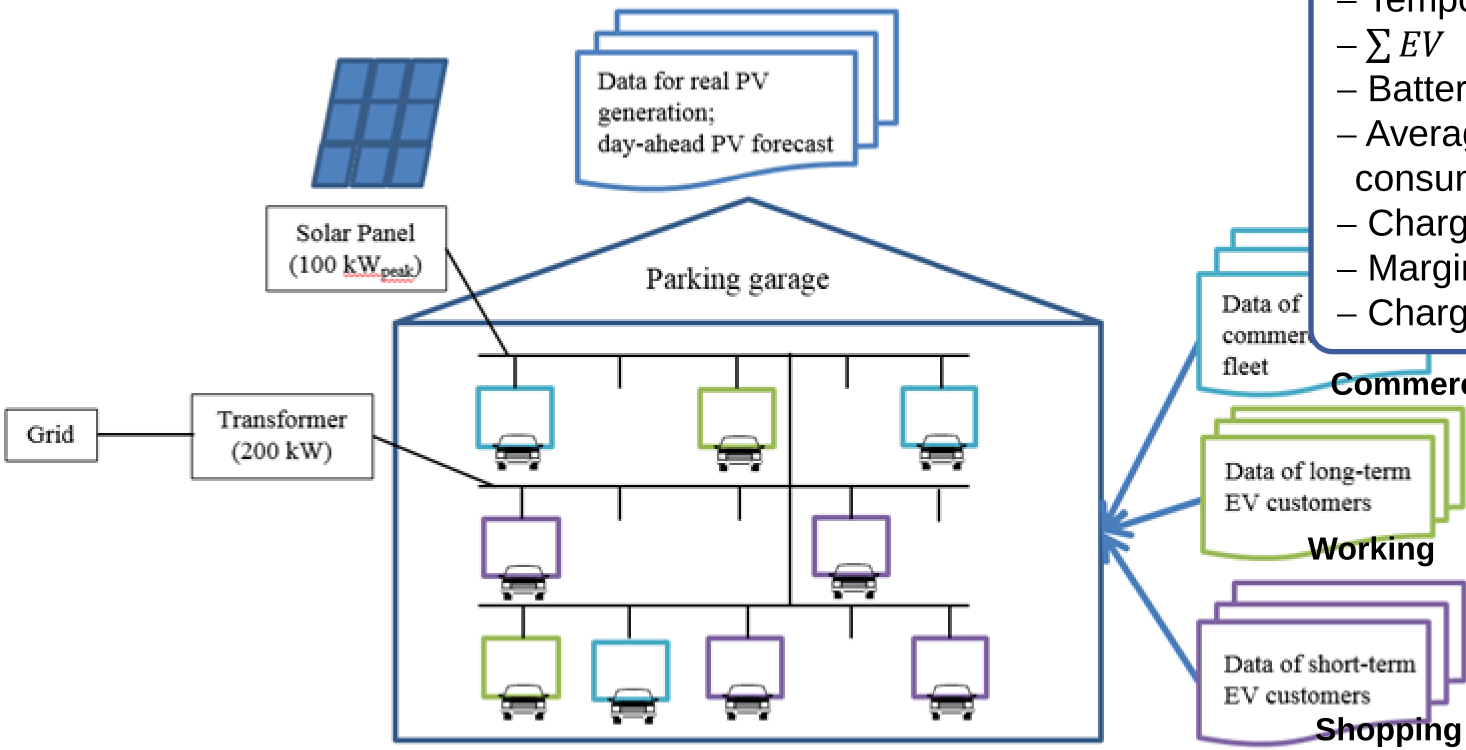
Overview model structure of the parking garage use case



