# INVESTIGATION OF HEAT NETWORK OPTIMIZATION MODELING: RESULTS FOR A RESIDENTIAL DISTRICT FOCUSING ROOF ULITIZATION, MAIN HEAT GENERATION AND SCENARIO UNCERTAINTY

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## ABSTRACT

This study builds on a scenario development method to optimize the operation of a district heat network with 200 residential units. The heat network is based on a combined heat and power system (CHP), which allows comprehensive investigations on adaptation steps for further decarbonization, including centralized and decentralized heat and power generation. The applied methodology contains an expanded scenario transfer for three core and four additional scenarios as well as modeling and optimization of the adaptations for heat and power supply under these scenarios. From possible 5.040 calculations, a subtotal of 384 calculations is evaluated in detail for this paper.

The optimization results are evaluated according to three dimensions: the share of renewable heat in the heat grid, operating expenses for electricity and fuels enhancing revenues and subsidies, and the sum of direct and indirect district-related $CO_2$ emissions. Furthermore, the analysis of the optimization results focuses on the utilization of roof surfaces for solar energy technologies, the choice of the central heat supply system and the impact of the core and additional scenarios on the adaptation steps.

The findings demonstrate that pv systems offer greater cost reductions and a positive impact on $CO_2$ emissions compared to solar thermal systems, making them the preferred choice for rooftop utilization. A correlation is observed between higher renewable energy shares in the heat network and reduced operating expenses, with heat pumps meeting significant heat demand through subsidies and higher efficiency. However, heat pump adaptations do not lead to a complete renewable heat supply due to the natural gas boiler back-up system implemented in every adaptation step. The comparison of the impact of scenario differentiation and the heat generation system reveals, that the scenarios show a significantly lower influence on the results, both costs and RE-share.

Overall, the study provides valuable insights for decision-making and planning processes for the transition of district heat networks, highlighting the importance of renewable energy integration and cost-effective operations to reduce $CO_2$ emissions and enhance sustainability.

## 1 INTRODUCTION

District heat islands with gas-powered CHP based heat generation has been recently a transitional concept for enabling heat networks. This has been made possible by low natural gas prices and subsidies for CHPs in Germany. Although gas-powered CHP are more efficient than gas boilers, they are still not greenhouse gas neutral, but they enable the network infrastructure that is more suitable for emission reduction adaptations in the future compared to individual building solutions. **Figure 1** illustrates the energy supply concept, which has been implemented in several districts in Oberhausen in recent years.



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By anticipating the development to a renewable heat generation, the systems are designed to adaptively respond to changing future conditions (Fraunhofer UMSICHT 2024) by including higher thermal storage capacities than usual. The district heating plant consists of a CHP with a thermal output of 381 $kW_{th}$ (Wolf Power Systems 2021a) two gas boilers each providing 300 $kW_{th}$ (Wolf Power Systems 2021b), and five thermal storage tanks with a capacity of 3 m³ each (Huch 2021). The buildings are connected to the district heating plant via ten connection points distributed over two heat pipelines. At these connection points, a total number of 35 500-liter decentral heat storage units are installed to manage the peak demands of the buildings and to provide additional flexibility (Cosmo 2021).

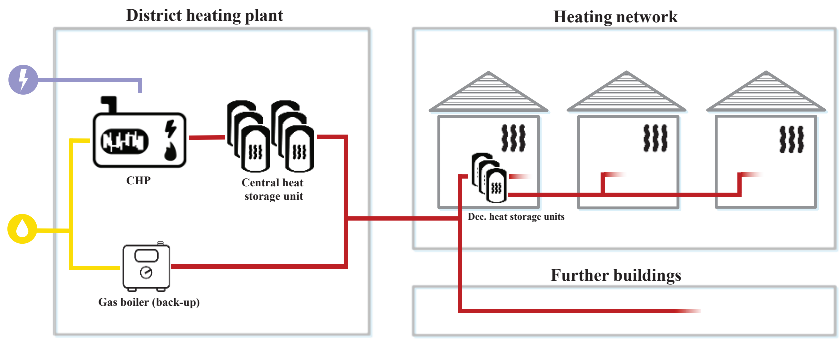


**Figure 1:** Energy supply concept of district heating islands in Oberhausen, Project *QUENTIN* (Fraunhofer UMSICHT 2024)

This paper focusses on 12 adaptations for the district heating plant and three options to use the rooftops of the buildings. The major goal is exploring the adaptations for the heating and electric power supply, both central at the heating plant and decentral at the network connection points. We aim to reveal the causes of the occurring effects of these adaptations in three core and four additional scenarios for the years 2035 and 2045 under the following three aspects:

**A) Impact of Rooftop Solar Installations:**
We investigate the different effects of photovoltaic versus solar thermal systems on the efficiency of the local energy system, evaluating $CO_2$ emissions and the cost implications of the residential district.

**B) Effect of Hybrid versus Single Heat Generation Systems:**
We evaluate the implications of hybrid heat generation systems by analyzing the renewable energy contribution to the grid and the operating costs, compared to the correspondent single systems.

