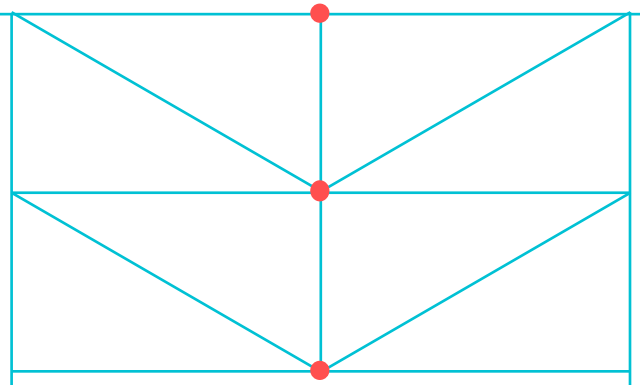
Evaluation of the impact of robustness regarding demand side uncertainty on the estimation of load flexibility bands for home energy systems



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TUHH
Hamburg University of Technology

Tizian Schug*, Kathrin Fischer

EffiziEntEE

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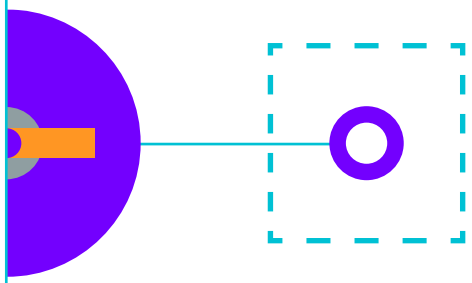
Agenda

1. Motivation
2. Basic concept of flexibility bands
3. Introduction to case study and intermediate results
4. Extension: Acceptance of possible loss of comfort
5. Preliminary results
6. Conclusion & Outlook



Motivation

- Increasing electrification of sector-coupling technologies in the distribution grid
- Flexibility of controllable components poses challenges; but it also offers opportunities like new business models
- Example:
  - Prosumers: have some flexibility potential, signed contracts with aggregator
  - Aggregator: pools multiple decentralized energy resources and wants to market flexibility from prosumers
  - Information needed:
    - How much flexibility is available from the prosumers?
    - At what price can the service be offered?

Motivation

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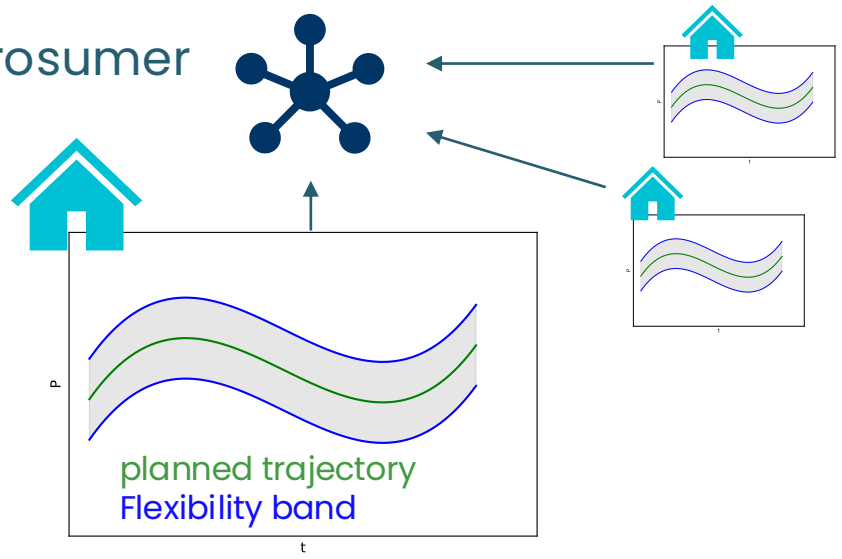
- Present approaches in literature have some short comings:
  - Flexibility is only evaluated at one point in time[1, 2]; **frequent re-evaluations** are necessary
  - Frequent exchange of information during operation[3, 4] → **Communication effort** is high

