Municipal Heat Planning to Exit from Coal, Oil and Natural Gas in a German Major City

T. Vaupel, H. Braas, I. Best, J. Orozaliev, K. Vajen, U. Jordan

University of Kassel, Institute for Thermal Engineering, Kassel (Germany)

Abstract

Following a decision by the city's municipal council in 2019, a climate protection council was formed in the German city of Kassel as an advisory body to develop possible concepts and measures with the help of specialist groups to outline how climate neutrality can be achieved in Kassel by 2030. A major challenge on the way to a climate-neutral city is the decarbonization of the heat supply. In Kassel, more than 85 % of the heat supply is based on fossil fuels. In order to investigate this transformation process as holistically as possible, using Kassel as an example, various scenarios are being developed for a heat supply without coal, oil and natural gas. These are based on a model for the development of heat demand, a building-specific heat atlas, a comprehensive determination of the local potential for renewable heat, and an hourly calculation of the heat supply variants with a subsequent profitability analysis

Keywords: district heating, transformation, district heating scenarios, roadmap, heat demand development, heat atlas, local renewable potentials

1. Introduction

An increasing number of German cities are setting themselves the goal of climate neutrality. One of these cities is Kassel, which in 2019, in connection with the "Climate Emergency Declaration", set itself the ambitious goal of becoming climate-neutral by 2030 and supplying itself with 100% renewable energies from local sources.

In some other studies, target scenarios and transformation paths to a climate-neutral heat supply are presented for large cities such as Hamburg and Berlin shown by *Egelkamp et al.* (2021) and *Kicherer et al.* (2021). However, the scenario for Hamburg only refers to the district heating supply and in the scenario for Berlin, constant assumptions were made for district heating expansion and densification. Therefore, the following study focuses on a holistic view of target scenarios and the transformation path towards decarbonization of the whole city of Kassel.

The methodology used in this study is based on procedures for municipal heat planning as described, for example, by the Climate and Energy Agency Baden-Württemberg (KEA-BW, Leitfaden kommunale Wärmeplanung by *Peters* (2020)) and already implemented, at least in part, in various research and practical projects.

Important components of municipal heat planning are, for example, an inventory analysis of heat consumption, a potential analysis for the use of renewable energies, the development of target scenarios and transformation paths from the status quo to the target scenario, an allocation of local and district heating areas and the development of concrete measures and transformation paths.

2. Heat Supply in Kassel: Status Quo

Decentralized gas heating systems cover about 2/3 of the total heat demand in Kassel. Based on data on existing oil tanks, it was estimated that about 9 % of the heat demand is generated with decentralized oil heaters. For the remaining 4 % of heat generators, the energy source is unknown; it is possible that these are also oil heating systems or other technologies, such as pellet burners and heat pumps (*Hinz* et al. 2020).

Approximately 21% of the total heat demand in Kassel is provided by a district heating network. Heat is generated

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by burning coal, waste, natural gas, processed waste wood (biomass) and sewage sludge in CHP plants, as well as fuel oil for peak load coverage. The heat supply is thus based entirely on fossil fuels and waste (see Figure 1).

The goal of the municipal energy supply company of Kassel, is to substitute coal combustion with sewage sludge and waste wood combustion by 2025. To this end, corresponding conversion measures are currently being carried out at the combined heat and power plants (Städtische Werke Kassel 2020).

