Exploring the trade-off between cost and security of supply for decentralized autonomous energy systems

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Motivation & Aim

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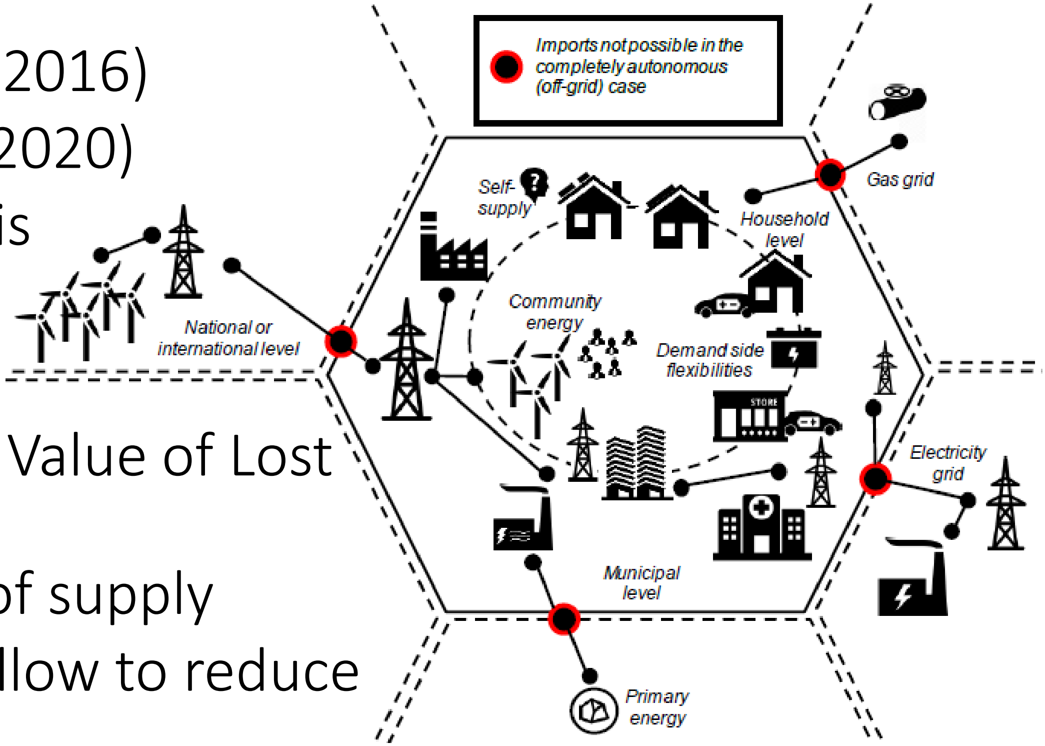
- Energy autonomy: Complete (off-grid) vs. Balanced (with imports)
- Municipal energy autonomy
  - Empowers local communities (Rae & Bradley, 2012; Boon & Dieperink, 2014)
  - Enables the energy transition (Engelken et al., 2016)
- Energy autonomy increases costs (Weinand et al., 2020)
- Demand-side measures can potentially mitigate this

- Project aim
  - Determine a spatially and temporally resolved Value of Lost Load for Germany
  - Analyze trade-offs between cost and security of supply
  - ➢ Can dispensing with 100% security of supply allow to reduce the cost increase from energy autonomy?



Value of Lost Load (VoLL)

- Economic indicator expressing the costs associated with an interruption of electricity supply (Schröder & Kuckshinrichs, 2015)
- Allows to translate reduced supply security from load shedding into monetary terms
- Production-function requires little and relatively easily obtainable data

$$\text{VoLL} = \frac{\big((8760 - H_{PC} - H_w) \cdot W\big) \cdot Sf \cdot (Pop_e + cf \cdot Pop_{ne})}{EC_a} \left[\frac{€}{kWh}\right]$$

- H_{PC} : Hours spent on personal care (11h per day by default)
- H_w : Hours spent working
- W : Net hourly wage
- Sf : Substitutability factor (0.5 by default)
- Pop_e : Employed population
- Pop_{ne} : Non-employed population
- cf : Leisure value relative to employed person (0.5 by default)
- EC_a : Annual household electricity consumption

(de Nooij et al., 2007)

VoLL calculation for Germany

$$VoLL_d = \frac{\left(\left(4745 - H_{w,d}\right) \cdot W_{net,d}\right) \cdot 0.5 \cdot \left(Pop_{e,d} + 0.5 \cdot Pop_{ne,d}\right)}{EC_{a,d}}$$