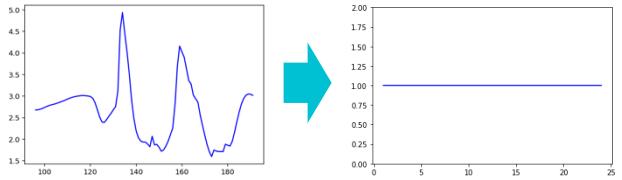
- Proposed solution: Definition of a flexibility band for every prosumer
  - Total power demand trajectory (schedule of DERs)
  - Flexibility potential for every point in time
- Requirements:
  - Band is created ahead of operation
  - Usage of flexibility is feasible
  - Intervention is of short notice, is not anticipated
  - Planning reliability for succeeding interventions



[1] De Coninck & Helsen (2016): Quantification of flexibility in buildings by cost curves – Methodology and application
[2] Faqiry et al. (2019): HEMS-enabled transactive flexibility in real-time operation of three-phase unbalanced distribution systems
[3] Munankarmi et al. (2020): Quantification of Load Flexibility in Residential Buildings Using Home Energy Management Systems
[4] Saavedra et al. (2022): Flexible load management using flexibility bands

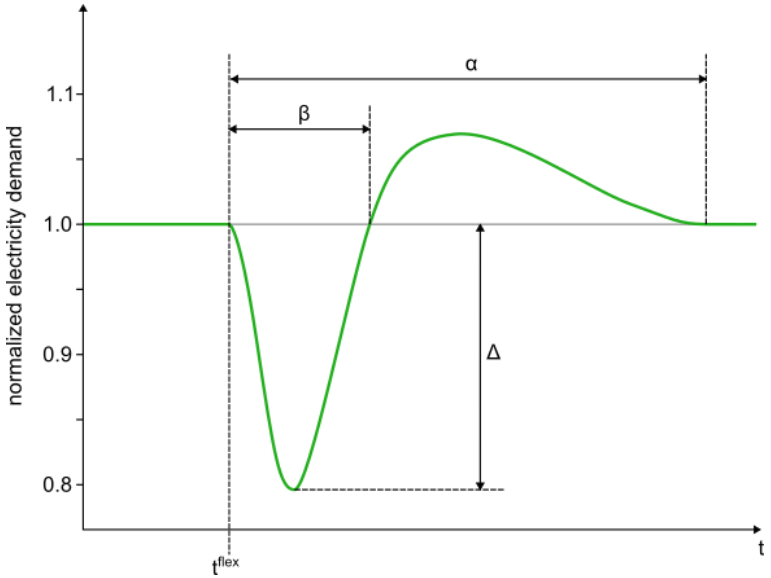
Basic concept of flexibility bands

- Starting point: HEMS creates schedule for next planning period
  → Baseline (normalized in the following)



- Quantities to characterize deviation from an original trajectory (based on IEA[5]):

–	Baseline trajectory
–	actual trajectory
t^{flex}	time of flexibility usage
Δ	deviation from baseline
α	time duration until flexibility can be used again (cooldown)
β	duration of intervention



[5] IEA EBC Annex 67 (2017): Energy Flexibility as a key asset in a smart building future