**C) Impact of Core and Additional Scenarios on Heat Generation System Outcomes:**
We analyze the impact of different future projections on the efficiency of heat generation systems and reveal the future uncertainty of the results.

## 2 METHODOLOGY

The methodology applied to determine future scenarios builds upon the outcomes of the scenario development method according to Goetschkes and Witkowski (2023) and an expansion of the scenario transfer and a comprehensive modeling and operational optimization of the adaptation steps, shown in


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Goetschkes *et al.* (2024). There, three core scenarios (CS) and four additional scenarios (AS) are derived. These scenarios refer to the projection years 2035 and 2045, so 14 different sets of future framework conditions are defined. Combined with 360 adaptation steps as shown in Goetschkes *et al.* (2024), this results in a potential total number of 5,040 possible operational optimization calculations. In this paper, we investigate 384 of these calculations in detail, presented in the following sections.

### 2.1 Adaptation Steps

We investigate various adaptation steps for the natural gas-powered CHP heating district. **Figure 2** shows the specific two focusses evaluated for this paper: Adaptation of the heat generation in the central heating plant (12 options) and the different types of roof utilization (three options).

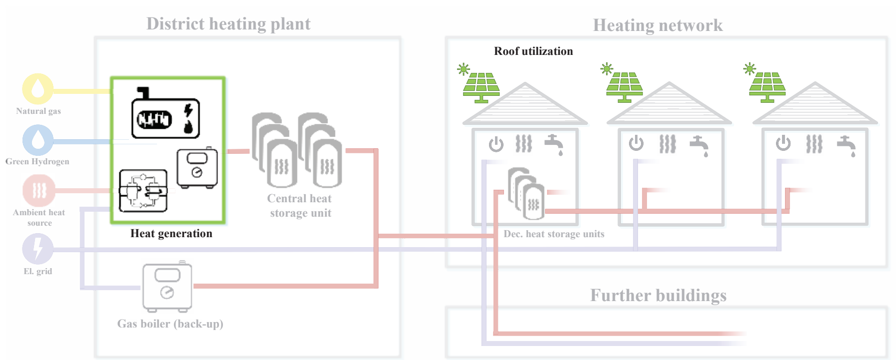


**Figure 2**: Analyzed adaptation steps for the local heating district

#### 2.1.1 Heat generation in the district heating plant

We distinguish adaptation steps in the district heating plant between single generation and hybrid generation systems:

- Natural gas-powered CHP (381 $kW_{th}$, Wolf Power Systems 2021a)
- Biomethane-powered CHP (381 $kW_{th,}$ Wolf Power Systems 2021a)
- Hydrogen-powered CHP (372 $kW_{th,}$ 2G Energy 2023a)
- Heat pump (412 $kW_{th}$, Ochsner 2023)

When designing the hybrid systems, the mentioned single generators are combined with either a heat pump (206 $kW_{th}$, Ochsner 2023) or an electric boiler (180 $kW_{th}$, Mobiheat 2023). The exception is the heat pump with 412 $kW_{th}$, which is supplemented by either a hydrogen-powered CHP (182 $kW_{th}$, 2G Energy 2023b) or an electric boiler. The dimensioning is based on the existing system sizes. The single generation systems are therefore designed with around 400 $kW_{th}$ and are supplemented by around 200 $kW_{th}$ in the hybrid system. In addition, a gas boiler provides a back-up solution in all combinations. The variation of the main heat generation results in 12 adaptation steps (four single and eight hybrid systems).

#### 2.1.2 Use of roof surfaces in the district

The other focus of the adaptation steps is the use of the roof surfaces by the installation of photovoltaic (pv) or solar thermal systems. If all roofs are equipped with pv modules, the total output of all modules is 706 $kW_{peak}$. This corresponds to a total annual yield of 628 $MWh_{el}$ for the south-west and south-east



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facing buildings. Similarly, an annual yield of 1,580 $MWh_{th}$ can be obtained by covering the roof surfaces with solar thermal modules. The simulation of both, the pv time series and the solar thermal time series with hourly output values, is carried out using the software tool ESyOpT® from Fraunhofer UMSICHT (Fraunhofer UMSICHT 2023). For reference, the option *not* using the roof surfaces for either pv or solar thermal systems is added to the investigation.

#### 2.1.3 Further conditions of the district

Home stations provide domestic hot water in the district electrically. Since 1955, the buildings in the district have been partially refurbished. The current refurbishment state is taken into account for the years 2035 and 2045. Therefore, the heat demand is only depended on the user behavior. The local heat network operates at 80 °C supply temperature.

### 2.2 Scenario Development and Scenario Transfer

We investigate the mentioned adaptation steps under different scenarios. The scenarios are based on a scenario development in five consecutive steps according to Goetschkes and Witkowski (2023). As a result of the fourth step (scenarios forming), the scenarios are generated, in which alternative developments of 21 key factors are formulated for the years 2035 and 2045. The year 2019 is defined as reference scenario.

