TRANSFORMATION PATHS OF LOCAL DISTRICT HEATING WITH ELECTRICITY AND HEAT SECTOR COUPLING IN GERMANY

Fraunhofer-Institute for Energy Economics and Energy System Technology

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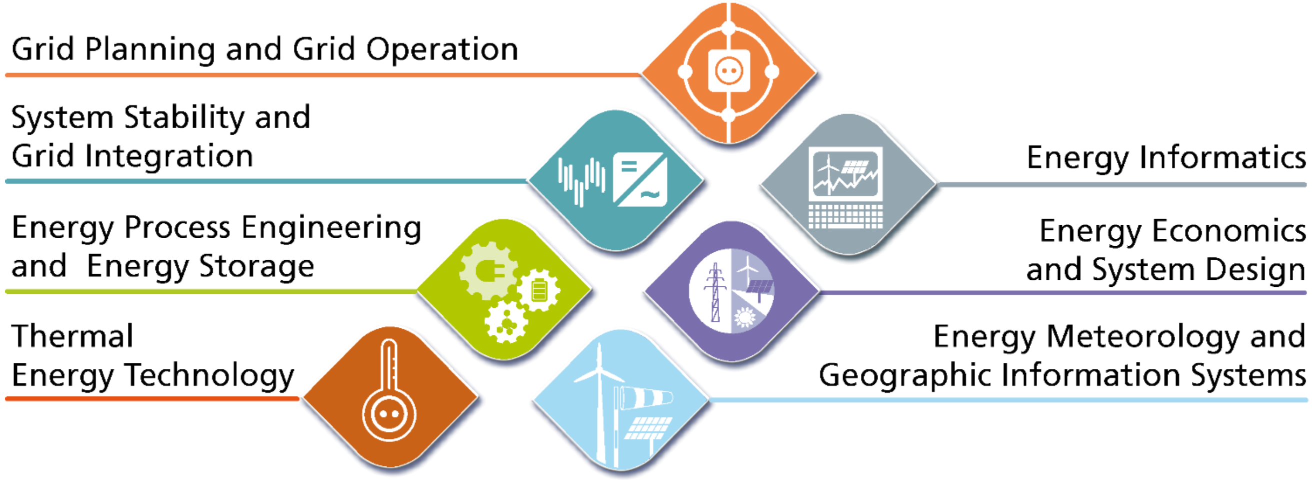
FRAUNHOFER INSTITUTE ENERGY ECONOMICS AND ENERGY SYSTEM TECHNOLOGY

The Fraunhofer IEE in Kassel researches in the fields of energy economics and energy system technology.

We explore and develop solutions for sustainably transforming renewable based energy systems.

Our service portfolio deals with current and future challenges faced by the energy industry and energy system technology issues.



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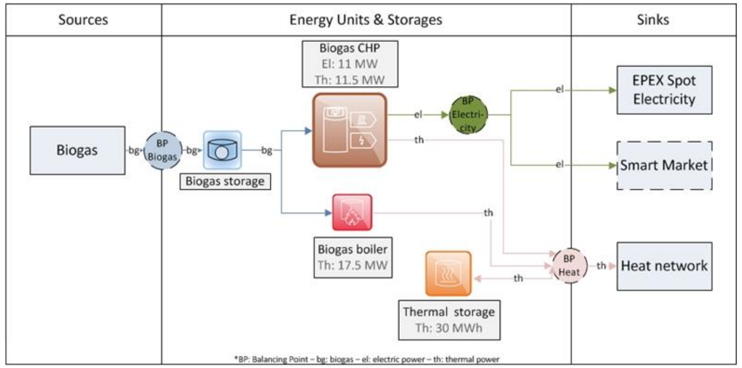
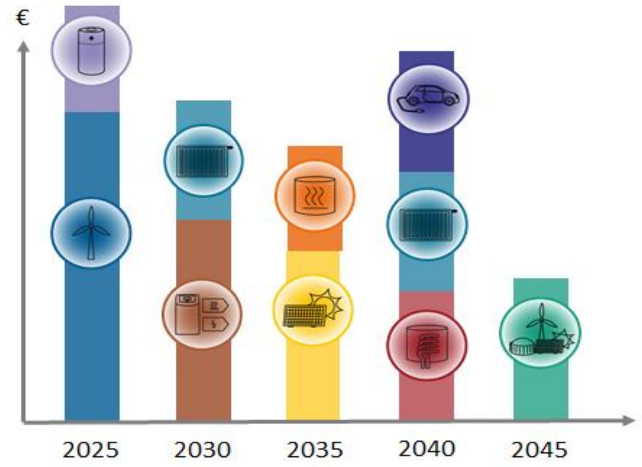
Problem formulation

- The scope is to combine a techno-economic approach to transformation processes in energy systems with a focus on district heating.
- The diferent technologies configuration in a given political framework (climate protection plan) are compared, considering their **(CAPEX) portfolio investments and energy coverage (OPEX)** over the planning horizon (35 years)
- What kind of portfolio is needed in order to achieve the climate protection targets with high RE shares in the heat supply?





