eceee Summer Study proceedings

Resident satisfaction with low-temperature district heating: The role of cost perceptions and energy-crisis protection

COLLECTION: CONSUMPTION, BEHAVIOUR AND ATTITUDES

PEER-REVIEWED PAPER

JESSICA BERNEISER

KARL SEEGER

*Author affiliations can be found in the back matter of this article

ABSTRACT

Peer-reviewed paper 1-229-26

Decarbonizing residential heating is essential for achieving climate targets in the building sector, yet the success of innovative heating systems also depends on residents' acceptance and satisfaction. This study examines tenants' perceptions of an energy concept incorporating low-temperature district heating (LTDH) in a climate-neutral neighbourhood in Germany. The analysis is based on a survey of 63 tenants conducted in September 2025.

Tenants' satisfaction with the energy concept was higher the more reasonable tenants find their current energy costs and the more they expect that climate-friendly heating can provide protection against future energy crises. Other factors including subjective knowledge, social norms, future price expectations, and perceived ability to influence energy consumption and costs did not significantly explain satisfaction. However, mean scores for expected future cost advantages of climate-friendly heating over fossil fuel use were high, indicating that tenants were aware of the risks associated with dependencies on oil and gas. Overall, awareness of the specific heating technology was limited, with only a minority of tenants aware that their neighbourhood uses an LTDH system and knowing their current energy costs. Most respondents also expressed a low willingness to pay a premium for climate-neutral heating. However, general support for decarbonizing heat generation was strong among the tenants of the neighbourhood and was higher the more tenants expect that using renewable energy can provide long-term cost advantages and greater resilience to future energy crises compared to fossil fuel use.

Taken together, our findings suggest that, among tenants in LTDH-supplied newly built multifamily houses, satisfaction with the energy concept is most strongly associated with their current exposure to energy costs. For more distal outcomes that capture the importance people attach to decarbonizing residential heat, anticipated future developments in cost advantages and energy security are more relevant.

CORRESPONDING AUTHOR:
Jessica Berneiser
Fraunhofer Institute for Solar Energy Systems ISE, Germany
jessica.berneiser@ise.fraunhofer.de

KEYWORDS:
district heating; residential buildings; decarbonisation; tenant satisfaction

TO CITE THIS ARTICLE:
Berneiser, J and Seeger, K. 2026. Resident satisfaction with low-temperature district heating: The role of cost perceptions and energy-crisis protection. *eceee Summer Study proceedings*, 1(1): 51, pp. 1–13. DOI: https://doi.org/10.66506/essp.1-229-26

DOI: 10.66506/essp.1-229-26

INTRODUCTION

The decarbonization of the building sector is a central pillar of German climate policy. In Germany, the heating demand of the building sector accounts for 16% of the national greenhouse gas emissions (German Environment Agency (UBA) 2025). Despite considerable progress in decarbonizing electricity generation, the heat sector has proven far more resistant to transformation (ERK 2025). Heat supply for space heating and domestic hot water remains heavily dependent on fossil fuels, with natural gas constituting the dominant energy carrier in German households (AGEB 2025). Recent legislative efforts, including the Building Energy Act (Gebäudeenergiegesetz, GEG) and to a lower extent also its planned successor, the Building Modernisation Act (Gebäudemodernisierungsgesetz, GMG), as well as the Municipal Heat Planning Act (Wärmeplanungsgesetz, WPG), underscore the political urgency of transitioning toward renewable heat sources. Alongside decentralized solutions such as heat pumps, the expansion and decarbonization of district heating (DH) networks is increasingly recognized as a necessary pathway, particularly in dense urban environments where individual building-level solutions face technical constraints and where DH is economically more attractive than in sparsely populated regions (Mathiesen et al. 2025). However, there are still open questions regarding how DH systems can be effectively decarbonized to meet climate targets.

LTDH systems represent an innovative and increasingly climate-neutral approach to urban heat supply, as they operate at considerably lower temperatures than conventional DH networks and integrate renewable and waste heat sources more efficiently, reduce distribution losses, and substantially lower the carbon intensity of heat provision (Wirtz et al. 2022). However, technical feasibility and favourable engineering assessments alone are insufficient to ensure the successful deployment and long-term operation of LTDH systems. Public acceptance among end-users, particularly among tenants in multifamily buildings, who experience these systems in their daily lives but typically have no influence over the choice of heating technology, is a critical yet underexamined precondition for the diffusion of this LTDH (Billerbeck et al. 2024). Understanding how such tenants perceive and evaluate these systems after moving into LTDH-supplied housing is therefore essential for informing both policy design and the marketing of sustainable urban quarters.

Questions around the resilience of energy systems, independence from fossil fuel imports, and protection against rising energy prices have gained renewed urgency in recent years. The Russian war on Ukraine and the European gas crisis of 2022–2023 exposed the vulnerability of fossil-fuel-dependent heating systems (Kockel et al. 2022). Germany was particularly affected, given that natural gas, together with heating oil, has served as the dominant heating fuel for decades and continues to do so. Wholesale gas prices surged to unprecedented levels, and the German government was compelled to introduce emergency measures including gas price caps and energy cost relief packages to shield households from the immediate financial impact (Praktiknjo et al. 2025). These events have reshaped how heating systems are evaluated, adding energy security, price stability, and crisis resilience to traditional concerns about cost and comfort (Baur et al. 2022). For tenants in districts supplied by renewable-based LTDH, this context may influence both their satisfaction with the heating system and their support for heat decarbonization.