Basic concept of flexibility bands

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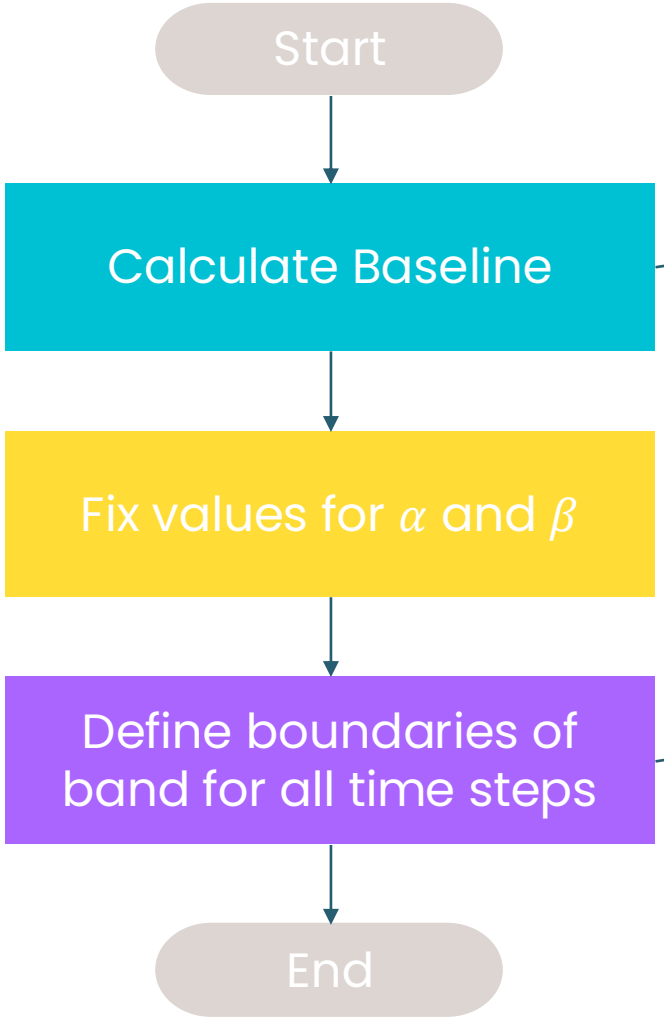
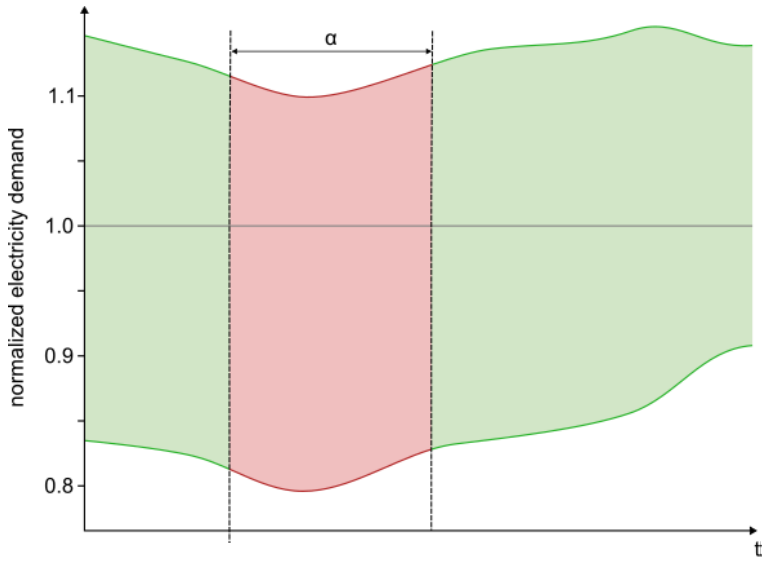


Create flexibility band with previously introduced requirements:

Baseline (once):
Minimize procurement costs
$\min \sum P_t \cdot \lambda_t$
s.t.
- Physical constraints
- Assurance of comfort

for all t^{flex}:
Maximize/Minimize Deviation
$\max \pm \Delta_{t\,flex}$

s.t.
- Physical constraints
- Assurance of comfort
- **Set initial and final values to baseline**



- Created ahead of operation
- Intervention is feasible
- Intervention is not anticipated
- Planning reliability is given

Case study and intermediate results

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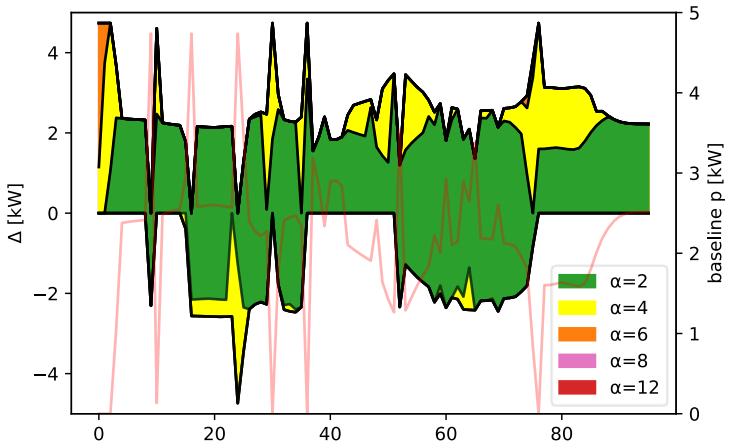
- Prosumers are based on SimBench dataset (13 households in total)
- Consider thermal energy system only (heat pump with buffer storage tank)
- Historical weather and price data for two days in January 2024
- Time horizon is discretized:
  - Temporal resolution of 15 minutes
  - Short-term Interventions: $\beta = 1$ time step

- **Robustness of baseline:**
  - Many uncertain factors, e.g. warm water demand
  - Assumption: lower limit of storage tank temperature always allows an energy intensive tapping event while keeping comfort room temperature

