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Municipal heat provision experiences and expectations in Germany

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Abstract

Background Compared to other sectors, the building sector is seriously lagging in efforts to mitigate climate change. In particular, heat provision needs to move to low-carbon options at greater speed. Municipalities are essential players in the transition to low-carbon heating. However, little is known about their experiences in developing heat provision infrastructure and their expectations of low-carbon options, such as district heating based on renewable energy. To explore how the experiences and expectations of municipalities concerning low-carbon heating are related, we conducted a survey of officers responsible for heating technology in municipal authorities across Germany. The questionnaires were analysed using multiple quantitative data analysis techniques.

Results Our findings suggest that officers in larger municipalities have more positive expectations of low-carbon heating technologies than those in smaller and medium-sized municipalities. They also have more experience with these technologies. We identified four different clusters of municipalities based on their attitudes towards heating systems. The findings suggest that attitudes and experiences have a significant influence on the desirability and expected feasibility of the expansion of district heating. Furthermore, there are differences between south, north, and east Germany.

Conclusions Exchange of experiences and expectations between larger and smaller municipalities could facilitate the transition to low-carbon heating. Public policy could strategically provide spaces for the required exchange, but it also needs to engage with more complex questions of finance and regulation.

Keywords Buildings, District heating, Survey, Municipalities, Experiences, Futures

Background

Efforts to mitigate climate change are gaining traction, but the building sector is seriously lagging behind [1]. Three-quarters of global energy generated are currently consumed in cities, where space limits imply challenges to low-carbon energy supply [2]. Cities can be powerful actors in curbing energy-intensive and greenhouse gas-emitting heat supply, but the lack of resources and expertise in mid- and small-sized towns calls for better integration of these actors in research efforts [3]. Municipalities are usually important actors in the energy supply, as they own critical infrastructures and have resources for planning energy supplies [4]. This is decisive for district heating, because it can include a range of low-carbon technologies and be the most economical heat supply in locations with sufficiently dense buildings through economies of scale [5, 6]. Although energy-saving technologies such as insulation seem to be generally useful to lower carbon emissions independent

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of location, heat pumps have been suggested as a complementary technology for less densely built-up spaces [6]. However, researchers argue that policy strategies, such as those of the European Union, risk ignoring the benefits of district heating, especially in urban areas, when they focus primarily on heat pumps and energy savings in the building sector to fulfil greenhouse gas emission targets [7]. In its energy efficiency directive, the European Union stated that district heating has great potential, including for small and medium-sized suppliers, but only if regulation is conducive [8]. The extent to which such regulation could be supportive and what other factors could drive district heating have not been established. Even when regulation aims to support district heating, it may not be effective, as municipal companies often provide incumbent technologies, such as gas grids and boilers. Moreover, because municipalities' views on alternative heating technologies, such as district heating, have not received research attention thus far, there may be further barriers that have not yet been uncovered. Whether and under what circumstances municipalities will embrace low-carbon technologies remain open questions.

In this paper, we empirically explore the expectations of persons in municipal authorities who are responsible for heat provision technologies, including district heating and heat pumps as low-carbon options and gas-based systems as currently popular technology. Our quantitative analysis draws on a survey of officers responsible for heating technologies in municipal authorities across Germany and links their future expectations of heating technologies to their experiences and locational attributes. Focusing on district heating, the analysis suggests that municipal officers differ in their experiences with and expectations of heat provision technologies, especially concerning climate change mitigation. Responsible officers in larger municipalities and municipalities in certain regions generally have greater experience with district heating, which could be shared with smaller municipalities that lack such experience.

Our study adds to the limited previous social and economic research on district heating and energy governance at the municipal level. Transitions research that complements the approaches of transitions management and of the multi-level perspective with investigations of development arenas and path dependency suggests that high investment costs of district heating, combined with very low marginal costs, imply only slow changes and path dependencies [9, 10]. However, economic modelling has shown that the capital costs of district heating are comparatively low, even concerning competing heat supplies and typical prices when cities are dense [11]. In these areas, district heating should cope with reduced heat demand when energy savings are made [11]. Economic drivers may still be insufficient for rolling out district heating at scale. Transitions research with a focus on path dependency of technology and governance of heating systems points out that the provision of district heating infrastructure can have a long tradition in cities, including combined heat and power, thus implying great expectations of reliable provision [10]. Although external factors, such as oil and gas crises, can destabilise existing arrangements, realignment of policy and these actors is required to implement alternatives. Such realignment seems more straightforward when district heating is already present because it integrates expertise and interest.

Another application of the multi-level perspective shows that actors matter, particularly because district heating is often combined with electricity within municipal utility firms [12]. These markets were given up when municipalities sold these firms [12]. A new trend is the re-municipalisation of such utilities, which varies among locations, as studies on municipal utility governance from Sweden and Germany suggest [12–14]. In Germany, municipalities have a great influence on local infrastructure and planning, founded on the German constitution, but to pursue heat provision objectives, they also need to have control over regional utilities [9, 15]. In the UK, for example, regulation of relevance to district heating is still aligned with incumbent energy regimes, as suggested by a study on approaches of socio-technical systems and infrastructure governance [16].