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Introduction

- **Political Framework**
  - Germany aims to reduce greenhouse gas emissions by 40 % by 2020 and by at least **55 % by 2030** compared to 1990 emission levels.
  - Complete greenhouse gas neutrality is to be achieved by 2050.
  - Legal framework:
    - 'Federal Climate Change Act', the **'Climate Action Programme 2020'** and the **'Climate Action Plan 2050'**.
    - "Act to reduce and end coal-fired power generation"
  - The impact of the political framework on social, regulatory framework and technology innovation are important for the transformation paths of district heating in Germany.

Umwelt Bundesamt

Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit

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Introduction

- **Regulatory Framework**

  In addition to the burdens (e.g. EEG levy) and incentives (e.g. CO2 price) of end-user prices, the subsidy conditions are decisive for the attractiveness of investments.

  - Combined-Heat-and-Power Act (Kraft-Wärme-Kopplungsgesetz – KWKG)
  - Federal funding for efficient heating networks (Bundesförderung für Effiziente Wärmenetze - BEW)
  - Section 14a of the German Energy Industry Act (Energiewirtschaftsgesetz – EnWG)

	KWKG incentive	Thermal generation premium	Variable network charges
< 2030	30,000 Full Load Hours	Renewable Energy heat in €/MWh	Cost Reduction for heat pumps
>2030	40 % CAPEX	40 % CAPEX	

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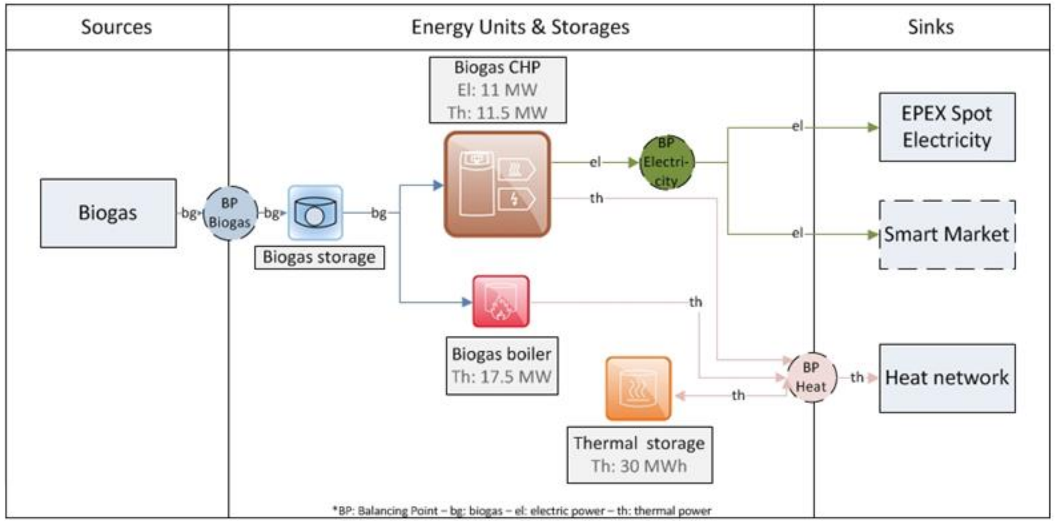
Methodology and portfolio optimization

Operational decision making combined with investment decisions



- **Objective Function**
  - $maximizing \sum_{t\in T}(i_t - c_t)\cdot f - \boldsymbol{c_{inv}}\cdot f$
- The net present value discount factor f
  - $f = \frac{1}{(1+EER)^{year}}$
- The income i_t considers for every hour *t*, the purchasing price $\rho_{l,t}$ of each electrical or thermal energy consumption *sink l* of set *L*
  - $i_t = \sum_{l\in L} P_{l,t}\cdot\rho_{l,t} + \sum_{e\in E}(\boldsymbol{premium}_{e,t} + \boldsymbol{incentive}_{e,t})$
- The cost c_t
  - $c_t = \sum_{e\in E} s_{e,t}^{start}\cdot\rho_e^{start} + p_{e,t}^{out}(\rho_{e,t}^{on} + \rho_{e,t}^{fuel} + \rho_{e,t}^{CO2}) + s_{e,t}^{on}\cdot\rho_{e,t}^{fix}\cdot P_e^{max}$

- Heat pumps COP
  - $COP_{hp,t} = \eta_{hp}^{prim}\cdot\frac{T_{hp,t}^{sink}}{T_{hp,t}^{sink}-T_{hp,t}^{source}}$

