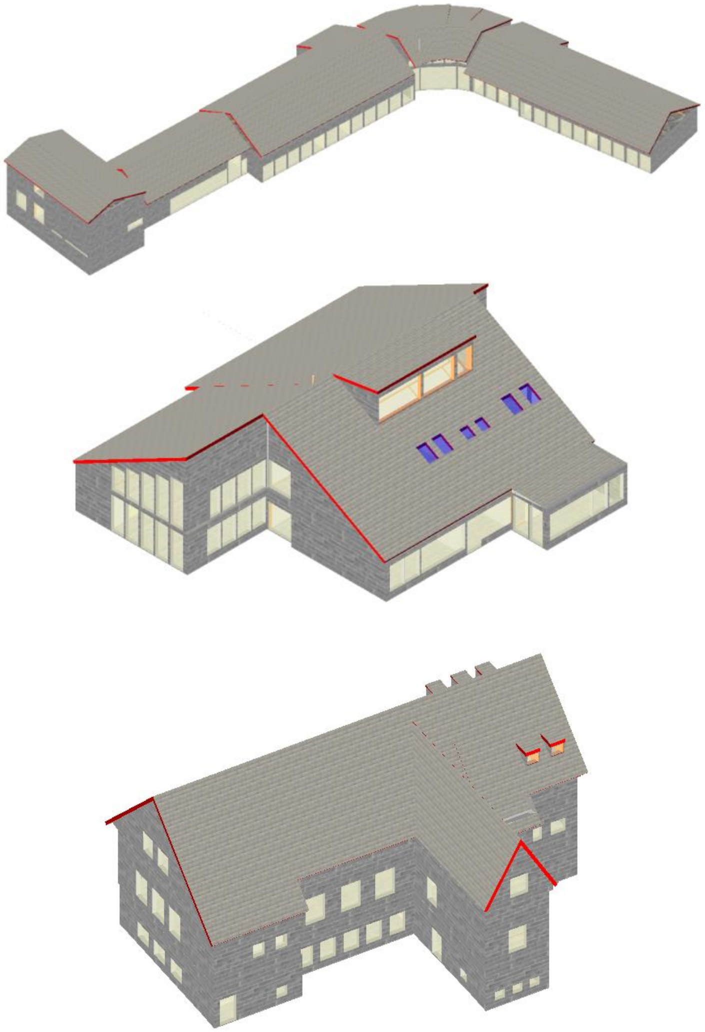

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MULTI-OBJECTIVE ENERGY SYSTEM MODELLING TO DEFOSSILISE THE EXISTING COMMERCIAL BUILDING STOCK OF A MUNICIPALITY

EURO 2022 (3.–6. July 2022) – Christine Nowak

A Collaboration with Jonas Finke and Valentin Bertsch

Agenda

Motivation — heating transition in the existing **commercial building stock**

Methods — feasibility study and **energy system model**

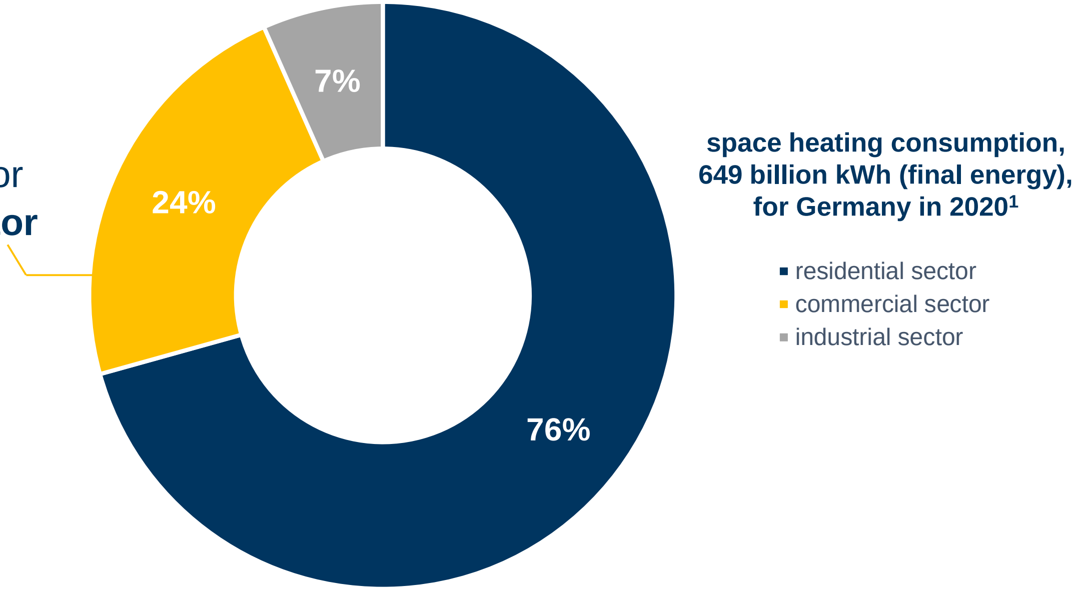
Results & Discussion — **multi-objective** optimisation findings, **trends** and **objective conflicts**