Similar studies on local energy governance and planning emphasise the role of actors and regulations, particularly of local authorities. When new heat grids are planned, local authorities can be key actors within larger networks of stakeholders. Part of their networks can be community energy groups with detailed expectations and private district heating firms with expertise and experience in other projects [17]. Although experiences and expectations can be shared in such networks, coordination costs can be very high if no mutual priority areas or supportive regulation and financing mechanisms are in place [18]. Moreover, the lack of experience of local authorities in district heating can imply stronger risk perceptions [17]. However, local authorities can also write requirements for certain heat technologies in development plans to which developers then need to respond [19]. When municipalities plan alternative energy supplies, they can consider multiple objectives and technologies. In practice, economic feasibility can be a driving concern early on, limiting the scope of possibilities [20]. Local authorities may have great or even over-ambitious expectations in influencing improved energy provision, which falters when projects seem less feasible than

previously thought and when poor experience with previous projects builds up [21].

The ease of implementing and running financially viable alternative heating infrastructure of municipalities would also depend on their acceptance among citizens and heat consumers. However, research on the perspective of heat consumers is limited. A survey of district heating users in Germany identified costs, energy source dependence, organisation, security of supply, environmental impacts, and construction works as the most relevant factors identified by consumers regarding district heating [22]. Network design and supply security were the next most important attributes. Mirroring these findings, a discrete choice experiment found district heating based on renewables as the heat source with the highest willingness to pay by far among participants [23]. The findings suggest that user requirements should be considered in grid planning, and communication about district heating should be improved. Similarly, pricing mechanisms for consumers may need to be adapted to new consumer demands and sustainable development of district heating, among others, with more transparent prices and seasonal rates [24]. However, as a case study based on socio-technical transitions theory suggests, even municipalities that are frontrunners of using renewable energy and energy saving, because of proactive local groups, benefit from national institutions, regulation, and support programmes [25].

Against this backdrop, the German government aims at an almost carbon-neutral building sector by 2050, while about 35 percent of energy is still consumed for heat and hot water [26]. Besides energy savings, it aims at higher shares of renewables for heating, including district heating, for which it provides planning subsidies. Grants and soft loans for renewable heating technology are available to private persons, businesses, and public utilities that municipalities often run. Municipalities are key actors in Germany's energy transition, as they engage in renewable energy and energy-saving projects and the re-municipalisation of utilities [14]. They are also involved in development planning that can help support heat supply alternatives. However, it is still unclear how national heat policy incentives connect to the experiences and expectations of persons engaged in municipalities and which heating technologies they would prefer to implement.

In Germany, municipal utilities are traditionally part of large cities as well as smaller towns. Even in the periphery, some municipal utilities resisted the liberalisation of energy markets from 1990 onwards and partly grew again [14]. However, larger utility companies gained shares in smaller municipal utilities and fully bought them, and new mergers occurred or were re-municipalised. This led to very diverse municipal energy companies (see also [13]). It is, therefore, unclear whether persons responsible for heating in German municipalities have different experiences with and expectations of alternative heating technology. Answers to this question are important for developing effective strategies to develop low-carbon heating infrastructure at the required pace to meet greenhouse gas emissions goals.

This paper contributes to filling this gap in knowledge on how municipalities engage with the transition to low-carbon heating. The empirical methods of our study are set up to explore how the experiences of persons responsible in municipalities influence expectations of heat provision. This study aims to answer the following research questions:

a) Does the experience of municipal officers with district heating have a positive influence on their preference for district heating and their desirability to expand it?
b) Do their attitudes towards heating systems in general influence the stated preference for district heating and the stated feasibility of implementing it at the municipal level?
c) Do their attitudes towards heating systems in general and district heating in particular differ across locations in Germany?

Our empirical analysis is the first to offer insights into the experiences and expectations of the persons responsible for heat and energy at the municipality level. The findings of our quantitative survey of municipal officers in Germany can inform strategies to empower municipalities to develop low-carbon heat supplies, which is an inherently complex task.

In what follows, we first introduce our sample of persons responsible for heating in German municipalities, the methods of our survey, and the subsequent steps of quantitative analysis. This includes descriptions of the use of complementary demographic and geographical data. The next section presents the results in detail. After a subsequent discussion of our findings, we conclude with key implications for research and policy.

Data and methods

Data and sampling

We use quantitative approaches to uncover the experiences and expectations of different heating systems in German municipal authorities with a focus on district heating. The German Federal Statistical Office provided a list of the email addresses of German municipal authorities, of which $n=4973$ had valid email addresses. We considered all of them suitable and invited them to

participate in the survey. In the cover letter, we asked to forward the link to the online survey to a person responsible for energy and buildings. In total, $n=677$ municipal officers accessed the online survey that was hosted via the EFS Survey by the company Questback, resulting in a participation rate of 13.6 percent. Out of these, $n=320$ respondents finished the questionnaire (termination rate of 47.3 percent). Considering the high workload of the target group, we did not force the respondents to answer all the questions. Consequently, the responses per question varied between $n=226$ and $n=274$. Majors made up 22.6 percent of the sample (full-time: 14.9 percent; unsalaried: 7.7 percent), another 19.2 percent had a leading function in the administration, 43.7 percent had a specialist function in the administration, and 14.5 percent had other positions. Table 1 provides an overview of the sample.

Municipalities in southern Germany (Baden Württemberg, Bavaria, Hesse) are overrepresented in the sample. Besides demographic data on the municipalities, the online questionnaire captures experiences with different forms of heating systems (gas boilers, heat pumps, and district heating), attitudes towards heating systems, providers, price, sustainability of heating systems, and perceptions of future scenarios of district heating in the municipalities.