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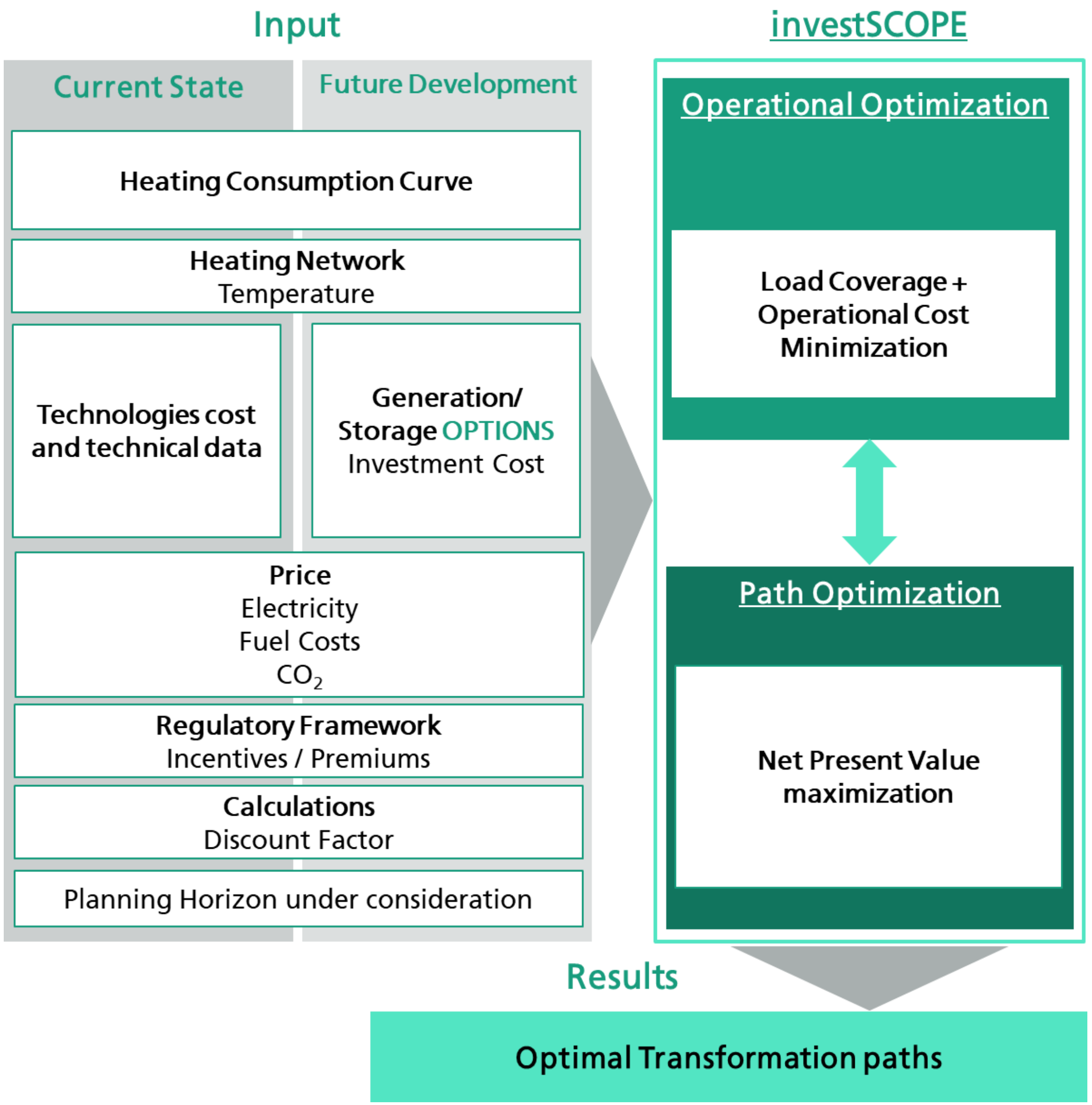
Simulation and definition of parameters

- The Fraunhofer IEE tool **investSCOPE** is used for the microeconomic optimization of transformation paths.
  - It is based on the Python package Pyomo.
  - The period under consideration is 35 years (2018-2052), taking representatives of 5-year periods, defining **7 support years**, i.e. 2020, 2025, 2030, 2035, 2040, 2045 and 2050.



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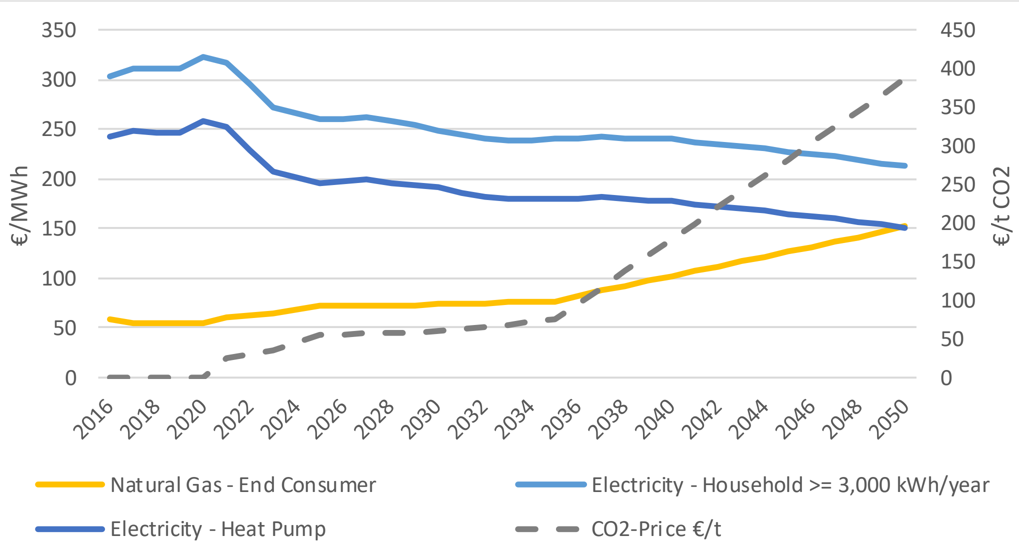
Simulation and definition of parameters

- Annual demand of 770 GWh/year in support year 2020, **with hourly resolution** and **future heat demand** with a network densification until 2030 to 900 GWh/year and maximum heat load of approx. 410 MW. The heat demand decreases due to refurbishment measures, etc. to 620 GWh/a in the support year 2050.