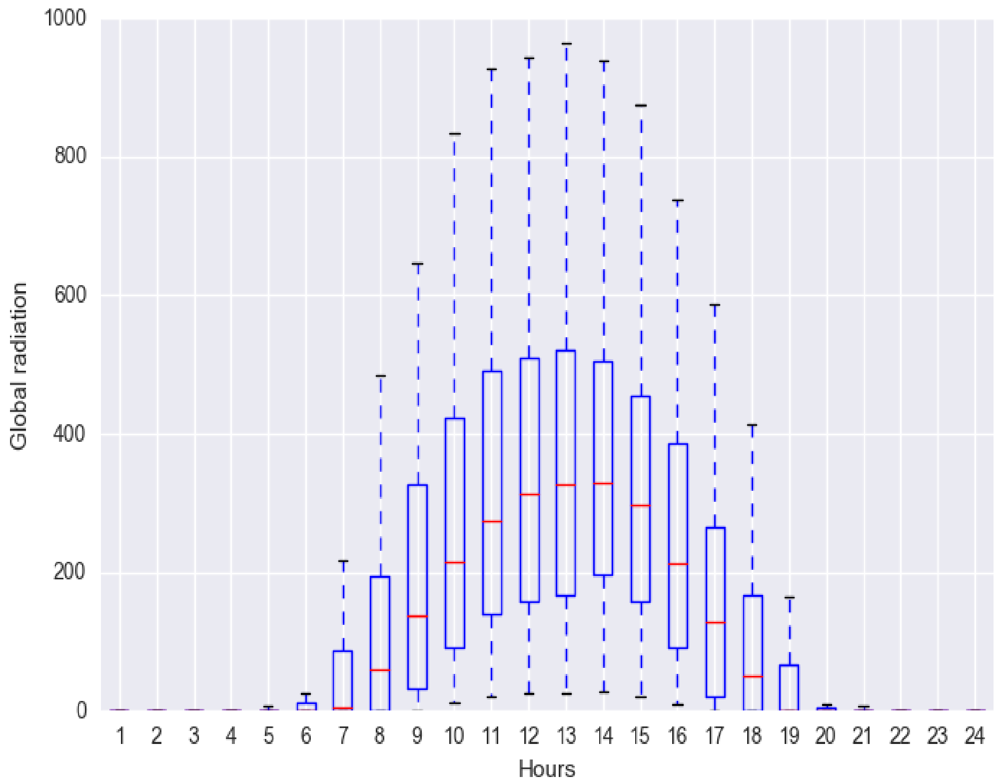
Main assumptions:
– Simulation horizon (1 day)
– Temporal resolution (15min)
– $\sum EV \leq \sum Charging\ Points$
– Battery capacity: 24 kWh
– Average gross electricity consumption: 0.2 kWh/km
– Charging power 11 kW
– Marginal costs of PV = 0
– Charge only if connected

Further characteristics of the three EV fleets:

- Each EV fleet is modeled with a three-dimensional kernel density estimation (arrival and departure time, energy demand)

Uncertainties of RES generation

Fluctuation of PV generation over one year



Data source: Meteotest (2014)

For considering this uncertainty we constructed three scenarios for PV generation

1 Perfect Foresight

hypothetical a-priori known PV curves

2 Day-Ahead Foresight

prediction of the day-ahead PV generation

3 Historic Foresight

empirical perturbed forecast-curves reflecting the uncertainty with time series analysis (time-dependent normal-distribution)

Model conception for cost minimization with PV utilization

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Perfect Foresight PV optimization (MILP)

Objective: Minimizing cost *c* of external needed charging power *x* (with a-priori known PV curve)

$$\min_x C = \sum_t (c_t \cdot x_t)$$

Day-Ahead Foresight PV optimization (MILP)

1st stage objective: Planning with forecasted PV and energy demand

$$\min_x C = \sum_t (c_t \cdot x_t)$$

Deviation cost of realized day

2nd objective: Deviation of forecasted/ realized PV and energy demand

$$\min_x C = \sum_t \left(a \cdot c_t \cdot pos\left(x_t^{real} - x_t\right) + b \cdot c_t \cdot neg\left(x_t^{real} - x_t\right)\right)$$

Historic Foresight PV optimization & uncertain energy demand (Two-stage stochastic optimization with Sample Average Approximation (SAA))

Objective: Minimize the cost of the 1st stage decision plus the expected cost of the 2nd stage decision

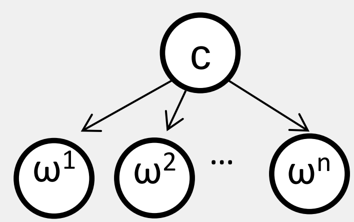
$$\min_x \sum_t (c_t \cdot x_t) + E_\omega(Q(x,\omega))$$

