TECHNISCHE UNIVERSITÄT WIEN
Vienna | Austria

Energy Economics Group

Sustainable municipality modelling: Clustering-based modeling framework of a decentralized municipality energy and resource treatment infrastructure portfolio

Matthias Maldet
Georg Lettner
Christoph Loschan
Daniel Schwabeneder

Content

- Introduction and motivation
- Investigation setup and case study
- Optimization model
- Results investment decisions
- Modeling framework applicability
- Summary and conclusions

Introduction and Motivation

- European climate targets by interaction of centralized and decentralized generation and conversion technologies
- Community establishment to promote local energy use
- Often missing driving force for establishment and operation
- Municipal governments as community operators
- Take responsibility for operation and performs investments
- Development local sustainable municipalities (LSM)

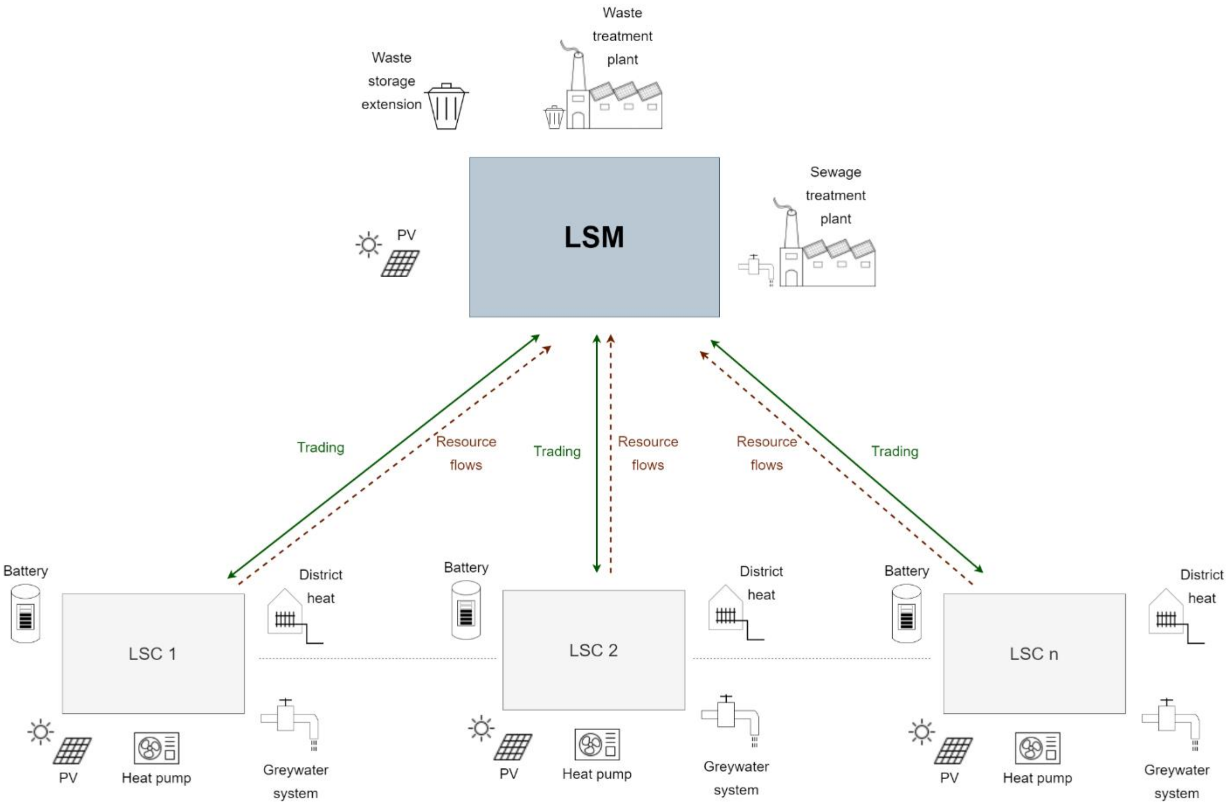
Introduction and motivation

- Local sustainable municipality (LSM)
  - Association of communities in a municipality → extension of local communities
  - Municipality as operator of the LSM
  - Similar to regional energy communities, but within municipalities
  - Energy- and resource utilization business models and investments
  - Goal: Promote sustainable development at municipal level
- LSM investment
  - Investment decisions for LSM
  - Performed at multiple locations within the municipality
  - Primary investment in resource treatment plants
  - Dependent on configuration and policy
  - Also PV investments possible if areas can be provided