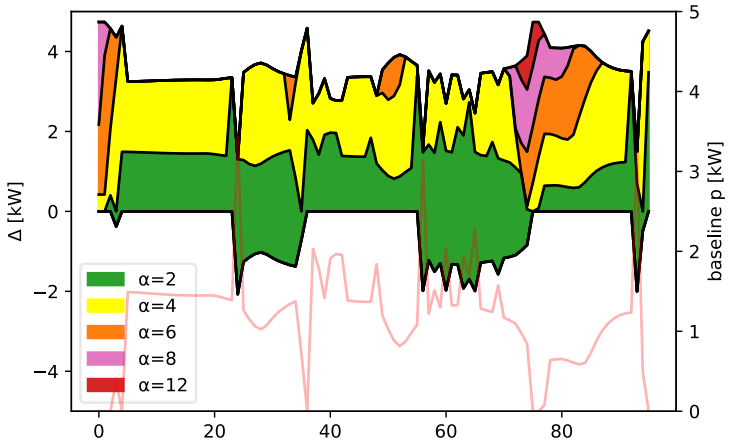
Case study and intermediate results

- Intermediate results:
  - Load reduction flexibility is limited
  - Variation of parameter α has only meaningful impact on positive deviation
  - HPs are running most of the time!
    → Untapped potential?
- Reasons for low load reduction potential:
  - Cost optimization (& no anticipation of intervention) leads to temperatures close to limits
  - But: “robust” limits may be too conservative
- Extension: for short periods of time, allow violation of comfort constraints

Prosumer 3, day 1



Prosumer 3, day 2



Extension: Acceptance of possible loss of comfort

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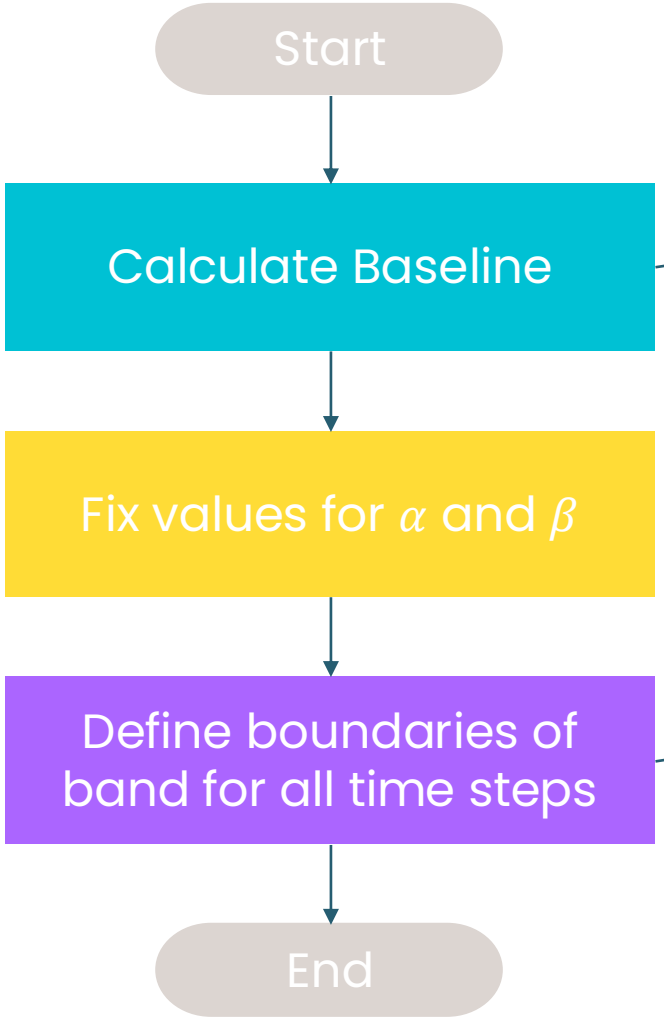
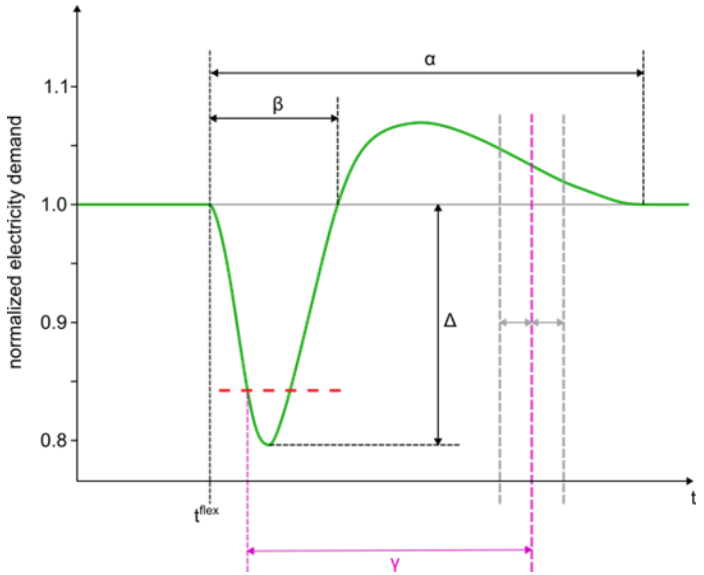