Summary & Outlook

Motivation

Motivation

- **heating transition** is inevitable, and a lot still needs to be accomplished
- **existing building stock** is especially challenging
- a lot of research for the residential sector – not so much for the **commercial sector**



[1] Bundesverband der Energie- und Wasserwirtschaft e.V. (2022): *Entwicklung des Wärmeverbrauchs in Deutschland. Basisdaten und Einflussfaktoren.* 6. Ausgabe.

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Motivation

- **energy system modelling**
  suited to find optimal heating supply

- **multi-objective optimisation**
  to understand **trade-offs**

Research Question

How can the **heating supply**

for **existing municipal commercial buildings**

be **optimally** designed

in terms of **costs,**
greenhouse gas emissions and
self-sufficiency?

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Methods

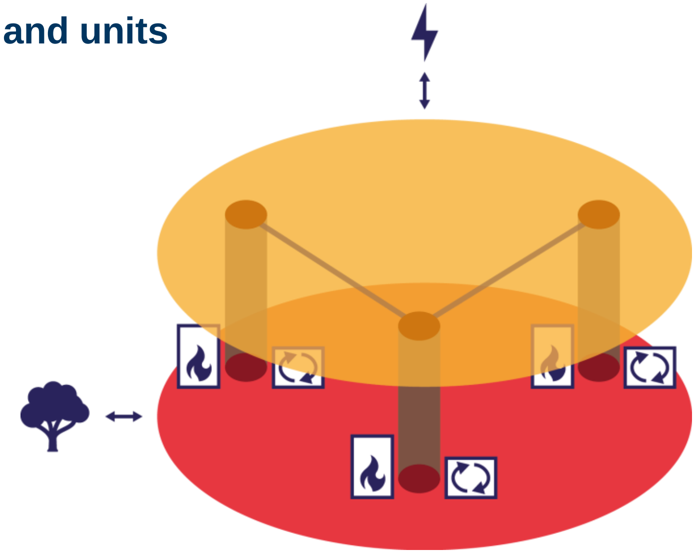
Energy System Optimisation Framework Backbone

Network Model:

- highly **adaptable** structure with **grids, nodes, lines and units**
- various **energy carriers** and **sectors**
- **flexible spatial** and **temporal resolution**

Optimisation:

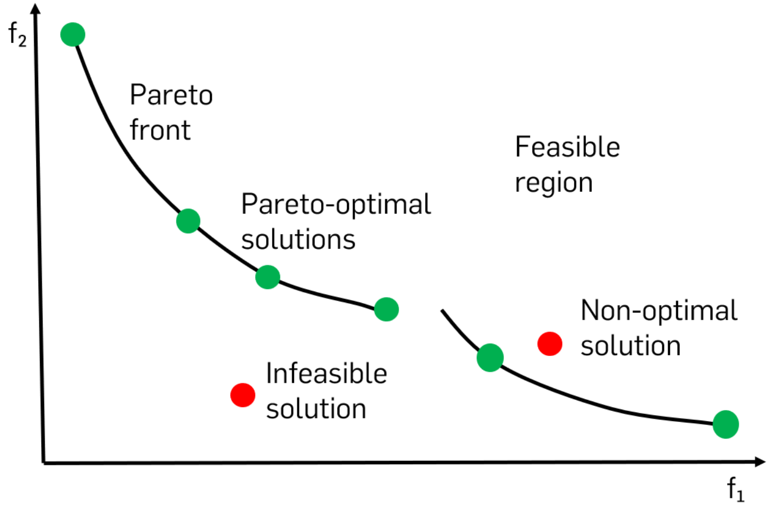
- **investment** and **operational** planning
- **cost** minimisation



Helistö et al., Backbone – An Adaptable Energy Systems Modelling Framework, Energies 2019.

Multi-objective Optimisation

- new features in Backbone:
  emission minimisation as well as
  self-sufficiency maximisation
- optimisation of **multiple objectives**
- **Pareto-front**: set of Pareto-optimal solutions



<u>Augmented Epsilon-Constraint Optimisation Method (AUGMECON):</u>

- reformulate all but one objective to **constraints**
- implemented AUGMECON in Backbone
  for **three objectives**

Finke, J. & Bertsch, V. (2022): *Implementing a highly adaptable method for the multi-objective optimisation of energy systems.* In preparation.