- Spatial resolution: NUTS 3 Districts
- Temporal resolution: Hours
- Obtaining net hourly wage by district:

$$W_{net,d} = \frac{12 \cdot W_{gross,d}}{H_{w,d}} \cdot \left(1 - \frac{TTC_d}{TI_d}\right)$$

- Scaling VoLL to hourly profile:

$$VoLL_{t,d} = \frac{VoLL_d}{EC_{mean,d}} \cdot \frac{SLP_t \cdot EC_{a,d}}{SLP_a}$$

$\boldsymbol{H_{w,d}}$	Annual working hours	Erwerbstätigenrechnung (StBA)
$\boldsymbol{Pop_{e,d}}$, $\boldsymbol{Pop_{ne,d}}$	(Non-) Employed population	Gemeindeverzeichnis (StBA), Erwerbstätigenrechnung (StBA)
$\boldsymbol{EC_{a,d}}$	Annual household electricity consumption	Electricity Consumption of Private Households per Country (Ffe, StBA, BMWi)
$\boldsymbol{W_{gross,d}}$	Median gross monthly wage	Bruttoarbeitsengelte (BA)
$\boldsymbol{TTC_d}$, $\boldsymbol{TI_d}$	Total Taxes collected, Total Income	Lohn- und Einkommensteuerstatistik (StBA)
$\boldsymbol{SLP_t}$	Household Standard Load Profile	Standardlastprofile (BDEW)

The RE^{3}ASON [(1)] model

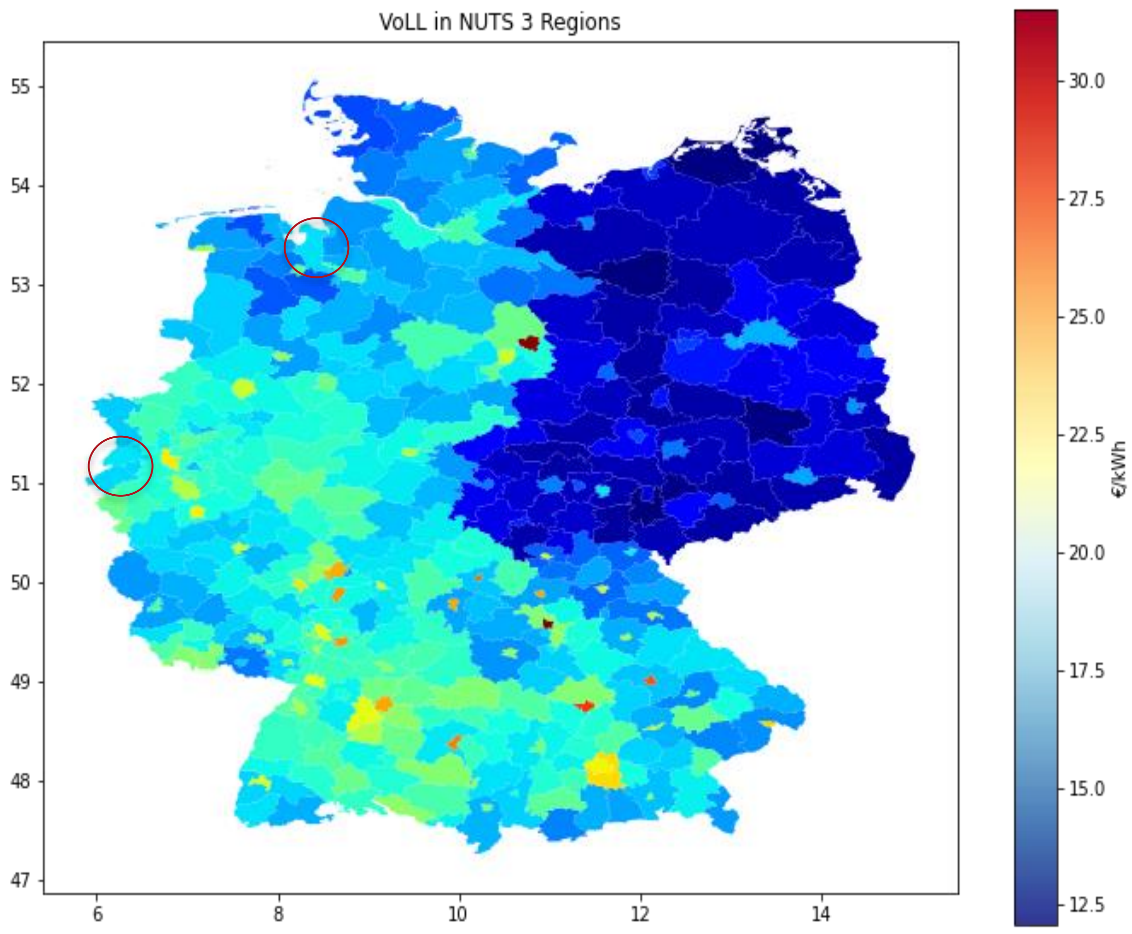
- Municipal energy systems modeling
- Energy demand and renewable potential assessment using open data
- Typified timeslice structure
- Residential heat and electricity demand
- Mixed-integer programming (MIP) to minimize discounted system cost