Creation of flexibility band with extension:

Baseline (once):
Minimze procurement costs
$\min \sum P_t \cdot \lambda_t$
s.t.
- Physical constraints
- Assurance of comfort

for all t^{flex}:
Maximize/Minimize Deviation
$\max \pm \Delta_{t\,flex}$
s.t.
- Physical constraints
- Assurance of comfort (except t^{flex} to $t^{flex}+\gamma$)
- **Set initial and final values to baseline**



new symbol:
γ – duration of relaxation

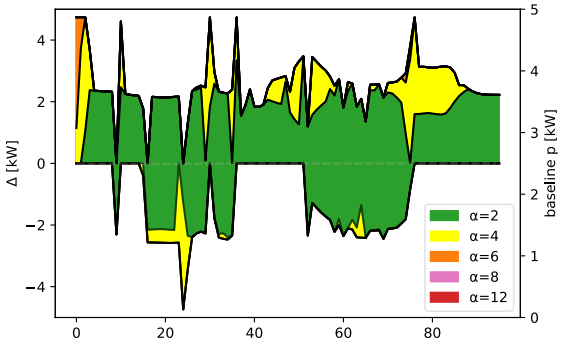
Preliminary results – I

- Safety margin is cut by half for γ time steps

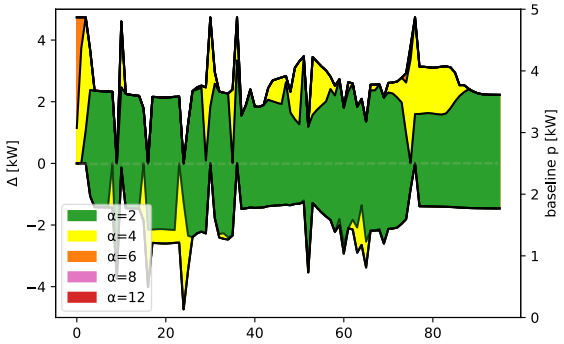
- Nb. of time steps with load red. potential:
  - $\gamma = 0$: ~1.000
  - $\gamma = 1$: ~2.200
- Nb. of time steps with heat pump activation but no potential for reduction:
  - $\gamma = 0$: ~1.300
  - $\gamma = 1$: <100

- How much additional flexibility potential is unlocked?
  - $\alpha = 2$: **+106%** (418 kWh vs. 862 kWh)
  - $\alpha = 12$: **+91%** (519 kWh vs 991 kWh)

