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Comparative Study of Sustainable Heating Decision-Making: Insights from the Residential and Industrial Sectors

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***Abstract*— To accelerate the transition in the heating sector, barriers and drivers need to be addressed. The analysis of this paper relies on an online survey in the residential sector and investigates influencing factors and perceptions of heating options in eleven EU member states. Further, it employs a case study in the industrial sector. The results reveal that in the residential sector ratings, as well as decisions to adopt heat pumps and district heating, are primarily influenced by technical or financial constraints, followed by self-centered aspects, trust, attitudes and personal interests. Conversely, the industrial sector is predominantly driven by economic considerations, regulations, and corporate strategies.**

***Index Terms*-- energy transition, heating, trust, residential and industrial sector, values, survey**

Introduction and Background

To meet climate change targets, there is an urgent need to address barriers preventing a rapid transition in the heating sector towards sustainable energy production and use. Within the energy sector, energy use in buildings accounts for about 35 % of the energy-related CO_2 emissions in the European Union [1]. While space and water heating in buildings amount to about 60%, industrial heat demand accounts for about one-third of heating and cooling needs [2]. Therefore, the availability and use of low-carbon heating options in buildings and industry is central for a successful transformation of the heating sector, complementing efforts aiming at energy savings on the demand side. Several studies (e.g. [3–5]) suggest a high deployment of heat pumps (HP) as individual heating solutions for buildings or in district heating (DH) networks potentially combined with excess heat from industrial processes. Given the high significance of HP and low-carbon DH for the energy transition, a comprehensive analysis of factors driving or hindering the diffusion and adoption of these heating options is still missing. Therefore, this paper investigates which factors strongly influence the adoption of these heating options among citizens and in industry.

Reluctance to change habits and routines, and factors beyond logic and rationality [4–6] seem to be the main barriers to the transition in the heating sector. Moreover, [6] investigated the contrasting values behind energy consumption decisions, such as altruistic and biospheric values, versus egoistic and hedonic values intended "to help oneself". In this line, [7] found that environmental and climate concerns are essential but weighted against egoistic values such as financial aspects. Ref. [8] emphasized that local environmental concerns matter more than global environmental concerns. These findings were supported by [9] , who identified economic and environmental issues as key factors but also found that hedonic values such as indoor climate, quality of heating technology, and service are also important factors shaping users' satisfaction and, hence, adoption. Other authors supported the significance of building features and technology requirements regarding energy use decisions [10–12].

In contrast, in the industrial sector, a strong focus is on financial and regulatory conditions (price) and technical competencies [13]. This is complemented by aspects such as the need for "energy" competence, time to inform and decide, financial return, corporate objectives, and awareness of responsible persons [14]. Further, the type of heating technology has to fit the technical features of the production process [15]. Overall, the general key elements driving decisions are the performances of the technology, i.e., its expected financial, technical, and environmental performance [16].

This study postulates that in the residential sector, ratings as well as decisions to adopt HP and DH, are primarily influenced by technological or financial constraints, followed by self-centered aspects, trust, attitudes, and personal interests. Conversely, the industrial sector is predominantly driven by economic considerations, regulations, and corporate strategies.

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DATA AND METHODS

A. Residential sector

Our research methodology involves an online survey of citizens across eleven EU countries (see Appendix 1) and a detailed case study of the industrial sector in one German city. The survey, which included around 8000 participants, encompassed questions regarding socio-economic and demographic factors and evaluations of the heating option DH or HP, attitudes, interests and trusts in actors and institutions. We employed non-parametrical tests for data rank sum tests analysis in Stata (Kruskal-Wallis equality-of-population rank test, two-sample Wilcoxon rank-sum test (Mann-Whitney U-test), or Chi^2-test and used the following variables (see also Appendix 2):

1) Ratings, attitude, trust and evaluation

The perception of households regarding HP and DH (**rating**) is determined by calculating the mean of two questions. These questions ask for a rating of the heating option and the acceptance of that option. Similarly, we derived three **attitudes**: (1) environmental awareness, (2) technology interest, and (3) climate concerns. The first two attitudes are each based on three questions asking for a self-assessment of its environmental behavior and interest in new technologies. The concern on climate change has been addressed by one question. Moreover, a rating of **trust** in competencies of seven institutions or actors was used to create a trust metric (mean of the seven trust variables in Appendix 2).

