METHODOLOGY FOR **TECHNO-ECONOMIC ANALYSIS OF HEATING AND COOLING SOLUTIONS** AT THE NEIGHBORHOOD LEVEL CONSIDERING UNCERTAINTIES

IEWT 2025

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Nyasha GRECU, Bernhard MAYR, Ralf-Roman SCHMIDT, Johannes CONRAD, Nicolas MARX

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BACKGROUND: THE CLEANHEATSELECTOR PROJECT

Aim

Development of a **decision-making framework** for the selection of areas for the implementation of **sustainable heating (and cooling) technologies** using economic, regulatory and ecological-social criteria.

Details

Duration: 01/24 – 06/25

Budget: ca. 250.000 €

Funding: FFG - Energie.Frei.Raum 3. AS/BMK

Project type: feasibility study

Consortium: AIT Austrian Institute of Technology; Energieinstitut an der Johannes Kepler Universität Linz; BOKU Institut für Raumplanung, Umweltplanung und Bodenordnung

Methode

1. Analysing the national and international legal framework
2. Analysis of energy & spatial planning instruments
3. Matrix: H&C technology vs. energy space type with techno-economic & socio-ecological assessment
4. Stakeholder dialogue and regulatory recommend-dations

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MODEL OBJECTIVES & EXPECTED RESULTS

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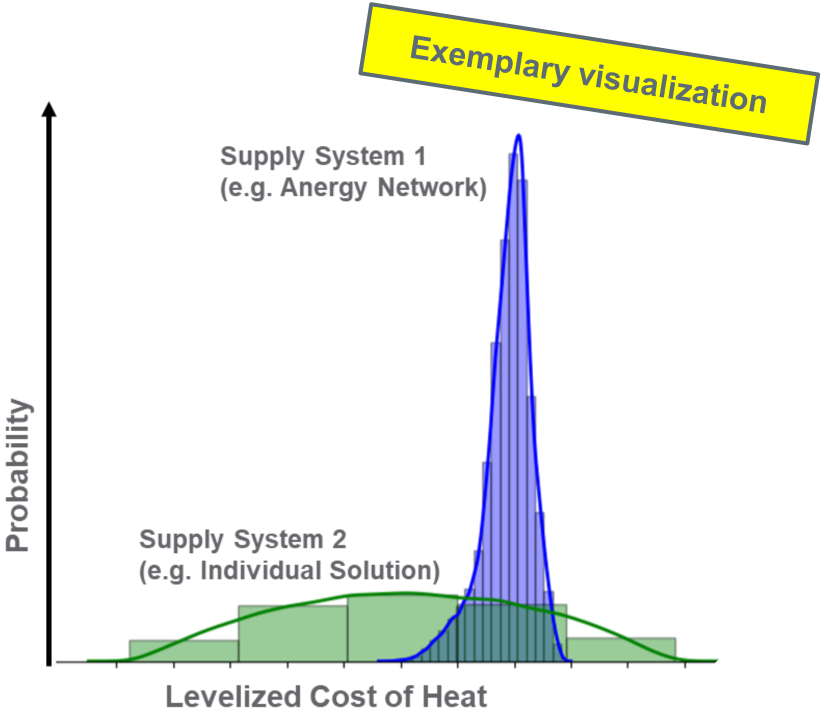
- Techno-economic comparison of **sustainable heating and cooling systems for a building complex**
- Evaluation of **expected costs and performance** over a 20-year period
- Assessment of **system risks under uncertainty**
- Monte-Carlo based variation of key influencing parameters :
  - **Electricity prices[1,2,3]**
  - **Weather years (Normal, Heatwave, Dark doldrum)[1,2,3]**
  - **Climate change scenarios[1,2,3]**
  - **Building renovations**



1) https://www.secures.at/publications
2) Formayer H, Nadeem I, Leidinger D, Maier P, Schöniger F, Suna D, et al. SECURES-Met: A European meteorological data set suitable for electricity modelling applications. Sci Data 2023;10:590. https://doi.org/10.1038/s41597-023-02494-4
3) SECURES-Met -Dataset- A European wide meteorological data set suitable for electricity modelling (supply and demand) for historical climate and climate change projections (1.0.0) [Data set]. Zenodo. 2023. https://zenodo.org/records/7907883.

METHODS OVERVIEW

Building selection and data collection → **Supply systems definition** → **Investment optimization** → **Operation optimization** → **LCOE calculation**

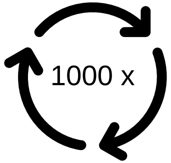
H&C-system #1

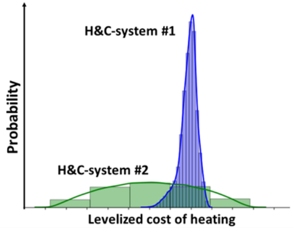
H&C-system #2

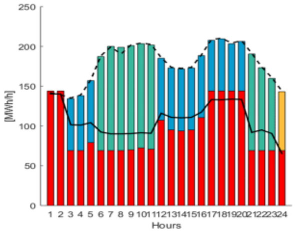
Determines **optimal component sizing** and **investment costs** under design weather conditions

1x

Operation optimization over 20-years considering uncertainty in future **electricity prices, weather years, climate change scenarios** and **building renovation** through Monte Carlo analysis







Exemplary application of the methodology to a case study

CASE STUDY

A neighborhood in Vienna, which is currently mainly supplied with gas, was selected as the first case study. Different supply solutions were to be evaluated.

Case study buildings

Key facts

- **Spatial Energy Typology**: High-density multi-story residential area
- **Total heating demand**: ~ 5,500 MWh (~ 1,000 MWh/ha)
- **Cooling demand**: Increasing
  - Waste heat could be used for heating purposes
- **Geothermal potential**:
  - Available area for probes: 7,000 m^2
  - Probe depths: 80 – 250 m
  - Max. probe numbers: 100
  - → Capacity: max. 40 GWh
- **Photovoltaic & solar thermal potential**:
  - Available roof-area: 5,600 m^2 (1/3 of total roof area)
- **Industrial waste heat potential**: Not in vicinity

SUPPLY SYSTEMS

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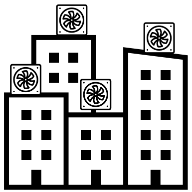
Individual



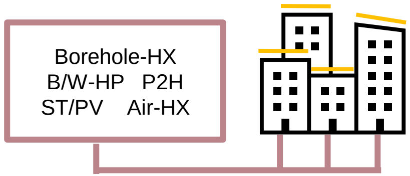
Heating:

- Air/Water HP per building

Cooling:

- Air/Water HP per building

Local anergy network (12° C)



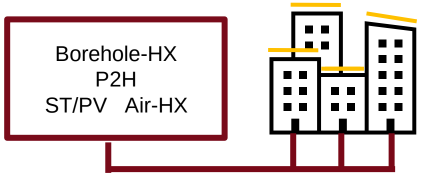
Heating:

- Local network (12°C) with: PV, ST, P2H, Air HX, Borehole HX
- Water/Water HP per building

Cooling:

- Free-cooling

Local heat network (70° C)



Heating:

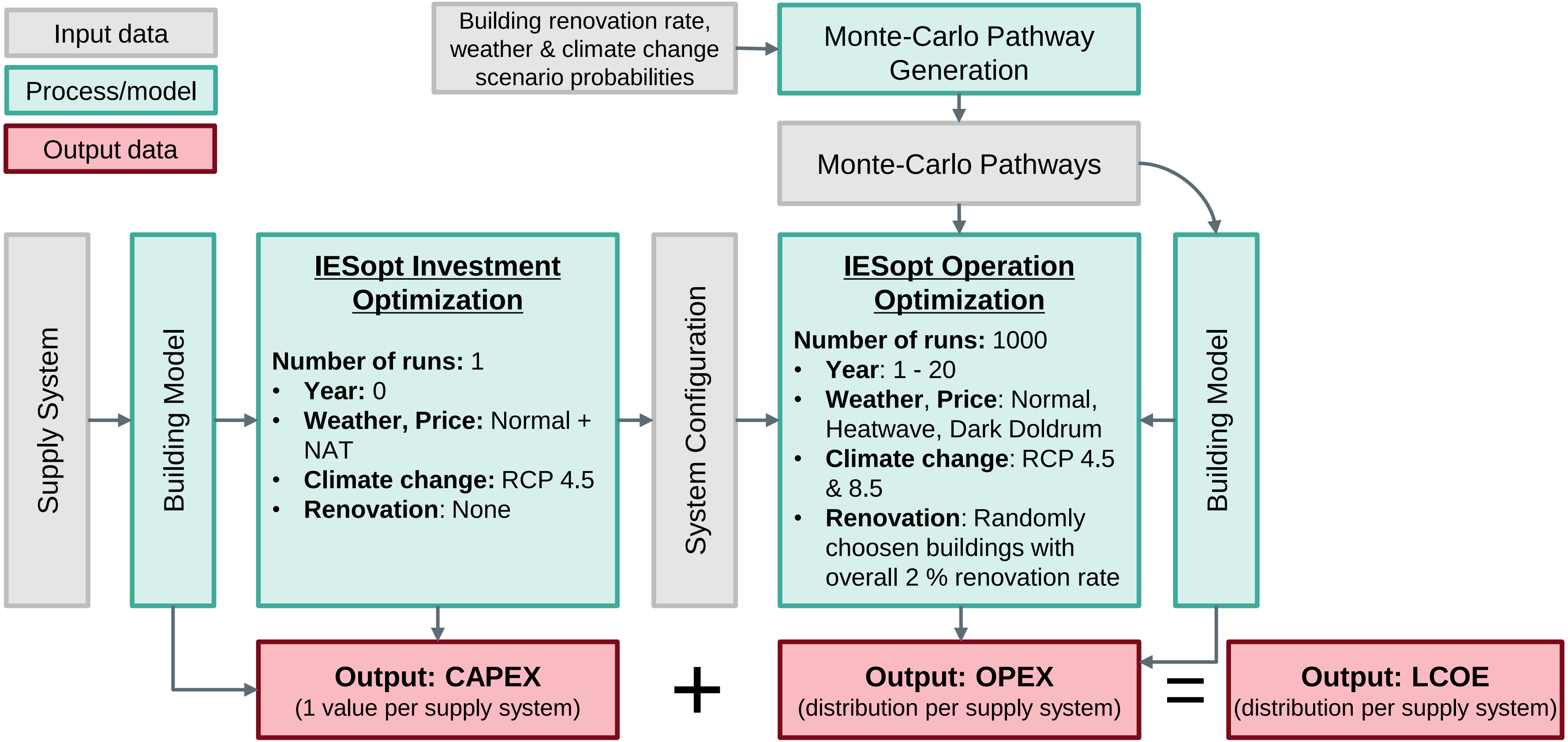
- Local network (70°C) with: PV, ST, P2H, Air HX, Borehole HX combined Brine/Water HP

Cooling:

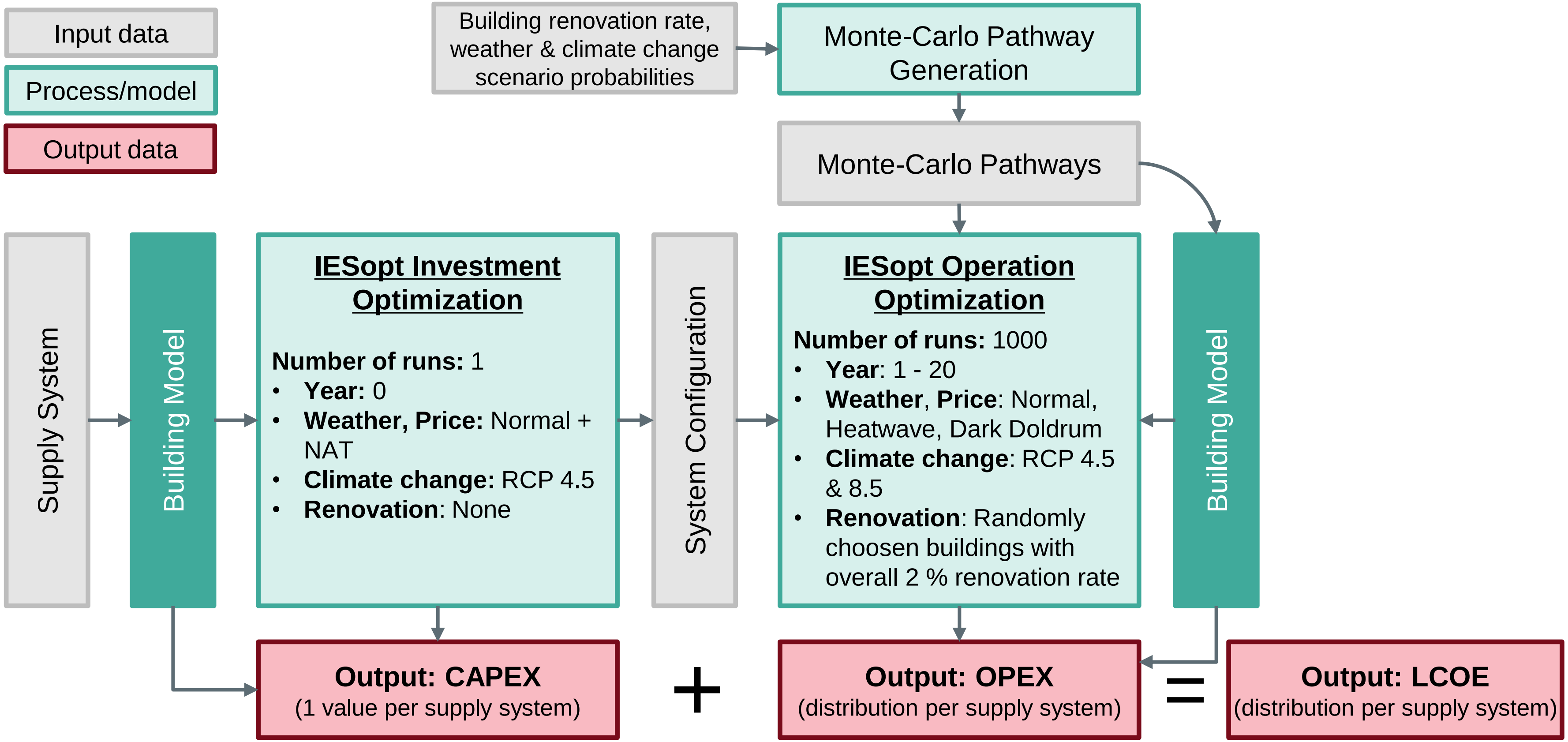
- Air/Water HP per building

HP = Heatpump, PV = Photovoltaic, ST = Solar Thermal, HX = heat exchanger, P2H = Power to Heat

MODEL OVERVIEW



MODEL OVERVIEW



BUILDING MODEL

Model constructor based on case study

Building data (ren/unren)

Weather data

City Energy Analyst (CEA)
Urban building energy model

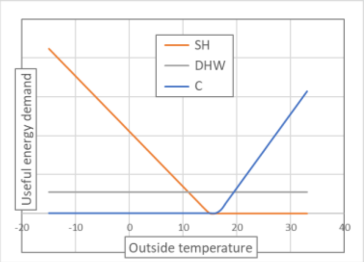
Weather data
- Outside temperature
- Global horizontal radiation

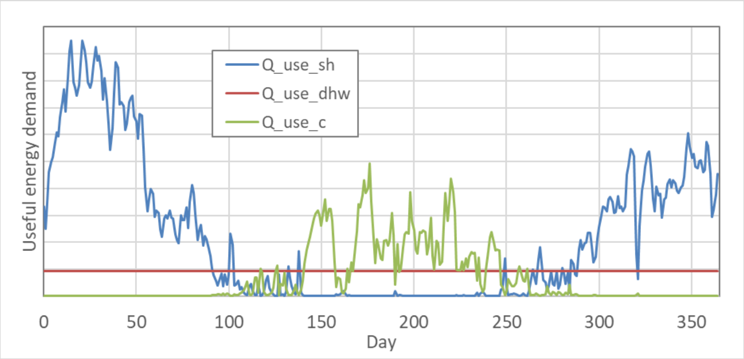
Building demand data:
- Domestic hot water (use)
- Space heating (use)
- Cooling (use)

SECURES weather data
Outside temperature & Global horizontal radiation for 9 scenarios

Renovated buildings

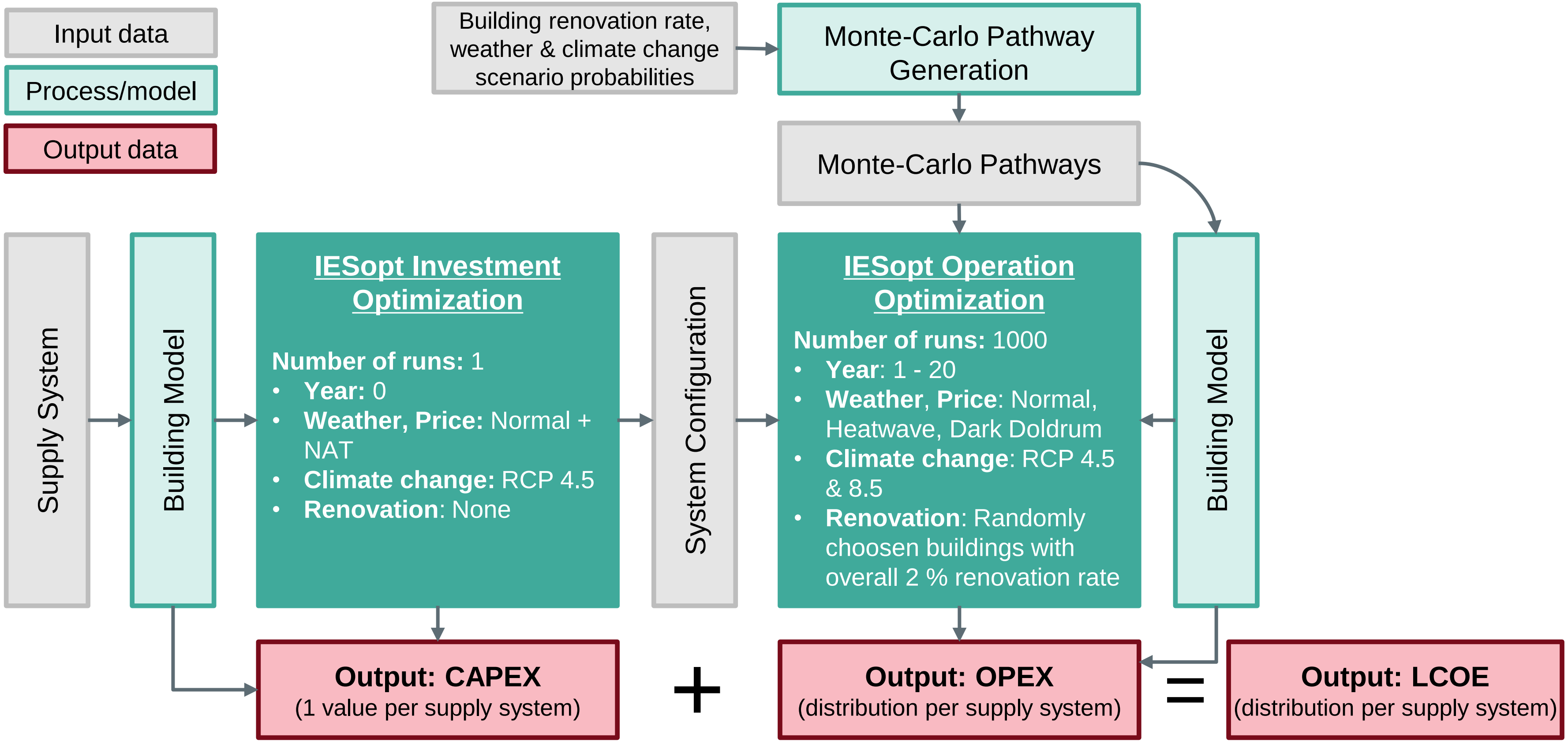
Linear building demand curve model (use)