5 Scenarios considered:

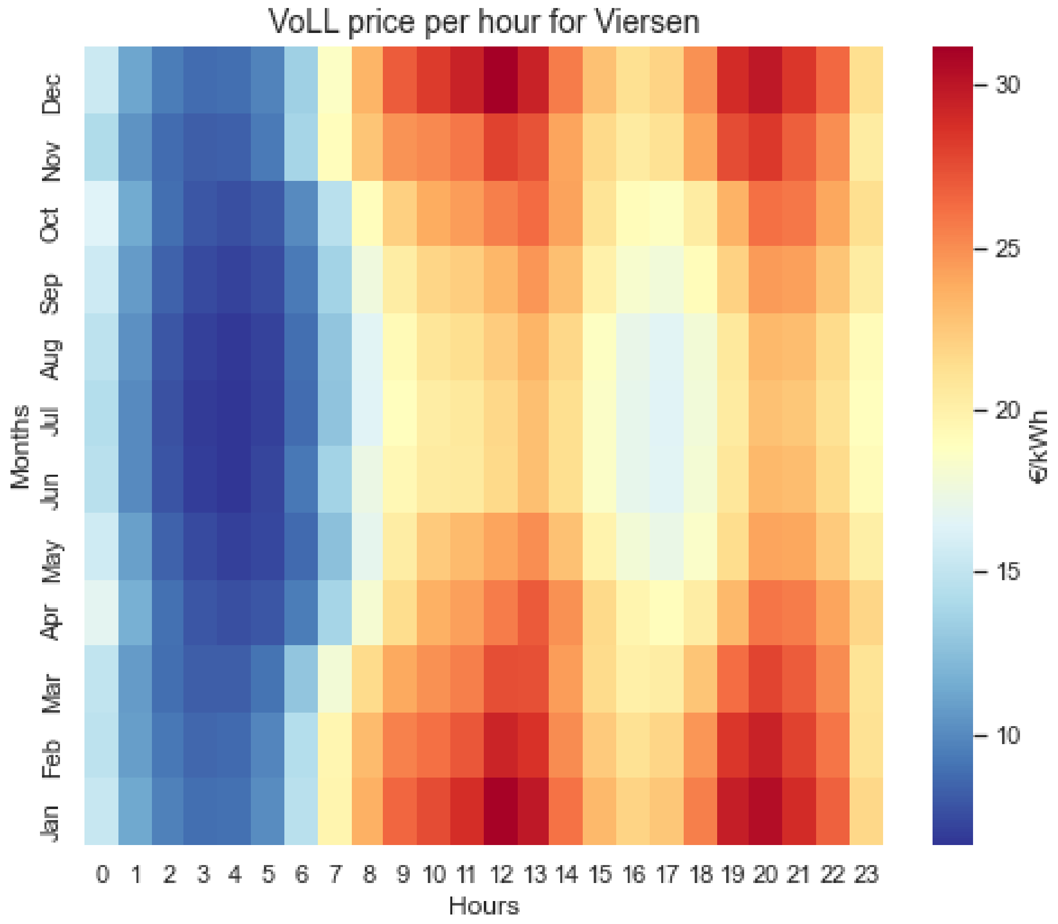
Scenario	Baseline	ElAut	ElAutVoll	Aut	AutVoll
Power imports	X				
Fuel imports	X	X	X		
VoLL			X		X

(1): Renewable Energies and Energy Efficiency Analysis and System OptimizatioN, developed according to Mainzer (2018) and Weinand (2020)