Table 1 Sample of the surveyed municipalities

	Sample of municipalities in %	Municipalities in Germany in % [27]
Federal states	($n=226$)*	
Baden Württemberg	20.4	9.96
Bavaria	36.3	18.60
Berlin	–	0.00
Brandenburg	–	3.77
Bremen	–	0.00
Hamburg	–	0.00
Hesse	8.4	3.85
Lower Saxony	8.4	8.55
Mecklenburg Western Pomerania	–	6.81
North Rhine-Westphalia	1.3	3.58
Rhineland Palatinate	7.5	20.85
Saarland	2.7	0.47
Saxony	7.5	3.82
Saxony-Anhalt	3.5	1.97
Schleswig-Holstein	.4	10.04
Thuringia	3.5	7.68
Population	($n=264$)*	
Small town (pop. < 5000)	36.4	73.50
Small city (5000–20,000)	37.5	20.17
Medium city (20,000–100,000)	18.9	5.60
Large city (> 100,000), centre	7.2	0.72

* Respondents were not forced to answer questions. Therefore, the response rates per question can vary

Methods

The methods used in this study serve several purposes. First, the methods measured the attitudes that officers in German municipalities have towards different forms of heating systems and their experiences with these heating systems. Second, clusters were generated based on statements regarding environmental protection, local supply, and economic preferences. These were measured on 5-point scales and reduced via factor analysis. Third, the clusters and the knowledge and attitudes were linked to perceptions about future scenarios of heating systems that the survey participants rated in terms of desirability and feasibility. Lastly, the findings were related to the socio-demographic and geographical data of the municipalities. These analytical steps help uncover comprehensive and contextualised pictures of how persons responsible in municipalities experience different heating systems and what they expect from them. Where our analysis focuses on differences between municipalities and not on individual respondents, we refer to municipalities as such and not to specific officers in municipal authorities.

The analysis began with a description of experiences. On a five-point scale, the respondents rated their experience with the three heating systems that were most often newly installed in residential construction in Germany in 2019. Based on data from the Federal Office of Statistics in Germany, these were gas boilers (36.8 percent), heat pumps (29.8 percent), and district heating (26.5 percent) [28]. As the experiences with the different heating systems correlate significantly with each other ($p<0.001$) and with medium-sized effects ($r=0.468$ to 0.551), we summarised the experiences with the heating systems to a sum scale. A semantic differential that measures the connotative meanings of each heating system is used to describe the expectations of different heating systems.

Next, we estimated the extent to which experiences affect the different clusters of municipalities that rate the attributes of heating systems homogeneously established via cluster analysis. The segmentation of these homogeneous clusters is based on the rated attributes of heating systems. For the segmentation, we used 13 items with a five-point rating scale ranging from "important" (1) to "unimportant" (5), covering responsible officers' statements on their attitudes towards the environment, providers, and economics of heating systems. We used principal component analysis to reduce the 13 statements to a lower quantity of latent dimensions, since cluster analysis faces problems of multicollinearity and

complexity if too many statements are included. The final number of the latent dimensions was determined by the Kaiser criterion (Eigenvalue > 1) and compared with the visual scree plot [29]. Varimax rotation was applied to improve the interpretation of the results. Cronbach's alpha scores were used to measure internal scale reliability. Subsequently, we performed a k-means cluster analysis to segment the municipalities into homogeneous subgroups. The cluster analysis reduced the variance within the different groups of municipalities and hence led to a solution that offered homogeneous subgroups. After we eliminated outliers through single linkage clustering, we used the Ward method to determine the final cluster solution with the squared Euclidian distance to calculate the distances between the municipalities. We used a dendrogram for visualisation and the elbow criterion to identify the optimal number of clusters.

We also estimated the influence of the clusters of municipalities in which the officers responsible rate heating systems attributes similarly and their experiences on the desirability and subjective probability of different future scenarios, for which the respondents assessed two different predictions of the relevance of district heating in 2030. Concerning the first scenario, we asked the participants to rate the desirability and feasibility of a strong increase in district heating mainly based on renewables and to estimate the percentage of households connected to district heating. For the second scenario, they rated the desirability and feasibility of a publicly financed expansion of district heating. The respondents also had to determine the percentage of investment costs of district heating that should be publicly funded.

Lastly, we compared the results with the demographic aspects of the municipalities with the help of Nielsen-Areas for marketing research. Nielson differentiates Germany into seven Nielsen areas that include one or more coherent federal states, based on economic strength and consumer behaviour [30]. For our research, we categorised areas 1, 2, and 3A as the west, areas 3B and 4 as the south, and areas 5, 6, and 7 as the east. East consists of municipalities in Berlin, Brandenburg, Mecklenburg Western Pomerania, Saxony, and Saxony-Anhalt. The south consists of Baden Württemberg and Bavaria. North consists of municipalities in Bremen, Hamburg, Hesse, Lower Saxony, North Rhine-Westphalia, Rhineland Palatinate, Saarland, and Schleswig–Holstein. This approach ensured a sufficient number of participants for each geographic area.

Results

Experiences with and perceptions of heating systems

Of the 274 surveyed German municipalities, 239 responsible officers reported at least little experience with all three heating systems (Fig. 1). The respondents had the most experience with gas boilers. However, 25.2 percent of the sample claimed high or very high levels of experience with each kind of heating system. Much more (62 percent) reported at least some experience with each heating system.