Building-side supply system
- Building side component sizing (based on NAT and daily full load hours)
- CAPEX for building side system
- Building side component operation
- Aggregated heating, cooling, DHW and electricity demand for network

MODEL OVERVIEW



IESOPT INVESTMENT OPTIMIZATION

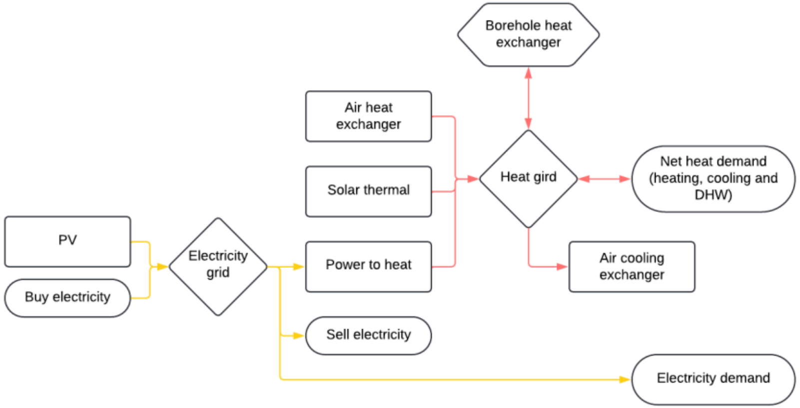
Input data

IESopt Optimization model

Model outputs

Timeseries data:

- Heating, cooling, DHW, and electricity demand (with -14°C minimum temperature)
- Electricity prices
- Air temperature (with -14°C minimum temperature)
- Global horizontal irradiance



- Installed capacity per technology
- Roof area used for PV and/or solar thermal
- Investment costs per technology

Static data

- Specific investment costs[1]
- Available roof area
- Variable operational costs

Energy generation units and energy flows between them

1) Danish Energy Agency, “Technology Catalogues” https://ens.dk/en/analyses-and-statistics/technology-catalogues

IESOPT OPERATION OPTIMIZATION

Input data

Timeseries data :

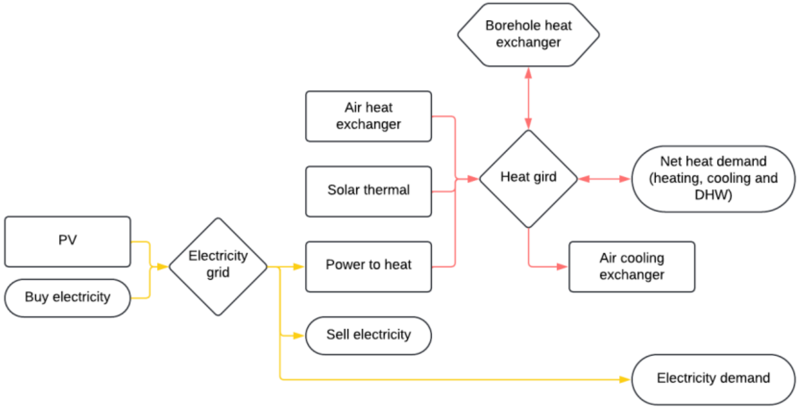
- Heating, cooling, DHW, and electricity demand
- Electricity prices
- Air temperature
- Global horizontal irradiance

For weather, climate change and renovation scenario for each year

Static data

- Installed capacity per technology
- Roof area for PV and solar thermal
- Variable operational costs

IESopt Optimization model



Energy generation units and energy flows between them

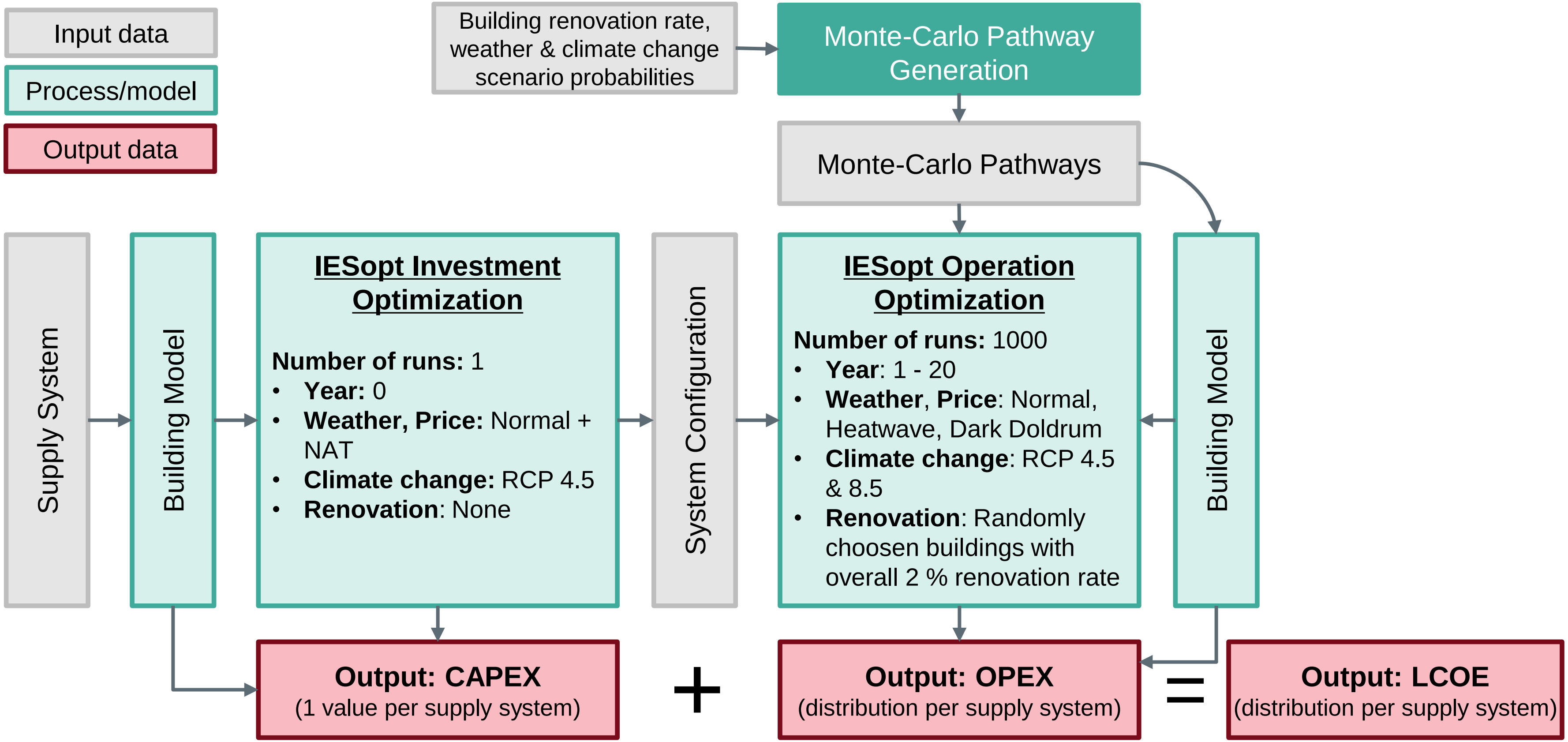
- PV
- Air heat exchanger
- Solar thermal
- Power to heat
- Borehole heat exchanger
- Air cooling exchanger