In addition, we included questions where respondents had to **evaluate** different heating options (natural gas, solar thermal, HP, biomass, DH) by selected characteristics. The characteristics included climate friendliness, costs, price risks, reliability, and dependency on suppliers. Ratings were given on a 5-point Likert scale. To obtain an individual overall evaluation of the different heating options, we employed an indicator that compares the rating of an option to the average rating across all options. It is based on the following formula:

Equation 1: Evaluation of heating option

$$e_h = \sum_{c=1}^{6}(e_{ch} - m_c)$$

h*: type of heating option (fossil gas, solar thermal, DH, HP, biomass)*
c: characteristics, c = 1 to 6
e: indicated evaluation value of c and h, by respondent
m: mean of characteristics, by respondent

2) Importance of self-centered aspects

To understand whether altruistic or **self-centered** aspects dominate decisions regarding heating systems, the respondents had to indicate the most (5) and least important (1) topic from a list displayed in Appendix 3. Self-centered aspects included individual needs, desires, and constraints.

3) Relevance of restrictions

To highlight the potential relevance of restrictions, we asked the respondents to select between two groups of aspects that are determining their decision regarding heating options: the first group includes restrictions of technical and financial nature, and the second group includes preferences (individual needs and desires) as presented in Appendix 4.

4) Influencing factors and value mix

Regarding factors potentially playing a role in households' energy decisions, different aspects (i.e., benefits, efforts, or other influencing factors) linked to altruistic, peers, or self-centered aspects were listed, and the respondents had to rate how strongly these aspects influence their energy decisions (see Appendix 5). Furthermore, we calculated the differences between the means of the self-centered, i.e., egoistic and hedonic factors (low effort, low cost, autonomy, no change, comfort, energy supply) and that of altruistic aspects (green heat and economy). The new variable is called **"value mix**," and the higher it is, the more important self-centered interests are for the respective respondent.

B. Industrial sector

The case study employed both a survey and in-depth semi-standardized interviews with twelve key decision-makers in industrial companies located in the German city of Mannheim. The survey and interviews were conducted with major decision-makers who were responsible for dealing with heating issues in their respective companies. They included energy, technical, or operational managers. Some of the companies (5) offered services, or operated production sites (3) or process heat facilities (4) in Mannheim. The survey included a total of five questions referring to energy consumption and the evaluation of the heating option. The interviews focused on the decision process and key factors influencing the adoption of heating technologies. The interviews' transcripts were analyzed with MAXQDA[1]. The interview partners were approached through the climate network of the city. Detailed information on the survey and the case study approach is available in [18].

RESULTS

C. Residential sector

1) Ratings, attitude, trust and evaluation

The **ratings of HP and DH** as heating options were positive: HP: mean=3.7 (n=4260); DH: mean=3.6 (n=4388).

All three **attitude** variables display above average scores. Technology interest is lowest (mean=3.4, n=8633), climate and environmental awareness reveal comparable mean scores (mean=3.8, n=8637 and 8628), but their correlation is at 0.46.

The highest **trust** is assigned to landlords, closely followed by the European Commission and energy suppliers regarding HP, and landlords, local authorities and industry regarding DH.

A high positive value of the **evaluation** of the heating option reveals a strong positive attitude towards the respective heating option. We find that solar thermal received the highest

[1] For the analysis of qualitative data, see [17].

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positive evaluation, followed by HP, while fossil fuels received the lowest evaluation (see Figure 1).