SOCIAL ACCEPTANCE OF DH

Existing research on district heating has focused predominantly on techno-economic aspects, including system design, infrastructure investment costs, network optimization, and the integration of renewable heat sources (Hoffmann et al. 2024). A growing body of literature has begun to examine public acceptance renewable heating technologies. For example, cost perceptions and performance expectations have been found to be relevant for consumers' preferences for heating technologies (Karytsas 2022; Rao et al. 2025), but also reactions to external threats (Michelsen & Madlener 2013) and influence of peers (Brown & Martiskainen 2024). Further, there is mixed evidence regarding the effect of information about heating technologies, with some studies suggesting that knowledge about heating technologies increases willingness to adopt them, e.g., via strengthening perceived behavioural control (Martens et al. 2025), others found that there is no relationship between adoption interest and accuracy of knowledge (Attari et al. 2026). Yet only few have examined the acceptance of DH. Further, the vast majority of these studies adopt

DOI: 10.66506/essp.1-229-26

an ex ante perspective, investigating attitudes, preferences, and willingness to pay before implementation through hypothetical choice experiments or stated preference surveys (Ruokamo 2016; Krikser et al. 2020). However, ex ante acceptance (before installation) and ex post acceptance (after installation) of DH systems can diverge, as has been reported for users vs. non-users of DH in Germany (Billerbeck et al. 2024).

Empirical research on tenant satisfaction with DH after implementation remains scarce (Onencan et al. 2024), particularly for innovative low-temperature systems in newly built urban quarters.

PROTECTION MOTIVATION THEORY AND PERCEIVED IMPORTANCE OF CLIMATE-FRIENDLY HEATING

Moreover, the role of the recent energy crisis in shaping tenants' post-occupancy perceptions of DH, and heating solutions in general, has not been systematically addressed in the literature. Protection Motivation Theory (PMT) is a socio-cognitive model for understanding how individuals assess threats and decide on protective actions in response (Rogers 1975; Floyd et al. 2000). PMT distinguishes between two parallel cognitive processes: threat appraisal and coping appraisal. In the context of our study, which investigates perceptions of climate-friendly heating systems in the aftermath of Germany's fossil fuel energy crisis, these processes may be helpful for understanding how people relate the challenges of fossil fuel dependence to personal heating attitudes. In our study, coping appraisal comprises three constructs: response efficacy (the perceived effectiveness of climate-friendly heating systems in protecting against future energy crises), self-efficacy (confidence in one's ability to reduce energy consumption and costs), and response costs (perceived long-term costs of climate-friendly heating compared to fossil fuels). Higher coping appraisal is expected to be associated with greater importance placed on decarbonizing heat and higher satisfaction with LTDH systems.

Given the growing public focus on the resilience of the energy system and the German government's effort to preventing future energy crises, we investigate the significance of these coping appraisals for tenant satisfaction with climate-friendly LTDH.

RESEARCH AIMS AND HYPOTHESES

In this study, we address the identified gaps in literature by investigating the extent to which long-term price expectations, perceived ability to reduce energy costs and perceived energy-crisis resilience of climate-friendly heating explain tenants' satisfaction with LTDH after occupancy and the importance they place on decarbonizing heat. Drawing on an original survey of tenants in the Seestadt Mönchengladbach, a newly developed urban quarter in North Rhine-Westphalia supplied by an innovative LTDH system, we provide one of the first empirical assessments of post-occupancy acceptance of LTDH in Germany. Specifically, we address the following research questions:

1. How aware are tenants of the LTDH system and their current energy costs?
2. How satisfied are tenants with a LTDH system in a climate-neutral neighbourhood, and which factors explain satisfaction and how important tenants consider the decarbonization of heat in general?

Building on previous studies and PMT (Rogers, 1975), we examine the following hypotheses:

- **H1**: The more important tenants find the decarbonization of heat generation the more satisfied they are with the energy concept in their neighbourhood.
- **H2**: The more knowledgeable tenants feel about the energy concept, the more they believe that their current energy costs are reasonable and that climate-friendly heating will have long-term cost advantages over fossil fuels and protect against energy crises, and the more they believe that their social environment thinks positively of climate-friendly heating solutions, the more satisfied they are with the energy concept in their neighbourhood.
- **H3**: The higher the perceived long-term cost advantages of climate-friendly heating, the greater the perceived protection against future energy crises, and the more tenants believe in their ability to reduce energy consumption and costs, the more important they find the decarbonization of heat generation.

DOI: 10.66506/essp.1-229-26

METHOD

STUDY CONTEXT AND PROCEDURE

The empirical setting for this study is the Seestadt Mönchengladbach, a newly built sustainable urban quarter in North Rhine-Westphalia, Germany. The Seestadt mg+ district in Mönchengladbach is composed solely of multi-family houses and is supplied by an ultra-low-temperature DH network (sometimes referred to as a LowEx network) operating at a supply temperature of 39°C, which places it between conventional 4th generation DH and a true 5th generation energy network. Heat is generated centrally by a large heat pump that recovers thermal energy from the central sewage water and feeds it into the network. A gas boiler in the central energy station is available for peak load coverage. At each building, a transfer station delivers heat to the in-house distribution system. The network temperature of 39°C is sufficient for space heating but not for domestic hot water, which is therefore prepared via decentralised electric reheating at the building level.

The questionnaire was created using the online survey tool SoSci Survey and was conducted in both German and English from September 1, 2025, to September 15, 2025. Although the survey was not conducted during the heating season, all participating households had experienced at least one full winter in their LTDH-supplied apartment. The survey complies with the General Data Protection Regulation (GDPR); data were collected anonymously, remain confidential, and are used exclusively for research and internal feedback. Data analysis was carried out using Excel (Office 365) and the statistical software JASP.