Case Study

Three Existing Commercial Buildings in a Small Municipality:

- municipality hall, primary school and kindergarten

Feasibility Study:

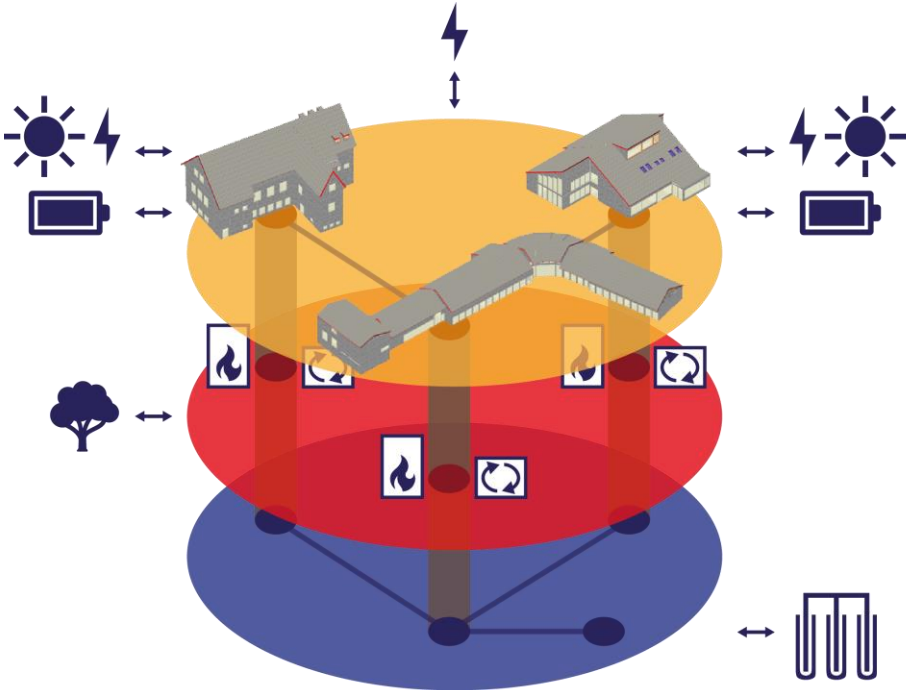
- "A low-temperature heating network with heat pumps/geoth. probes is feasible if refurbishments are conducted."
  → provides **real world data**

Energy Supply and Storage Options:

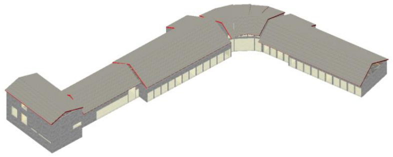
- geothermal probes, heat pumps, pellet boilers, public electricity grid, photovoltaics (PV), battery storages

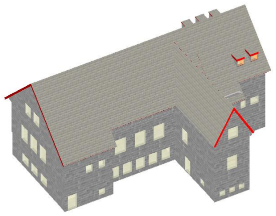
Scenario:

- year 2030, some refurbishments



Case Study





<u>Data:</u>

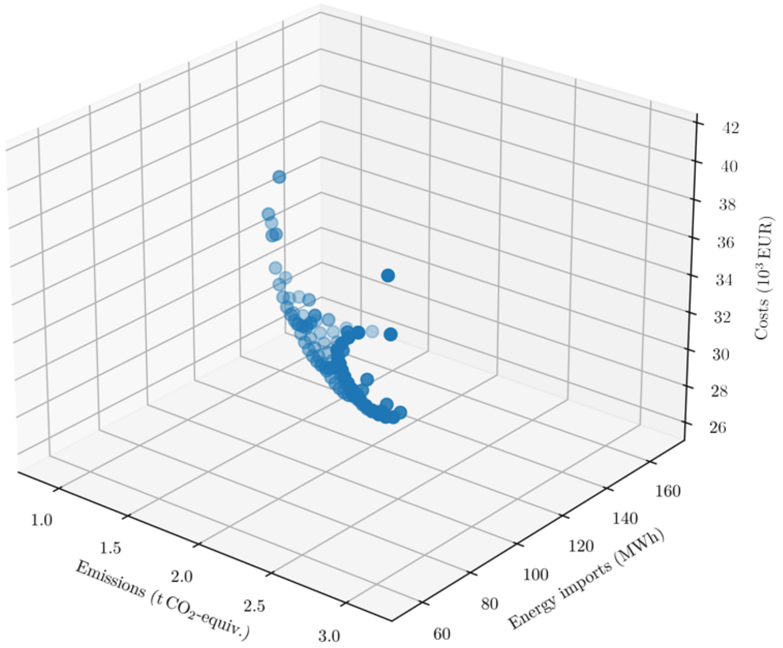
- **costs**, **technical data and electricity demand** from feasibility study
- **heating demand** and **capacity factor time series** for PV based on locational weather data for the year 2021
- **variable emission factors** for the public electricity grid, scaled for 2030
- **variable electricity prices** (consumer prices including scaled variable wholesale prices + inflation) for 2030
- electricity **selling prices** for PV included