A set of all influencing factors, each with one projection, forms a scenario. The core scenarios (CS) are coordinated in such a way that, as far as possible, every characteristic of the influencing factors can be found in the scenarios. This results in the scenarios *CS1 - Persistence*, *CS2 - Focus on hydrogen* and *CS3 - Focus on electrification*. When naming these scenarios, it should be noted that they reflect a development trend. In all scenarios, electrification and the expansion of a hydrogen infrastructure are driven forward. The names therefore serve to better differentiate between them and, in combination, form a consistent future scope. In order to investigate further sensitivities, four additional scenarios (AS) are created. These depict developments beyond the core scenarios and are called *AS1 - Low-cost green hydrogen*, *AS2 - Extremely expensive natural gas*, *AS3 - Extremely high & volatile el. price* and *AS4 - Extremely high el. RE-share*. The given names reflect the basic characteristic of the respective scenario. For example, the projection low-cost green hydrogen is inconsistent in every core scenario, therefore the scenario AS1 reflects the most probable scenario, if low-cost green hydrogen will be given.

In the last step of the scenario development, the scenario transfer, the qualitative characteristics of each key factor are translated and quantified into constant values and time series as input parameters for the operation optimization model. Compared to Goetschkes *et. al* (2024), the scenario transfer is applied accordingly for AS1 to AS4. In total, we quantify 18 parameters and time series as model input parameters, shown in **Table 1**.

### 2.3 Operation Optimization Framework and Objective Function

The requirements and costs for each scenario and year as well as each adaptation step with the defined system sizes are integrated into an operational optimization model. The model is implemented in ESyOpT® from Fraunhofer UMSICHT. ESyOpT® is an in-house software tool for the evaluation of energy systems. ESyOpT® is based on the open-source licensed software oemof, which is developed in Python and offers a toolbox specifically for modeling and analyzing energy systems (Fraunhofer UMSICHT 2023, Reiner Lemoine Institut 2023).


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**Table 1:** Scenario-dependent Model Input Parameters
*(costs and revenues given in $ct_{€}$/kWh, demands given in MWh, time series given as averages (Ø))*

| Model Input Parameter | 2019 | 2035 | | | | | | | 2045 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | **Ref** | **CS1** | **CS2** | **CS3** | **AS1** | **AS2** | **AS3** | **AS4** | **CS1** | **CS2** | **CS3** | **AS1** | **AS2** | **AS3** | **AS4** |
| Cost natural gas | 2.4 | 8.9 | 5.1 | 10.2 | 8.9 | 11.5 | 10.2 | 5.1 | 10.7 | 5.5 | 12.0 | 10.7 | 13.3 | 12.0 | 5.5 |
| Cost biomethane | n.a. | 7.7 | 6.3 | 7.3 | 6.3 | 6.3 | 7.3 | 6.3 | 5.6 | 7.3 | 5.6 | 5.6 | 7.3 | 7.3 | 5.6 |
| Cost green hydrogen | n.a. | 13.1 | 13.1 | n.a. | 10.2 | 13.1 | 13.1 | 10.2 | 11.5 | 11.5 | n.a. | 8.4 | 11.5 | 11.5 | 8.4 |
| Price el. spot market (Day Ahead, Ø) | 3.8 | 8.0 | 5.0 | 8.0 | 5.0 | 8.0 | 10.0 | 6.0 | 7.0 | 5.0 | 7.0 | 5.0 | 7.0 | 9.0 | 5.0 |
| Daily volatility | 0.8 | 3.0 | 2.1 | 3.5 | 2.1 | 3.5 | 4.3 | 2.9 | 3.0 | 2.1 | 3.8 | 2.1 | 3.8 | 4.9 | 3.1 |
| Resulting el. cost operator (Ø) | 9.1 | 13.6 | 10.9 | 14.3 | 10.9 | 14.3 | 16.3 | 12.3 | 12.8 | 11.3 | 13.8 | 11.3 | 13.8 | 15.8 | 11.8 |
| Resulting el. cost tenants | 30.9 | 30.3 | 28.2 | 32.1 | 28.2 | 32.1 | 34.1 | 30.1 | 30.0 | 29.1 | 32.2 | 29.1 | 32.2 | 34.2 | 30.2 |
| Reward grid feed, nat. gas CHP | 7.7 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 | 0.0 |
| Reward grid feed, biomethane CHP | n.a. | 6.4 | 11.9 | 6.4 | 9.4 | 8.9 | 6.9 | 8.4 | 5.7 | 11.9 | 5.7 | 7.7 | 9.9 | 7.9 | 7.7 |
| Reward grid feed, green hydrogen CHP | n.a. | 20.0 | 23.0 | n.a. | 18.6 | 20.0 | 18.0 | 17.6 | 17.3 | 19.3 | n.a. | 14.3 | 17.3 | 15.3 | 14.3 |
| Lower bound reward for grid feed, pv | n.a. | 5.5 | 5.5 | 4.9 | 4.9 | 5.5 | 5.5 | 4.9 | 4.6 | 4.6 | 4.1 | 4.1 | 4.6 | 4.6 | 4.1 |
| Subsidy used pv-el. by tenants | n.a. | 1.7 | 1.7 | 0.0 | 0.0 | 1.7 | 1.7 | 1.7 | 1.7 | 1.7 | 0.0 | 0.0 | 1.7 | 1.7 | 1.7 |
| Subsidy heat pump, own el. generation | n.a. | 7.7 | 7.7 | 0.0 | 0.0 | 7.7 | 7.7 | 0.0 | 7.7 | 7.7 | 0.0 | 0.0 | 7.7 | 7.7 | 0.0 |
| Subsidy heat pump, el. grid | n.a. | 1.4 | 1.4 | 0.0 | 0.0 | 1.4 | 1.4 | 0.0 | 1.4 | 1.4 | 0.0 | 0.0 | 1.4 | 1.4 | 0.0 |
| Subsidy solar thermal | n.a. | 1.0 | 1.0 | 0.0 | 0.0 | 1.0 | 1.0 | 0.0 | 1.0 | 1.0 | 0.0 | 1.0 | 1.0 | 1.0 | 0.0 |
| Heat demand | 1,041 | 963 | 1,011 | 915 | 1,011 | 915 | 915 | 1,011 | 933 | 970 | 877 | 970 | 877 | 877 | 970 |
| Hot domestic water demand | 168 | 168 | 176 | 159 | 176 | 159 | 159 | 176 | 168 | 176 | 159 | 176 | 159 | 159 | 176 |
| Electricity demand | 561 | 561 | 589 | 533 | 589 | 533 | 533 | 589 | 561 | 589 | 533 | 589 | 533 | 533 | 589 |