Spatio-temporal VoLL

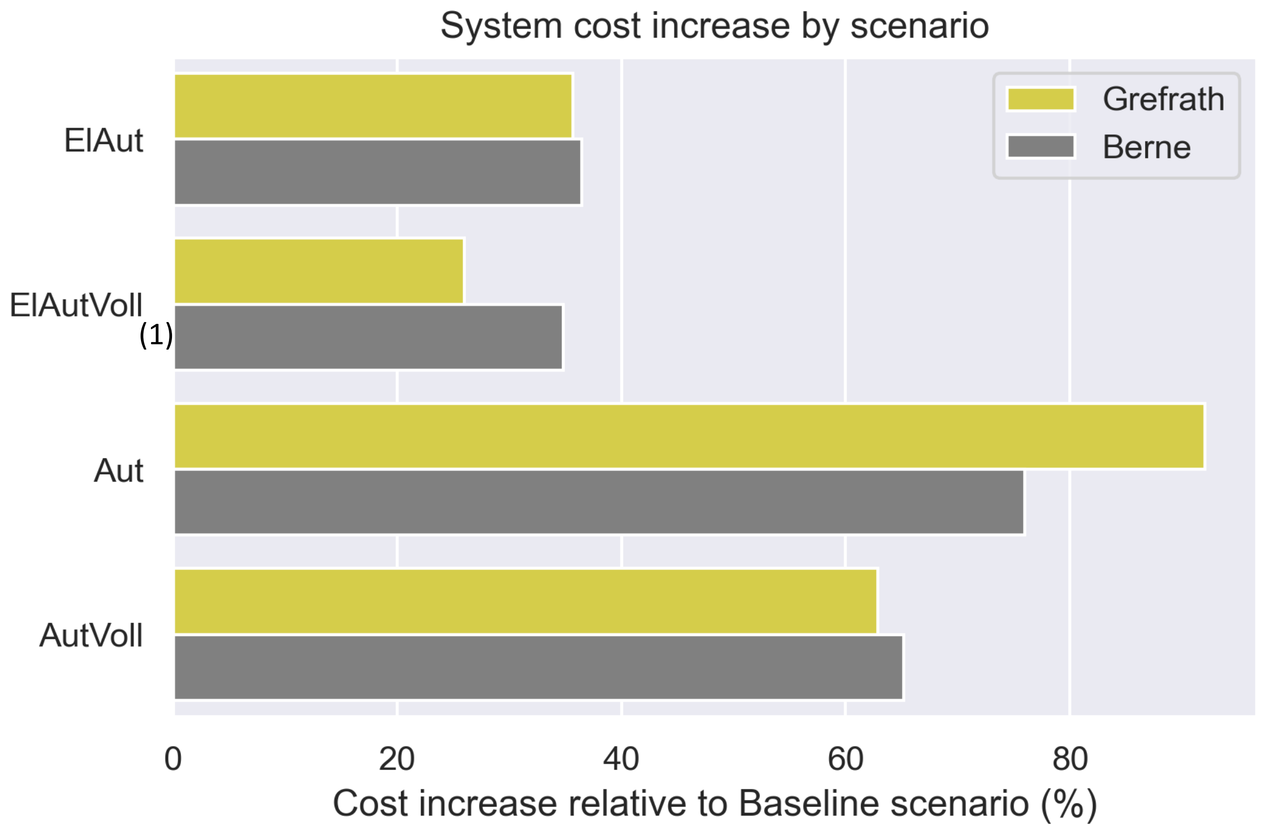


VoLL is highest in urban areas



VoLL is higher in winter than in summer and highest around noon and 20h

Energy system overview



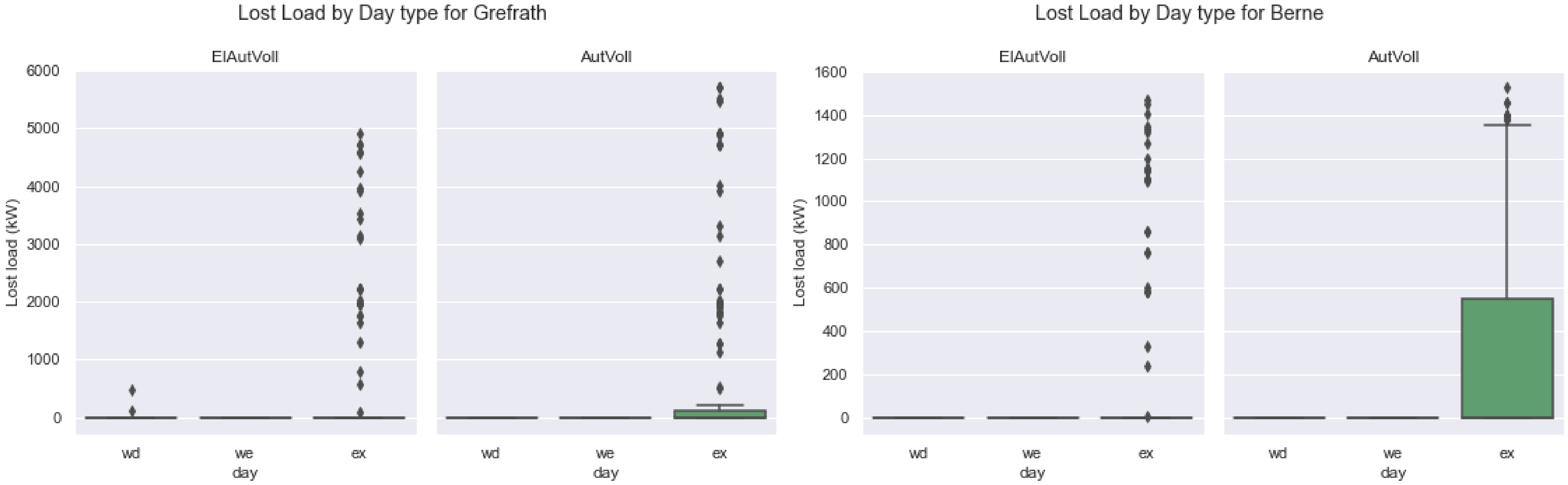
Share of total load that is shed

	Grefrath	Berne
ElAutVoll	0.39 %	0.16 %