<u>Implementation in Backbone:</u>

- 1 year, hourly resolution
- **linear programming**, **investment planning**
- three objectives: **costs, emissions and self-sufficiency (i.e. energy imports)**

Results & Discussion

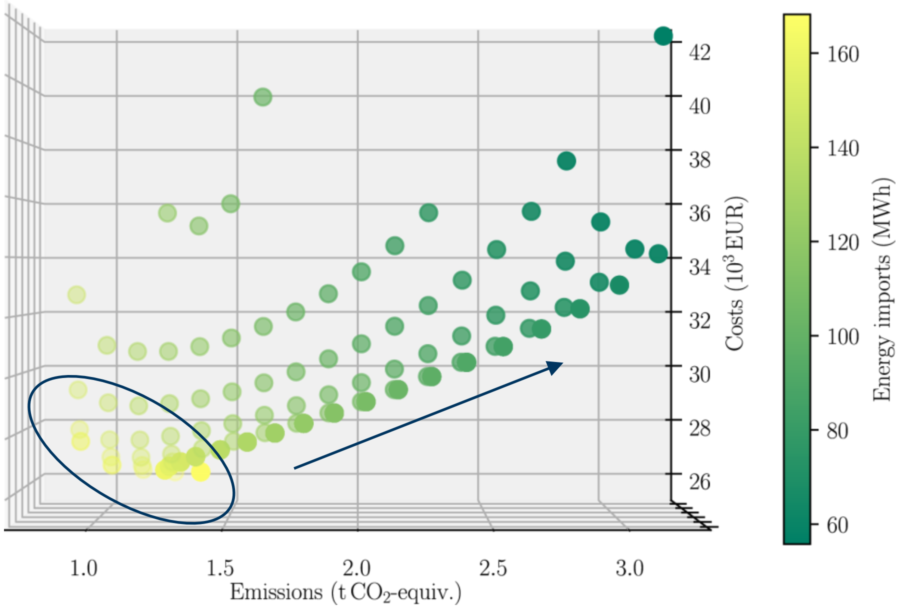
Tri-Objective: **Costs, Emissions and Self-sufficiency**



Objectives Influences:

- min **costs**
  from investments, operation costs and fixed operation and maintenance costs
- min **emissions** & max **self-sufficiency**
  from pellets and public grid electricity

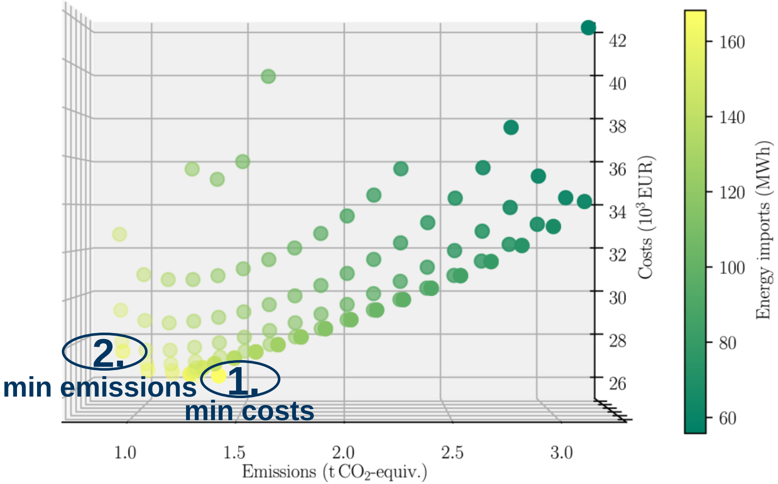
Tri-Objective: **Costs, Emissions** and Self-sufficiency