- Characteristic data on the heat network (e.g., current and future temperatures)

Year	2020	2030	2040	2050
Winter Flow Temperature	90°C	90°C	80°C	72°C
Transition Flow Temperature	90°C	90°C	80°C	72°C
Summer Flow Temperature	75°C	75°C	75°C	72°C

- Electricity prices, levies, CO2 prices, gas prices from macroeconomic future scenarios based on political decisions in "Climate Action Programme 2020"



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Simulation and definition of parameters: Technology options

- The Coal-fired CHP technology is not available as an investment option. The Natural Gas (NG) fired CCGT are available for investment.

Technology	Maximum Capacity	Available for investment.
Coal-fired CHP [MW_{el}]	46 x 2	No
NG-fired CCGT [MW_{el}]	200	Yes

- Optional technologies in the form of blocks, which investSCOPE can be combined optimally for all scenarios.

Optional Technology	Capacity per Block	Lifetime [years]
NG-fired medium CHP [MW_{el}]	40	30
NG-fired small CHP [MW_{el}]	20	20
NG Boiler [MW_{th}]	40	20
Wood Boiler [MW_{th}]	30	20
Electrical Boiler [MW_{th}]	30	20
Large-scale Heat Pump [MW_{th}]	20	25
Solarthermal [MW_{th}]	15	25
Industrial Waste Heat [MW_{th}]	15	35
Short-term Heat Storage [MWh_{th}]	1,450	35

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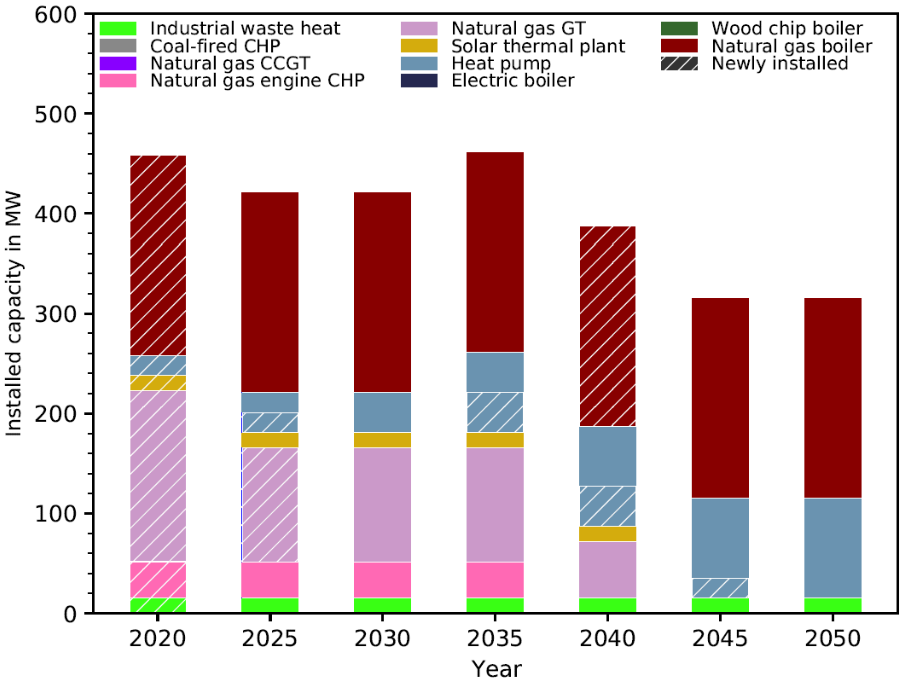
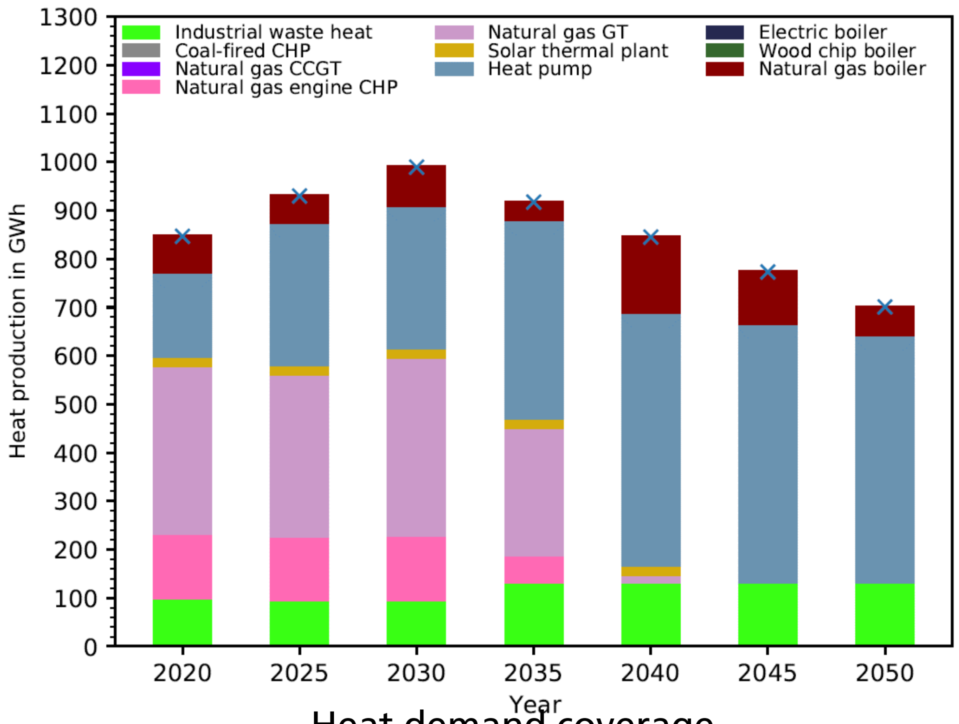
Simulation and definition of parameters: Scenario definition