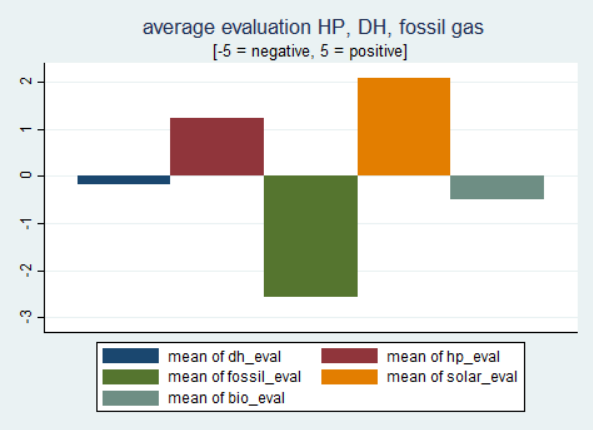

Figure 1: Average evaluation of heating options

2) *Importance of self-centered aspects*

The results illustrated in Figure 2 reveal a high importance of constraints & needs followed by transparency & fairness, both mirroring a focus on caring for oneself (self-interests).

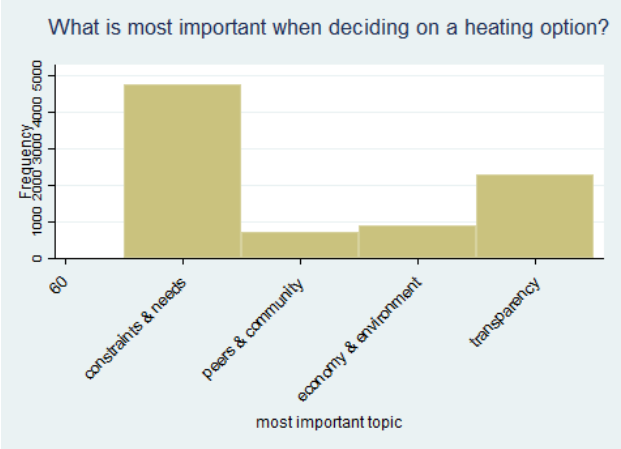

Figure 2: What is most important?

In contrast, most respondents selected peers' behavior & community support as the least preferred item, whereas economy & environment (caring for others, altruistic) are rated slightly more important. Using this "importance" as a grouping variable[2] for non-parametric tests for group differences, we find highly significant differences in:

- climate change concerns (p=.0001): the highest concerns are among those that indicate altruistic aspects as the most important topic when deciding on a heating option (Cohen's d of .24).
- environmental awareness and technology interest: the scores are significantly higher in the group that opted for altruistic aspects than for self-centered aspects (p=.0000 and .0004, Cohen's d= .27 and .13 for environ. awareness. and technology interest, respectively).
- the rating of HP (p=.001) and DH (p=.02): it differs as well by "importance" showing the highest rating of HP and DH for those selecting altruistic aspects as the most important topic.
- education and ownership (Chi2 and t-test, each with p=.007): i) respondents with the highest education level opted more for self-centered interests, while respondents with the lowest level opted the least for self-centered interests. ii) respondents living in villages or own houses tend to select self-centered aspects as the most important, while those living in huge cities or rented apartments selected self-centered aspects as the least important.

3) *Relevance of restrictions*

Regarding the relevance of restrictions (of a technical and financial nature) versus preferences (needs and desires) as presented in Appendix 4, we found a stronger dominance of restrictions than of individual preferences (see Figure 3). A small majority valued both options, i.e. restrictions and individual preferences as equally important.

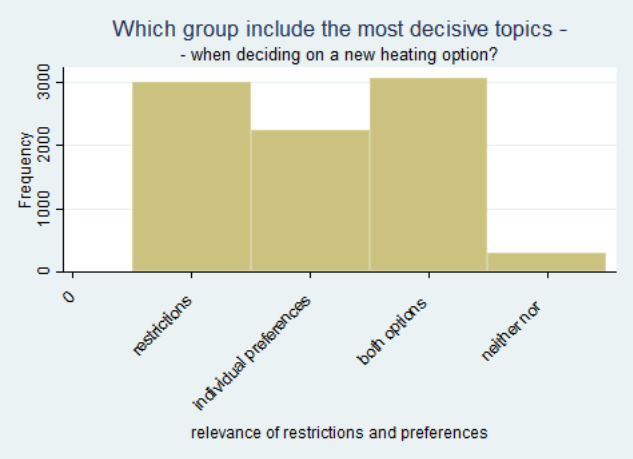

Figure 3: Relevance of restrictions and preferences

Applying non-parametric tests for group differences, we receive the following results of ratings and attitudes:

- respondents indicating preferences as more relevant also displayed a significantly higher climate and environmental awareness, and interest in in technology (p=.0000, Cohen's d= .33, and .39 and .17, respectively) than those opting for restrictions.
- significant differences in their rating of HP (p=.0001, Cohen's d=.21) and DH (p=.003, Cohen's d=.11). Those with high rating scores of HP and DH indicate a strong relevance of preferences.
- significant differences (p=.018) for country, location, ownership, and age. Those living in villages tended to opt for restrictions, and those in huge cities for preferences. Apartment owners also displayed a tendency for

[2] 1&2 group: selecting/not selecting constraints & needs as most important

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restrictions, while tenants of apartments rather selected preferences.

4) Influencing factors and value mix

The results show that novelty and acceptance of the technology by friends and community played the least role, followed by impacts on jobs and economic growth when buying a heating technology. In contrast, high supply security, stable prices, and high comfort and low costs were selected as the most important features of a newly installed heating system (see Appendix Figure 8).

Applying non-parametric tests for group comparisons, we found highly significant differences in the **value mix** between different groupings. Concerning environmental attitude (see Figure 4), climate change concerns and technology affinity, the value mix between low and high awareness and interest significantly differs (p=.0001). The value mix displays a more altruistic focus for those reporting heightened awareness for climate and environment, and high interest in technologies. This underpins the suitability of the variable "value mix".

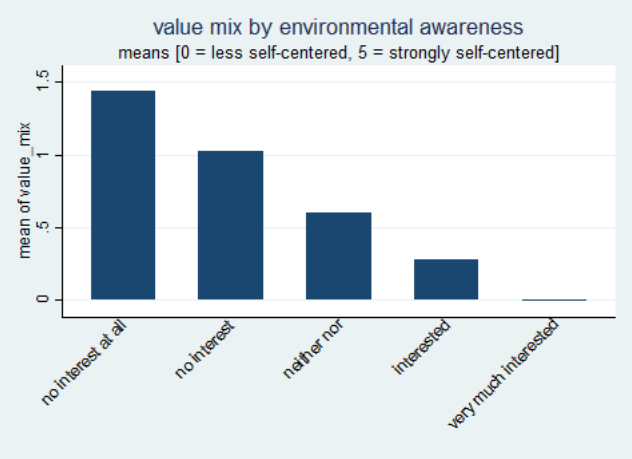

Figure 4: Value mix by environmental awareness

Respondents selecting self-centered aspects as the most important topics when deciding for a heating option also reveal more self-centered aspects than those indicating altruisticaspects as most important (p=.0001, Cohens' d=.58). Moreover, respondents assigning more relevance to restrictions when deciding for a new heating option show more self-centered aspects than those assigning more relevance to preferences (p=.001, Cohen's d=.51). Regarding socio-demographic, we find the following differences in value mixes:

- respondents with an academic education (Appendix Figure 6) display a more self-centered aspect set than those with high school education or training (p=.0003, Cohen's d =.09).
- owners of a house or a flat (Appendix Figure 7) display a more robust self-centered aspect mix than those that have rented a house (p=.007, Cohen's d=.11) or a flat (p=.0000, Cohen's d=.20), respectively.
- the value mix differs between countries (p=.0001) as illustrated in Appendix Figure 9.
- the higher the general trust in institutions and actors, the more altruistic aspects become important (see Figure 5). Cohen's d by trust categories is: .39 for "neither nor" compared to "no" (p=.0000), .39 for "no" compared to "not at all" (p=.0000), .23 (p=.0000) for "neither nor" compared to "yes", and .27 (p=.004) for "yes" compared to "completely". Figure 5 illustrates an increasing tendency of altruistic aspects (decreasing value mix score, vertical axis) with increasing trust on the horizontal axis.