Investigation setup and case study

- Muncicipality: Breitenau am Steinfeld
- Aggregation of inhabitants to 4 communities
- Additional communities with public buildings
- Predefined
  - Energy and water demands
  - Accruing waste
  - Consumer and household numbers
  - Technology potential public buildings
- Assumed
  - Demand profiles
  - Technology potential private buildings
  - Technology investment costs and operational costs
  - Different tariffs
  - Distances, grid lengths and efficiencies between LSCs

Investigation setup and case study



Investigation setup and case study

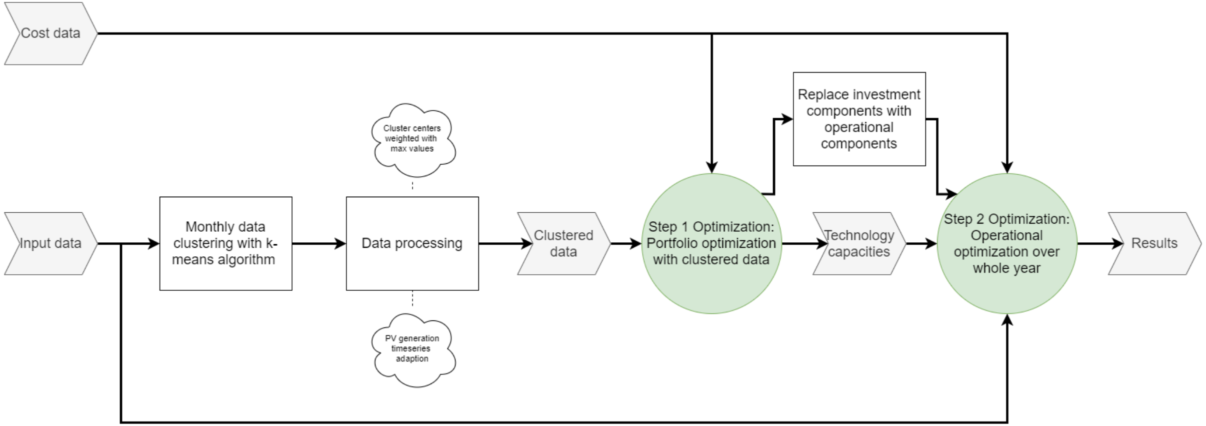
- Quantify the impact of renewable energy provision
- Investigation of different waste treatment options and their establishment under different frameworks and conditions
- Analysis of water circular economy with sewage treatment and sludge treatment
- Development of an optimization model with local investment decisions

Investigation setup and case study

- Quantify the impact of renewable energy provision
- Investigation of different waste treatment options and their establishment under different frameworks and conditions
- Analysis of water circular economy with sewage treatment and sludge treatment
- **Development of an optimization model with local investment decisions**