*n.a.: not available*

The optimization model includes all relevant components and aims to minimize all costs of the operation for the entire district for each adaptation step in each scenario, independently of the actors involved (see objective function in Goetschkes et. al 2024). The optimization horizon is one calendar year in hourly time intervals. In order to achieve a shorter calculation time for the high number of optimizations, the decentralized technologies are not modelled for each grid connection point but aggregated for the two heating circuits in the district. Furthermore, the model does not include an electricity grid that connects the households with the central heating plant. The electric energy generated by the CHP can in consequence either be used for the heat pump or it must be fed into the public grid. Conversely, electric energy from the pv systems is used exclusively for the buildings and the surplus is fed into the public grid. The heat network and the storage units are parameterized in the same way as in Goetschkes and Witkowski (2023).



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### 2.4 Main Evaluation dimensions

We evaluate the results of the optimization calculations in three main evaluation dimensions:

**1) The share of renewable heat generated (RE-share of heat network):** Electricity from the public grid is rated according to the current share of renewable energies in the public grid; the method is used for the electricity consumption of heat pumps and electric boilers; natural gas is assumed to be not renewable (RE-share: 0). Biomethane and green hydrogen are considered as renewable (RE-share: 1).

**2) Relative operating expenses (OPEX-R):** The operating costs for electricity and fuel for the system operator and the electricity costs for residents, considering both revenues for feed-in electricity and subsidies for renewable heat generation; the OPEX-R are considered relative to the results of the reference system (2019).

**3) $CO_2$ equivalents of the heat network and households ($CO_2$ emissions):** The sum of $CO_2$ emissions from the combustion of fuels including supply chains (see **Table 2**), indirect $CO_2$ emissions for electricity used from the public grid, and negative $CO_2$ emissions for CHP electric power fed into the public grid, using Carnot Method.

**Table 2:** Emission factors of fuels

| Fuel | Emission factor [$g_{CO2e}$/kWh] | Reference |
|---|---|---|
| Natural gas | 247.0 (2019), 233.0 (2035, 2045) | KEA 2024 |
| Biomethane | 37.2 (2035, 2045) | Fehrenbach *et. al.* 2016 |
| Green hydrogen | 7.6 (2035, 2045) | Pfluger *et al.* 2022, Heuser 2021 |

## 3 INVESTIGATION OF RESULTS

The results of the operation optimization are analyzed in the following three research aspects, as mentioned in the introduction.

### 3.1 Impact of Rooftop Solar Installations

**Figure 3** displays the results of different solar installations in the core scenarios. The evaluation focuses on the dimensions $CO_2$ emissions and OPEX-R to assess the impact on the entire district. The different colors indicate the roof system. Each data point in each color set represents a specific heating generation system. Despite variations in heat generation systems and scenarios, the overall trend of each color set is similar. On average, the pv systems achieve a higher cost reduction compared to solar thermal systems, with a reduction of – 42.7 % compared to – 4.5 %.

Both pv and solar thermal systems have a positive impact on $CO_2$ emissions. The reduction potential of emissions in the district depends on the emissions of the main heating system. The greater the emissions of the main heating system of the corresponding *no roof system*, the higher the potential emission reduction by utilizing pv or solar thermal systems. On average, the reduction of $CO_2$ emissions is - 7.0 % for pv systems and - 10.8 % for solar thermal systems.