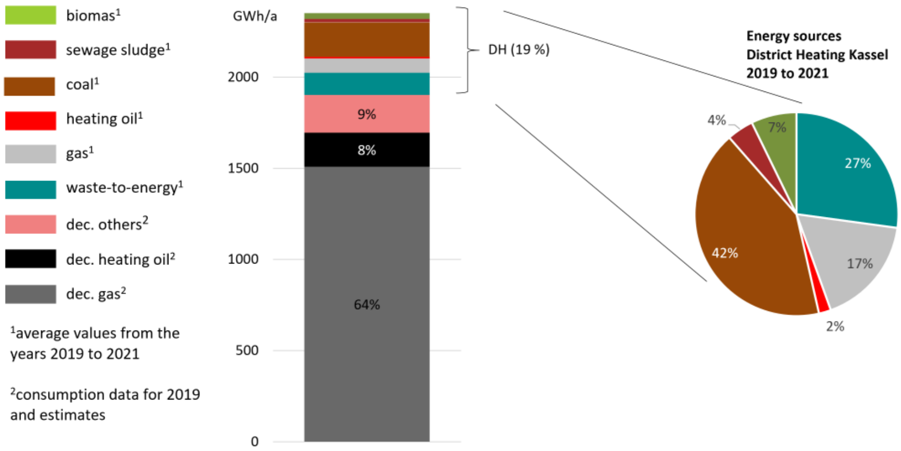

Fig. 1: Current energy sources in the heat supply of Kassel

3. Prioritization of Areas for Heat Networks and Decentralized Heat Supply

So far, about 21 % of Kassel's heat demand is provided by district heating. However, various studies on future decarbonized heat supply assume a much higher district heating share in large cities of 50 to 80 % (*Thamling and Langreder* 2020; *Gerhardt et al*. 2019; *Maaß et al*. 2021).

Figure 2 shows an example scenario for an allocation of 60 % of Kassel's heat demand. The evaluation is based on statistical blocks as the smallest administrative unit of a city, usually comprising blocks of houses separated by streets, rivers or similar (*Dieckmann and Trutzel* 1991).

Heat consumptions of individual buildings and path lengths are summed in the statistical blocks and heat occupancy densities, defined as the ratio of heat consumption to path length, are evaluated.

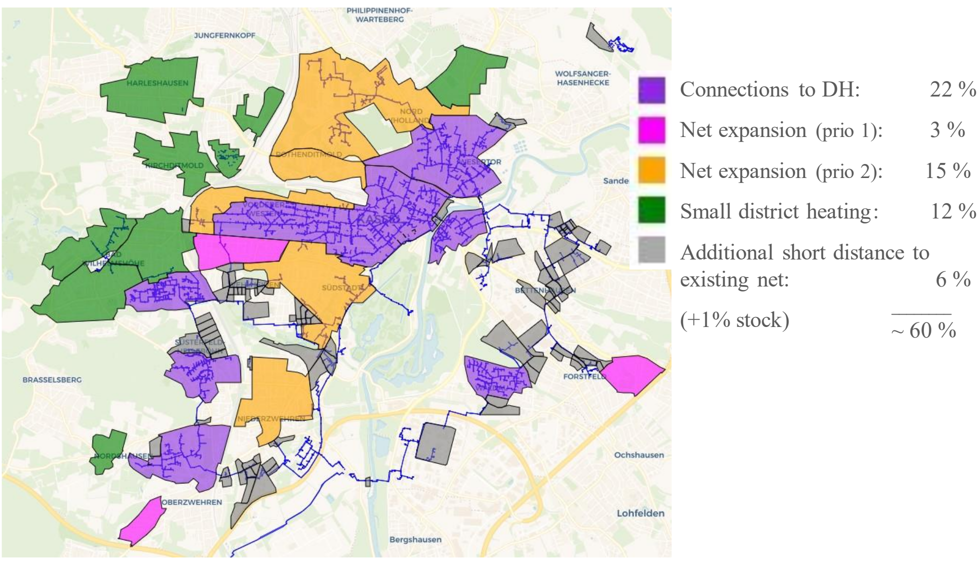

Fig. 2: Areas assigned to district heating in Kassel

4. Heat generation scenarios

4.1. Load Profile

The seasonal distribution of heat consumption is modeled by a synthetic standard load profile (SLP for short) in hourly resolution (BDEW, 2016) and it is based on an average outdoor temperature profile (Meteonorm) for the Kassel site. The load profile contains components for centralized and decentralized supply. For centralized supply, constant heat distribution losses of 15 % of the heat sales are taken into account for simplification purposes.

4.2. Calculation Tools

The heat input to the heat grid and the loading and unloading of the seasonal storage are calculated on an hourly basis using simplified Python-based balance models. The profile for solar thermal heat supply is determined by weather data (solar radiation and outdoor temperature) and the calculation of collector field efficiencies (for flat plate collectors) and then scaled over the installed area.