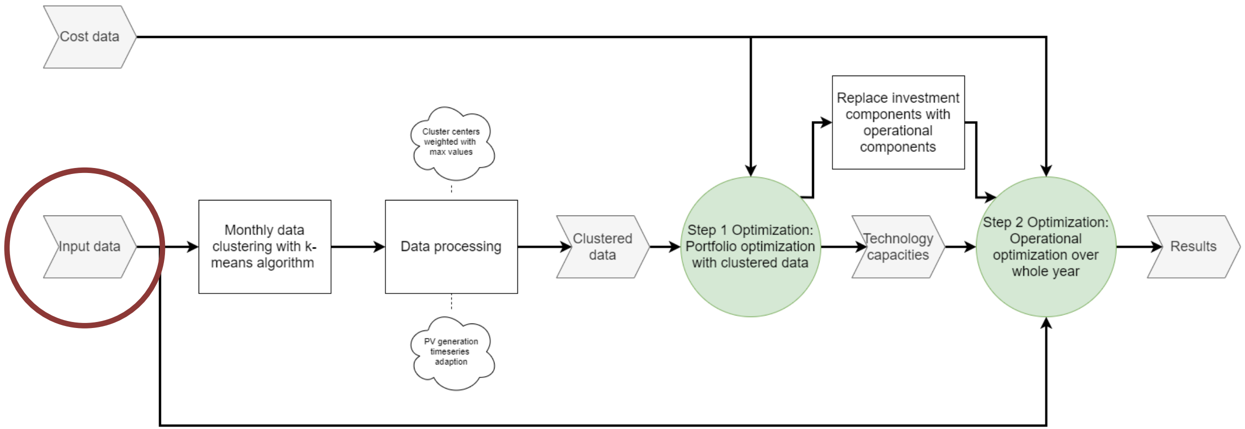
Optimization model

- Multiple step modeling framework
  - Step 1: Determine investments
  - Step 2: Optimize LSM operation
- Data clustering for portfolio optimization
  - K-means algorithm
  - Decrease computing time of solving



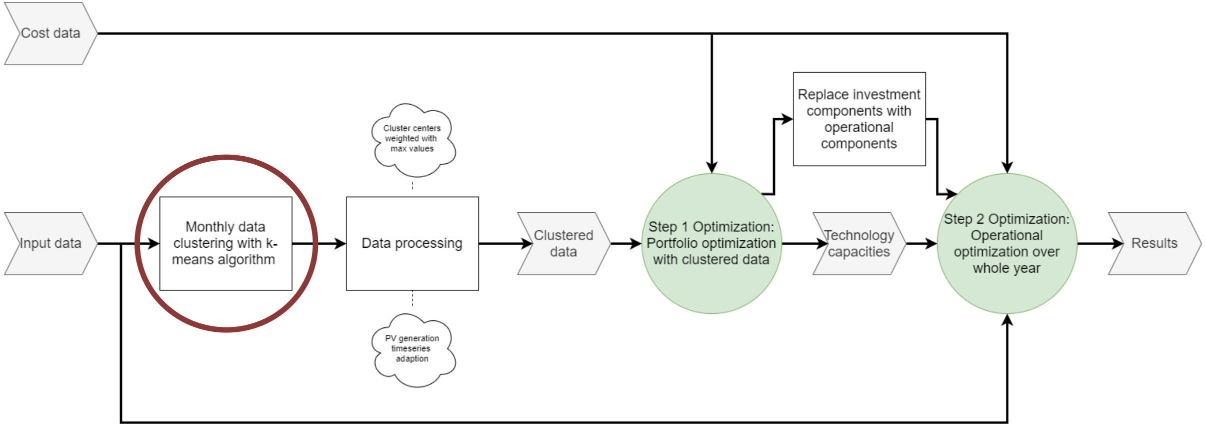
Optimization model

- Load input data into the model
  - Predefined input data including costs, technology parameters and demand timeseries