Model outputs

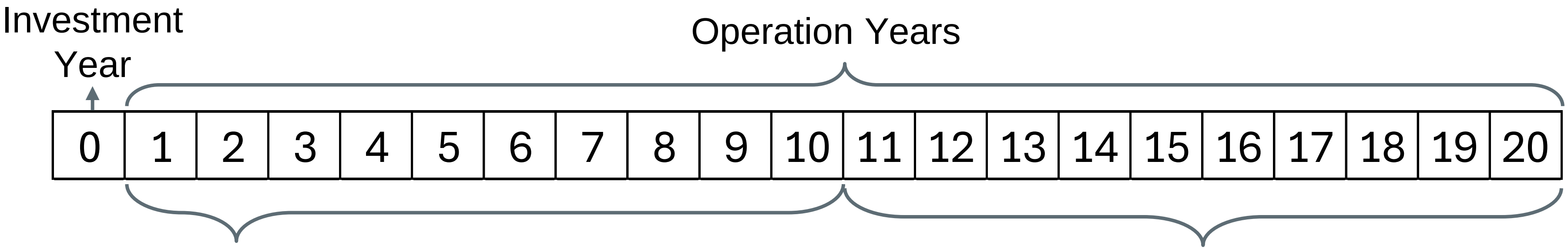
- Daily heat, electricity and cooling output per technology
- Daily variable operational costs per technology

Run for 20 years and combine CAPEX to calculate LCOE

MODEL OVERVIEW



PATHWAY ASSUMPTIONS: WEATHER & CLIMATE CHANGE SCENARIOS



Secures scenarios probability:

- RCP4.5-DN2030-normal: 46 %
- RCP4.5-DN2050-heatwave: 33 %
- RCP4.5-DN2050-dolldrum: 10 %

Secures scenarios probability:
50/50 %

Decarbonisation Needs (DN)

- RCP4.5-DN2050-normal: 46 %
- RCP4.5-DN2050-heatwave: 33 %
- RCP4.5-DN2050-dolldrum: 10 %

Reference Scenario (REF)

- RCP8.5-REF2050-normal: 46 %
- RCP8.5-REF2050-heatwave: 33 %
- RCP8.5-REF2050-dolldrum: 10 %

1) https://www.secures.at/publications
2) Formayer H, Nadeem I, Leidinger D, Maier P, Schöniger F, Suna D, et al. SECURES-Met: A European meteorological data set suitable for electricity modelling applications. Sci Data 2023;10:590. https://doi.org/10.1038/s41597-023-02494-4
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4) Extreme Weather Events Probabilistic: A Residual Load-Based Methodology for Assessing Climate Change Impacts on Electricity Systems and Identifying Extreme Events by Demet Suna, Franziska Schöniger, Gustav Resch, Florian Hasengst, Peter Widhalm, Gerhard Totschnig, Nicolas Pardo Garcia, Herbert Formayer, Philipp Maier :: SSRN
5) https://www.wien.gv.at/statistik/lebensraum/tabellen/eis-hitze-tage-zr.html

Results

MEAN LCOH OF SUPPLY SOLUTIONS

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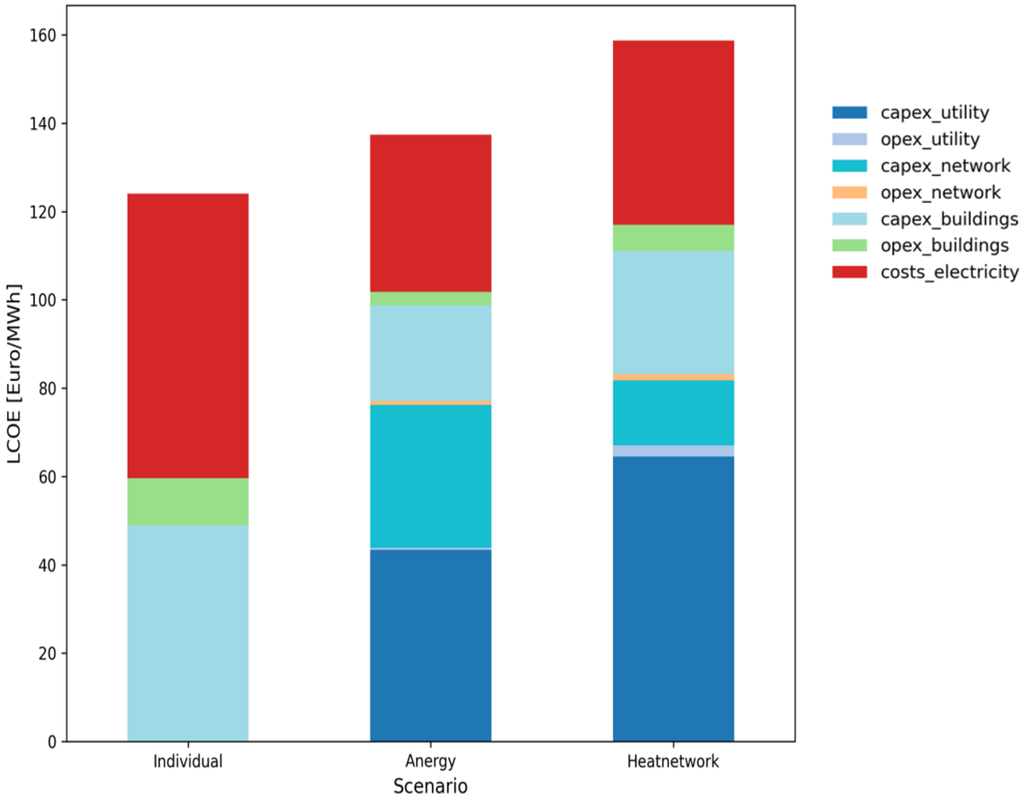
KEY-INSIGHTS

	Individual	Anergy	Heatnetwork
CAPEX [m. €]	3.6	7.2	8.0
OPEX [€/MWh]	75	40	52
LCOE [€/MWh]	125	140	160

- **OPEX savings** of **local network based** systems are **outweighed** by **high CAPEX**
- **Waste heat emission:**
  - Individual and heat network supply scenarios use air-source heat pumps for cooling, emitting waste heat into the built environment in summer → **Problematic**!
  - The anergy and heat network supply scenarios benefit the area by recharging the BHX during the summer through ambient air cooling. → **Beneficial**!



