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A case study on long-term investment planning for the decarbonization of Western Europe's most complex district heating network

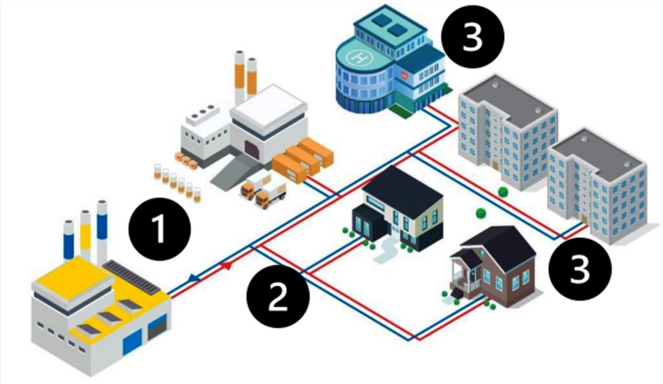
Stephanie Riedmüller, Fabian Rivetta, Maxwell Dykes, Janina Zittel

Zuse Institute Berlin

Decarbonization of District Heating Networks

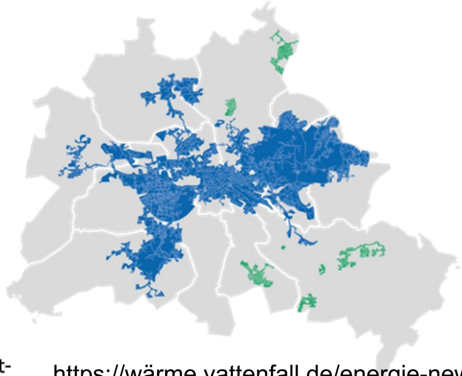
District heating networks (DHNs) distribute heat from an energy source or sources to residential and commercial users

A DHN consists of:
1. Energy source (or sources)
2. Distribution network
3. End users

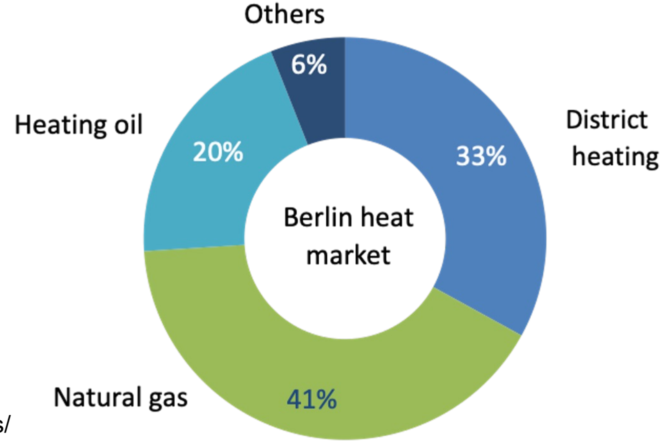


Baerbel Epp, *Support for Renewable District Heating in Slovenia*, Solarthermalworld.org, 12.06.2019, https://www.solarthermalworld.org/news/support-renewable-district-heating-slovenia