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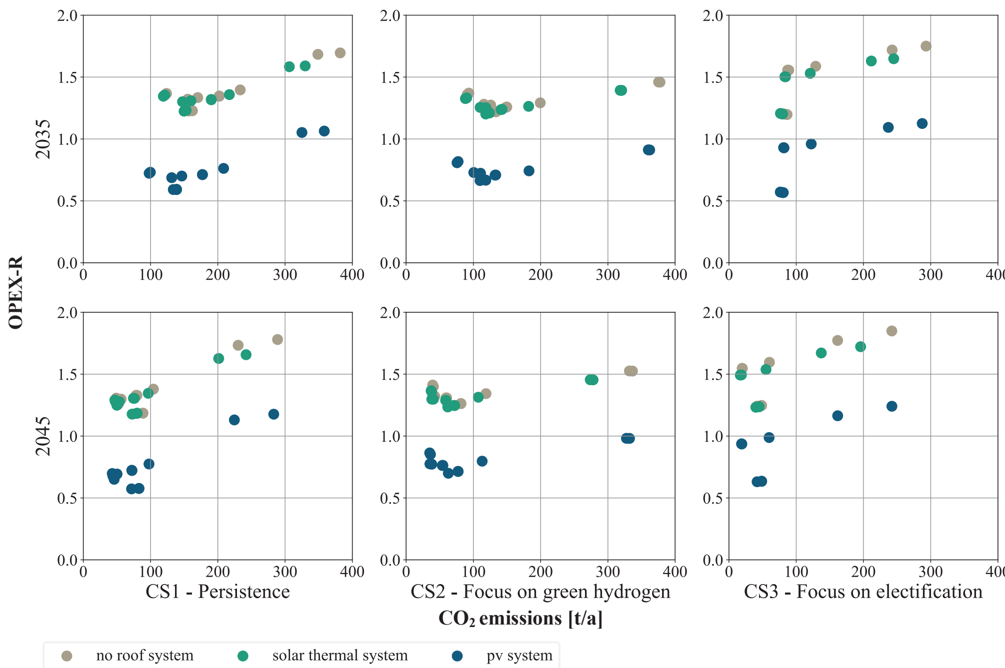


**Figure 3:** $CO_2$ emissions and OPEX-R by roof system

In order to assess the self-consumption of energy generated by rooftop systems, an analysis of their average usage is presented in **Figure 4**. The average self-consumption rate of the pv systems is 38.1%. Regarding the solar thermal systems, the district uses 11.4% of the solar heat. The decentral installation of both systems limits their ability to transfer the solar energy between the two modelled pipelines and to the district heating plant. Therefore, any energy generated by these systems is not utilized for heat generation in the district heating plant, but instead is used only in the local distribution pipeline.

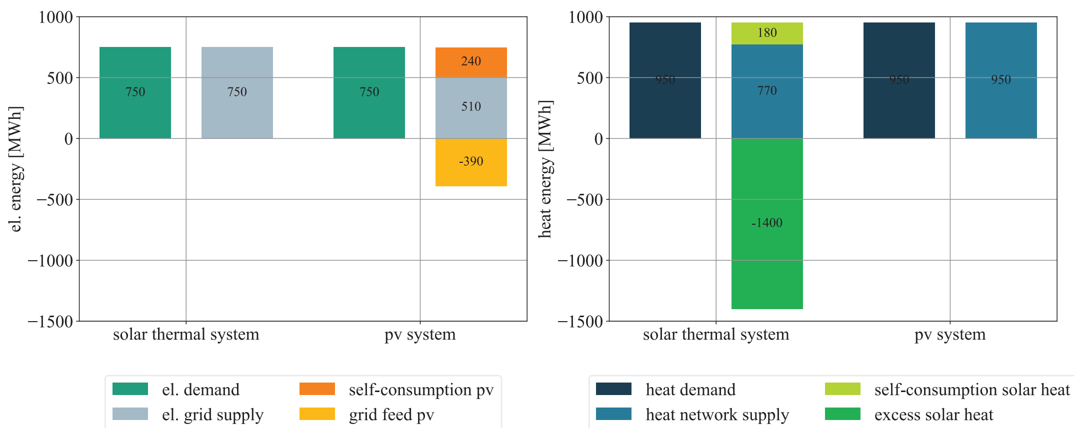


**Figure 4:** Self-consumption of generated energy by roof system (average values)



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Solar thermal energy can be stored in decentral heat storage units, thereby reducing the energy demand from the heat network during the heating period. Accordingly, electricity generated by the pv system can be utilized for household power demands only, including the generation of domestic hot water, but not for heating purposes. Overall, the utilization of the solar systems is limited due to the mismatch between high heat demands during winter and the generation of most energy during summer.

Based on the higher self-consumption rate, depicted in **Figure 4**, and the overall greater impact on OPEX-R, pv systems appear to be the preferred choice for roof utilization and are therefore assumed in the subsequent research aspects.

### 3.2 Effect of Hybrid versus Single Heat Generation Systems

To reveal the effect of the various heating generation systems, we evaluate the implications by assessing the RE-share of the heat network and OPEX-R as shown in **Figure 5**.