SAMPLE

The target group of the survey was tenants of the Seestadt district in Mönchengladbach. The survey was sent to 247 households. A total of 63 households participated, resulting in a response rate of 25.5%. Out of the 63 completed questionnaires, only 50 participants provided demographic information at the end of the survey. Of these 50 participants, 18 identified as female, 31 as male, and one did not specify. There were no participants identifying as diverse. The average age of respondents is 39.2 years, with ages ranging from 20 to 80 years. The majority of participants are between 20 and 36 years old, while older age groups are represented only sporadically. Regarding household size, 21 participants live in single-person households, 17 in two-person households, 7 in three-person households, and 5 in four-person households. This indicates that most respondents live in smaller households. The length of residence in Seestadt also varies: 48 respondents have lived there for more than a year, five for 6 to less than 12 months, five for 3 to less than 6 months, and four for less than 3 months. This shows that the majority of respondents have been tenants of Seestadt for a "longer" period for a comparatively new climate-neutral neighbourhood. The overwhelming majority answered the questionnaire in German (n = 50), while twelve participants responded in English.

MEASURES

The questionnaire consists of a total of 18 overarching questions and could be completed in about ten minutes. The questions were divided into various thematic areas that addressed both the satisfaction and attitudes of the tenants toward sustainability and climate-friendly heating supply. Additionally, expectations regarding future price increases and price stability of renewables compared to fossil fuels were assessed. All items relevant to this study and their means, standard deviations, and frequencies can be found in Table 1.

Table 1 Means, standard deviations and frequencies for all items.

DESCRIPTIVE STATISTICS	*M* (*SD*)	FREQUENCIES					
SCALE AND ITEMS		*1*	*2*	*3*	*4*	*5*	*DON'T KNOW*
Satisfaction with energy concept	3.19	11	3	21	18	9	2
"Since you have been living in the Seestadt, how satisfied are you today with these aspects? Climate-neutral energy concept."	(1.27)						
Importance of decarbonization	4.02	1	0	12	26	16	1
"I consider the transformation of heat generation to renewable energy sources to be an important issue."	(0.83)						

(Contd.)

DOI: 10.66506/essp.1-229-26

DESCRIPTIVE STATISTICS SCALE AND ITEMS	*M* (*SD*)	FREQUENCIES *1*	*2*	*3*	*4*	*5*	*DON'T KNOW*
Subjective knowledge *"I am well informed about the heating supply concept in the Seestadt."*	2.83 (1.14)	9	14	18	16	3	3
Reasonability of energy costs *"I consider the amount of my current costs for hot water and heating to be reasonable."*	2.76 (1.32)	11	6	10	12	3	17
Self-efficacy to reduce energy costs *"I feel capable of reducing my energy consumption and thus the amount of my future energy costs."*	3.13 (1.14)	4	11	11	17	4	12
Long-term cost advantages of RE *"Climate-friendly heating systems are more cost-effective in the long term than those using natural gas and heating oil."*	3.95 (0.89)	0	2	17	18	18	8
Price stability *"I expect climate-friendly heating systems to provide more stable energy prices than those that use natural gas and heating oil."*	4.16 (0.88)	1	0	11	20	23	8
Protection against energy crises *"Climate-friendly heating systems protect against energy and raw material crises."*	4.09 (0.85)	0	2	11	22	20	8
Social norms *"In my social environment, using climate-friendly heating systems is viewed positively, while natural gas and heating oil are rather rejected."*	3.46 (0.96)	1	5	27	12	10	8
Willingness to pay premium: 10% *"Generally, I am willing to pay a premium for climate-friendly heating supply (instead of using heating oil and natural gas): approximately 10% higher energy costs."*	2.56 (1.12)	12	13	19	9	2	8
Willingness to pay premium: 20% *"Generally, I am willing to pay a premium for climate-friendly heating supply (instead of using heating oil and natural gas): approximately 20% higher energy costs."*	2.33 (1.09)	14	19	14	6	2	8

RESULTS

In the following, we present results from our study by first describing descriptive results, next the results from correlation analyses and finally we explore which factors explain satisfaction with the energy concept and the importance tenants assign to decarbonizing heat generation.

DESCRIPTIVE RESULTS

Awareness of LTDH and energy costs

Participants were asked to what extent they knew where the heat for heating and hot water in their current apartment in Seestadt came from. Around half of those surveyed stated that they knew the heat source (31 out of 60 answered yes). Those who answered yes were asked to specify which technology or energy source they thought was used to provide heat. Of these, 13 people correctly ticked heating network and also 13 instantaneous water heaters, but 6 also ticked solar thermal energy and 1 person ticked natural gas boiler. 13 indicated heat pump, which is, together with the gas boiler for peak loads, only indirectly correct in relation to the heating network, but not in relation to the direct heating of the building (which was specified in the answering scale). Most of the tenants surveyed therefore have a significant lack of information about heat supply. Participants were also asked to indicate whether they knew the amount of their monthly expenses for heating and hot water. The majority of respondents had no overview of their heating and hot water costs in Seestadt (37 didn't know, 23 indicated to know). However, when asked whether they knew their monthly expenses for heating and hot water in the flat they lived before, the answering pattern changed, the majority (n = 34) indicated to know about the costs, whereas 25 said they don't.

DOI: 10.66506/essp.1-229-26

Tenants' satisfaction with the climate-neutral energy concept based on a low-temperature DH system

Respondents reported a moderate level of satisfaction with the climate-neutral energy concept, indicated by a mean score of 3.19 (SD = 1.27). While some tenants expressed satisfaction, a notable portion remained neutral or dissatisfied, indicating areas for potential improvement. We examined whether satisfaction differed between respondents who reported being aware of the heating supply concept and those who were not, as well as between respondents who indicated that their heat was supplied via LTDH and those who did not. Satisfaction did not differ significantly between respondents who reported knowing about the heating supply concept and those who did not (M_{know} = 3.00, SD_{know} = 1.34; $M_{don't\ know}$ = 3.35, $SD_{don't\ know}$ = 1.23; p = 0.31). Among those who have indicated to know about the concept, respondents who indicated that their heat came from LTDH reported somewhat higher satisfaction (M_{LTDH} = 3.23, SD_{LTDH} = 1.30) than those who did not (M_{noLTDH} = 2.83, SD_{noLTDH} = 1.38), although this difference was also not statistically significant (p = 0.43). As there is no statistically reliable evidence that satisfaction differs by knowledge of the system or by awareness of LTDH, the descriptive patterns could be explored in future, better-powered studies.