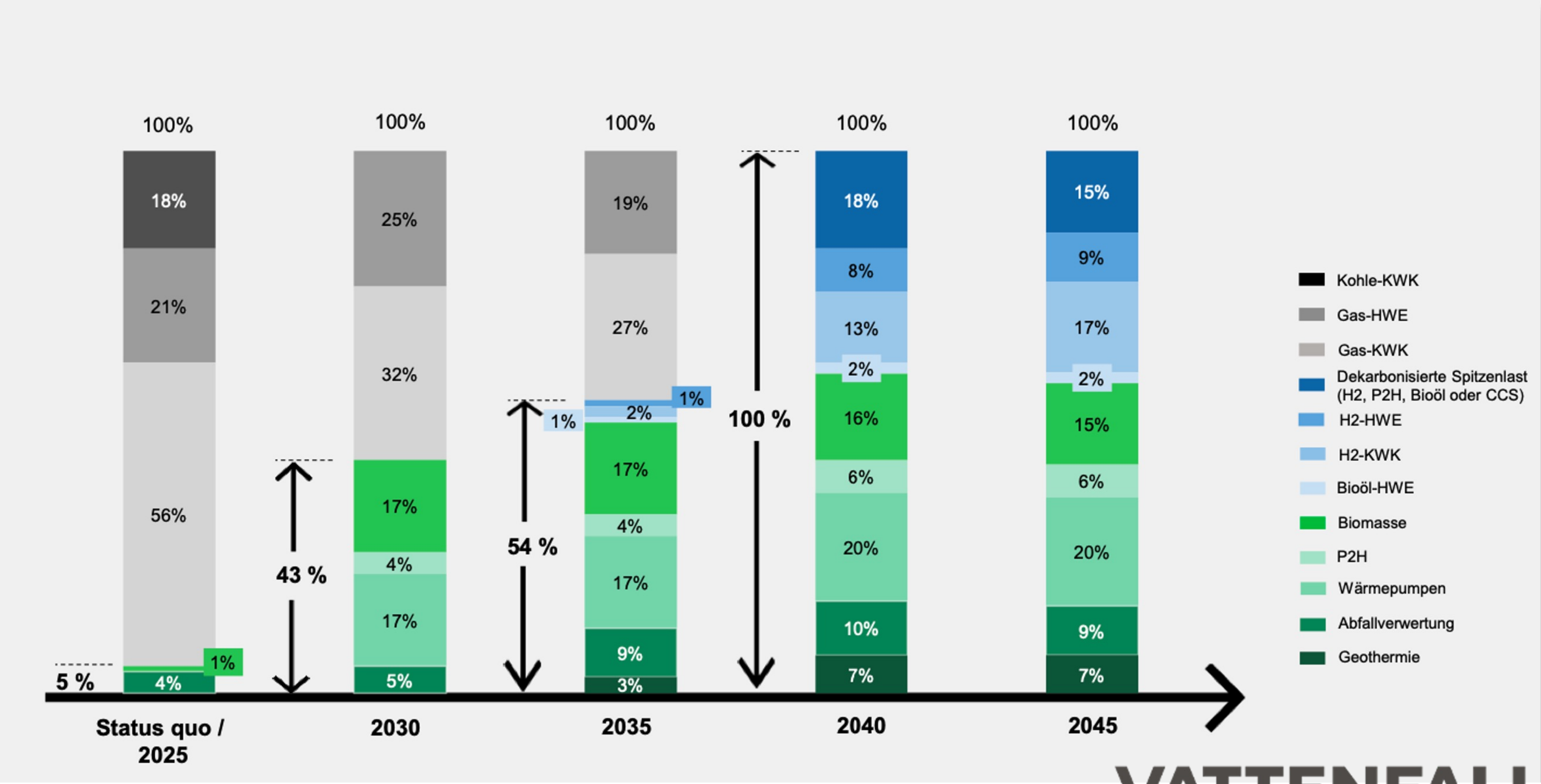
- ➢ Decarbonizing heat sources in DHNs enables effective, cost-efficient, and reliable decarbonization of the building sector in densified areas
- ➢ 6 million German households (= 14%) are connected to DHNs
- ➢ 33% of Berlin's heat market are covered by DH