<u>**Trends:**</u>

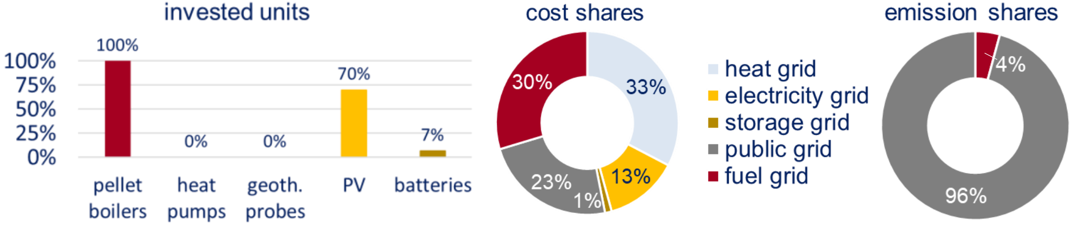
- when **allowing low self-sufficiency**:
  - clear **correlation** between **costs and emissions**, both are low
  - but there is **still a conflict**, due to investments in battery storages and PV
- the **higher** self-sufficiency, the **higher** costs and emissions

Tri-Objective: **Costs, Emissions** and Self-sufficiency

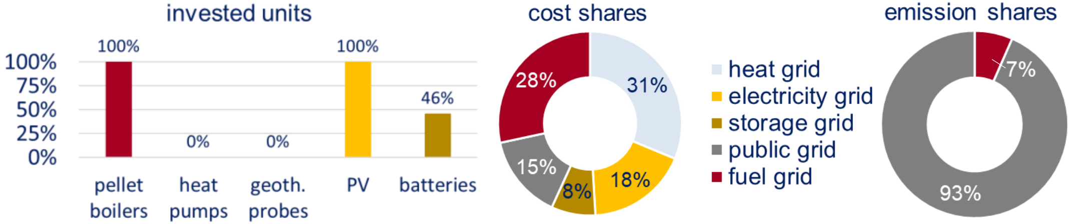


Results:

1. **min costs: 26 126 €**, 1.35 t $CO_{2\text{-equiv.}}$ and 168.24 MWh



2. **min emissions:** 27 289 €, **0.87 t $CO_{2\text{-equiv.}}$** and 160.88 MWh



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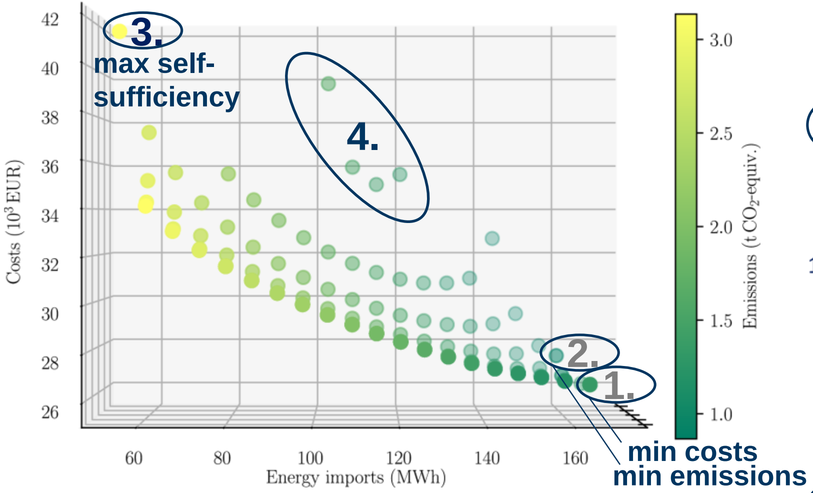
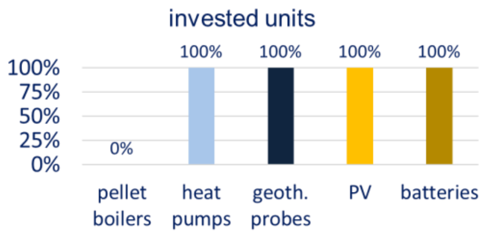
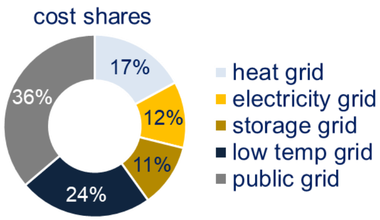
Tri-Objective: **Costs**, Emissions and **Self-sufficiency**

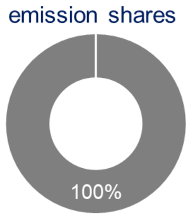


Results:

③ **max self-sufficiency:** 41 219 €, 3.14 t $CO_{2\text{-equiv.}}$ and **55.77 MWh**