AutVoll	0.66 %	0.20 %

The introduction of VoLL allows to reduce the cost premium of energy autonomy by up to a third while less than 1% of load is shed

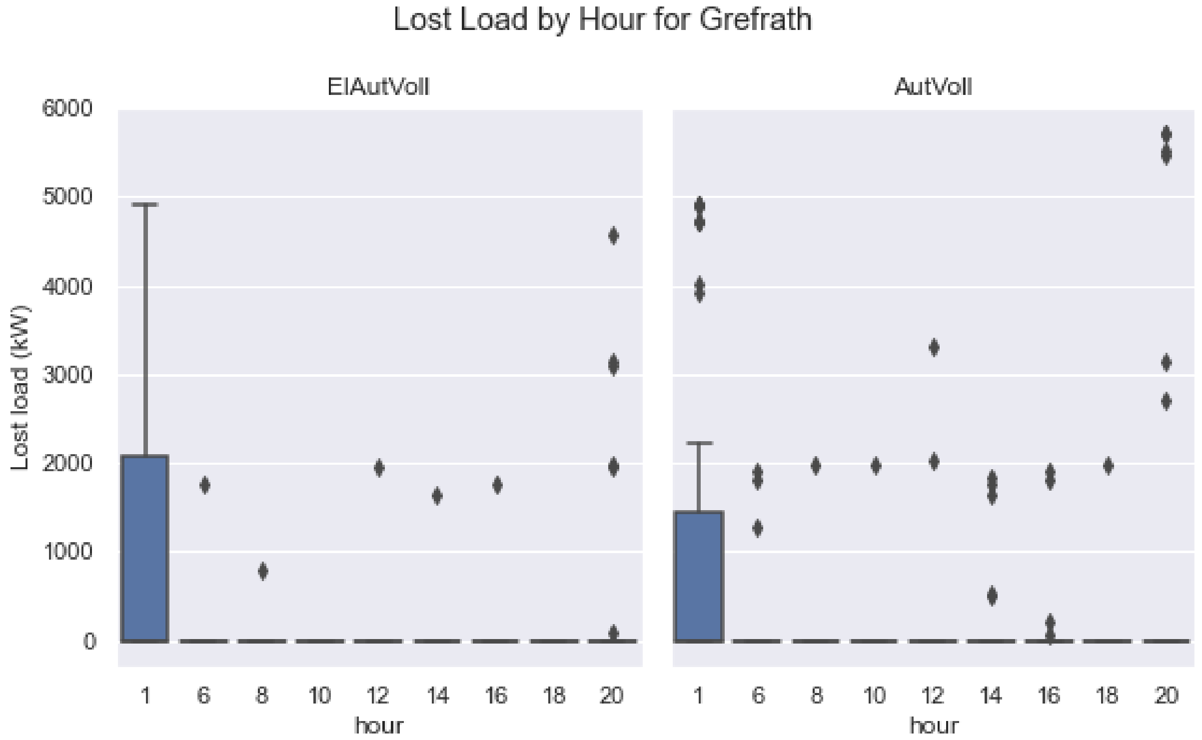
(1): Optimality gap for Berne in ElAutVoll above 9% whereas it is less than 5% for all other scenarios