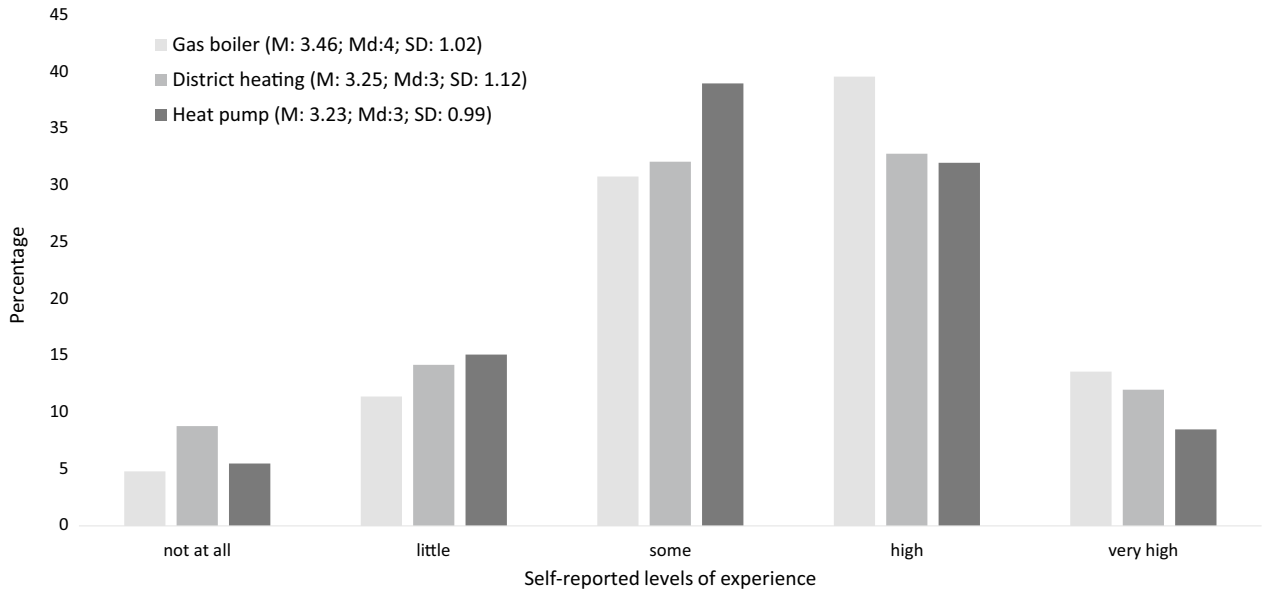

Fig. 1 Levels of experience with different heating systems among German municipalities

We used the variable "experience" for further calculations, which consisted of a sum scale of the experience with all heating systems. This variable had values from 0 ("no experience") to 12 ("very good experience") ($M = 6.93$, Md = 7, SD = 2.53). Persons responsible in larger municipalities reported significantly higher levels of experience with heating systems than persons responsible in smaller municipalities (Pearson correlation, $p < 0.001$, $r = 0.349$).

Figure 2 shows how the respondents perceived gas boilers, heat pumps, and district heating systems on a semantic differential. Heat pumps were considered the most modern and environmentally friendly heating system but also the least reliable and the most expensive one. Gas boilers were perceived as polluting and obsolete systems. Further, district heating seemed to be perceived as a compromise between good practicability, low prices, great reliability, environmental friendliness, and modernity.

Pearson correlations of experiences with the heating systems with perceptions of heating systems attributes showed that the higher the experience, the more flexible ($p = 0.044$; $r = -0.122$), reliable ($p = 0.006$; $r = -0.166$), and the less expensive ($p = 0.046$; $r = 0.121$) district heating was perceived. With greater experiences, gas boilers were perceived as more negative with respect to environmental issues ($p < 0.001$; $r = 0.263$) and modernity ($p < 0.001$; $r = 0.317$) but more positive regarding practicability ($p = 0.004$; $r = -0.175$). With greater experience with them, heat pumps were perceived as less environmentally friendly ($p = 0.018$; $r = 0.144$). However, the effects of experiences on these perceived attributes were small.

Segmentation of municipalities

Table 2 shows the results of a principal component analysis with 13 items on the attributes of heating systems. The results yielded three factors after varimax rotation: preference for a local provider (F1), preference for price and financial security (F2), and responsibility for sustainable development (F3). The factors explained 56.61 percent of the total variance. Cronbach's alpha scores were above 0.70 for all factors, which is considered a "good" internal scale reliability.

Based on these three factors, four homogeneous clusters of municipalities that rate the attributes of heating systems similarly were identified via cluster analysis, as shown in Fig. 3. In the cluster analysis, one municipality was identified as an outlier and was eliminated. The results suggest that there were different segments of municipalities that had heterogeneous demands for heating systems. The largest cluster, "Local Ecologists", represents 45.4 percent ($n = 119$) of the municipalities of the sample. These municipalities wanted reliable providers and sustainable systems. The second largest cluster, "Price Sensitives", represents 19.8 percent of the municipalities ($n = 52$). Municipalities within this cluster found environmental and sustainability aspects unimportant while considering price and financial security as the most important. The "Ecologists" cluster consists of 18.7 percent of the municipalities ($n = 49$). Municipalities in this cluster demanded environmental sustainability but did