④ **full investments**

in PV and battery storages

partial investments

in pellet boilers and heat pumps/geoth. probes

due to lowering of energy imports/emissions

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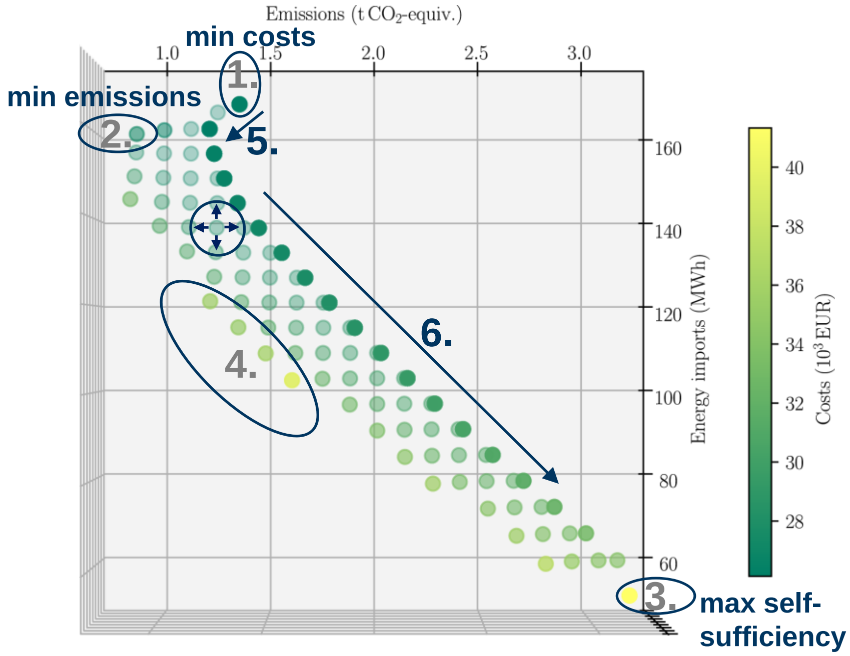
Tri-Objective: Costs, **Emissions and Self-sufficiency**



regularity due to **constraints formulation**

5. **stricter constraint** on self-sufficiency: **first decrease** in emissions
   - due to investments in **PV and partially in battery storages**
   - pellet boilers investments almost constant
   - no heat pumps/geoth. probes

6. **even stricter constraint** on self-sufficiency: **increase** in emissions
   - due to add. investments in **heat pumps/geoth. probes**
   - pellet boilers investments decrease

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Summary & Outlook

Summary & Outlook

Summary:

- energy system model of **three commercial municipal buildings**, optimised for **costs**, **emissions** and **self-sufficiency**
- overall: the **higher** the self-sufficiency, the **higher** costs and emissions
- **when self-sufficiency is heightened**, first there is a **decrease** and after that an **increase in emissions**
- Pareto front shows **conflicts** and equips **stakeholders** for investment decisions

Outlook:

- extension of model: **mixed-integer** linear programming, scenarios with **data for multiple years** and with **different refurbishment levels**
- preparatory step to **load shifting investigations**

thank you

Christine Nowak, M.Sc.
Ruhr-University Bochum
Chair of Energy Systems and Energy Economics
Universitätsstr. 150
44801 Bochum, Germany

Phone: +49 234 32 26378
E-Mail: christine.j.nowak@rub.de
Homepage: www.ee.rub.de

@energy_rub

Backup - Node to Node

p_gnn

	A	B	C	D	E	F	G	H	I	J	K	L
					[MW]	[-]	[-]	[MW]	[€/MW]	[-]	[MW]	[-]
1	*GRID*	*FROM_NODE*	*TO_NODE*		*Define parameters for transfer and diffusion between nodes*							
2				*PARAM_GN*	transferCap	transferLoss	investMIP	transferCapInvLimit	invCost	annuity	unitSize	availability
3	low_temp	sch_low_temp	low_temp_distributor		eps	0.05		0.06	97950	0.083679	0.06	1
4	low_temp	low_temp_distributor	sch_low_temp		eps	0.05		0.06	97950	0.083679	0.06	1
5	low_temp	gem_low_temp	low_temp_distributor		eps	0.05		0.03	203492	0.083679	0.03	1
6	low_temp	low_temp_distributor	gem_low_temp		eps	0.05		0.03	203492	0.083679	0.03	1
7	low_temp	kita_low_temp	low_temp_distributor		eps	0.05		0.04	153447.8	0.083679	0.04	1
8	low_temp	low_temp_distributor	kita_low_temp		eps	0.05		0.04	153447.8	0.083679	0.04	1
9	low_temp	geo_field	low_temp_distributor		eps	0.05		0.13	3302	0.083679	0.13	1
10	low_temp	low_temp_distributor	geo_field		eps	0.05		0.13	3302	0.083679	0.13	1
11	elec	kita_elec	sch_elec		100	0						1
12	elec	sch_elec	kita_elec		100	0						1
13	elec	gem_elec	sch_elec		100	0						1
14	elec	sch_elec	gem_elec		100	0						1