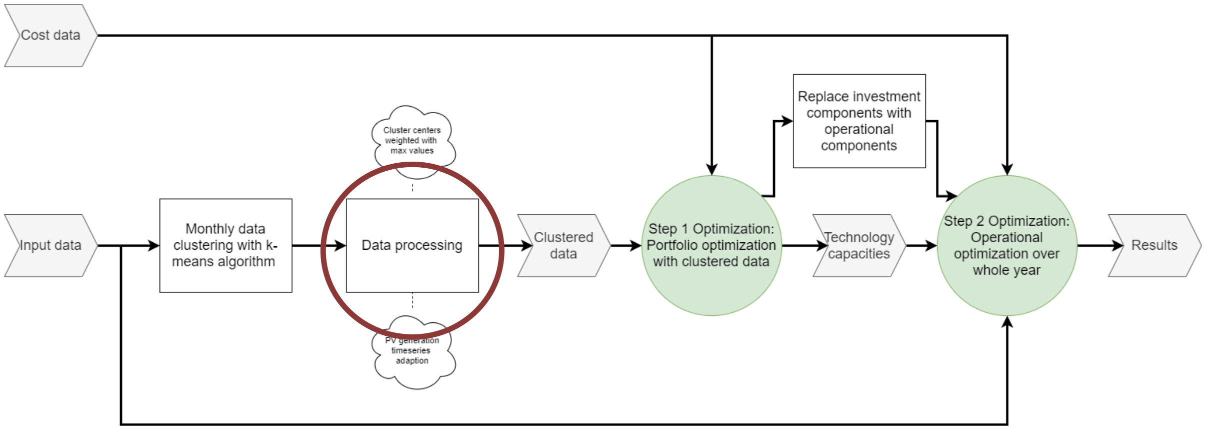
Optimization model

- Clustering of input data
  - Application of K-means algorithm
  - Clustering to 360 clusters
  - 30 clusters per month to consider seasonal variance of PV generation



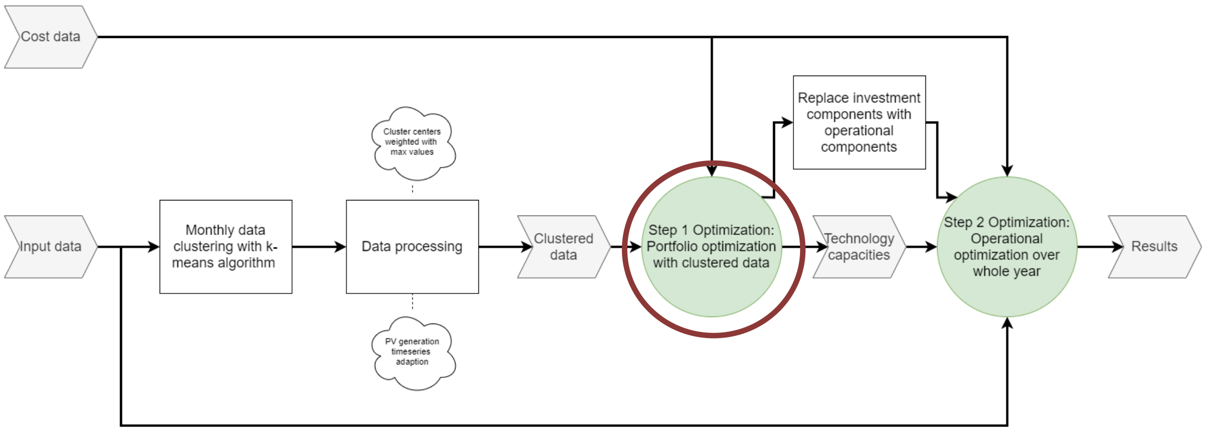
Optimization model

- Data processing
  - Weighting with cluster centers
  - Maximum accruing resources that must be treated crucial for treatment capacity determination
  - PV generation timeseries adapted to prevent overestimation
  - Reduction in regard with anual generation data