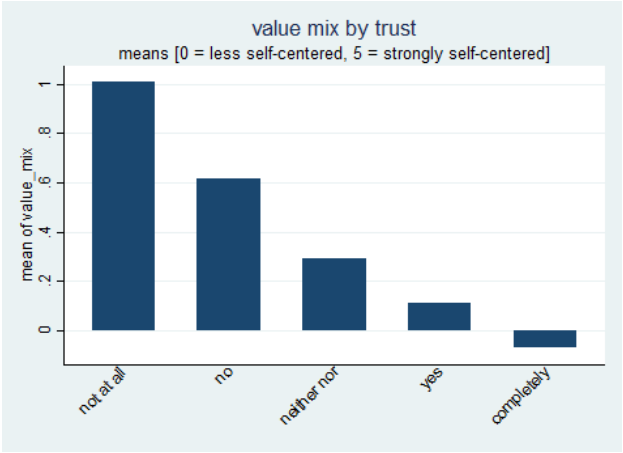

Figure 5: Value mix by trust categories

Finally, we identified a significant relationship (p=.0001) between the value mix and the rating of HP and DH. Respondents with a positive rating of HP or DH also displayed a value mix that includes more altruistic elements (see Appendix Figure 11). Thus, respondents adopting clean heating options reveal a preference for more altruistic-oriented decision factors.

D. Industrial sector

In Mannheim, a public DH supplier has operated a local network that was first established in 1959 and has supplied till today not only households but also businesses with offices, warehouses, production halls, and some industries with high-temperature process heat. Currently, the approx. 800 km long DH network operates with flow temperatures of 83 °C to 130 °C, mostly used for space heating, but it also provides high-temperature steam of 385 °C to 430 °C for industrial processes in a second network [19,20].

The interviewees with key decision-makers for their companies indicated that different heating options were used, including the combination of DH with an additional fossil fuel heating option (two companies). Apart from DH, more than one heating technology was used to cover the different heating demands in several cases. According to the interviewed decision-makers, the need for different high-temperature processes, for backup options to cover peak demands, and for ensuring a general security of supply as well as the possible usage of small-scale renewable heating options (such as individual solar or HP applications) and waste heat were reasons for the various technology combinations.

Regarding the decision process with respect to energy technologies and supply options, locally or nationally active

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companies without an international presence directly make decisions about the appropriate energy and heat supply on site. In several cases, the company's energy manager suggested energy options, which were then discussed with external experts knowing local requirements and conditions. No external consultants had been hired. The final decision rests with the CEO. Subsidiaries of international (or global) operating companies must comply with their corporate sustainability goals, strategies, and standards. At the local level, their individual decision rights are limited. In some cases, external experts are involved in preparing a proposal for sustainable heating options. The final decision is made either locally or by the parent company, usually depending on the investment volume involved.

Overall, the interviewees felt some pressure to use clean energy options. This pressure came from several sources:

- European and national authorities committing to phasing out of coal to ambitious renewable energy targets and emission reduction targets. Although the EU and national policymakers have clearly signaled to decision-makers in the industry the envisaged "development paths," decision-makers face uncertainties regarding the further procedure and implementation, especially regarding alternative energy carriers' options and their costs. In addition, there are regional challenges and uncertainties associated with the speed of decarbonisation of the energy and district heat supply in Mannheim;
- shareholders calling for compliance with policy targets since carbon and other emissions have become part of the annual environmental reporting and might affect the value and perception of the company:
- customers' and society's growing preference and demand for climate-neutral and sustainable products and services;
- local public and media demanding measures to mitigate climate change and environmental negative impacts.

All interviewees reported that key drivers for installing new heating systems were of an economic nature, i.e., the return on investment, which also depends on financial support and exemptions. However, other influencing factors were the required technical competencies, own expertise, and access to experts in energy issues. This has been perceived as a low barrier for DH as expertise could be provided by the local DH supplier. Moreover, the existing, strong social networks between energy suppliers, the city of Mannheim, and the companies at the local level have created an atmosphere of trust, provided quick access to partly confidential information, and thus, entailed certainty regarding the potential of and transition to sustainable energy supply in the city.

Regarding our hypothesis, we find a partial confirmation. Economic issues are very important but of second order. Existing regulations and political and societal commitments determine the transition pathway of the industrial sector in the heating transition. This will then be pursued in a cost-effective manner, ideally embedded in a corporate strategy and, at the local level, with the support of an active network, a trusting atmosphere, and extensive exchange.