- **Base scenario/ Reference scenario:** No existing plants.
  - Represents the basis system where all the generation units are available since the first simulation year, without pre-installed capacity.
- **Scenario CCGT2035:** Combined cycle plant gas turbine phase-out in 2035.
  - Represents a system with an existing Natural Gas CCGT (200 MWel) that needs to be full decommissioned by 2035, because its life time ends.
- **Scenario Coal-CHP 2025:** Coal CHP phase-out of first unit in 2025 and the second unit in 2030.
  - Represents a system with an existing Coal-Fired CHP that needs to be partially decommissioned by 2025 (46 MWel) and in 2030 (46 MWel) full shut-down, according to the Coal Fire Phase out Act.
- **Scenario Coal CHP 2030:** Coal CHP phase-out of first unit in 2030 and the second unit in 2035.
  - Represents a system with an existing Coal-Fired CHP that needs to be partially decommissioned by 2030 (46 MWel) and in 2035 (46 MWel) full shut-down, according to the Coal Fire Phase out Act.

Results Analysis and Discussion: Reference scenario without existing plants



Installed and newly installed capacity



Heat demand coverage

- Solar thermal and heat pumps are installed as early as 2020 and 2025 with a limited potential.
- **NG-fired CHP are also installed (2020)** due to KWK-G incentive and the 30,000 full load hours.
- NG Boilers are being pushed back (2040) to peak load due the shut-down of NG-fired CHP, combined with **additional heat pumps (2035)**
- Waste heat from industry is used as base load.