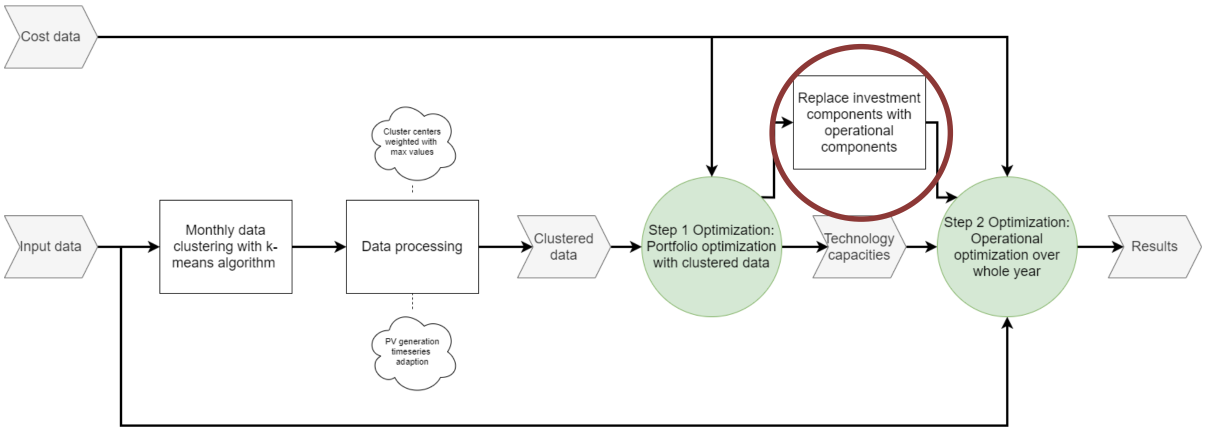
Optimization model

- Performing investment decision with clustered data in first optimization step
  - Clustered data and cost data input
  - Investment optimization over shorter period
  - Model size reduction optimization over shorter period
  - Results provide technology capacities



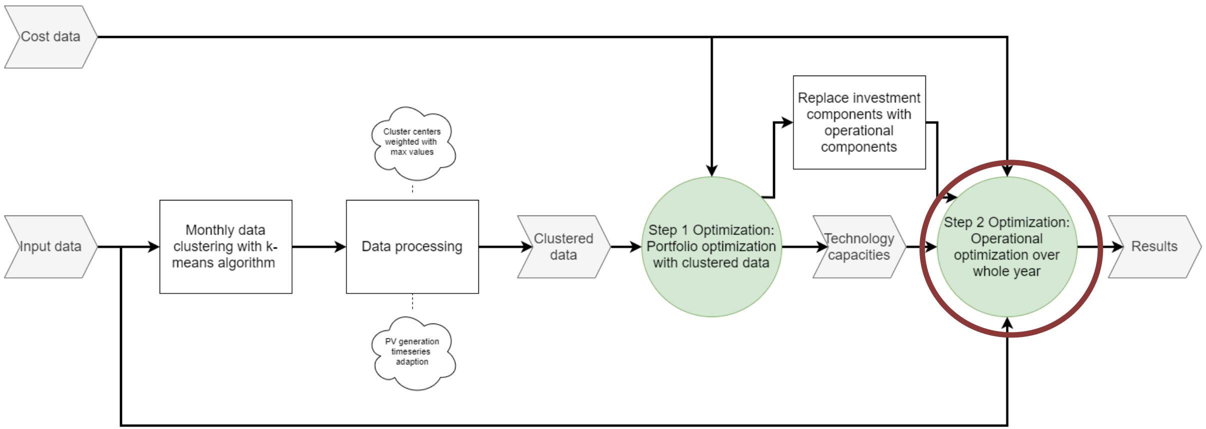
Optimization model

- Replacement of investment components by operational components
  - Model adaption to operational technology components
  - Maximum capacities based on investment decision
  - Other than that, no configuration changes



Optimization model

- Second optimization to determine results
  - Operational optimization
  - Performance over year in hourly resolution
  - Model size reduction by only considering technology operation



Optimization model

- Cost minimization
  - $z = \min(c^{total})$
- Conversion relation
  - $x_t^{out} = F^{conversion} \cdot x_t^{in}$
- Technology limitations
  - $x_t \leq \frac{X^{max}}{\Delta t}$
- Balance rule for all consumers and sectors
  - $\sum_{inputs} x_{t,i,j} = \sum_{outputs} x_{t,i,j} \ \forall\, i \in Sectors, j \in Consumers$
- Storage equations
  - $soc_{t+1} = soc_t + x_t^{in} \cdot \eta^{in} - \frac{x_t^{out}}{\eta^{out}}$
  - $soc_0 = SOC^{start}$