Attitudes and beliefs about climate-friendly heating and decarbonization of heat

Respondents emphasized the *importance of decarbonization*, with a strong mean score of 4.02 (SD = 0.83), indicating that respondents widely recognize the need for a transition to renewable energy sources. In terms of how well informed tenants felt about the heating supply concept (subjective knowledge in Table 1, the mean score was 2.83 (SD = 1.14), suggesting that many tenants feel somewhat uninformed, which corresponds with the finding that many were not aware of the LTDH. Respondents viewed the reasonableness of energy costs with scepticism, scoring a mean of 2.76 (SD = 1.32). This indicates dissatisfaction with current pricing among a substantial share of the tenants, whereas others indicated to find their heating costs as very reasonable. However, a large share of the respondents (n = 17) used the answering option "don't know", reflecting that many were not aware of their current energy costs. Further, tenants felt able to reduce energy consumption, and therefore costs, to some extent (M = 3.13, SD = 1.14). The perceived self-efficacy varied among the respondents, indicating mixed confidence in their capacity to manage energy consumption effectively. Many felt unable to reduce their energy costs. However, there was a strong belief in the long-term cost advantages of renewable energy systems, reflected in a mean score of 3.95 (SD = 0.89), suggesting optimism about the financial benefits of adopting such technologies. Also, tenants expressed high expectations for price stability with a mean score of 4.16 (SD = 0.88), indicating confidence that climate-friendly heating systems would provide more stable energy prices compared to traditional sources. In addition, respondents also believed quite strongly that climate-friendly heating systems could offer protection against energy crises (M = 4.09, SD = 0.85). Finally, respondents had a mixed perception of whether their social environment views climate-friendly heating systems rather positively, while natural gas and heating oil are rather rejected. Many respondents chose the neutral option (n = 27), indicating that many were not entirely sure or aware of their surroundings' attitudes.

Willingness to pay a premium for climate-neutral heating

The willingness to pay a premium for climate-neutral heating was assessed with two questions: a 10% premium (M = 2.56, SD = 1.12) and a 20% premium (M = 2.33, SD = 1.09). Both scores indicate low willingness among tenants to pay extra for climate-friendly options. However, some respondents indicated to be willing to pay a premium for climate-friendly heating.

CORRELATIONS

The correlation Table 2 presents the relationships between the different variables. There was no significant correlation between our two dependent variables (DVs), tenants' satisfaction with the energy concept and how important they generally consider the decarbonization of heat. However, the analysis revealed significant correlations among the independent and dependent variables, as well as intercorrelations between the IVs.

DOI: 10.66506/essp.1-229-26

VARIABLE	1	2	3	4	5	6	7	8
Satisfaction with energy concept								
Importance of decarbonization	0.26							
Subjective knowledge about energy concept	0.25	0.10						
Reasonability of energy costs	0.65***	0.46**	0.46**					
Self-efficacy to reduce energy costs	0.21	0. 30	0.05	0.31				
Long-term cost advantages of RE	0.22	0.66***	0.27*	0.45**	0.27			
Price stability	0.09	0.48***	0.03	0.22	0.13	0.39**		
Protection against energy crises	0.16	0.50***	0.22	0.30	0.15	0.55***	0.35**	
Social norms	–0.02	0.29*	–0.04	–0.05	0.11	0.29*	0.11	0.52***

Table 2 Bivariate correlations between satisfaction, importance of decarbonization, costs perceptions, self-efficacy, energy crisis protection and social norms.

Note. $*p < 0.05$, $**p < 0.01$, $***p < 0.001$.

DV: Satisfaction with the energy concept

The only factor that had a significant and strong positive correlation with tenants' satisfaction with the climate-neutral energy concept was the perceived reasonability of energy costs, indicating that tenants who perceive their current energy costs as more reasonable tend to report higher satisfaction with the energy concept. Neither how important respondents found decarbonization, nor how much they believed to know about the energy concept, how able they felt to reduce their energy consumption and costs, how advantageous they perceive the cost and price stability of renewable compared to fossil heating sources, nor expectations regarding the protection against future energy crises were significantly related to tenants' satisfaction. In addition, one's personal satisfaction with the energy concept was not related to how other people in their social environment view climate-friendly heating solutions.

DV: Importance of decarbonizing heat

Stronger perceptions that current energy costs are reasonable, greater belief in the long-term financial benefits and price stability of renewable energy, and stronger belief that climate-friendly heating systems protect against future energy crises are associated with greater perceived importance of transforming heat generation to renewable energy sources. Beliefs that one's social environment supports renewable heating were positively associated with the perceived importance of the transition The perceptions of long-term cost advantages of using renewable energy over fossil fuels had the strongest relationship with how important respondents see decarbonization of heat generation. Neither their subjective knowledge about the energy concept nor their perceived ability to reduce energy consumption and costs were significantly correlated with the importance of decarbonization.

Intercorrelations between independent variables

In addition to correlations of factors with the two dependent variables, satisfaction with energy concept, and importance of decarbonizing heat generation, we also found correlations between the independent variables. First, perceiving current energy costs as more reasonable was associated with greater self-reported knowledge about the energy concept in Seestadt and stronger expectations of long-term cost advantages from using renewable rather than fossil energy for heat generation. Second, expecting future cost advantages from renewable energy was associated with stronger beliefs that renewable heating provides greater price stability than fossil fuels and that climate-friendly heating systems protect against future energy crises. Third, we found a strong positive correlation between perceived social norms and perceived protection against energy crises, indicating that stronger beliefs that one's social environment supports climate-friendly heating systems were associated with stronger beliefs that these systems protect against future energy crises.