OPEX UNCERTAINTIES IMPACT

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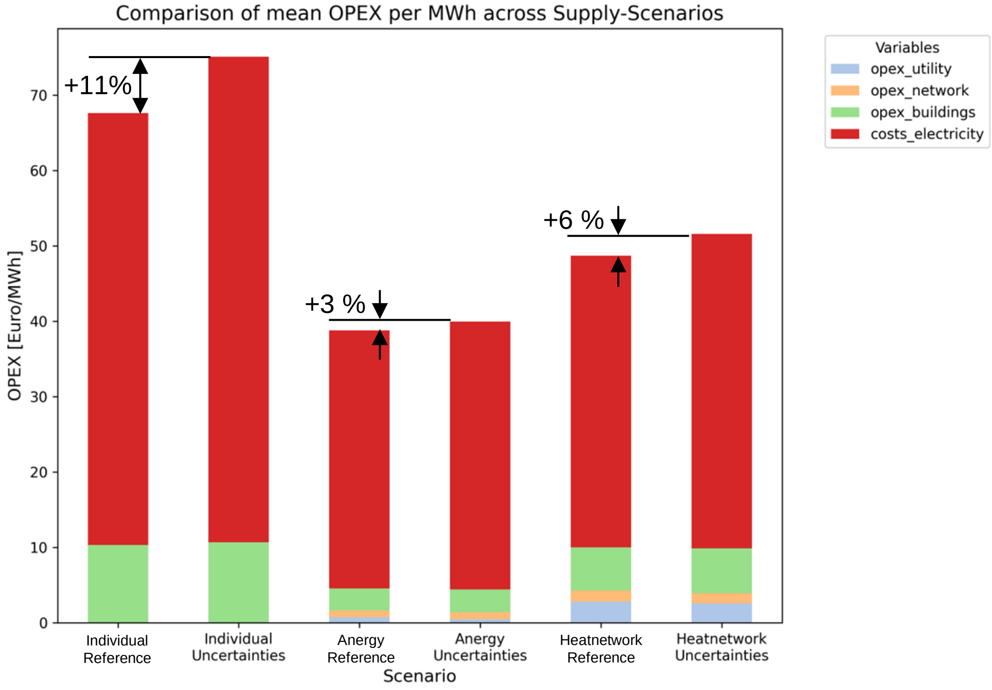
KEY-INSIGHTS

- All solutions LCOEs have a simliar **standard deviation σ**:
  - **Individual**: ~ 5.0 €/MWh
  - **Anergy**: ~ 5.0 €/MWh
  - **Heatnetwork**: ~ 5.2 €/MWh
- Plot shows **OPEX per MWh** for each supply solutions for **reference scenario** (RCP 4.5, no uncertainties) and with **uncertainties** (varying climate change, renovation, weather scenarios)
- Uncertainties affect **costs for electricity** and **heating/cooling demand**
- Uncertainties have a **negative impact** on **mean OPEX** per MWh of all supply solutions. **OPEX Risk Exposure:**
  - **Individual**: + 11 %
  - **Anergy**: + 3 %
  - **Heatnetwork**: + 6 %

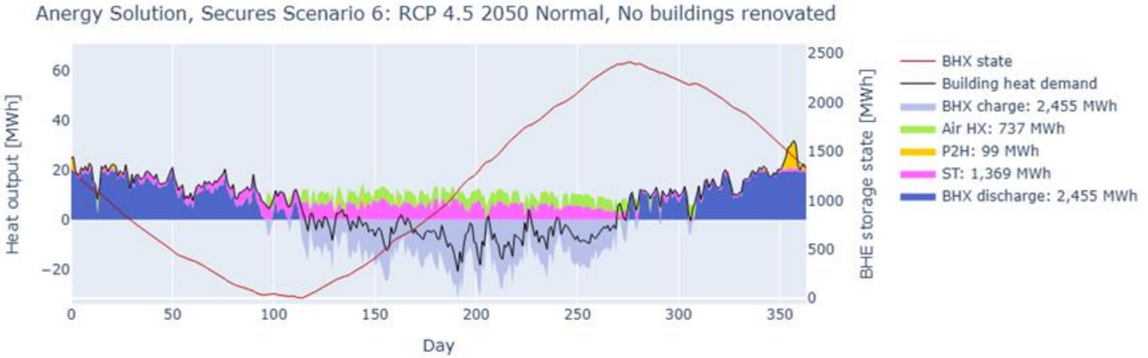


DAILY OPERATION OF ANERGY AND HEATNETWORK FOR A NORMAL YEAR

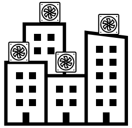
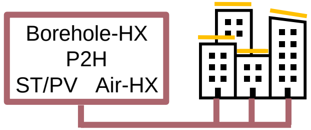
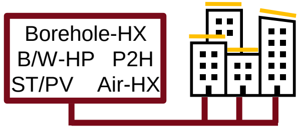
KEY-INSIGHTS

- BHX discharges over winter and charges over summer through ST and air HX → cools ambient air
- **Heatnetwork**:
  - Higher heat demand for network because of higher temperature
  - Heating supplied by BHX (+ Brine/water HP), ST, and P2H
- **Anergy**:
  - Air-HX, free cooling, and ST charge BHX in summer
  - Heating supplied by BHX, ST, and P2H

BHX = Borehole heat exchanger, ST = Solar Thermal, Air HX = Air heat exchanger, HP = Heatpump, P2H = Power to heat



RESULTS SUMMARY

	ERT 7	SUPPLY SOLUTION		
		**Individual** 	**Anergy** 	**Heatnetwork** 
KPIs	**ø LCOE [€/MWh]**	~ 125	~ 140	~ 160
KPIs	**σ (LCOE) [€/MWh]**	~ 5.0	~ 5.0	~ 5.2
KPIs	**ø OPEX [€/MWh]**	~ 75	~ 40	~ 52
KPIs	**OPEX Risk Exposure**	+ 11 %	+ 3 %	+ 6 %
KPIs	**CAPEX [mio.€]**	~ 3.6	~ 7.2	~ 8.0
KPIs	$P_{el,max}^{total}$ **[MW]**	~ 1,9 (buildings)	~ 1,9 (1,2 utility: 0,7 buildings)	~ 2,1 (utility)
KPIs	**Waste Heat Emission (WHE) in Summer**	High (cooling with Air/Water HPs)	Negative (Borehole-HX regeneration in summer by cooling ambient air)	Neutral (cooling with Air/water HPs, Borehole HX regeneration in summer by cooling ambient air)
Result	**Economic indicator and tendency**	economic →	economic ↗	economic ↗

SUMMARY AND OUTLOOK

Summary

- A high-performance model was developed for the techno-economic analysis of sustainable heating and cooling solutions at the neighborhood level.
- The model optimizes investment and operation while accounting for uncertainties in electricity price, weather, climate change, and building renovation scenarios.
- Applied to a case study in Vienna, the model demonstrated strong perfromance and practical applicability
- 1,000 Monte Carlo pathways are processed in 5 hours on a standard business laptop with potential for even faster execution using a computer cluster.
- Results for a selected case study show that the high CAPEX of local network-based solutions outweighs their OPEX savings, leading to a a higher LCOE.
- However, network-based solutions exhibit lower risk exposure under future uncertainties.