Optimization model: Investment decision

- Determination of maximum technology capacity
- Result as input to operational model
- Costs considered in total cost analysis
  - $c^{total} = c^{operationalmodel} + c^{investment}$
- Investment costs with variable costs and fixed costs (for certain technologies)
- Prevent multiple resource treatment plants at different locations
- Considered with annuities
- Weighted with period of year (e.g. clustering based only for about 2 weeks → consider in costs)
  - $\alpha_{technology} = \frac{(1+WACC)^n \cdot WACC}{(1+WACC)^n - 1}$
  - $c_{technology}^{inv,fix} = \alpha_{technology} \cdot C_{technology}^{fix} \cdot \frac{T}{T^{year}}$
  - $c_{technology}^{inv,var} = \alpha_{technology} \cdot C_{technology}^{var} \cdot \frac{T}{T^{year}}$

Modeling framework applicability

- Test of the framework application in municipality
- Comparison with 4 hourly resolution and single step optimization
- Impact assessment on local generation technology investments, battery investments and treatment facility investments
- Determination of total costs
- Computation time, respectively model size

Modeling framework applicability

4 hourly resolution

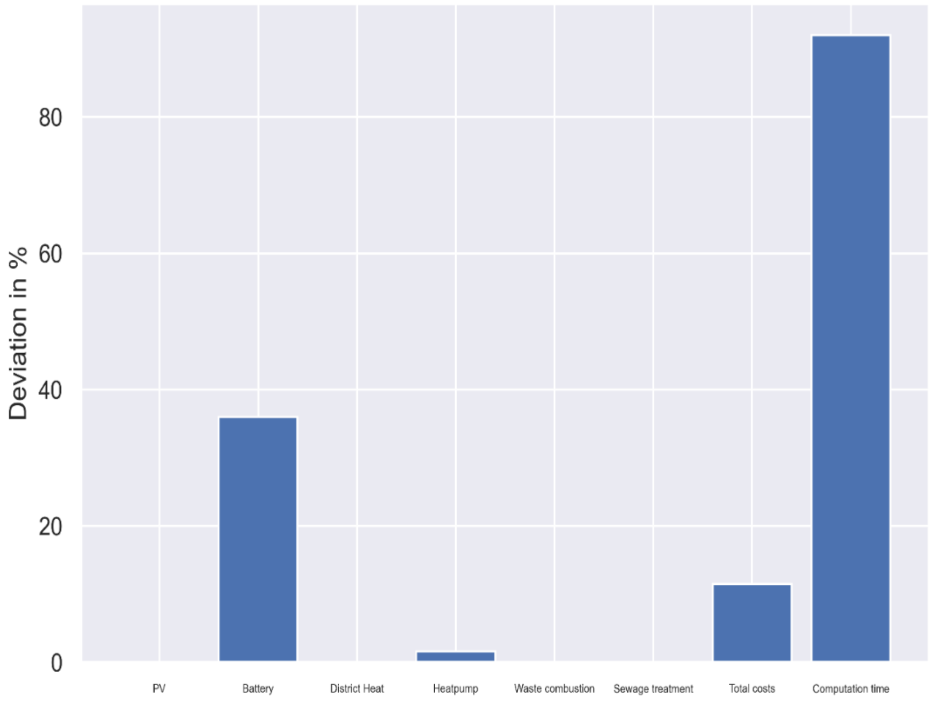
Tech.	LSC1	LSC2	LSC3	LSC4	LSC5	Sum
PV in kWp	1630	2162	2000	1010	412	7214
Battery in kWh	21	22	8	8	0	59
District heat in kW	0	126	105	0	0	231
Heat pump kW	804	853	796	732	214	3399
Waste comb in kW	0	0	580	0	0	580
Sewage treat in m^3	0	0	9	0	0	9
Total costs in €	1,201,762					
Computation time	10h 7min 5sec (36 425 s)					

Modeling framework

Tech.	LSC1	LSC2	LSC3	LSC4	LSC5	Sum
PV in kWp	1630	2162	2000	1010	412	7214
Battery in kWh	0	16	9	10	3	38
District heat in kW	0	119	112	0	0	231
Heat pump kW	816	875	803	743	217	3454
Waste comb in kW	0	0	580	0	0	580
Sewage treat in m^3	0	0	9	0	0	9
Total costs in €	1,358,035					
Computation time	0h 49min 36sec (2976 s)					