https://wärme.vattenfall.de/energie-news/fahrplan-zur-dekarbonisierung/



Decarbonization Roadmap Berlin

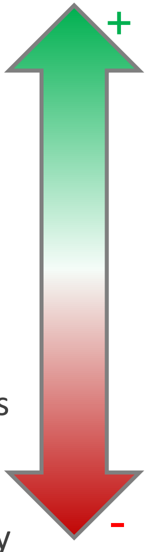


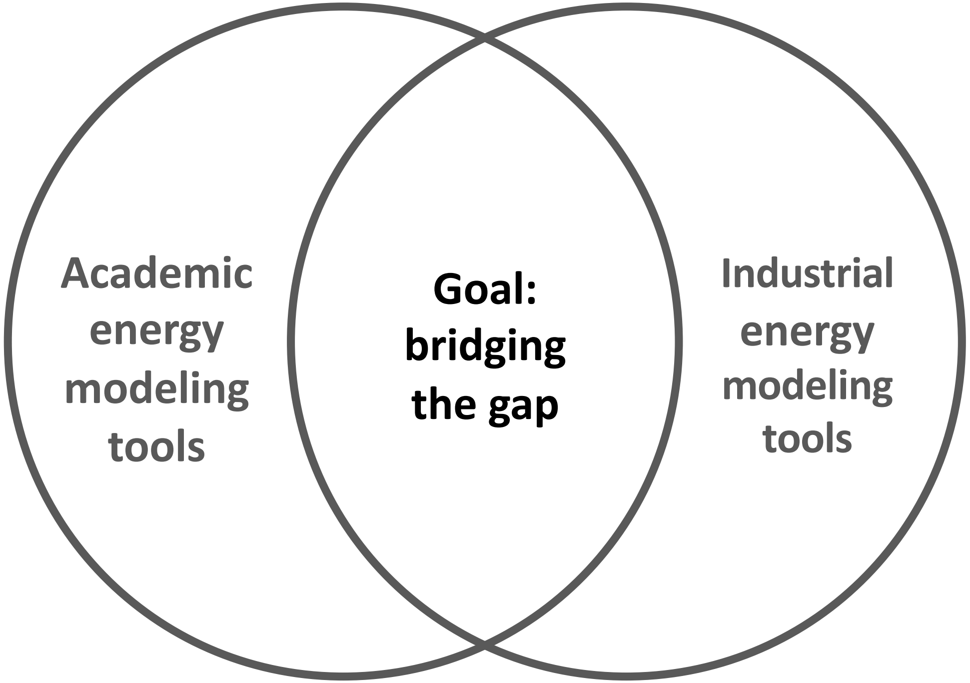
https://wärme.vattenfall.de/energie-news/fahrplan-zur-dekarbonisierung/

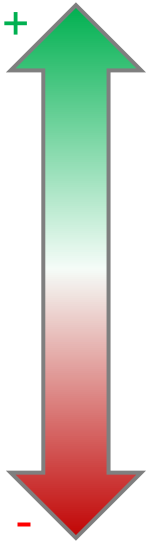
The Model

- Efficient solution methods
- High performance for specific problem classes

- Not transferable to other problems
- Too broad for detailed planning
- Coarse granularity