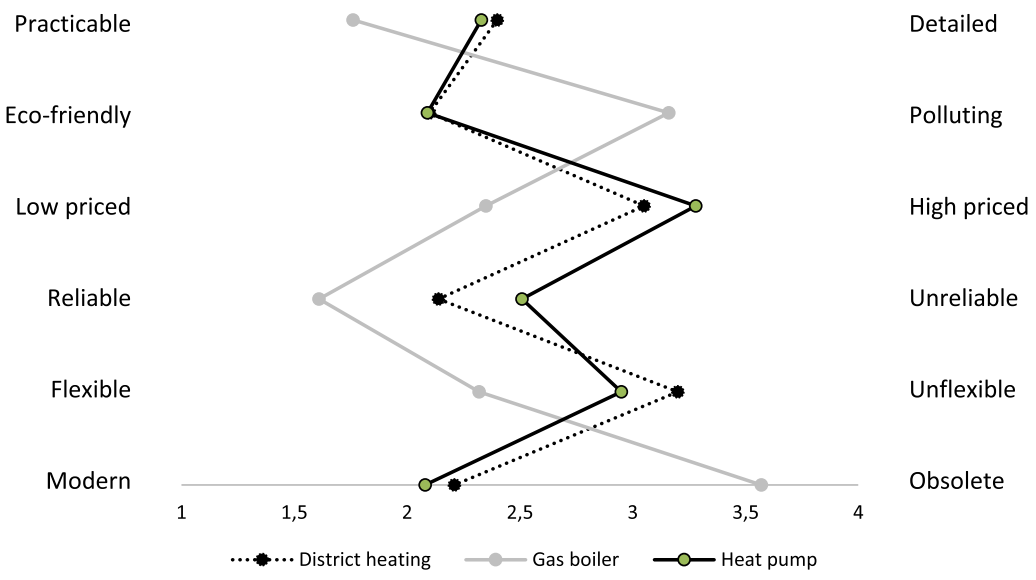

Fig. 2 German municipalities' perceptions of different heating systems

Table 2 Factor loadings from principal component factor analysis.*

Item	Factor loading			
	1 Reliable provider	2 Price and financial security	3 Sustainability	Communality
Local contact person	**0.804**	0.001	0.005	0.646
Direct contact to the provider	**0.755**	0.133	0.066	0.592
Long-term partnership	**0.640**	0.270	0.083	0.490
High trust in provider	**0.600**	0.354	0.214	0.532
Local provider	**0.563**	0.000	0.359	0.446
Reasonably priced heating system	0.022	**0.810**	− 0.004	0.657
Reasonably priced initial investment	0.126	**0.795**	− 0.027	0.649
Low price fluctuations	0.373	**0.598**	− 0.017	0.497
Transparent accounting	0.220	**0.503**	0.378	0.444
High security of supply	0.125	**0.482**	0.453	0.453
High share of renewable energy	0.155	− 0.151	**0.832**	0.739
Low pollution	0.122	0.000	**0.784**	0.629
Future efficiency of energy source	0.009	0.408	**0.646**	0.585
Eigenvalue	4.082	1.765	1.512	
Variance explained in %	19.707	19.523	17.380	
α	0.752	0.730	0.710	

* Communalities, eigenvalues, percentages of variance, and alpha values for ratings of attributes of heating systems ($N = 263$), KMO = 0.794. Boldface indicates the highest factor loadings

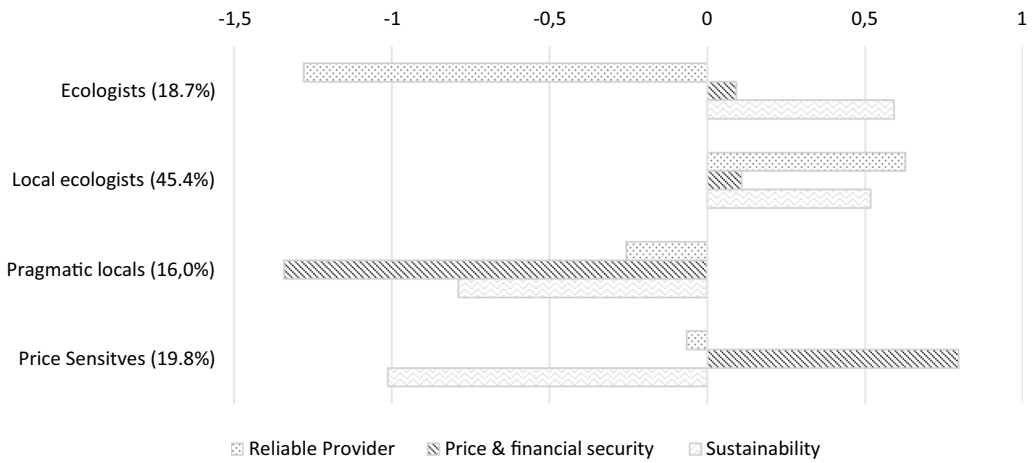

Fig. 3 Four clusters of municipalities that rate attributes of heating systems in similar patterns

not care that much about a local provider. The cluster "Pragmatic Locals" represents municipalities that rated different items moderately. In this cluster, all factors had a lower importance than the average of the municipalities in the survey. The municipalities in this cluster had a more pragmatic view on the attributes of the heating systems and rated them with a tendency towards the neutral position. Nevertheless, a reliable provider was by far the most important demand in this cluster.