Backup – Units

p_unit

	A	B	C	D	E	F	G	H	I	J	K
			[-]	[-]	[-]	[-]	[-]	[-]	[-]	[-]	
1	***UNIT***		*Define parameters for units, regardless of node*								
2			availability	eff00	eff01	op00	op01	maxUnitCount	investMIP	useTimeseries	
3	heat_pump_gem		1	1	1	0	1	1			
4	heat_pump_kita		1	1	1	0	1	1			
5	heat_pump_sch		1	1	1	0	1	1			
6	pv_gem		1	1	1	0	1	65			
7	pv_kita		1	1	1	0	1	35			
8	battery_charge_gem		1	0.90	0.90	0	1	5			
9	battery_discharge_gem		1	0.90	0.90	0	1	5			
10	battery_charge_kita		1	0.90	0.90	0	1	3			
11	battery_discharge_kita		1	0.90	0.90	0	1	3			
12	pellet_boiler_gem		1	0.93	0.93	0	1	1			
13	pellet_boiler_kita		1	0.93	0.93	0	1	1			
14	pellet_boiler_sch		1	0.93	0.93	0	1	1			
15	elec_sell_gem		1	1	1	0	1				
16	elec_sell_kita		1	1	1	0	1				
17	geo_probes		1	1	1	0	1	30			
18	u_emissions_ts		1			0	1			1	
19	u_emissions_inputRatio_sch		1	0.5	0.5	0	1				
20	u_emissions_inputRatio_gem		1	0.5	0.5	0	1				
21	u_emissions_inputRatio_kita		1	0.5	0.5	0	1				

Backup – In- and Outputs

p_gnu_io

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
1	*GRID*	*NODE*	*UNIT*	*input_output*		*Define parameters for units in certains nodes of certain grids*									
2					*PARAM_GNU*	[-] conversionCoeff	[MW] capacity	[MW] unitSize	[€/MWh] vomCosts	maxRampUp	maxRampDown	[€/MW] invCosts	[€/MW/a] fomCosts	[-] annuity	[MWh/MW] upperLimitCapacityRatio
3	heat	gem_heat	heat_pump_gem	output		1	eps	0.0273				697500	20925	0.0837	
4	elec	gem_elec	heat_pump_gem	input		1									
5	low_temp	gem_low_temp	heat_pump_gem	input		1									
6	heat	kita_heat	heat_pump_kita	output		1	eps	0.04				565953.75	16978.61	0.0837	
7	elec	kita_elec	heat_pump_kita	input		1									
8	low_temp	kita_low_temp	heat_pump_kita	input		1									
9	heat	sch_heat	heat_pump_sch	output		1	eps	0.0605				539687.6033	16190.63	0.0837	
10	elec	sch_elec	heat_pump_sch	input		1									
11	low_temp	sch_low_temp	heat_pump_sch	input		1									
12	elec	gem_elec	pv_gem	output			eps	0.00034				1400000	28000	0.0837	
13	elec	kita_elec	pv_kita	output			eps	0.00034				1400000	28000	0.0837	
14	elec	gem_elec	battery_charge_gem	input		1		0.005							
15	storage	gem_battery	battery_charge_gem	output		1	eps	0.005				1000000		0.116	6
16	storage	gem_battery	battery_discharge_gem	input		1		0.005							
17	elec	gem_elec	battery_discharge_gem	output		1	eps	0.005							
18	elec	kita_elec	battery_charge_kita	input		1		0.005							
19	storage	kita_battery	battery_charge_kita	output		1	eps	0.005				1000000		0.116	6
20	storage	kita_battery	battery_discharge_kita	input		1		0.005							
21	elec	kita_elec	battery_discharge_kita	output		1	eps	0.005							
22	fuel	pellet	pellet_boiler_gem	input		1									
23	heat	gem_heat	pellet_boiler_gem	output		1	eps	0.0295				711864.4068	########	0.0996	
24	fuel	pellet	pellet_boiler_kita	input		1									
25	heat	kita_heat	pellet_boiler_kita	output		1	eps	0.048				510416.6667	########	0.0996	
26	fuel	pellet	pellet_boiler_sch	input		1									
27	heat	sch_heat	pellet_boiler_sch	output		1	eps	0.0654				428134.5566	########	0.0996	
28	elec	gem_elec	elec_sell_gem	input		1									
29	public_grid	public_grid_sell	elec_sell_gem	output		1	1000	1000	-72.5						
30	elec	kita_elec	elec_sell_kita	input		1									
31	public_grid	public_grid_sell	elec_sell_kita	output		1	1000	1000	-72.5						
32	ground	geo	geo_probes	input		1									
33	low_temp	geo_field	geo_probes	output		1	eps	0.0052				1153846.154	########	0.0591	
34	public_grid	public_grid_buy	u_emissions_inputRatio_sch	input		1									
35	public_grid	public_grid_emissions_ts	u_emissions_inputRatio_sch	input		1									
36	elec	sch_elec	u_emissions_inputRatio_sch	output		1	1000	1000							
37	public_grid	public_grid_buy	u_emissions_inputRatio_gem	input		1									
38	public_grid	public_grid_emissions_ts	u_emissions_inputRatio_gem	input		1									
39	elec	gem_elec	u_emissions_inputRatio_gem	output		1	1000	1000							
40	public_grid	public_grid_buy	u_emissions_inputRatio_kita	input		1									
41	public_grid	public_grid_emissions_ts	u_emissions_inputRatio_kita	input		1									
42	elec	kita_elec	u_emissions_inputRatio_kita	output		1	1000	1000							
43	public_grid	public_grid_emissions_cons	u_emissions_ts	input		1									
44	public_grid	public_grid_emissions_ts	u_emissions_ts	output		1	1000	1000							