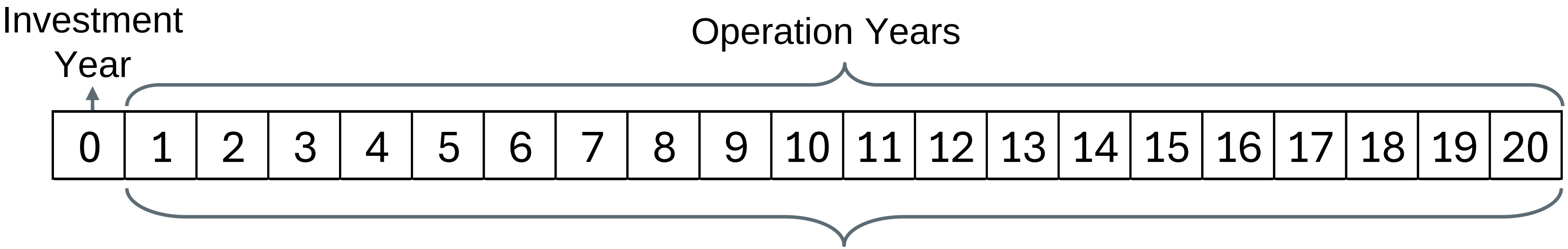
Outlook

- Implementing hourly resolution for investemnt optimization.
- Integrating battery storage into local network solution models.
- Expanding the analyis with additional electricity price scenarios.
- Enhancing the borehole heat exchanger model.
- Improved modelling of cooling demand.

Thank you

AIT Austrian Institute of Technology – Center for Energy
Nyasha Grecu
Junior Research Engineer
Nyasha.Grecu@ait.ac.at
www.ait.ac.at/energy

PATHWAY ASSUMPTIONS: BUILDING RENOVATION



Building renovation

- 2% building renovation rate
- The buildings renovated each year varies
- ~10 renovated buildings at the end of the study period

Change in useful energy demand:

- ~80% reduction in space heating demand for each renovated building
- Cooling demand is not affected by the renovation scenario

BUILDING DEMAND MODEL

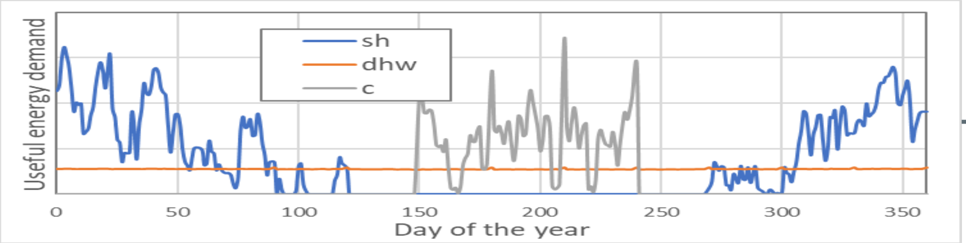
Model constructor based on case study

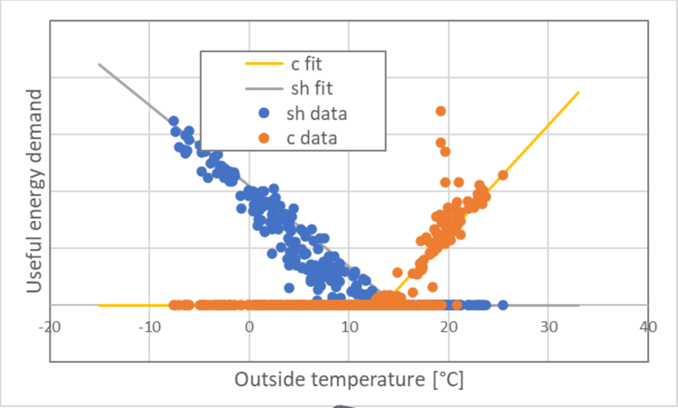
Building data (ren/unren)
GIS-shapes, envelope,…

Weather data:
Comprehensive (epw)

City Energy Analyst (CEA)
Urban building energy model

Building demand data:
- Domestic hot water (use)
- Space heating (use)
- Cooling (use)





$$ued_{h/c} = k_1 \cdot tmp + k_2 \cdot glo + d$$

$$ued_{dhw} = d_{dhw}$$

Linear building demand curve model (use)

$ued_{h/c} = k_1 \cdot tmp + k_2 \cdot glo + d$

HW AND DD PROBABILITY

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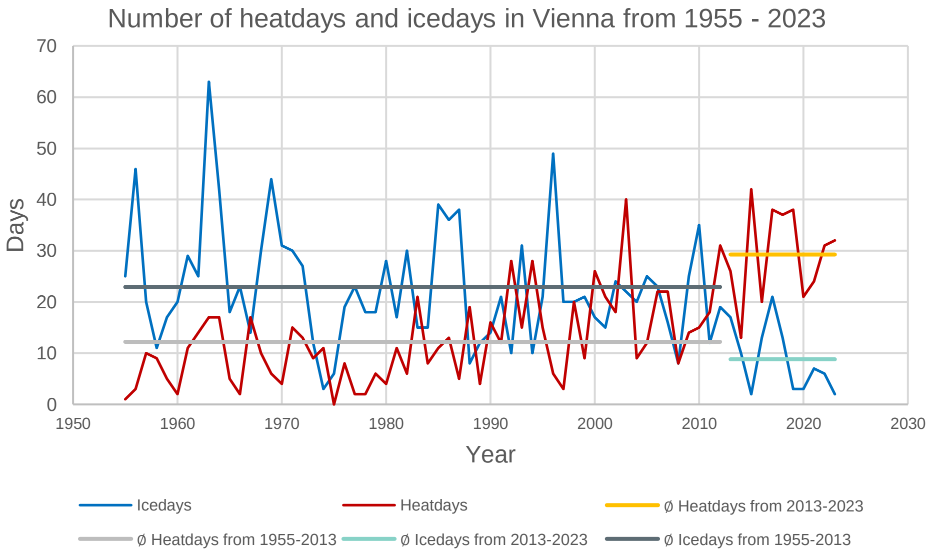
History Data[1] on Heat- and Icedays in Vienna