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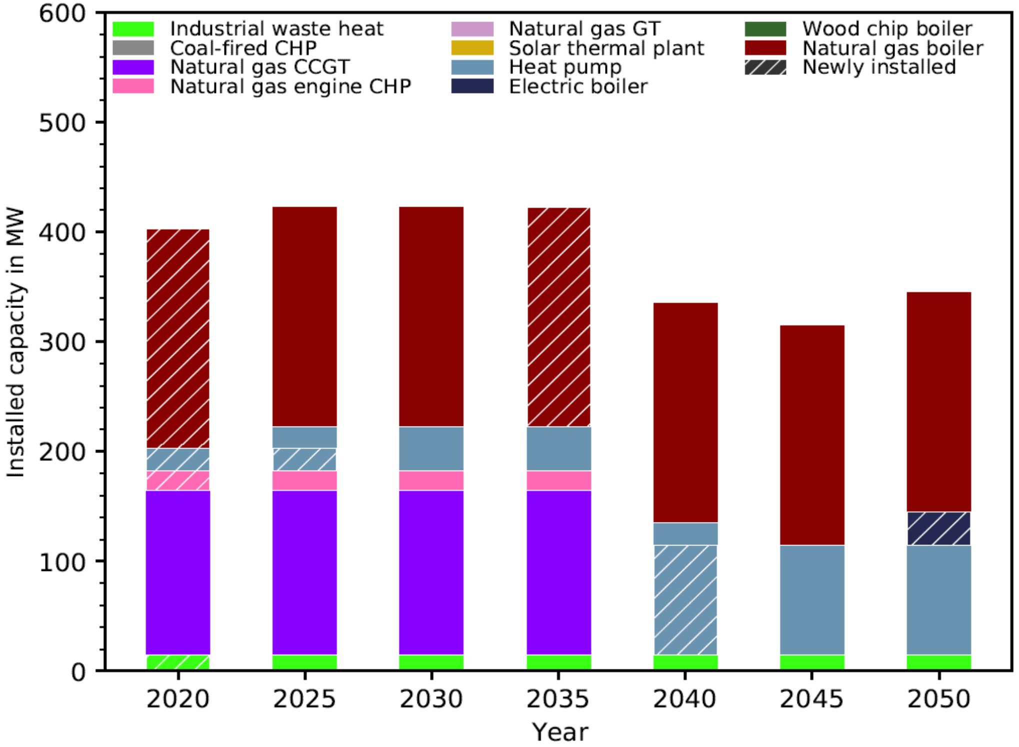
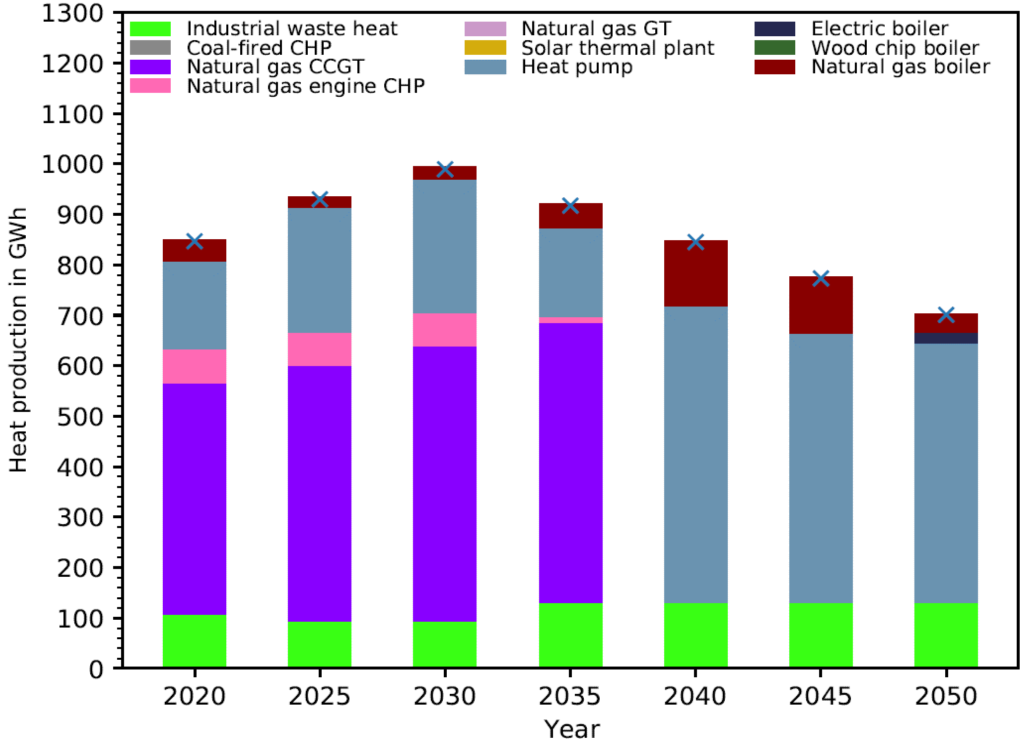
Results Analysis and Discussion: Large existing CHP (Scenario CCGT2035)



Installed and newly installed capacity



Heat demand coverage

- **Solar thermal** solar thermal collectors would not be economical despite the RE premium.
- NG-fired CHP are also installed due to KWK-G incentive and the 30,000 full load hours.
- NG boilers satisfies **the peak demand since 2020**, because the delay of the other **RE technologies (2040).**
- Waste heat from industry is used as base load. Also it has a reduced production the first years.