With SAA

$$\min_x \sum_t (c_t \cdot x_t) + \frac{1}{N}\sum_{j=1}^{N} Q(x,\omega^j)$$

1st stage — pricing + scheduling

2nd stage — deviation price for volatile PV & energy demand



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Two-stage stochastic optimization with SAA

Objective

$$\underbrace{\min_{x} C = \sum_t (c_t \cdot x_t)}_{\text{First stage (costs for electricity from grid)}} + \underbrace{\frac{1}{N} \sum_j \left(\sum_t \left(a \cdot c_t \cdot pos\left(x_{j,t}^{scen} - x_t\right) + b \cdot c_t \cdot neg\left(x_{j,t}^{scen} - x_t\right)\right) + s_{i,j} \cdot f \right)}_{\text{Second stage}}$$

Constraints First Stage

Sum of all chargings fulfills demand of all accepted queries:	$\sum_t \frac{1}{4} \cdot p_{i,t} = d_i$	$\forall\, i$
Defines demand of all accepted queries:	$d_i = q_i \cdot v_i$	$\forall\, i$
At least 90% of queries are fulfilled:	$\sum_i q_i \geq 0.9$	$\forall\, i$
Sum of overall charging considers global wattage limit:	$\sum_i p_{i,t} \leq GW$	$\forall\, t$
External needed charging power from the grid:	$x_t \geq \sum_i p_{i,t} - PV_t$	$\forall\, t$
Positive needed external charging power from the grid:	$x_t \geq 0$	$\forall\, t$
No negative chargings:	$p_{i,t} \geq 0$	$\forall\, i, t$

Variables

External charging power from the grid	x
External charging power from the grid, scenario	x^{scen}
Binary if EV query is served	q
Total EV demand	d
Charging power	p
EV query demand	v
Binary if EV query is served in SAA scenario	s

Parameters

EEX-Price	c
Deviation penalty demand	a
Deviation penalty supply	b
PV power	PV
Global Wattage	GW
Local Wattage	LW
Number of scenarios of SAA	N
Penalty for not serving SAA scenario EV query	f

Indices

Index for time steps	t
Index for number of vehicles	i
Index for number of scenarios of SAA	j

Two-stage stochastic optimization with SAA

Objective

$$\min_{x} C = \sum_t (c_t \cdot x_t) + \underbrace{\frac{1}{N} \sum_j \left(\sum_t \left(a \cdot c_t \cdot pos\left(x_{j,t}^{scen} - x_t\right) + b \cdot c_t \cdot neg\left(x_{j,t}^{scen} - x_t\right)\right) + s_{i,j} \cdot f \right)}_{\text{Second stage (penalties for not meeting the load forecast)}}$$

Second stage

(penalties for not meeting the load forecast)

Constraints Second Stage

Sum of all chargings and error term equal demand of all queries:	$\sum_t \frac{1}{4} \cdot p_{i,j,t}^{scen} + e_{i,j} = d_{i,j}^{scen}$	$\forall$ i,j
Demand of all scenario queries:	$d_{i,j}^{scen} = \mathrm{q_i} \cdot v_{i,j}^{scen}$	$\forall$ i,j
Sum of overall scenario charging considers global wattage limit:	$\sum_\mathrm{i} p_{i,j,t}^{scen} \leq \mathrm{GW}$	$\forall$ j, t
Required electricity from the grid:	$x_{j,t}^{scen} \geq \sum_\mathrm{i} p_{i,j,t}^{scen} - PV_{j,t}^{scen}$	$\forall$ j, t
Error term for infeasibility states in second stage:	$\mathrm{e}_{i,\mathrm{j}} \leq \mathrm{s}_{i,\mathrm{j}} \cdot v_{i,j}^{scen}$	$\forall$ i, j
No discharge:	$p_{i,j,t}^{scen} \geq 0$	$\forall$ i, j, t
Positive error term:	$\mathrm{e}_{i,\mathrm{j}} \geq 0$	$\forall$ i, j