4.3. Future Energy Sources and Heat Pumps

The following technologies and energy sources are considered for a heat supply without coal, oil and natural gas:

- Feeding into heat grids: Waste incineration, biomass (waste wood), industrial waste heat, large-scale heat pumps, large-scale solar thermal systems, and biogas peaking boilers.
- Building-specific heat supply: Heat pumps, solar thermal and biomass boilers.

In the district heating supply, waste and sewage sludge incineration and the use of industrial waste heat serve as base loads and are assumed to be constant for simplicity. Biomass (waste wood) and biogas serve to cover peak loads. The potential of sewage sludge, waste wood and waste incineration estimated by the municipal energy supplier and the estimated waste heat potential amount to a total of approx. 700 GWh/a. This corresponds to a share of total heat consumption in Kassel of approx. 30 %. Waste and residual waste incineration already generates high surplus heat in summer, which has so far been dissipated with river water (Fulda). In order to make this surplus heat usable in winter, a seasonal storage facility is necessary.

For large heat pumps feeding into heat grids, an average system annual performance factor (SPF) of 3.1 is assumed. Possible heat sources for large-scale heat pumps are low-temperature waste heat from industry, as well as river, sewage plant and other wastewater, and shallow and deep geothermal energy.

Due to the limited availability of biomass, it is assumed that only about 5% of Kassel's total heat demand is assumed to provided by decentralized biomass. In addition, it is assumed that the summer heat demand for all biomass heating systems is covered by a solar thermal system.

Since air-source heat pumps are predominantly used in large cities and the vast majority of buildings will not have been renovated by 2030, a mean system annual performance factor (SPF) of building heat pumps of 2.7 is assumed, following the results of *Bergmann and Erhorn* (2017); *Langner et al.* (2014); *Günther et al.* (2020). In addition, it is assumed that every fourth heat pump heating system is combined with a solar thermal system.

4.4. Seasonal Storage

A pit storage tank is considered as seasonal storage. To increase the seasonal storage capacity, the storage tank is additionally charged with an internal heat pump, which cools the lower part of the store down to 20°C. The temperature in the upper part of the store is assumed to be 85°C.

Such storage facilities with volumes between approx. 60,000 m³ and 200,000 m³ have already been built in the Danish cities of Dronninglund, Marstal, Gram and Vojens, for example. Another storage facility with a volume of

700,000 m³ is currently being planned in Odense, Funen (DK).

Feasibility studies and technical investigations on the upscaling of such earth reservoirs can be found, for example, in the publications by *Tziggili et al*. (2013), *Weinhold and Rühling* (2019) and van Helden (2022), respectively. New liner materials are currently being developed that should enable a storage temperature of 95 °C in the future. The publication also shows that storage volumes of up to 2 million m³ are feasible (van Helden 2022).

4.5. Scenario with a District Heating Share of 60 %

Fig. 3 shows the seasonal distribution of the heat supply for the scenario with 60 % district heating. With the highest priority in the heat supply, combustion processes are considered from heat carriers that can only be stored to a limited extent (i.e. waste and sewage sludge) and waste heat from industry and commerce, followed by solar thermal energy. The storage is designed in such a way that no unused surpluses remain from these heat carriers. Additionally, the storage tank is fed from the internal heat pump to a certain extent.

To save as much biomass as possible for the peak load demand, the seasonal storage water is used to provide the heat demand, as soon as all heat sources other than biomass together don't cover the demand. The heat that is then still required (beyond the provision of heat from the storage and biomass), is provided by an additional peak load boiler, which can be operated with biogas, for example.

For the waste incineration plant, a maintenance interval of 2 weeks in September is taken into account, based on today's operating mode. Today, the waste incineration plant runs at reduced capacity during summer. In the scenario however, it is assumed that the waste incineration plant is also operated at full load in the summer, in order to be able to provide as much heat as possible. For peak load coverage, the discharge capacity of the storage tank is increased. The number of storage cycles per year is 1.34.

In the scenario shown in Fig. 3, the share of the overall heat demand provided by district heating is 60%, of which 12% is local heating. About 12% of the heat demand is covered by river heat pumps and 5% by the wastewater heat pump. Decentralized and large heat pumps for local heat supply cover 38% of the total heat demand of the city of Kassel. A small share of solar thermal and biomass is also planned for the local heat supply. The share of solar thermal energy from central collector fields is 2.3% of the total heat demand. This corresponds to a collector area of about 100,000 m².