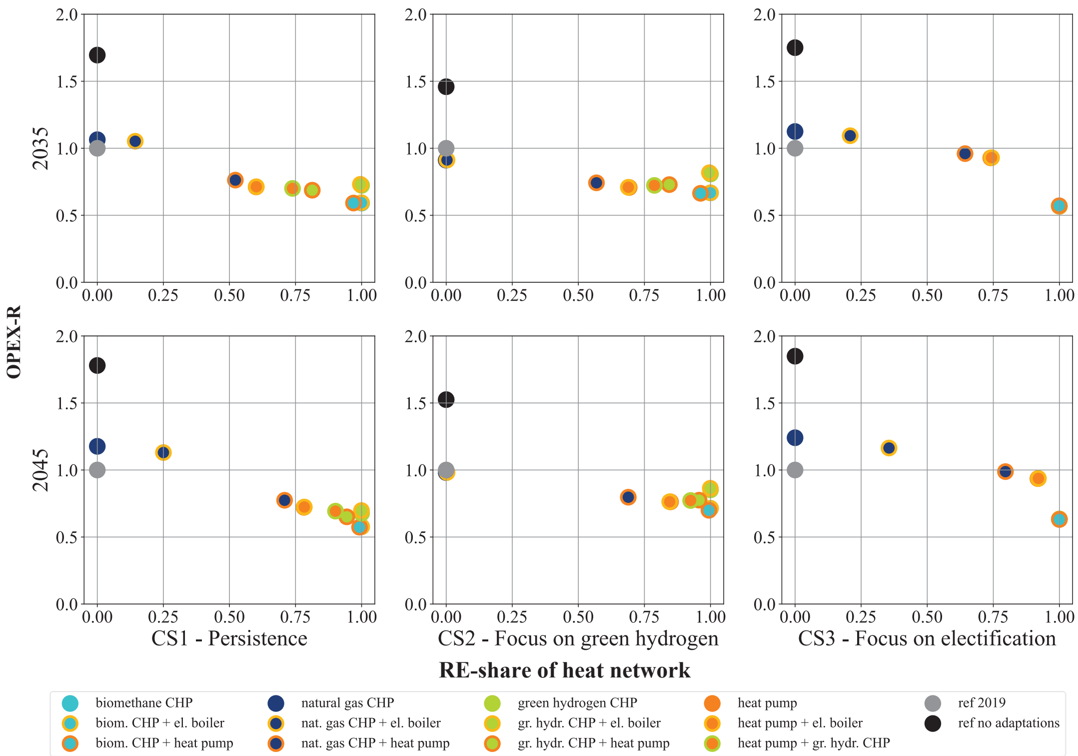


**Figure 5:** RE-Share and Operating Expenses by central heating system; configurations equipped with pv systems except of *ref 2019* and *ref no adaptations*

The results are compared to the status quo 2019 (*ref 2019*) and the status quo in 2035 and 2045, referred as *ref no adaptations*, where no pv system is installed. Apart from the natural gas CHP system, the impact of the electric boiler as a secondary system in various configurations and scenarios is negligibly small. As a result, the data point in **Figure 5** is hidden behind the corresponding single heat generation system. The reference *ref no adaptations* demonstrates the spread of results, particularly in terms of




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OPEX-R. Overall, the results vary depending on the scenario, but there are consistent trends recognizable: Higher shares of RE in each scenario correspond to lower operational costs. Systems relying on natural gas exhibit the highest costs. To increase the RE-share in the district, it is therefore necessary to switch to electric-driven systems or utilize green gases. However, some of these systems do not achieve a RE-share of 1, even in CS3, where power generation in the German electricity grid is considered greenhouse gas neutral in 2045. The use of heat generation technologies within each system explains the effect, which is shown in **Figure 6**.

Referring to the natural-gas-based systems, the gas boilers generate most of the heat across all core scenarios, ranging from 53,7 % to 57.3 %. This means, that the gas boiler is the cheapest technology at most times. In CS1 and CS3, the el. boiler and CHP cover the remaining heat demand almost evenly. In CS2, the CHP covers the remaining demand predominantly. The results for 2045 exhibit similar patterns (not shown in **Figure 6**).