Variables

External charging power from the grid	x^{scen}
Total EV demand	d^{scen}
Charging power	p^{scen}
PV power	PV^{scen}
Binary if EV query is served	q
EV query demand	v
Binary if EV query is served in SAA scenario	s
Auxiliary variable for SAA scenario	e

Parameters

EEX-Price	c
Deviation penalty demand	a
Deviation penalty supply	b
Global Wattage	GW
Local Wattage	LW
Number of scenarios of SAA	N
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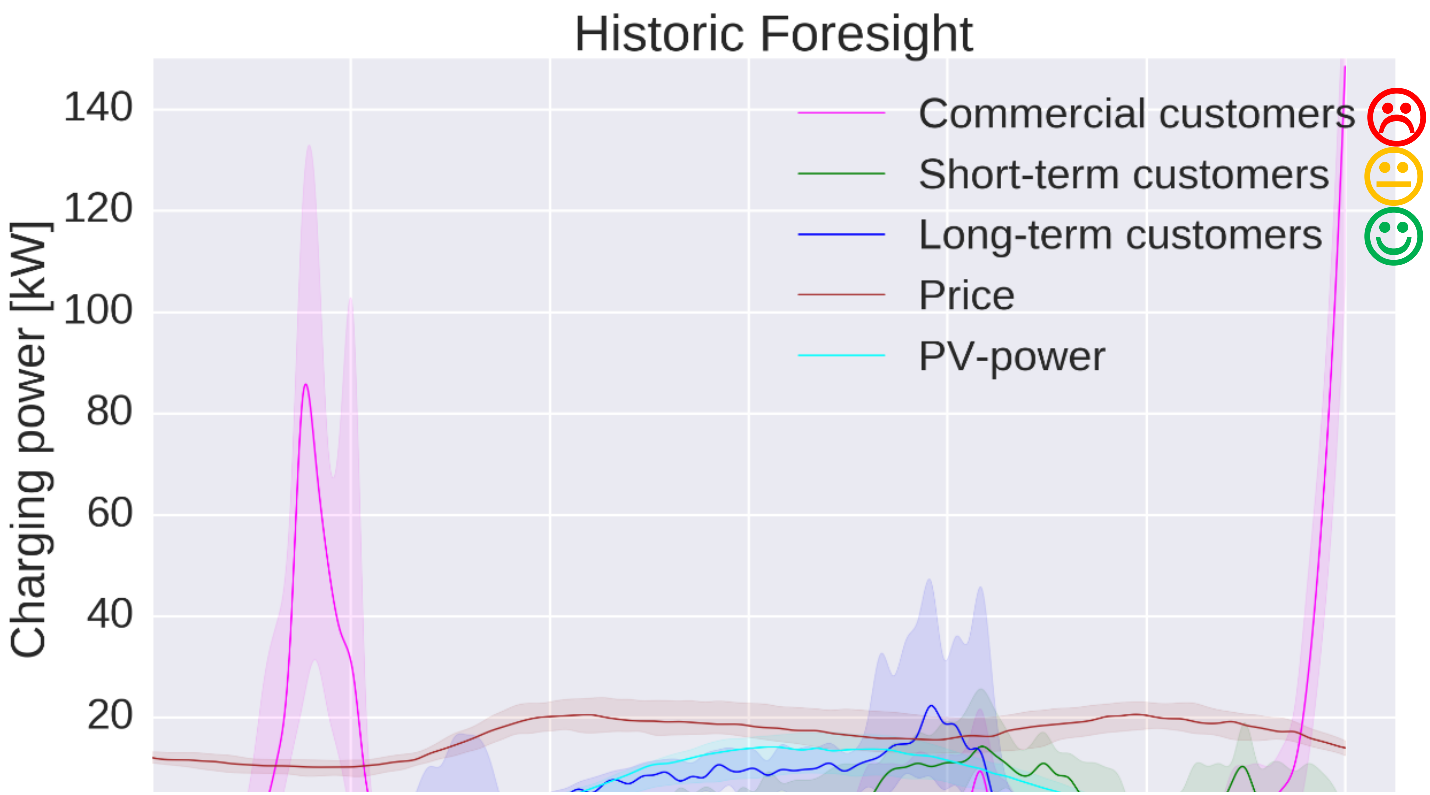
Load management of EV fleets with uncertain PV generation & energy demand