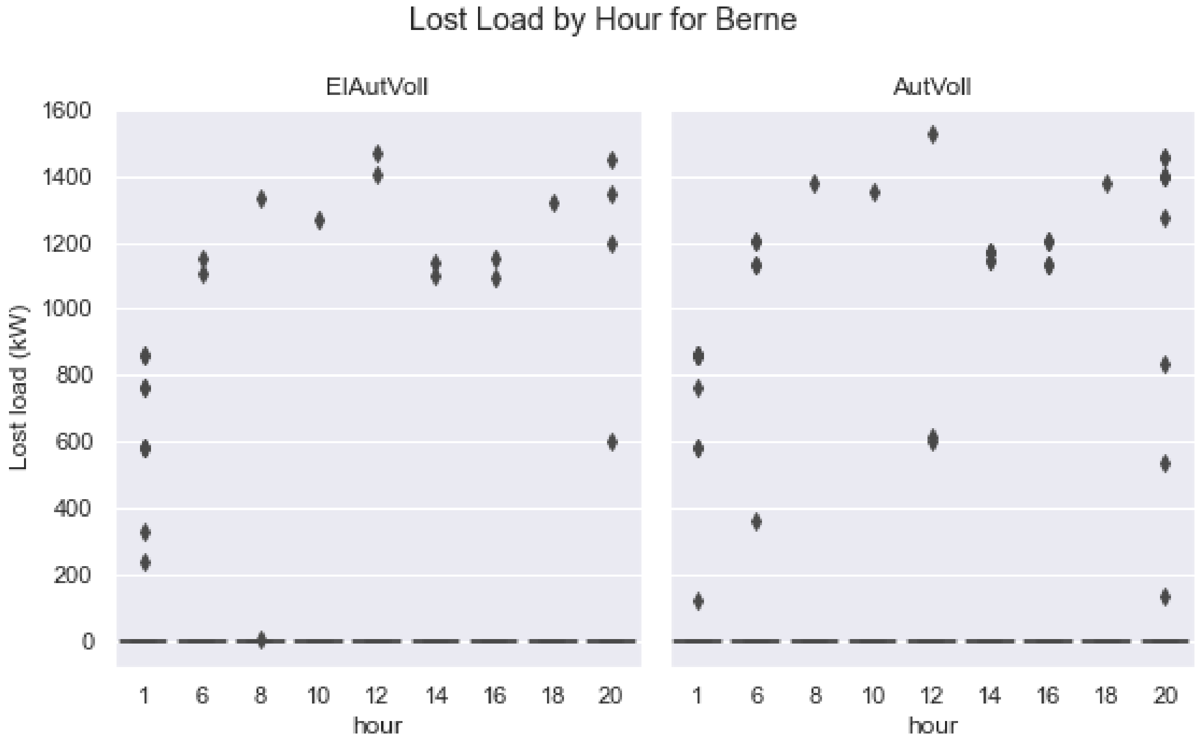
Use of VoLL by daytype



Cost-effective solution for extreme states

Use of VoLL by hour





Mainly used to shed load at night

Limitations & Outlook

- Limitations
  - Net wage approximation for VoLL
  - Temporal structure with typified days
  - Robustness of results

- Outlook
  - Full-year hourly model resolution
  - Analysis of different municipalities and energy system layouts

Key findings

- Spatio-temporal VoLL
  - VoLL is higher in urban areas and during hours of peak load
  - Taking average VoLL leads to a significant loss of information
- VoLL allows to moderate system cost increase while maintaining a high supply security
- PV-dominated energy autonomy seems to benefit more from VoLL
- Demand-side flexibility provides resilience to exceptional circumstances

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Thank you for your attention

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