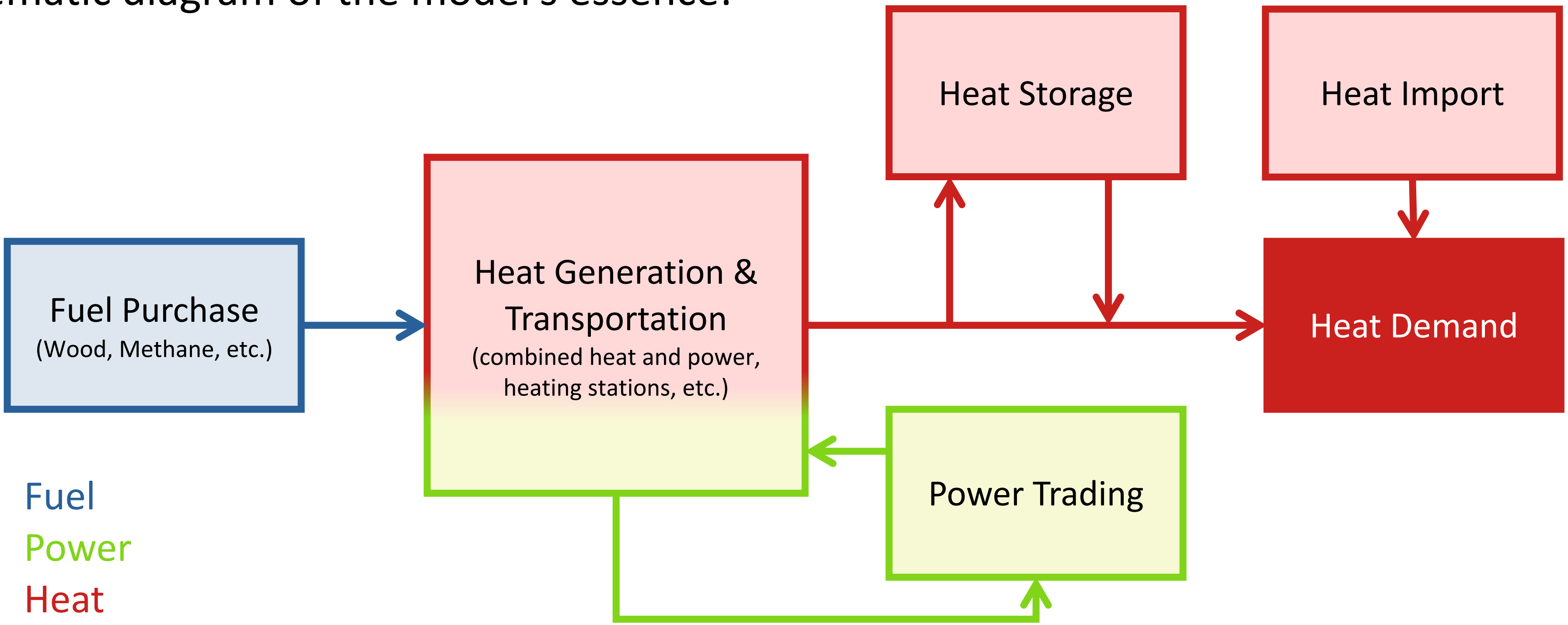


- High modeling flexibility
- Highly detailed
- Fine granularity

- Out-of-the-box use of solvers
- Performance plateau reached
- Highly restrictive (short-term, single objective, etc.)

The Model

Schematic diagram of the model's essence:



Mathematical formulation

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MILP-formulation: combining unit commitment and investment planning

$$\min_{\hat{z},z,s,x,h} c^{inv}(\hat{z}) + \sum_{t\in T} c_t(z_t, s_t, x_t, h_t)$$ ***(Investment and operational cost)***

s. t. $z_t \leq \hat{z}$	$\forall t \in T$	***(Status depending on investment)***
$A_t^{act,s}(s_t) + \sum_{\tau \in T_t^{act}} A_\tau^{act,z}(z_\tau) \leq b_t^{act}$	$\forall t \in T$	***(Activation, minimum up and down time)***
$A_t^{storage}(x_t, h_t, h_{t+1}) = 0$	$\forall t \in T$	***(Storage constraints)***
$D_t(z_t, s_t, x_t, h_t) \leq d_t$	$\forall t \in T$	***(Operational constraints: fuel purchase, produced heat, demands, …)***
$x_t, h_t \geq 0$	$\forall t \in T$	***(Non-negativity)***

$\hat{z}$ binary	(Investment variables)
z_t binary	(Status variables: whether power plant is active or inactive)
s_t binary	(Activation variables: whether start-up happened)
x_t binary, continuous	(Operation variables: purchased fuel, produced power, …)
h_t continuous	(Storage variables)

~300M Variables
(~15M binary)
~300M constraints

Case Study

Instance:

- district heating network of Berlin (Verbundnetz)
- + 38 strategically chosen potential investments

Goal:

- explore different transformation pathways on achieving decarbonization targets in line with reasonable economic decisions.