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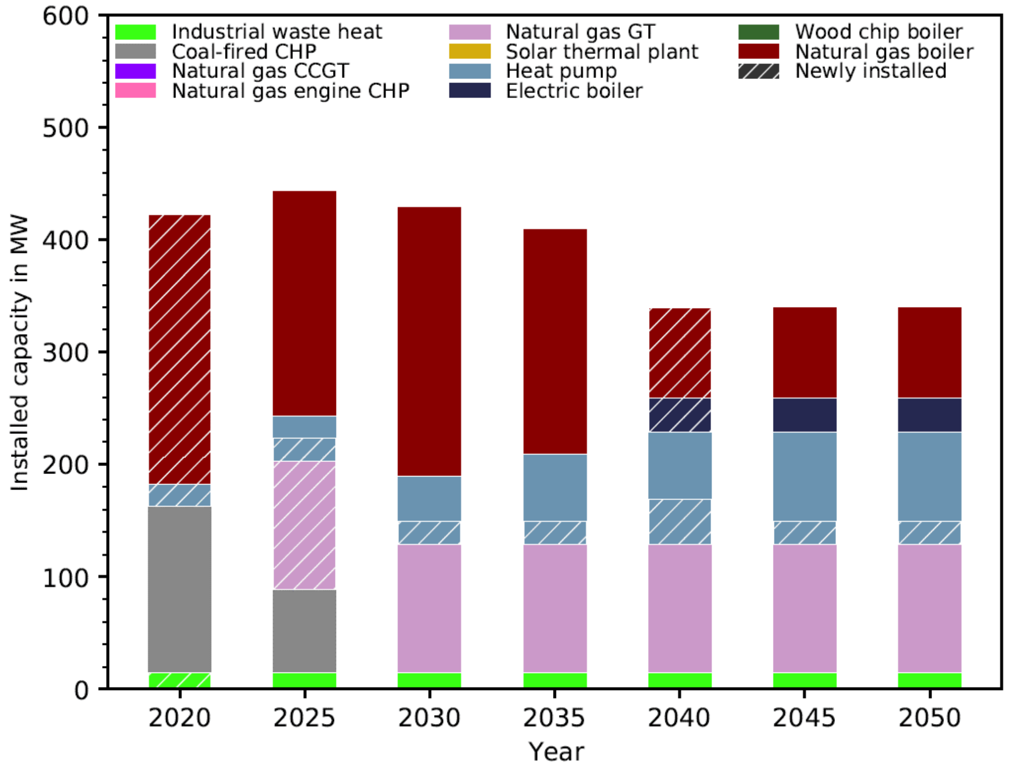
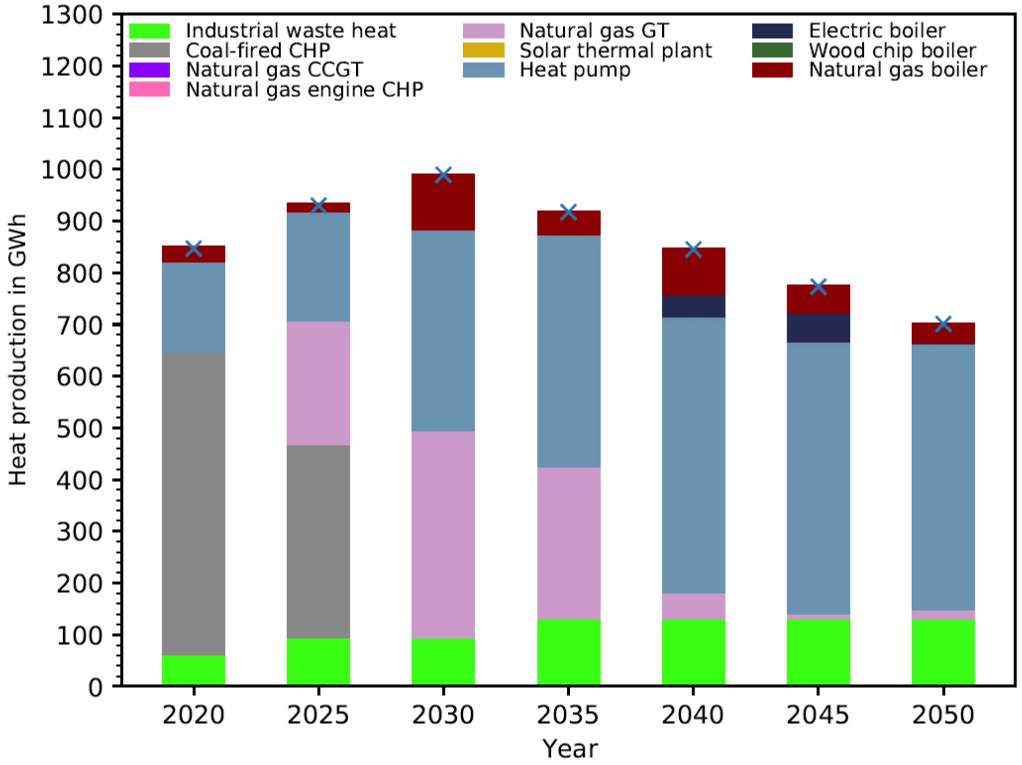
Results Analysis and Discussion: Scenario Coal-CHP 2025



Installed and newly installed capacity



Heat demand coverage

- Solar thermal solar thermal collectors would not be economical despite the RE premium.
- NG-fired CHP **<u>are installed (2025) due to KWK-G incentive</u>** and the 30,000 full load hours.
- NG and **<u>electrical boilers</u>** (2040) satisfies the peak demand, due the delay of Heat Pumps.
- Waste heat from industry is used as base load. Also it has a reduced production the first years, due the RE premium of heat pumps. Efficiency of the grid increases through the years