PREDICTORS OF SATISFACTION WITH ENERGY CONCEPT AND IMPORTANCE OF DECARBONIZATION

Next, we examine the extent to which the different factors explain tenants' satisfaction with the energy concept and the importance respondents see for decarbonizing heat generation. First, we conducted multiple regression analysis to investigate the relative importance of the factors for satisfaction with the energy concept.

DOI: 10.66506/essp.1-229-26

The model explained a significant portion of the variance in satisfaction, with an $R^2_{adj.}$ of 0.45 ($F(8, 27) = 4.54$, $p < 0.001$). The regression coefficients are presented in Table 3. The analysis revealed that the perceived reasonability of current energy costs ($\beta = 0.76$, $SE = 0.18$, $p < 0.001$) and expectations that renewable energy would bring cost advantages in the long term ($\beta = 0.49$, $SE = 0.34$, $p < 0.05$) were significant predictors of satisfaction with the energy concept in Seestadt.[1]

Table 3 Multiple regression analysis explaining satisfaction with energy concept.

MODEL	UNSTANDARDIZED COEFFICIENT	STANDARDIZED COEFFICIENT	*SE*	*t*	*p*
(Intercept)	0.98		1.19	0.82	0.42
Reasonability of energy costs	0.79	**0.75**	0.18	4.48	**<0.001**
Protection against energy crises	0.90	**0.49**	0.34	2.67	**0.01**
Long-term cost advantages of RE	0.01	0.01	0.27	0.03	0.98
Self-efficacy	–0.03	–0.03	0.18	–0.18	0.86
Importance of decarbonization	–0.21	–0.14	0.29	–0.71	0.48
Social norms	–0.32	–0.20	0.24	–1.33	0.20
Price stability	–0.32	–0.22	0.22	–1.44	0.16
Subjective knowledge	–0.27	–0.23	0.19	–1.42	0.17

Second, we conducted multiple regression analysis to investigate the relative importance of reasonability of energy costs, self-efficacy to reduce energy costs, subjective knowledge about the energy concept, long-term cost advantages of renewable energy, protection against energy crises, and social norms for the perceived relevance of decarbonizing heat generation.

The model explained a significant share of the variance in importance of decarbonization ($R^2_{adj.} = 0.47$; $F(8, 27) = 4.80$, $p < 0.001$). Only beliefs that renewable energy will bring long-term cost advantages over fossil fuel use significantly predicted how important respondents thought the decarbonization of heat generation was ($\beta = 0.41$, $SE = 0.16$, $p < 0.05$). Yet, also the perceived reasonability of one's current energy costs and expectations that using climate-friendly heating system will protect against energy crises were marginally significant ($p < 0.1$). Coefficients are illustrated in Table 4.

Table 4 Multiple regression analysis explaining perceived importance of decarbonizing heat generation.

MODEL	UNSTANDARDIZED COEFFICIENT	STANDARDIZED COEFFICIENT	*SE*	*t*	*p*
(Intercept)	0.51		0.78	0.66	0.52
Long-term cost advantages of RE	0.39	**0.41**	0.16	2.48	**<0.05**
Reasonability of energy costs	0.26	**0.37**	0.14	1.79	**0.08**
Protection against energy crises	0.45	**0.37**	0.23	1.95	**0.06**
Price stability	0.07	0.08	0.15	0.49	0.63
Social norms	–0.01	–0.01	0.16	–0.04	0.97
Self-efficacy	–0.03	–0.03	0.12	–0.21	0.83
Satisfaction with energy concept	–0.09	–0.13	0.12	–0.71	0.48
Subjective knowledge	–0.21	–0.26	0.12	–1.66	0.11

DISCUSSION

This study aimed to explore tenants' satisfaction with a LTDH system in a climate-neutral neighbourhood and to examine factors that explain satisfaction. Our first main finding is that tenants were satisfied with the energy concept to some extent, but many knew little about LTDH

1 To assess robustness to missing data, we re-estimated the model using full information maximum likelihood (FIML) in a structural equation modelling framework including all respondents ($N = 63$). The pattern remained similar: perceived reasonability of current energy costs was again a strong, statistically significant predictor of satisfaction ($\beta = 0.78$, $p < 0.001$), whereas expectations that renewable energy would protect against future energy crises were positive but smaller and not significant ($\beta = 0.39$, $SE = 0.25$, $p = 0.12$). Because missing values concentrated on the cost-reasonability item and cost-related predictors are only meaningful for tenants who feel able to judge their current costs, we retain the complete-case regression on this cost-aware subsample as our primary analysis and treat the FIML estimates as a sensitivity check.

DOI: 10.66506/essp.1-229-26

and their current energy costs. Respondents reported a moderate satisfaction with the climate-neutral energy concept, with a notable portion remaining neutral or dissatisfied, highlighting areas for improvement. Only half of the participants were somehow aware of the source of heat for their apartments, and only few reported to be well-informed about the energy concept, indicating a substantial lack of information and some misconceptions about heat supply. This finding supports previous research indicating that owners of innovative heating technologies have stronger misconceptions about the technology than those who don't own the technology, such as heat pumps (Attari et al. 2026). In addition, most tenants lacked an overview of their heating and hot water costs. This lack of awareness among many tenants may contribute to dissatisfaction, as tenants who believed they were better informed also believed that renewable energy would bring cost advantages in the future compared to using fossil fuels, and reported higher satisfaction levels, even though this correlation was not significant, potentially due to low number of respondents. Enhancing communication and education about the LTDH system could bring a better understanding of the climate-friendly heating supply to the tenants. In addition, we expected that tenants who find the decarbonization of heat generation important would also be more satisfied with the climate-neutral energy concept in their neighbourhood (**H1**). Surprisingly, we found no relationship between the two variables. Maybe tenants were not sufficiently aware of the climate-friendliness of their energy supply which is to some extent reflected in the low awareness of many tenants about the LTDH and other sources of heat.