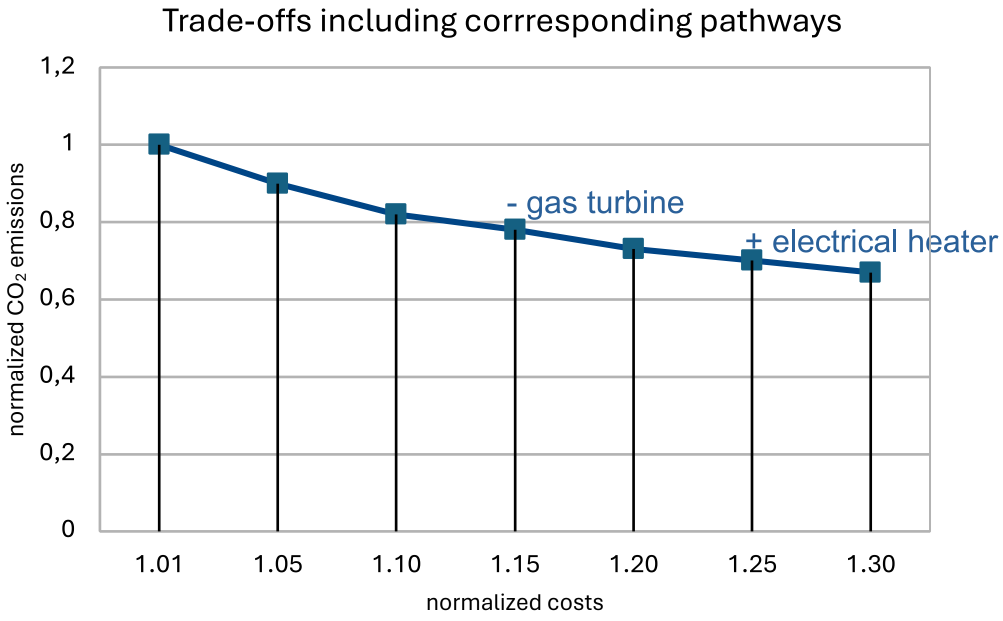
→ two objectives: costs, CO_2-emissions

Method:

- over 25 years (2020 – 2045)
- 24-hourly granularity
- lexicographic optimization
- varying cost tolerance gaps ranging up to 30% of the cost optimum
- increments of 5%

Results

Costs	CO_2	No. of Investments
101%	100%	11
105%	90%	11
110%	82%	11
115%	78%	10
120%	73%	10
125%	70%	11
130%	67%	11



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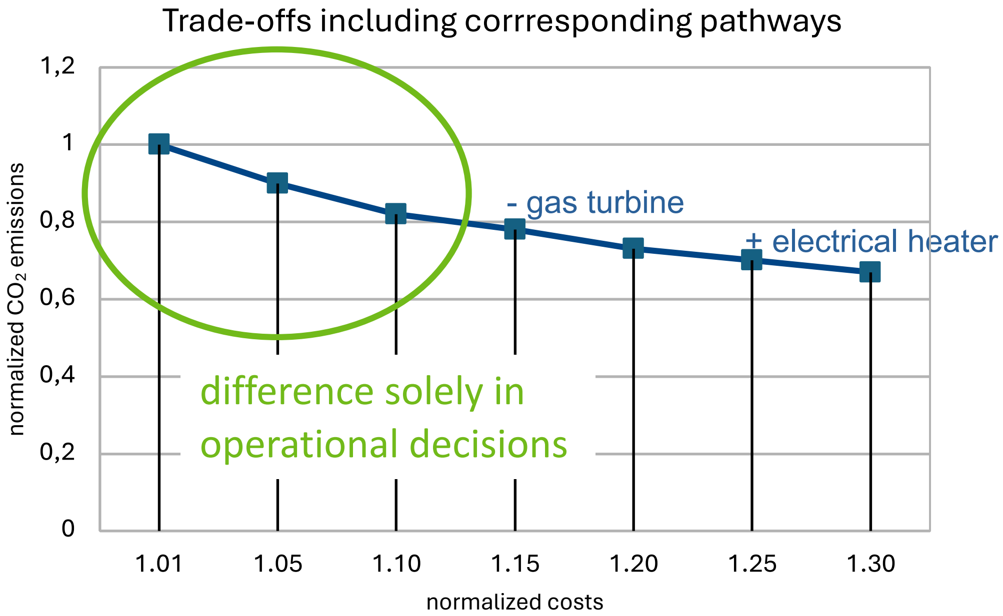


→ Integrating investment planning into unit commitment is important to make informed decisions!