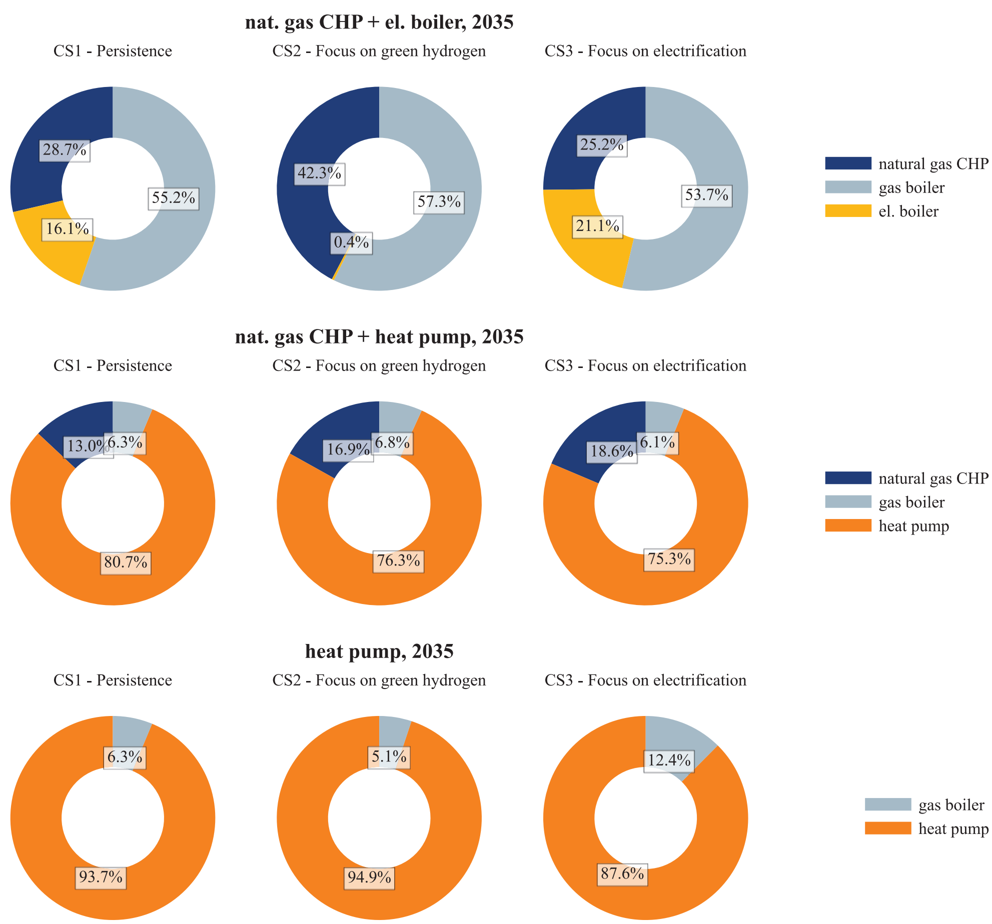


**Figure 6:** Share of heat generation by central heating plant of exemplary adaptations in 2035



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When a heat pump is installed instead of the el. boiler, it produces 75.3 % to 80.7 % of the heat demand although it is designed as a secondary system with a lower nominal heat power compared to the CHP. This effect has two causes: the higher efficiency of the heat pump (SCOP: 2.2) compared to the electric boiler (efficiency: 1), and the subsidies provided in CS1 and CS2 for heat generated by the heat pump. In CS3, despite having the highest electric costs for operators, the price levels are low enough to support the operation of the heat pump. When the heat pump serves as the single heating system, the RE-share does not reach 100%. The gas boiler remains the more cost-efficient technology in certain time periods, resulting in a heat share of 5.1% to 12.4% in 2035, as depicted in **Figure 6**. The share is smaller in 2045, due to higher natural gas prices, resulting in even higher RE-share in the heat network.

### 3.3 Impact of Core and Additional Scenarios on Heat Generation System Outcomes

**Figure 7** displays the influence of the core and additional scenarios. The figure shows the results for each primary heating technology, so the potential uncertainty of the adaptation step becomes visible, dependent on the scenarios.