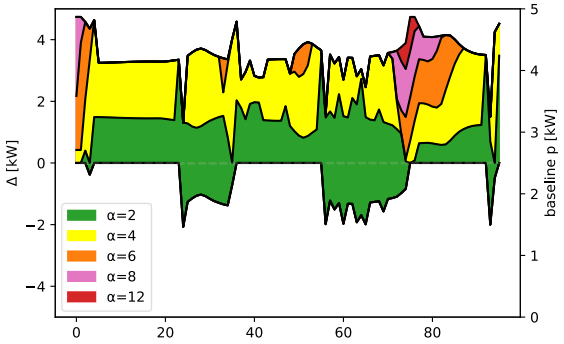
Prosumer 3, day 1, γ=0



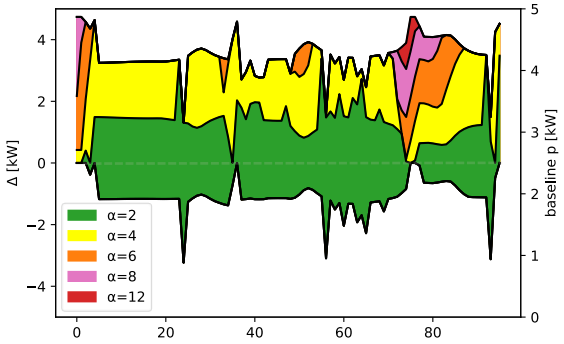
Prosumer 3, day 1, γ=1



Prosumer 3, day 2, γ=0



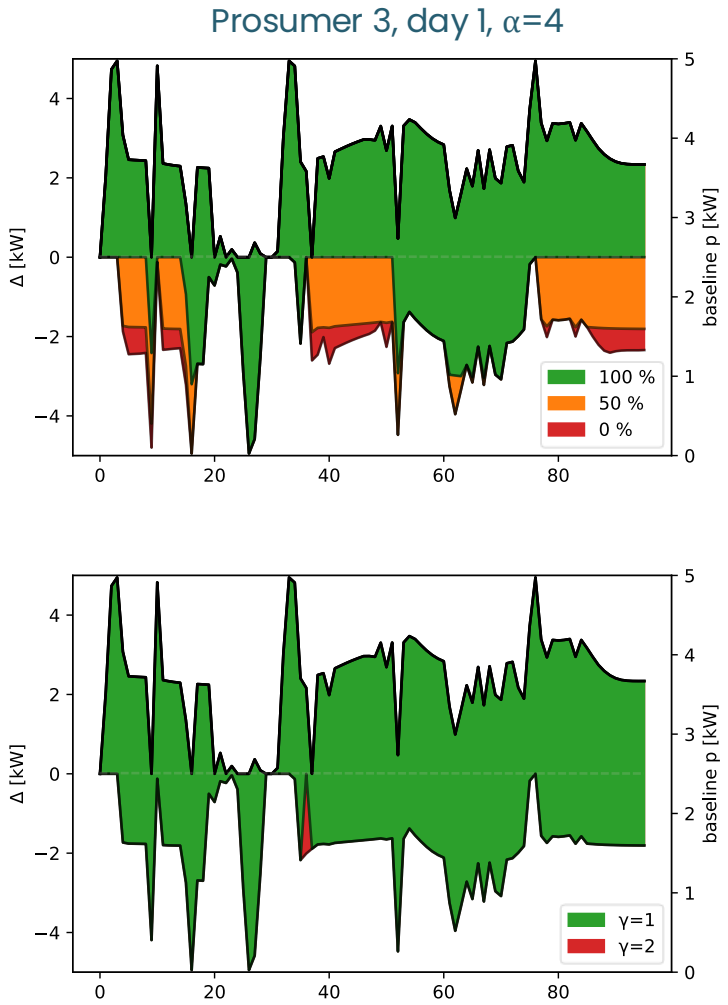
Prosumer 3, day 2, γ=1



Preliminary results – II

- Safety margin: 50% vs. 0% of original margin
  - Nb. Time steps with no reduction potential:
    $\alpha = 2$: both 61
    $\alpha = 12$: 7 → 4
  - Reduction potential:
    $\alpha = 2$: **+11%** (863 kWh →956 kWh)
    $\alpha = 8$: **+10%** (991 kWh → 1.094 kWh)

- Is the relaxation in more than one time step beneficial?
  - Reduction potential for $\alpha = 12$:
    50%: **+0.9%** (991 kWh → 999 kWh)
    0%: **+3.5%** (1.092kWh → 1.130 kWh)



Conclusion & Outlook

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- Concept for load flexibility estimation satisfies specified requirements
- Relaxation of comfort constraints can unlock flexibility potential
  → However, marginal utility decreases as buffers and limits are reduced
  → Uncertainty can still be accounted for while also providing flexibility

- Outlook:
  Integration of concept in potential analysis regarding ancillary services offered by aggregators
- Challenges:
  - Discrepancy between relaxation of lower bounds and required guarantee of feasibility
  - How to translate deviations into monetary terms (esp. possible loss of comfort)?

Thank you!

Tizian Schug
Institute for Operations Research and Information Systems
Am Schwarzenberg-Campus 1
21073 Hamburg
www.tuhh.de

tuhh.de

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