Backup – Constraints

p_unitConstraintNode

[-]

	A	B	C	D	E	F	G
1	*UNIT*	*CONSTRAINT*	*NODE*	*Constants for unit specific constraints*			
2	heat_pump_gem	eq1	gem_low_temp	-1			
3	heat_pump_kita	eq1	kita_low_temp	-1			
4	heat_pump_sch	eq1	sch_low_temp	-1			
5	heat_pump_gem	eq1	gem_elec	2.3			
6	heat_pump_kita	eq1	kita_elec	2.48			
7	heat_pump_sch	eq1	sch_elec	2.48			
8	u_emissions_inputRatio_sch	eq2	public_grid_buy	-1			
9	u_emissions_inputRatio_sch	eq2	public_grid_emissions_ts	1			
10	u_emissions_inputRatio_gem	eq3	public_grid_buy	-1			
11	u_emissions_inputRatio_gem	eq3	public_grid_emissions_ts	1			
12	u_emissions_inputRatio_kita	eq4	public_grid_buy	-1			
13	u_emissions_inputRatio_kita	eq4	public_grid_emissions_ts	1			

Backup – Prices

ts_PriceChange

[€/MWh] …

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	***Node***		*Define initial fuel price, and subsequent changes in fuel prices as additions or reductions (in €/MWh)*											
2		***Time index***	t000001	t000002	t000003	t000004	t000005	t000006	t000007	t000008	t000009	t000010	t000011	t000012
3	public_grid_buy		196.72	-2.68	-3.51	-1.76	-2.53	-0.19	-0.57	0.46	1.18	3.61	0.12	2.20
4	pellet		50											

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Backup – Emissions

p_nEmission

[kg_{CO2eq}/MWh], equivalent to [g_{CO2eq}/kWh]

	A	B	C
1	*Node*		
2		*Emission*	CO2
3	pellet		0.368
4	public_grid_emissions_const		1

implemented: time series of carbon intensity for grid electricity in kg_{CO2eq}/MWh, i.e. operational emission factors (takes into account imports)

	A	B	C	D	E
1		Anteil EE (%)	Anteil Gas (%)	durschnittlicher CO2-Emissionsfaktor Strommix (g/kWh)	Skalierungsfaktor für Zeitreihe von 2021
2	2021			420	1.000
3	2030	80	20	79.4	0.189
4	2040	95	5	19.85	0.047

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Backup – Demands

ts_influx

[MW] …

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	*GRID*	*NODE*	*Forecast index*			winter, summer, mixed	*External power inflow/outflow time series (only relevant if several nodes are integrated -*							
2				*Time index*	*SUM [MWh]*	t000001	t000002	t000003	t000004	t000005	t000006	t000007	t000008	t000009
3	heat	sch_heat	f00		-58.14	0	0	0	0	0	-0.020729	-0.02131	-0.026304	-0.02652
4	heat	kita_heat	f00		-54.09	0	0	0	0	-0.020077	-0.020627	-0.021165	-0.021654	-0.021982
5	heat	gem_heat	f00		-31.74	0	0	0	0	0	0	-0.005921	-0.006103	-0.009347
6	elec	sch_elec	f00		-9.15	-0.000226106	-0.000234	-0.00023	-0.000222	-0.000221	-0.000244	-0.000259	-0.000256	-0.000268
7	elec	kita_elec	f00		-12.80	-0.000316332	-0.000327	-0.000322	-0.000311	-0.000309	-0.000342	-0.000363	-0.000357	-0.000375
8	elec	gem_elec	f00		-19.51	-0.001207545	-0.001009	-0.000848	-0.000772	-0.000761	-0.000774	-0.00097	-0.001016	-0.000947
9														