An analysis of variances between the four clusters of municipalities and the variable on experiences with heating systems showed a significant difference between the cluster of Ecologists and the cluster of Price Sensitives. Based on a Bonferroni post hoc test, the Ecologists (M: 7.94; SD: 2.55) had a significantly higher experience level ($p = 0.004$) than the Price Sensitives (M: 6.25; SD: 2.35). There were no significant differences between the Local Ecologists (M: 6.89; SD: 2.27) and Pragmatic Locals

(*M*: 7.10; SD: 2.78) or between these clusters and other clusters.

A comparison of the perceptions of different forms of district heating that were measured via the semantic differential showed no differences for gas and district heating among the four clusters of municipalities. However, heat pumps were perceived as more practicable ($p=0.027$), eco-friendlier ($p=0.047$) and modern ($p=0.009$) by the Local Ecologists than by the Pragmatic Locals.

Scenarios

In the next step of the questionnaire, the participants were asked to rate the desirability and feasibility of two different scenarios of future district heating. Concerning the first scenario, they had to rate the desirability and feasibility of district heating based mainly on renewables in 2030 (see Fig. 4).

The desirability of the scenario in which district heating mainly based on renewable energy dominates municipal heat provision in 2030 is rated highly, while its feasibility is rated at a medium level. However, only around 20 percent of households are expected to be connected to heat grids. The desirability of this scenario increased slightly with greater experience ($p=0.016$; $r=0.084$) and size of the municipalities ($p=0.049$; $r=0.122$). Both desirability ($p<0.001$; $r=0.267$) and feasibility ($p=0.001$; $r=0.204$) expectations increase with greater preference for sustainability. Otherwise, there were no significant correlations between the experiences and sizes of municipalities with the scenario attributes.

The second scenario focuses on allocating the costs of installing district heating to the public.

Figure 5 shows that the desirability and feasibility of the scenario in which district heating plays an important role and the costs of expanding grids are borne by the public in 2030 were rated at medium levels. On average, less than a quarter of the costs of grid expansion were expected to be borne by the public (median: 10 percent). The desirability of this scenario decreased with an increased preference for price and financial security ($p<0.001$, $r=-0.224$). By contrast, it increased with an increased preference for sustainability ($p<0.001$, $r=-0.214$).

Geographic differences

The experience with district heating differed between the southern (M: 7.10; SD: 2.56) and eastern (M: 6.45; SD: 2.17) parts of Germany. A one-way ANOVA with a Bonferroni post hoc test revealed that the experiences of the persons responsible were significantly greater in the southern part than in the eastern part ($p=0.004$). However, the experiences did not significantly differ from those of persons responsible in the northern part (M:6.89; SD: 2.57). As shown in the correlation of

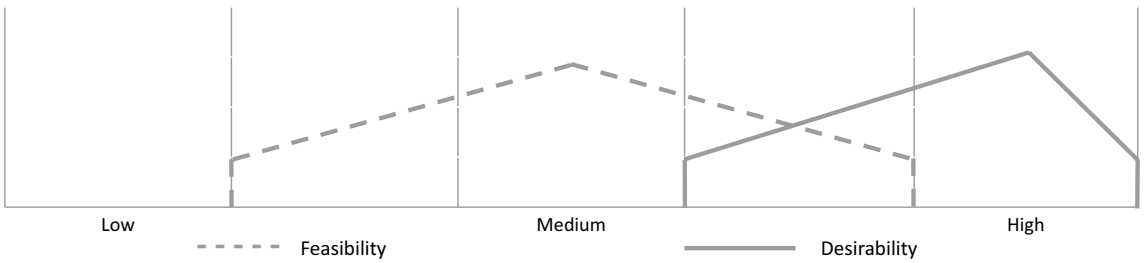

Fig. 4 Feasibility and desirability of district heating mainly based on renewable energy in 2030 (corners indicate quartiles and medians of the rating)

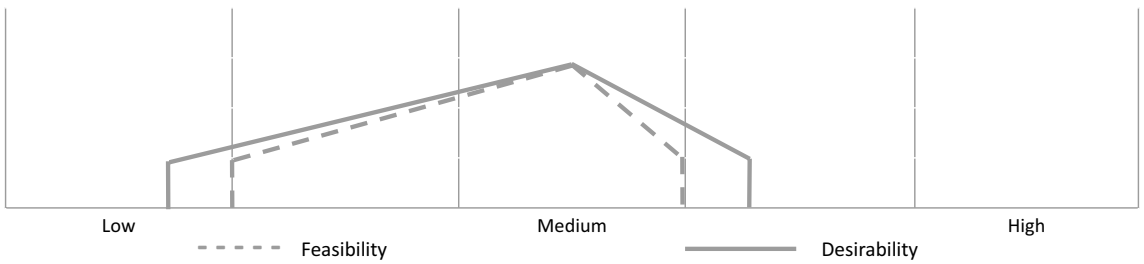

Fig. 5 Feasibility and desirability of allocating investment costs of district heating to the public (corners indicate quartiles and medians of the rating)

Table 3 Regional differences in the frequencies of German municipality clusters with similar demands for heating systems

	East	South	North	Total
Ecologists	0 (0%)	28 (22.4%)	12 (20.0%)	40
Local ecologists	14 (45.2%)	61 (48.8%)	27 (45.0%)	102
Pragmatic locals	4 (12.9%)	16 (12.8%)	12 (20.0%)	32
Price sensitives	13 (41.9%)	20 (16.0%)	9 (15.0%)	42
Total	31 (100%)	125 (100%)	60 (100%)	216

(χ^2 (6) = 17,93, p = 0.006, Cramer V = 0.204)

experience with the semantic differential, this difference entailed diverging perceptions of gas and district heating. In the eastern part of Germany, district heating was perceived as less modern than in the southern ($p < 0.001$; $r = 0.302$) and northern ($p < 0.001$; $r = 0.295$) parts of Germany, whereas gas was considered more modern in the eastern part than in the southern ($p = 0.022$; $r = 0.178$) and northern ($p = 0.002$; 0.221) parts. There were no significant differences regarding the heat pumps.