The second main finding of our study is that primarily perceived reasonability of current energy costs and perceived protection against future energy crises are most strongly associated with satisfaction with climate-neutral energy concept. While respondents varied in their evaluation of current energy costs, ranging from dissatisfaction to perceiving them as (very) reasonable, the correlational results indicate that perceiving energy costs as reasonable is associated with higher satisfaction with the energy concept. This finding is consistent with previous research highlighting that costs are a relevant factor why people prefer certain heating solutions over others (Ruokamo 2016). However, no metadata was collected on respondents' knowledge of pricing for alternative heating systems (e.g., natural gas), which limits the ability to assess how informed these evaluations were and whether dissatisfaction reflects absolute price levels or perceived affordability relative to other options.

In addition, the relative importance analysis suggests that perceived reasonableness of current energy costs and expectations that climate-friendly heating systems protect against future energy crises are the strongest predictors of satisfaction with the energy concept in Seestadt. Taken together, these associations suggest that both cost perceptions and perceived energy security play a central role in how tenants evaluate the concept. However, given the relatively small sample size and the number of predictors included in the regression models (k = 8), the results should be interpreted with caution. The limited ratio of observations to predictors increases the risk of overfitting, meaning that the identified predictors and their estimated effect sizes may be unstable and not fully generalizable. The regression results should therefore be considered exploratory. We found no statistically significant correlation with any other variable, therefore no further evidence for **H2** that also subjective knowledge, long-term cost advantages, self-efficacy, or social norms are related to satisfaction with the energy concept. However, those who find energy costs reasonable also feel more knowledgeable about the energy concept and expect long-term cost advantages from renewable energy over fossil fuels.

Improving tenants' understanding of the energy concept and identifying reasons why tenants are not pleased with their energy costs may help to improve satisfaction with the energy concept. The finding that many tenants don't find current energy prices reasonable is particularly relevant since many also indicated that they do not feel able to influence their energy consumption and costs, even though the correlation with satisfaction was not significant. Potentially, if tenants who consider their energy costs as too high felt more capable of identifying reasons for that and taking energy saving measures that can lower those costs without reducing comfort, satisfaction would increase. With our data, however, we cannot examine how much the subjective impression of costs aligns with objective cost parameters.

Third, most tenants find it important to decarbonize heat generation. In line with **H3**, the more they believe that climate-friendly heating will bring cost advantages in the long-term and protect against energy crises, the more important they find the decarbonization of heat generation.

DOI: 10.66506/essp.1-229-26

Overall, tenants revealed a strong recognition of the importance of decarbonizing heat generation. There was a strong belief in the long-term benefits of renewable energy systems and their potential to protect against energy crises. As hypothesized following Protection Motivation Theory, we found that response efficacy (in our case the perceived effectiveness of climate-friendly heating systems in protecting against future energy crises) and response costs (the perceived long-term cost advantages of climate-friendly heating over fossil fuel use) were significantly related to the importance tenants see in decarbonizing heat generation. Those who believed in the long-term advantages of using climate-friendly heating systems were more likely to prioritize the transformation to renewable heat generation.

Surprisingly, self-efficacy as third theoretical component of coping appraisal in PMT was not significantly related to satisfaction with the energy concept and importance of decarbonizing heat, nor to any other variable. The extent to which respondents felt able to reduce their energy consumption and costs varied, with many feeling unable to reduce costs. However, this was not related to how much they were satisfied with the energy concept or how important they find decarbonization. This null finding contrasts with prior expectations from PMT, where self-efficacy is typically considered a key predictor of protective behaviors and related attitude and prior research that has found self-efficacy to be a relevant factor for promoting pro-environmental behaviour (Hamann et al. 2024) and acceptance of climate policy that increases one's personal financial burden (Kaestner et al. 2025). One possible explanation is methodological: the result may be affected by the relatively small sample size and, consequently, a low ratio of observations per predictor, which can reduce statistical power and the likelihood of detecting existing effects. Another explanation could be that our sample already lives in a neighbourhood with climate-friendly heating but also energy-efficient buildings, where personal contributions such as turning down heating have a lower impact than in older building stock. Further, a potential lack of knowledge regarding effective energy-saving strategies may contribute to tenants feeling less capable, as knowledge and competence-related experiences precede feeling self-efficacious (Bandura, 1997). If individuals do not fully understand how to manage energy use or how they could most effectively save energy with their heating system, this may lead to lower self-efficacy.

Fourth, when respondents believe more strongly that their social environment supports climate-friendly heating systems, they consider decarbonizing heat as more important, and even more strongly, that climate-friendly heating systems can protect against future energy crises. A substantial share of responses was concentrated at the midpoint ("3"), which may have reduced variability and lowered significance. Nevertheless, this finding supports previous evidence that social norms can shape people's perceptions of technologies and their pro-environmental behaviour . It may also implicitly touch on the power of collective action: the more people use climate-friendly heating systems without fossil fuels, the greater the potential to mitigate vulnerability to future energy crises.

Our fifth and last main finding is that tenants in a climate-neutral neighbourhood have a low willingness to pay a premium for climate-neutral heating. Despite generally positive perceptions of renewable energy, most respondents were not willing to accept higher costs for climate-friendly heating. Considering our previous findings that many tenants perceived their current energy costs as relatively high, this result is not surprising. While experimental studies often find that individuals express a preference for renewable energy over fossil fuel-based options, such preferences may not necessarily translate into a higher willingness to pay in real-world contexts. This may be particularly relevant for tenants, who typically do not make the decision about which heating system is installed but still bear part of the associated costs.