Results

Costs	101%	105%	110%	115%	120%	125%	130%
CO_2	100%	90%	82%	78%	73%	70%	67%
CHP	1	1	1	1	1	1	1
CHP	1	1	1	1	1	1	1
Block CHP	1	1	1	1	1	1	1
CCGT	1	1	1	1	1	1	1
Heating station (Wood)	1	1	1	1	1	1	1
Gas turbine upgrade	1	1	1	1	1	1	1
Gas turbine	1	1	1	1	1	1	1
Gas turbine	1	1	1	1	1	1	1
Gas turbine	1	1	1	1	1	1	1
Gas turbine	1	1	1	1	1	1	1
Gas turbine	1	1	1	0	0	0	0
Electrical heater 120 MW	0	0	0	0	0	1	1
Seasonal Storage, heating station, electrical heater, heat pump, etc.	0	0	0	0	0	0	0

robust investments (CHP through the fourth Gas turbine)

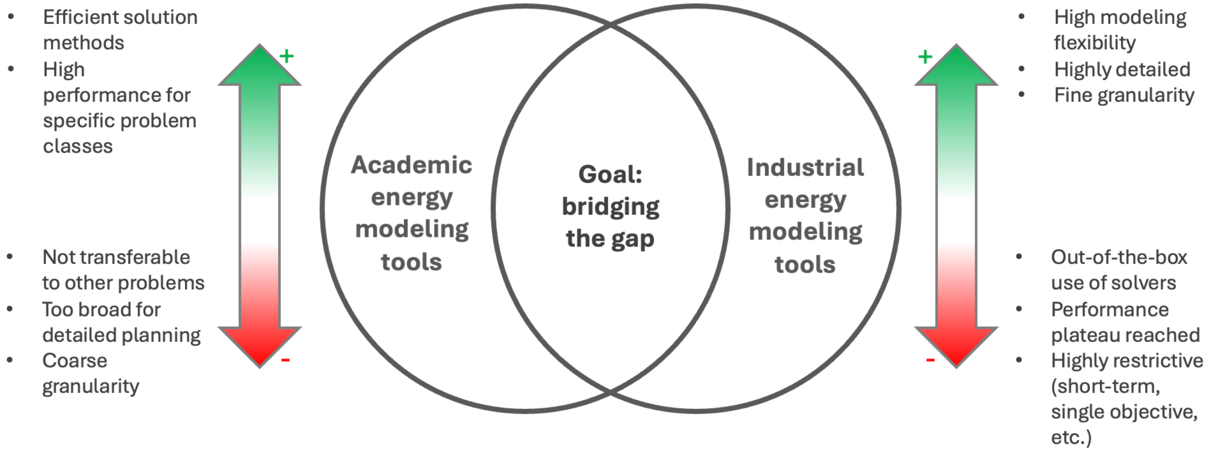
target-dependent investments (last Gas turbine and Electrical heater 120 MW)

Next steps

we showed that solving the model with long-term investments and finding pathways with reasonable trade-offs is possible, but:

- ✗ not efficiently solvable (e.g. the computation of a cost optimal solution takes >50h)
- ✗ solvable only under restrictions in time granularity and increased MIP-gap
- ✗ large model size

→ Remodeling the district heating network could potentially improve efficiency under small decrease in accuracy of the model.



Publications

Clarner, Tawfik, Koch, Zittel: Network-induced Unit Commitment – A model class for investment and production portfolio planning for multi-energy systems ZIB-Report, 2022.

Thank you!