The municipalities in the different geographic areas had a similar preference for reliable providers. Nevertheless, in eastern Germany, the factor "price and financial security" was significantly more important than in the northern part ($p = 0.021$). The factor "sustainability", in turn, was significantly less important in the eastern part than in southern Germany ($p = 0.031$). There was no significant difference between the northern and southern parts. Reflecting these differences in the factors, there were also significant differences in the clusters of municipalities with similar demands on heating systems between the geographical areas (χ^2 (6) = 17,93, $p = 0.006$), as shown in Table 3. However, the effect size was small (Cramer V = 0.204).

Discussion

The study offers first insights into the experiences and expectations of persons responsible for heat provision technologies in German municipalities. However, the sample used in this study has some limitations. All 4973 German municipalities were invited to participate in the survey, of which 320 officers responsible for heating completed the questionnaire. Hence, the response rate is adequate but not sufficient to suggest that the sample is representative. An unequal spatial distribution of responses across Germany could have affected our findings on geographical differences. Moreover, we only assumed that the participants in the survey were responsible for heat infrastructure in their municipalities, as it was not possible to control who exactly answered the questionnaire.

Nevertheless, the empirical analysis of experiences and expectations with different heating systems of persons responsible in German municipalities uncovered key differences among the municipalities that are relevant for the transition to widespread low-carbon heating. The segmentation of the municipalities into different homogeneous clusters based on their demands on heating systems shows that reliable and ideally local providers are most important for municipal officers responsible for heating technology. This is neither influenced by experience nor by the expectations of the officers or by the demographic attributes of the municipalities. As reliability also includes long-term partnerships, the importance of these attributes could lead to the preference of municipalities for district heating. A closer look at the semantic differential indicates that heat pumps and district heating were perceived as modern and eco-friendly but also as complex and expensive. These negative perceptions decrease with greater experience. Hence, the gradual accumulation of experiences could lead to increased interest in alternative heating systems.

The findings clearly show that experiences with heating systems among municipal officers significantly influenced preferences for and attitudes towards heating systems. In line with Rosenzweig et al. [3], we identified a lack of experience and information among officers responsible for heating small and mid-sized municipalities, which directly affected perceptions of heating systems. The smaller the experiences with heating systems in general, the higher the preference for gas boilers, which were perceived as old-fashioned. The greater the experiences with heating systems, the greater the preference for more eco-friendly alternatives, such as heat pumps and district heating. These findings match the suggestion of Lund et al. [6] that a mixture of heat pumps and district heating is preferred by more experienced decision-makers, especially in larger towns and cities. Thus, the more experienced officers of the larger municipalities could represent useful expertise for smaller municipalities.

This study also shows that more pragmatic and locally oriented municipalities considered heat pumps less practicable, less eco-friendly, and less modern than locally and environmentally oriented municipalities. This pattern correlates with levels of experience. It appears that for a sustainable shift to low-carbon heating systems, more information for municipal officers, especially in small and mid-sized towns, is needed to understand the complexity of the planning process and the long-term benefits of low-carbon heating systems that come along with lower operating costs [7, 9].

Most municipal officers covered in our study perceived district heating as a desirable alternative,

especially for mitigating climate change. The analysed scenarios show that the desirability of low-carbon district heating was very high. However, economic feasibility seemed to be the main problem, especially when experiences with heating systems were limited. This is in line with the findings of Hoppe [21], who found that local authorities often have ambitious plans for heating systems but fail due to low experience because implementation seems unfeasible.

The possibility of using public funds for the development of district heating was neither highly desired by municipal officers nor seen as feasible. Hence, private, or public utilities need to bear large shares of the costs for developing the infrastructure to obtain a higher price for low-carbon energy. Recent research points to the demand side and shows that the willingness to pay for district heating from renewables is high in Germany [22, 23]. Our cluster analysis found that for municipalities, eco-friendliness and local providers were the most important attributes of heating systems. To fulfil the desire for local provision and eco-friendliness, a stronger connection between the demand side and the supply side is needed. The transition to low-carbon heating could therefore be facilitated if municipalities could act as intermediaries for the other actors involved in developing and operating district heating [31, 32]. They could, for example, mediate tensions between private heat supply enterprises and private and public consumers of heat by offering local infrastructure for respective charges. Further, national and regional associations of municipalities and municipal utilities could act as intermediaries that pool and provide expertise and facilitate exchange among the actors more evenly across the sizes of municipalities and space.