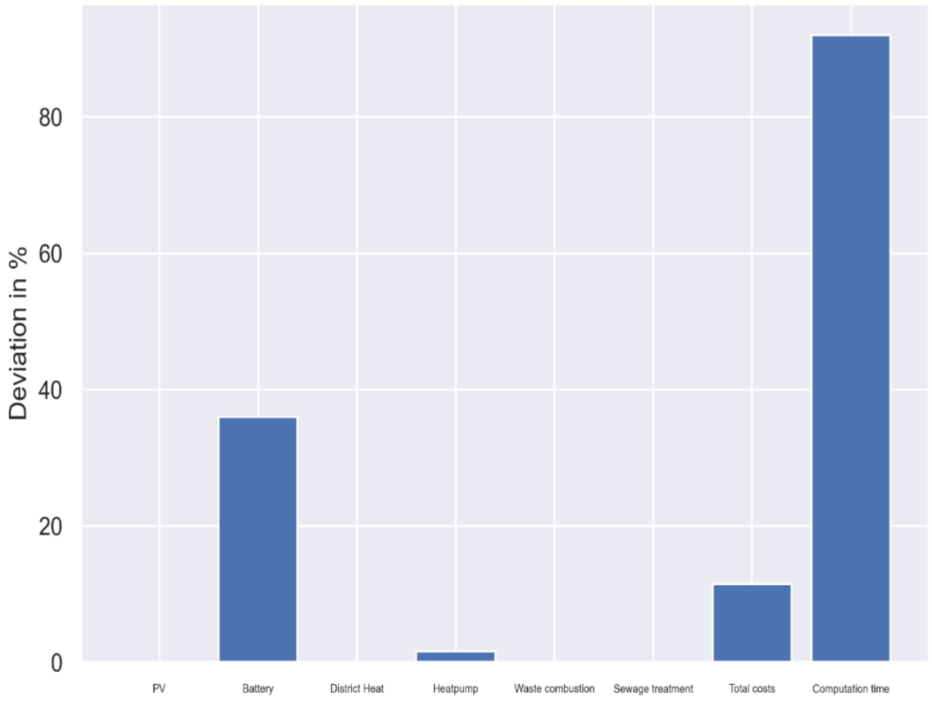
Modeling framework applicability

- PV determined at same values in both approaches
  - Limiting factor rooftop area rather than modeling approach
- Lower battery installation with modeling framework
- District heating with same total capacities but with different allocation to locations
- Increased heat pump installation with modeling framework
- Resource treatment facilities installed with same capacities at same locations



Modeling framework applicability

- Cost estimations differ between both approaches
  - 12% higher cost estimation with modeling framework
- Computation time decreases by 92% with modeling framework
  - Reduction from more than 10h to less than 1h
  - Computation time reduction for more complex configurations with multiple treatment options even higher



Modeling framework applicability

Framework applicable for	Framework not applicable for
Capacity estimation of technology installations	Detailed portfolio optimization analyses
Capacitiy localization within communities or municipalities	Determination of exact incurred costs
Potential analyses for technology implementations	Detailed capacity investment analyses

Summary and conclusions

- The proposed modeling framework lead to significant computation time reductions
- Capacity localization could be performed appropriately, while capacity investment could be estimated
- However, the framework is not appropriate for exact portfolio optimizations

Acknowledgement

- This work was performed under the “Hybrid Local Sustainable Communities” project, and was supported with funds from the Climate and Energy Fund and implemented in the framework of the RTI-initiative “Flagship region Energy” within the Green Energy Lab.

Matthias Maldet

Technical University of Vienna

Institute of Energy Systems and Electrical Drives

Energy Economics Group - EEG

Gußhausstraße 25-29 / E370-3

1040 Vienna, Austria

(T) +43 1 58801 370 365

(E) maldet@eeg.tuwien.ac.at

(W) www.eeg.tuwien.ac.at