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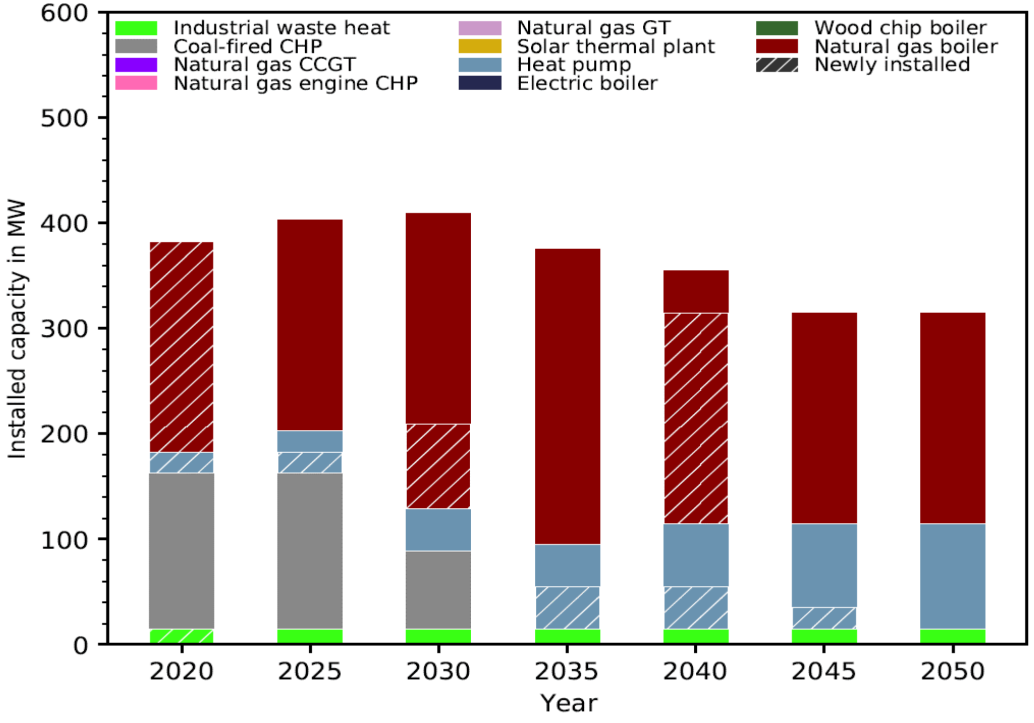
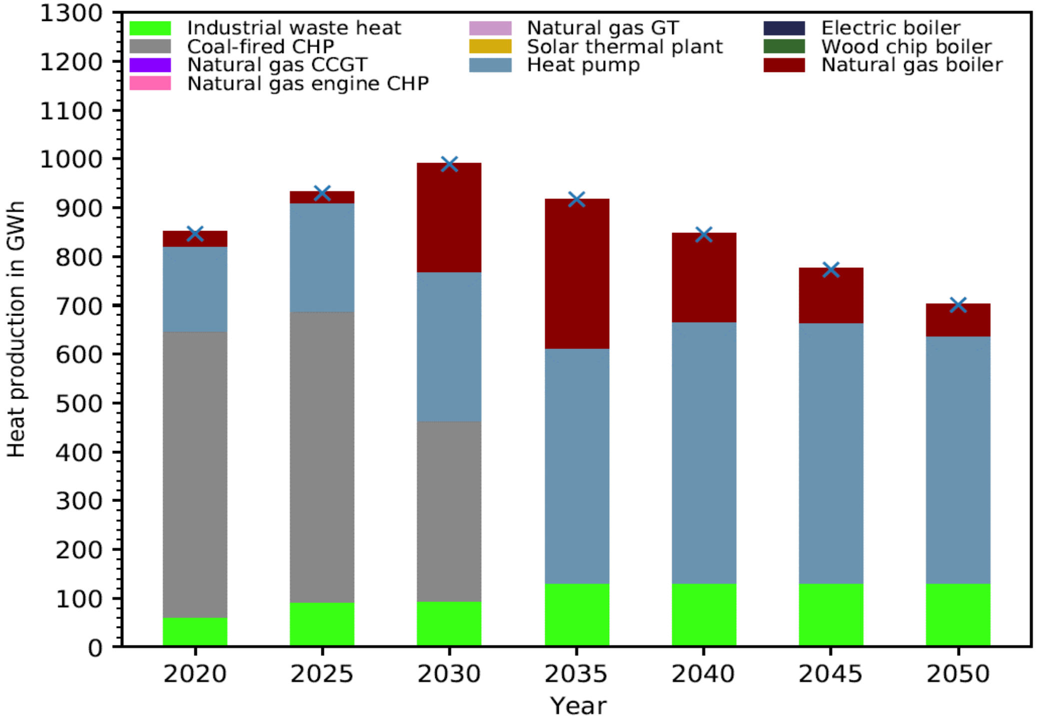
Results Analysis and Discussion: Scenario Coal CHP 2030



Installed and newly installed capacity



Heat demand coverage

- Large-scale heat pumps (RE heat) are installed over the planning horizon.
- The phase-out of the second <u>**Coal-fired CHP**</u> takes place at the same time as demand increases.
- NG boilers satisfies the peak demand, due the delay of heat pumps.
- Waste heat from industry is used as base load. Also it has a reduced production the first years.

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Discussion

- The key to a long-term absolute dominance of large-scale heat pumps lies in a cost-by-cause principle, **low electricity costs in the long run and an increase of efficiency** (efficient heat grids, technology development).
- Despite subsidies, ground-mounted **solar thermal energy is only being expanded to a minor extent**. Rooftop solar thermal technology is not included in these considerations.
- **A more dynamic development of the RE technology would be conceivable**, better RE premium in 2025 or a continuation until 2030 as well as projects with a larger capacity than 20 MW.
- Existing large CHP plant reduces the incentives to invest more quickly in RE heat. Smaller capacities of natural gas CHP and NG boilers are needed, nonetheless, **to build a technological bridge to a higher penetration of heat pumps in the future.**

Conclusions

- Regardless of the application type (large or small heat pumps), **the market ramp-up must start early** in order to achieve politically set climate protection targets with high RE shares in the heat supply.
- To achieve sufficiently high RE shares, strong (financial) support is needed for all RE heat generation technologies in the short to medium term:
  - **To support investment costs (solar thermal, geothermal),**
  - **incentivize high operating hours (heat pumps),**
  - **or adapt infrastructure (lowering supply temperatures, expanding networks and heat storage capacity).**
- In addition, industrial waste heat utilization and efficient peak load technologies in district heating networks are relevant. **Natural gas CHP and NG boilers are a technological bridge in district heating**.

VIELEN DANK!

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