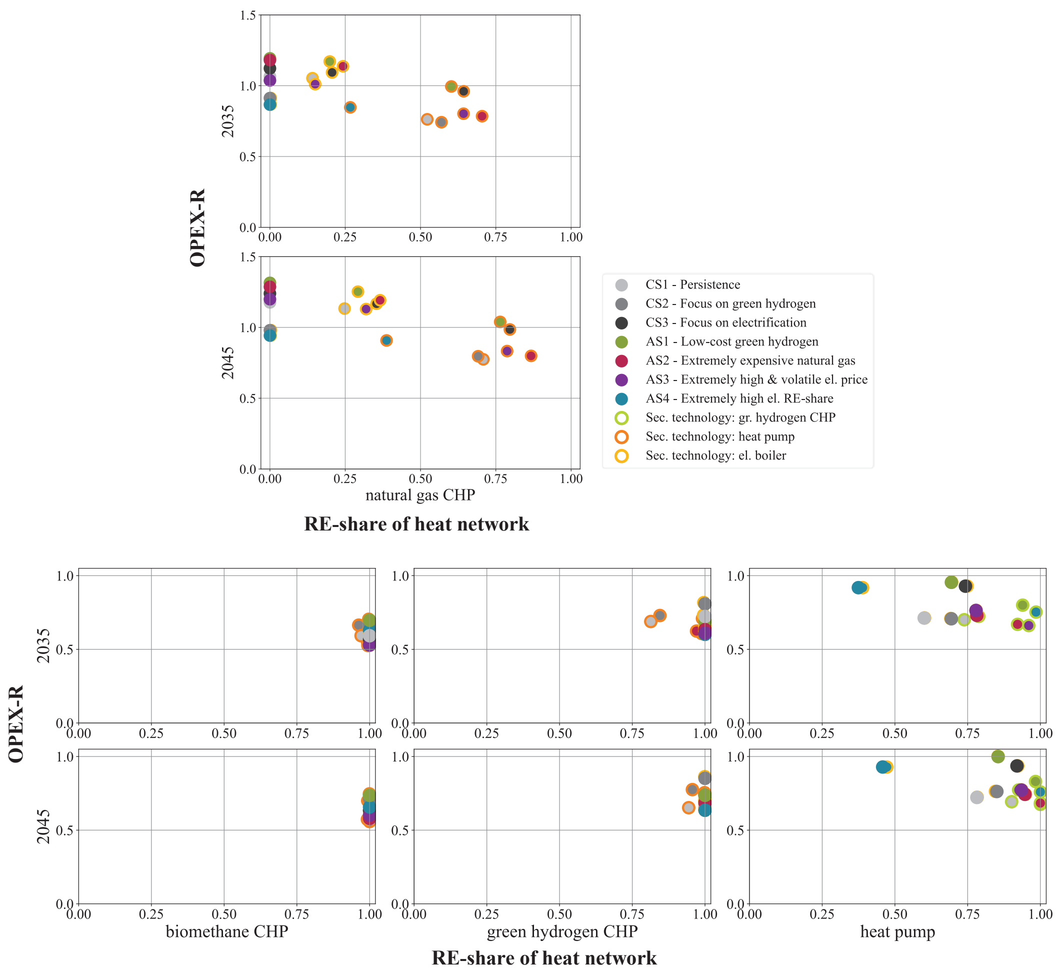


**Figure 7:** RE-Share and OPEX-R by primary heating technology and scenario



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The impact of el. boilers and heat pumps on natural gas-based CHP systems is also observed in the additional scenarios. Consequently, the chosen heat generation system has a larger effect on OPEX-R compared to the additional scenarios as well. Considering the biomethane CHP systems, green hydrogen CHP systems and heat pump systems, both the variation of RE-share of the heat network and the OPEX-R are lower between hybrid and single systems. Overall, these technologies contribute to OPEX-R values below 1.0. This implies that the OPEX-R of heat pumps and green gases are lower compared to the reference system 2019.

Regarding green gases (biomethane and green hydrogen), the high subsidies in each scenario for these energy sources cause this effect. However, the subsidy for green gases remains very uncertain. The modelled subsidy depends on the corresponding purchase price and the capacity tendering process regulated by the German Renewable Energy Sources Act (EEG), according to Goetschkes *et al.* 2024.

Regarding heat pump systems, even though the electricity from the grid is fully renewable in various scenarios (CS3, AS2, AS3, and AS4), they can only achieve a RE-share of 100%, if green gases would replace the used natural gas. This is observed across all these scenarios. Overall, the spread of the results is greater due to the influence the operation subsidies, given in four scenarios (CS1, CS2, AS2, AS3). In AS4, the combination of low natural gas prices and the lack of operation subsidies for heat pumps results in the more frequent operation of the gas boiler. Therefore, the single heat pump system in AS4 has the lowest RE-share compared to all other heat pump systems.

## 4 CONCLUSIONS

**A) Impact of Rooftop Solar Installations:**
PV systems achieve a higher cost reduction compared to solar thermal systems. Both have a positive impact on $CO_2$ emissions. Decentral rooftop systems have limitations in substituting energy in the district heating plant. Due to higher self-consumption rates and greater impact on OPEX-R, pv systems should be the preferred for rooftop utilization. These conclusions should be taken into consideration when planning and implementing measures for utilizing renewable energy on rooftops. The evaluation of overall profitability requires an examination of the capital costs (CAPEX), which will be part of future studies.

**B) Effect of Hybrid versus Single Heat Generation Systems:**
Increased RE-shares lead to lower OPEX-R, with natural gas systems being the most expensive. Heat pumps as secondary systems cover substantial heat demand due to their efficiency and subsidies, particularly in CS1 and CS2 scenario. Total renewable energy coverage is not achieved. Gas boilers still contribute to heating due to cost-effectiveness in certain periods. Applying the objective function to maximize the RE-share could provide an alternative approach to discover the cost elasticity of more sustainable systems.

**C) Impact of Core and Additional Scenarios on Heat Generation System Outcomes:**
This paper indicates that the uncertainty associated with the scenarios is less significant than the selected adaptations. This implies that the selected adaptations are major determinants of the study outcomes. They provide a solid basis to decarbonize the system, despite any scenario-related uncertainties. Regarding the investigated heat pump systems, it requires a substitution of natural gas with green gases for the used gas boiler or CHP to achieve a RE-share of 100%. The results vary significantly because



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of the operation subsidies. Furthermore, a revised design approach with multiple smaller heat pumps should be investigated.

The analysis of cost-effectiveness, encompassing CAPEX, and the exploration of other adaptations, such as the consideration of the el. demand for e-mobility, lower heat network supply temperatures alongside further refurbishments within the district, will depend on future research.

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