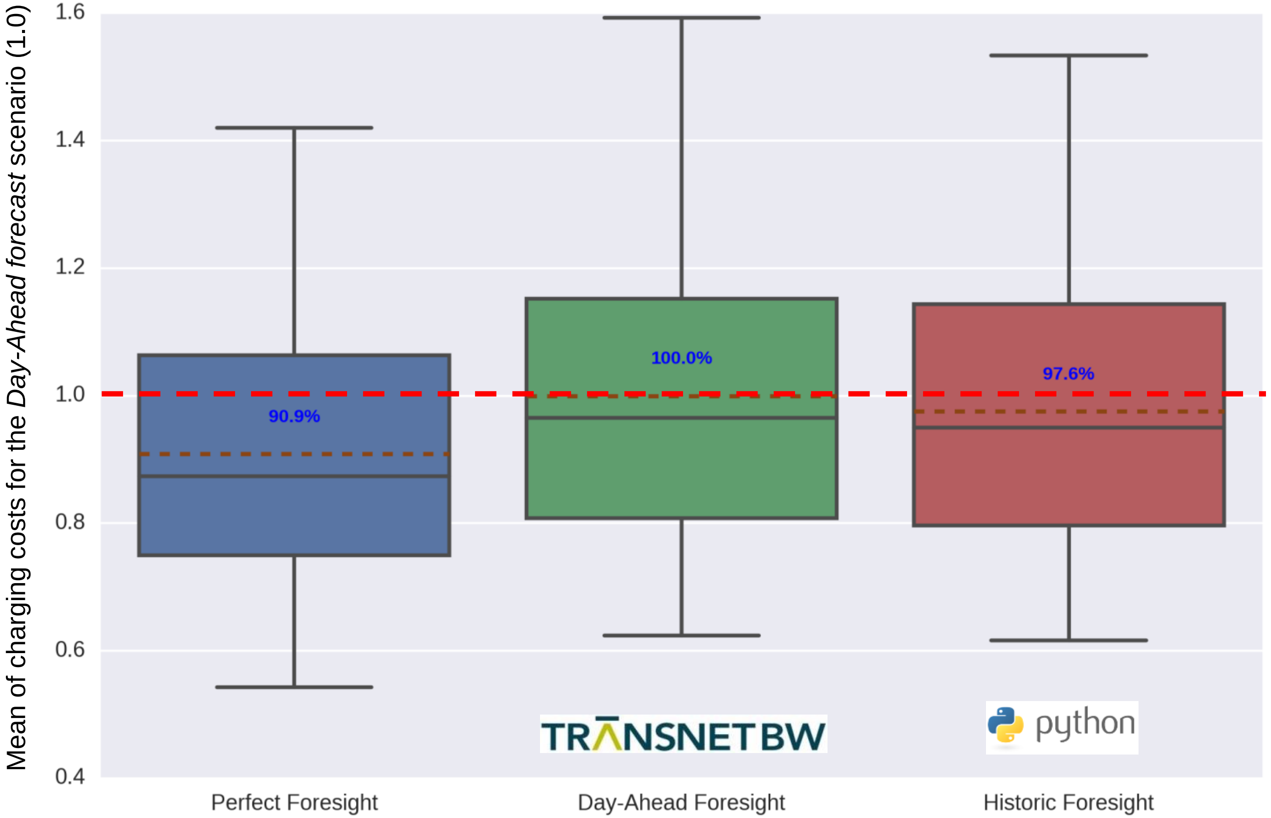
Charging load distribution of the three EV fleets after optimization with respect to PV integration and cost minimization



- ➢ All three EV fleets can use PV power for charging
- ➢ Long-term customers use the highest share of the PV power for charging