These findings highlight an important challenge for policymakers and energy providers: ensuring that the transition to renewable heating in the building sector does not lead to higher costs for households compared to fossil-based alternatives. Meeting tenants' expectations of long-term financial benefits and greater protection from future energy crises may be essential for maintaining satisfaction with climate-friendly heating systems. Ensuring that these anticipated benefits materialize in practice through competitive energy prices could play a key role in sustaining public support for heating decarbonization. Finally, the results suggest that different factors shape immediate satisfaction with a specific energy system and broader attitudinal support for heat decarbonization. Perceptions of current energy costs and expectations regarding future cost advantages appear central for tenants' satisfaction with

DOI: 10.66506/essp.1-229-26

their local energy concept, whereas the perceived importance of decarbonizing heat generation seems more strongly influenced by forward-looking beliefs about long-term cost advantages and protection against future energy crises associated with renewable energy.

LIMITATIONS AND FUTURE RESEARCH

There are three major limitations to our study that need to be considered when interpreting the results. First, the relatively small sample size, in combination with the number of predictors included in the regression models, increases the risk of overfitting. As a result, the models may not only have limited statistical power to detect true effects, but the estimated coefficients and effect sizes may also be unstable and sensitive to minor variations in the data, thereby constraining their generalizability. The regression results should therefore be interpreted with caution and regarded as exploratory rather than confirmatory. Further, the wording of survey items varied, particularly regarding terms such as "climate-friendly heating," "energy concept," and "renewable energy." This inconsistency may have led to confusion among respondents, potentially affecting their understanding and responses. Future research should prioritize the use of tested scales and standardized terminology to ensure clarity and improve the reliability of the data collected. Finally, a key limitation is that we do not know what respondents had in mind when evaluating the 'climate-neutral energy concept'; when they were not aware of the LTDH concept and thus, their ratings may reflect heterogeneous interpretations. They may range from general service experiences (e.g., comfort, costs) to broader environmental considerations rather than a consistent understanding of the concept itself.

However, the data we have collected is unique as there have rarely been any study on tenants' satisfaction with innovative, climate-neutral heating supply concepts (such as LTDH) and beliefs about how climate-friendly heating can protect against future energy crises and have long-term cost advantages over fossil fuel use.

POLICY IMPLICATIONS

From a practical and policy perspective, our findings underline that transparent communication about LTDH and the local energy concept is crucial. Tenants often lack knowledge about how their system works and about their current energy costs, yet those who feel better informed tend to perceive their costs as more reasonable. Clear, accessible information on the functioning of LTDH, its climate benefits, and the cost structure (including how prices are formed and what tenants can influence) may therefore improve acceptance and reduce perceived cost concerns.

At the same time, the results show that tenants' support for decarbonizing heat generation is closely linked to expectations of long-term cost advantages, price stability, and protection against future energy crises from climate-friendly heating. Policymakers and energy providers can build on these beliefs by explicitly emphasizing not only environmental benefits but also the potential of renewable-based LTDH to increase energy-system resilience and reduce exposure to fossil price shocks. Ensuring that climate-neutral heating remains cost-competitive in practice will be essential for maintaining satisfaction and broader public support.

CONCLUSION

This study examined tenants' perceptions of a climate-neutral heating supply including an LTDH network and identified factors associated with satisfaction and the perceived importance of decarbonizing heat generation. Satisfaction with the energy concept was strongly shaped by economic considerations, particularly perceptions of current energy costs, and to a lesser extent expectations of future cost advantages. Tenants who felt better informed about the energy concept perceived their costs as more reasonable, underlining the importance of transparent communication about innovative heating systems. Although tenants generally expressed positive attitudes toward renewable energy, their willingness to pay a premium for climate-neutral heating was low. Support for decarbonizing heat generation was linked to expectations that renewable energy can provide long-term cost advantages and protection against future energy crises, indicating that perceived affordability and resilience are central for public support of climate-friendly heating transitions.

ADDITIONAL FILE

The additional file for this article can be found as follows:

- **PowerPoint Slides.** PowerPoint Slides relating to this article. DOI: https://doi.org/10.66506/essp.1-229-26.s1

FUNDING INFORMATION

This work was part of the TransUrban. NRW project and is funded under the grant number 03EWR020D in the 7th Energy Research Program by the Federal Ministry for Economic Affairs and Energy (BMWE).

COMPETING INTERESTS

The authors have no competing interests to declare.

ECEEE PAPER ID

1-229-26

AUTHOR AFFILIATIONS

Jessica Berneiser orcid.org/0000-0001-6219-5227
Fraunhofer Institute for Solar Energy Systems ISE, Germany
Karl Seeger orcid.org/0009-0006-8965-0203
E.ON Energy Research Center, RWTH Aachen University, Germany

REFERENCES

AGEB. 2025. *Energy Consumption in Germany in 2024*. Hg. v. AG Energiebilanzen e.V. AG Energiebilanzen e.V. Berlin. Available at: https://ag-energiebilanzen.de/wp-content/uploads/AGEB_Jahresbericht2024_20250815_en.pdf.

Attari, SZ, Motz, BA, Mishra, A, Brautigam, GK, Trapp, T and **Graham, JD.** 2026. 'Do facts matter? Consumer misperceptions about adopting electrification technologies'. *Climatic Change*, 179(2). DOI: https://doi.org/10.1007/s10584-026-04120-9

Bandura, A. 1997. *Self-Efficacy: The Exercise of Control*. New York: W.H. Freeman and Company.