- In the period of 1955 – 2012 Vienna experienced on average ~ 12 days above 30 °C & ~ 22 days below 0 °C air temperature[1]
- From 2013 – 2023 on average ~ 30 days above 30 °C & ~ 8 days below 0 °C air temperature[1]
- **Assumptions for 1st 10 years (2025 – 2035)**:
  - Normal: 46 %
  - HW: 33 %
  - DD: 10 %
- **Assumptions for 2nd 10 years (2035 – 2045)**:
  - RCP4.5/RCP8.5: 50/50
  - Same assumptions for weather extremes as in 1st period



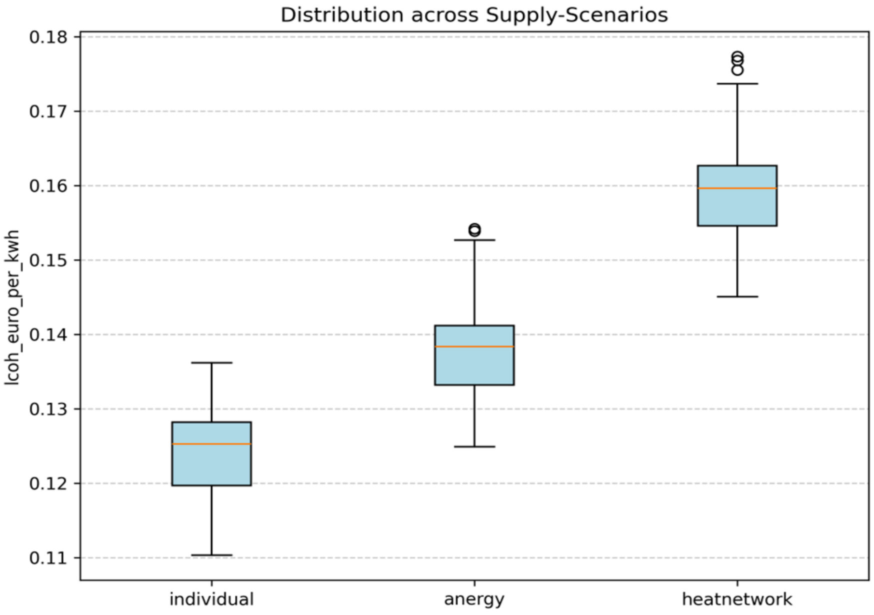
	DN-2030-normal	DN-2030-hw	DN-2030-dd	DN-2050-normal	DN-2050-hw	DN-2050-dd	REF-2050-normal	REF-2050-hw	REF-2050-dd
Number Heatdays (days > 30 °C)	7	52	16	10	24	16	17	72	6
Number icedays (days < 0 °C)	12	12	35	3	21	35	4	0	15

1) https://www.wien.gv.at/statistik/lebensraum/tabellen/eis-hitze-tage-zr.html

DISTRIBUTION OF LCOH

KEY-INSIGHTS

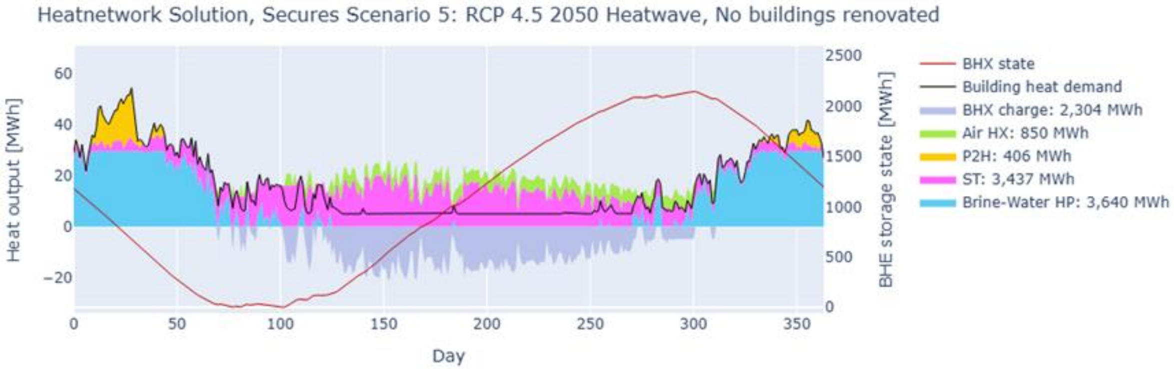
- All solutions LCOEs have a simliar **standard deviation σ**:
  - **Individual**: ~ 5.0 €/MWh
  - **Anergy**: ~ 5.0 €/MWh
  - **Heatnetwork**: ~ 5.2 €/MWh
- Interquartile range of LCOEs of supply solutions do not overlap
- Model evaluates „risk“ of each solution manageable in all possible (secures-) scenarios

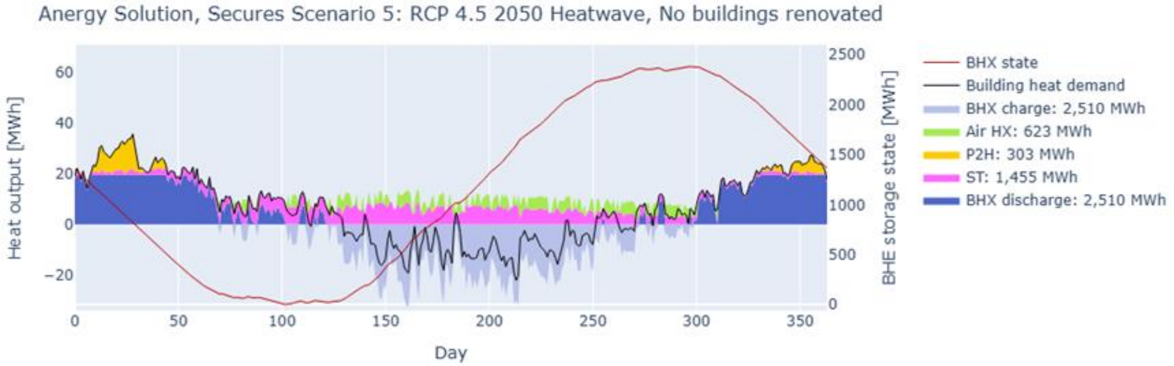


DAILY OPERATION OF ANERGY AND HEATNETWORK FOR A HEATWAVE YEAR

KEY-INSIGHTS

- ST and air HX provide heat up until later in the year
- Higher heat demand in january – february needs to be covered by P2H becasue of limits to BHX discharge capacity
- **Anergy**:
  - Greater cooling demand over the summer can still be covered by free cooling with the BHX





BHX = Borehole heat exchanger, ST = Solar Thermal, Air HX = Air heat exchanger, HP = Heatpump, P2H = Power to heat

DAILY OPERATION OF ANERGY AND HEATNETWORK FOR A DOLLDRUM YEAR

KEY-INSIGHTS

- Higher winter peak demand is covered by P2H
- P2H is also used to charge the BHX in the summer

BHX = Borehole heat exchanger, ST = Solar Thermal, Air HX = Air heat exchanger, HP = Heatpump, P2H = Power to heat