Cost evaluation of the uncertainty in PV generation and energy demand

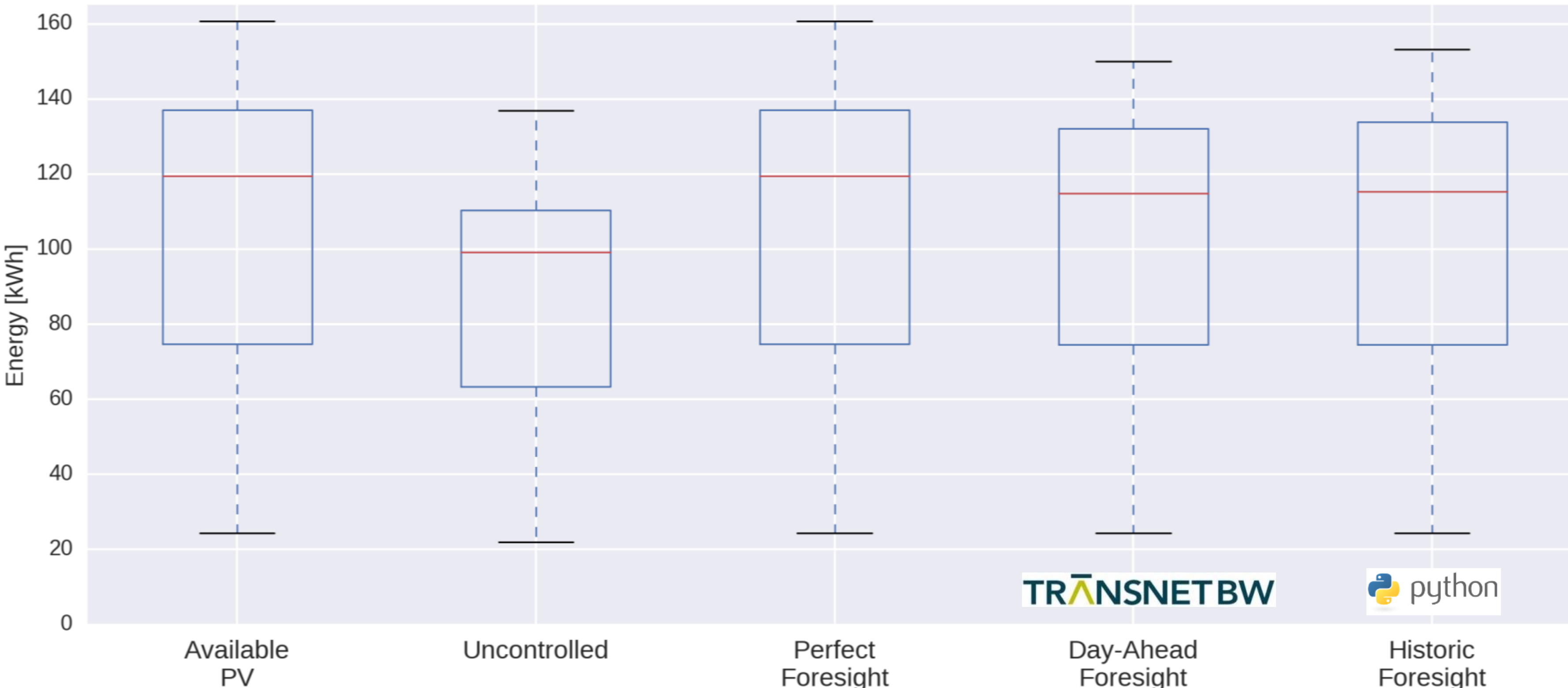
Comparison of the different costs for the applied strategies



- ➢ Stochastic programming is important when considering charging costs.
- ➢ *Historic Foresight* scenario leads only to marginal cost reductions.

PV integration by EV charging

Comparison of the PV utilization of the applied strategies



~80% | 100% | >90% | >90%

➢ PV on parking garage is synergetic

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Conclusions

- Uncertainties of PV generation (time and load) and EV charging (arrival and departure time, required electricity) have an impact on charging costs and PV usage for charging.
- It is wise to use stochastic programming when evaluating the share of flexible loads (such as PV) for EV charging.
- Especially commuter vehicles are highly suitable to be charged by electricity from (local) PV generation.
- Parking garage operators can reduce their electricity demand from grid significantly if PV is installed.
- We see high synergies with the *decarbonisation* of transport.

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Thank you for your kind attention!
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Back up – Model structure