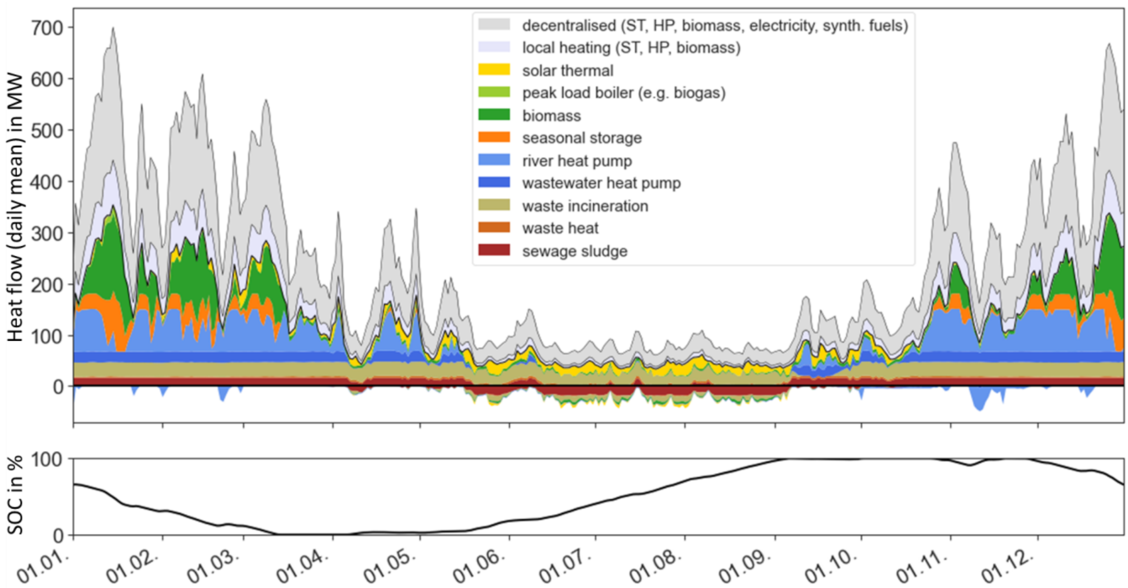

Fig. 3: Load profile of the 60% scenario with all heat generators used

5. Summary and Conclusion

A heat atlas has been developed for the city of Kassel in which heat consumption is mapped for each building. Scenarios for the development of the heat demand yield a decrease in heat demand of approx. 17 % by 2030 compared to 2019.

In order to achieve high coverage rates of renewable energies, a densification and expansion of the district heating network to approx. 60 % (includes 12% local heating) of the total heat demand of the city of Kassel is considered. Suitable district heating and local heating areas were identified using an algorithm as well as manual refinement taking into account additional constraints. The initial parameters used are the heat occupancy density and the spatial proximity of the areas to the district heating network.

For district heating, a medium-term potential for waste, sewage sludge and waste wood incineration as well as industrial waste heat of about 700 GWh/a was determined for Kassel. Biogas plants were considered to cover peak loads. Using simplified balance models, a storage volume of approx. 1 million m³ was determined in order to use the surplus heat from the incineration processes for the existing district heating system and to successively integrate large-scale heat pumps and solar heat into the central heat supply system in the event of a district heating expansion. With district heating accounting for 60 % of total heat consumption, the storage capacity is sufficient to achieve a solar thermal share of about 2.3 % of total heat demand (4 % of district heating demand) in Kassel.

The goal of operating the heat supply system in Kassel without the energy sources coal, oil and natural gas as early as 2030 proves to be extremely ambitious. All energy-saving and supply potentials must be fully exploited without delay. This involves, for example, broad-based building refurbishment, the installation of innovative heat supply systems in buildings, and the provision of additional resources and central infrastructure, such as the expansion of heating networks, the installation of large-scale heat pumps and the development of suitable low-temperature sources, the provision of large areas of land, and the installation of solar thermal systems and storage facilities. In particular solar thermal systems and ground-source seasonal storage require system sizes that have been projected in isolated cases but have not yet been implemented on this scale. The provision of the necessary regeneratively generated electricity will also be a major challenge in the coming years.

6. Acknowledgments

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