Baur, D, Emmerich, P, Baumann, MJ and **Weil, M.** 2022. 'Assessing the social acceptance of key technologies for the German energy transition'. *Energy, Sustainability and Society*, 12(1). DOI: https://doi.org/10.1186/s13705-021-00329-x

Billerbeck, A, Breitschopf, B, Preuß, S, Winkler, J, Ragwitz, M and **Keles, D.** 2024. 'Perception of district heating in Europe: A deep dive into influencing factors and the role of regulation'. *Energy Policy*, 184: 113860. DOI: https://doi.org/10.1016/j.enpol.2023.113860

Brown, D and **Martiskainen, M.** 2024. 'How sociotechnical norms shape transition pathways: The co-evolution of three European heating, ventilation, and cooling (HVAC) regimes'. *Energy Research & Social Science*, 107: 103346. DOI: https://doi.org/10.1016/j.erss.2023.103346

ERK. 2025. 'Review Report of the German Greenhouse Gas Emissions for the Year 2023 and the Projection Data of 2025'. German version only, status: 05.06.2025. *German Council of Experts on Climate Change (ERK)*. Available at: https://expertenrat-klima.de/en/review-report-of-the-german-greenhouse-gas-emissions-for-the-year-2023-and-the-projection-data-of-2025.

Floyd, DL, Prentice-Dunn, S and **Rogers, RW.** 2000. 'A meta-analysis of research on protection motivation theory'. *Journal of Applied Social Psychology*, 30(2): 407–429. DOI: https://doi.org/10.1111/j.1559-1816.2000.tb02323.x

German Environment Agency (UBA). 2025. National Greenhouse Gas Inventory 1990 to 2023 (as of 03/2025): for 2024 preliminary data (as of 15.03.2025).

Hamann, KRS, Wullenkord, MC, Reese, G and **van Zomeren, M.** 2024. 'Believing that we can change our world for the better: A Triple-A (Agent–Action–Aim) framework of self-efficacy beliefs in the context of collective social and ecological aims'. *Personality and Social Psychology Review*. DOI: https://doi.org/10.1177/10888683231178056

Hoffmann, M, Schyska, BU, Bartels, J, Pelser, T, Behrens, J, Wetzel, M, et al. 2024. 'A review of mixed-integer linear formulations for framework-based energy system models'. *Advances in Applied Energy*, 16: 100190. DOI: https://doi.org/10.1016/j.adapen.2024.100190

Kaestner, K, Sommer, S, Berneiser, J, Henger, R and **Oberst, C.** 2025. 'Cost sharing mechanisms for carbon pricing: What drives support in the housing sector?'. *Energy Economics*, 142: 108134. DOI: https://doi.org/10.1016/j.eneco.2024.108134

Karytsas, S. 2022. 'Residential heating systems' selection process: Empirical findings from Greece on the relations between motivation factors and socioeconomic, residence, and spatial characteristics'. *International Journal of Sustainable Energy*, 41(6): 572–593. DOI: https://doi.org/10.1080/14786451.2021.1960836

Kockel, C, Nolting, L, Pacco, K, Schmitt, C, Moser, A and **Praktiknjo, A.** 2022. 'How dependent are European power systems and economies on natural gas?—A macroeconomic optimization for security of electricity supply'. *Energies*, 15(23): 8991. DOI: https://doi.org/10.3390/en15238991

Krikser, T, Profeta, A, Grimm, S and **Huther, H.** 2020. 'Willingness-to-pay for district heating from renewables of private households in Germany'. *Sustainability*, 12(10): 4129. DOI: https://doi.org/10.3390/su12104129

Martens, E, Naeyaert, S, van Hove, S, Pelka, S, Preuß, S, Gabriel, M, et al. 2025. 'Transitioning towards sustainable heating: A mixed-methods study of heat pump acceptance among Flemish homeowners'. *Energy Research & Social Science*, 126: 104137. DOI: https://doi.org/10.1016/j.erss.2025.104137

Mathiesen, BV, Gonzalo, EG, Nikolic, J, Georgati, M and **Nielsen, S.** 2025. *Heat Roadmap Europe: Towards a sustainable, resilient and competitive heating sector by 2050 – Executive Summary*. Available at: https://coolheatingcoalition.eu/wp-content/uploads/2025/11/Heat-Roadmap-Europe-Towards-a-sustainable-resilient-and-competitive-heating-sector-by-2050-%E2%80%93-Executive-Summery.pdf.

Michelsen, CC and **Madlener, R.** 2013. 'Motivational factors influencing the homeowners' decisions between residential heating systems: An empirical analysis for Germany'. *Energy Policy*, 57: 221–233. DOI: https://doi.org/10.1016/j.enpol.2013.01.045

Onencan, AM, Ou, J and **de Koning, JIJC.** 2024. 'Social acceptance of district heating: Evidence from the Netherlands'. *Sustainability Science*, 19(3): 815–830. DOI: https://doi.org/10.1007/s11625-023-01452-8

Praktiknjo, A, Seeger, K and **Priesmann, J.** 2025. *Who Benefited from Relief? Distributional and Justice Impacts of Germany's 2022/23 Energy Crisis Policies*.

Rao, ND, Siam, MRK and **Bond, TC.** 2025. 'A critical review of heat pump adoption in empirical and modeling literature'. *iScience*, 28(1): 111666. DOI: https://doi.org/10.1016/j.isci.2024.111666

Rogers, RW. 1975. 'A protection motivation theory of fear appeals and attitude change'. *The Journal of Psychology*, 91: 93–114.

Ruokamo, E. 2016. 'Household preferences of hybrid home heating systems – A choice experiment application'. *Energy Policy*, 95: 224–237. DOI: https://doi.org/10.1016/j.enpol.2016.04.017

Wirtz, M, Schreiber, T and **Müller, D.** 2022. 'Survey of 53 fifth-generation district heating and cooling (5GDHC) networks in Germany'. *Energy Technology*, 10(11): 2200749. DOI: https://doi.org/10.1002/ente.202200749

TO CITE THIS ARTICLE:
Berneiser, J and Seeger, K. 2026. Resident satisfaction with low-temperature district heating: The role of cost perceptions and energy-crisis protection. *eceee Summer Study proceedings*, 1(1): 51, pp. 1–13. DOI: https://doi.org/10.66506/essp.1-229-26

Submitted: 19 March 2026
Accepted: 29 May 2026
Published: 27 August 2026