Especially in the southern parts of Germany, where there is much experience with modern district heating systems, willingness to expand eco-friendly heating systems was higher. As the financially stronger federal states are located in southern Germany, the municipalities and heat enterprises could act as early adopters to help develop a more mature market for low-carbon district heating. Larger municipalities generally seemed more experienced and positive about alternative heating systems, which makes sense, as they generally pool more experience and are more likely to have densely populated districts in which district heating is more economical. The larger municipalities could therefore take the lead in rolling alternative heating systems out, and the smaller municipalities could learn from them. Such learning could be organised via larger municipalities and municipal associations that act as intermediaries, as sketched out above. If funds and human resources for the necessary exchange are too limited, European or national programmes or offices could be set up to support such exchange. However, it is important that intermediaries act flexibly in addressing changing needs and emerging gaps [32]. Further, smaller municipalities, including those in the South, could use planning provisions or municipal taxation to demand or incentivise sustainable heating and evaluate the effects of such measures.

Our study suggests that municipal officers in the east of Germany were much less open towards low-carbon heating in general and particularly district heating while being very price sensitive. To approach this problem, deeper insight into the role of experiences in east Germany for expectations of heat grids would be useful, which our data do not offer. Past experience can affect current path dependencies of expectations, as has been shown for the industrial heritage of local communities, which continues to affect their development pathways [33]. The municipal officers considered district heating modern, although it was already widespread in the German Democratic Republic, with 30 percent of dwellings connected [34]. However, district heating did not expand after the unification of Germany. This suggests that there was a break of a path and possibly a new path created after unification, resting on a re-evaluation of past and current experiences with heat grids and their alternatives. Nevertheless, it appears that it will be much more challenging in the east of Germany to move towards eco-friendly heating. This challenge could be tackled through a more exchange between officers in eastern municipalities and municipal officers from other regions of Germany, which could lead to the development of shared commitment in strategic networks [35]. However, further research into the experiences and expectations of the relevant actors in East and West Germany seems necessary to develop fruitful exchange or other measures that generate more positive expectations of low-carbon heat grids in eastern Germany. As large areas of the east are economically disadvantaged and municipal finances typically poor, at least external funds, perhaps national or European, could be used to support sustainable heat infrastructure and keep the prices of these systems in check.

Conclusion

Municipalities are important players in the transition to low-carbon heating. However, little is known about the experiences of persons responsible in municipalities for developing heat provision infrastructure and their expectations of low-carbon options, such as district heating based on renewable energy. To explore how the experiences and expectations of municipalities concerning low-carbon heating are related, we conducted a survey of persons responsible for heating technology in municipal authorities across Germany. The quantitative

data analysis suggests that officers responsible in larger municipalities had more positive expectations of low-carbon heating technology than those in smaller and medium-sized municipalities. They also had more experience with these technologies. It seems, therefore, likely that larger municipalities will take the lead in developing their respective infrastructure. Smaller municipalities could then learn from larger ones. However, officers in smaller municipalities and the municipalities in the east of Germany that have less experience with these heating technologies expect financial feasibility to be limited. As public funding is generally less desired by municipalities, it will be difficult to design effective incentives for developing low-carbon heating in smaller municipalities.

The findings of our study are empirically grounded in a survey that covers persons responsible for heating technology in municipalities across Germany for which key demographic data are available. This could facilitate the transferability of the findings outside Germany. This also implies that the sample and methods led to general findings for Germany at large. However, they might not have uncovered specifics in some regions. They are also restricted to a limited set of technologies, which ignore further alternatives and do not cover the role of energy saving in detail. In addition, the findings focus on district heating, which should be more relevant to urban regions than rural municipalities with dispersed heat consumers. However, these are typical limitations of large-scale quantitative surveys covering a whole country, and our study still identified larger patterns of relevance to policy.

Our findings have implications for policy and municipal strategies. Larger municipalities could make their experiences available to smaller ones, who could then examine the experiences of others. Officers of larger municipalities could also share and explain their expectations of low-carbon technologies, such as district heating based on renewable energy, more strategically with other municipalities. Thus, municipalities have obvious roles in acting as intermediaries for low-carbon heating and forming strategic networks of actors involved with shared commitment. However, it is still open how exactly to organise the respective exchanges between persons responsible for heating technologies in municipalities. In part, larger municipalities could transfer their experiences and expectations through subsidiaries and joint ventures of their municipal energy utilities to smaller municipalities. Public policy could also facilitate exchange and demonstration projects that are strategically located across Germany. However, our findings suggest that devising policy for the financial support of district heating and other low-carbon technology will be difficult at the municipal level. Further research could identify acceptable financial mechanisms and effective designs for regulatory incentives, especially for smaller municipalities. Generally, there is still a need for research that explores the diffusion of experiences and expectations and effective interventions from both the municipal and higher levels.

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Author contributions
TK is the recipient of the funding and led the survey and analysis of empirical material, drafted the manuscript, and contributed to further editing. MHE reviewed the literature, drafted the manuscript, and contributed to further editing. AP contributed to the statistical analysis. All authors read and approved the final manuscript.

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Availability of data and materials
The data from the questionnaires that were analysed during the current study are available from author Dr. Thomas Krikser on reasonable request. Secondary data used for the study are available from The Nielsen Company [30] and Destatis (www.destatis.de, see references).

Declarations

Ethics approval and consent to participate
We did not collect sensitive or personalised data (e.g. age, gender, income, education). Hence, based on the ethical guidelines of the University of Kassel, where the research was conducted, ethical approval by the ethical committee of the University of Kassel was not necessary.

Consent for publication
Not applicable.

Competing interests
The authors declare that they have no competing interests.

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