Discussion and Conclusion

The results reveal that individuals prioritize their own needs (well-being) when choosing heating options in residential settings. Thereby, technical and financial constraints are the key driving factors when deciding for HP and DH. Subsequently, respondents have a focus on self-centered aspects. However, self-centered aspects do not always overshadow altruistic aspects. Empirical evidence highlights significant differences in the value mix by country, trust level, education, home ownership, climate and environmental awareness and interest in technology: Respondents who showed a greater interest in technology, environmental or climate awareness, and trust in actors and institutions tended to display fewer self-centered aspects. On the other hand, respondents who owned a house or apartment or had higher education levels tended to exhibit more self-centered decision-making patterns. This relationship between wealth (education and propriety) and self-interest could be grounded on an asymmetry in welfare consequences [21] for tenants and well-educated citizens associated with higher expenditures (losses) through the transition in heating. This is underpinned by the preferences regarding the characteristics of heating systems: a reliable and secure supply of heat at stable prices as well as low cost and high comfort in handling the heating system were rated as the most important. Finally, positive perceptions of HP and DH correlated with less self-centered aspects. In other words, the higher the rating of HP and DH, the more influential altruistic aspects become in decision-making. According to [22], egoistic values might activate the perception of economic benefits, and altruistic aspects might activate the perception of environmental benefits. This might establish the link to HP and DH as they are recognized as environmentally friendly heating options [10,18].

For the industrial sector, the qualitative analysis showed that the guiding principle is economic return. However, this is constrained by regulatory frameworks and standards, local conditions, corporate strategies, existing networks of relationships, and evolving societal preferences. According to our analysis, the transition towards a sustainable heating system in industry is best facilitated by a regulatory framework, along with an increase in societal awareness of climate issues guiding corporate strategies. Within this framework, industries optimize their operation by selecting the most cost-effective heating option. In locally operating firms, sustainable energy use is often driven by individuals.

In contrast, the results indicate that decisions in the residential sector are more complex, with multiple factors influencing the uptake of sustainable heating solutions. In particular, it underlines the significance of trust in institutions and actors for altruistic aspects to become a guiding aspect in energy decisions. Further, it questions the impact of wealth on the value mix and, hence, the decision for HP or DH. To conclude, this research underscores the importance of better understanding the diverse motivations and barriers in the transition toward sustainable heating, including HP and DH heating options for both the residential and industrial sector.

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APPENDIX

Appendix 1: Online-Survey in the Member States of the EU

DH	HP
Lithuania	
Poland	
Denmark	
The Netherlands	
Slovakia	
Italy	
Germany	
France	Czech Republic
Sweden	Spain

Appendix 2: Overview of variables

Variable	***Name***	**values or code**
HP rating	*How do you rate HP? -> HP_rating*	1 very negative - 5 very positive (5 points Likert scale)
	How acceptabel do you consider the use of HP? -> HP_acceptance	1 fully inacceptable - 5 fully acceptable (5 points Likert scale)
DH rating	*How do you rate DH ? -> DH_rating*	1 very negative - 5 very positive (5 points Likert scale)
	How acceptable do you consider the use of DH? DH_acceptance	1 fully inacceptable - 5 fully acceptable (5 points Likert scale)
environmental awareness: mean of these categories (highly significant correlation between 0.7 and 0.8)	*To what extent do you agree or disagree with the following statements?*	1 fully disagree - 5 fully agree (5 points Likert scale)
	• *Acting environmentally-friendly is an important part of who I am*	
	• *I am the type of person who acts environmentally-friendly*	
	• *I see myself as an environmentally-friendly person*	
technology interest: mean of these categories (highly significant correlation between 0.6 and 0.7)	*To what extent do you agree or disagree with the following statements?*	1 not interested at all - 5 very much interested (5 points Likert scale)
	• *I am very interested in the latest technology developments*	
	• *It does not take me long to learn to like new technology developments*	
	• *I am always keen to use the latest technological device*	
climate concerns	*In my view, climate change is .... -> climate change*	1 no problem - 5 huge problem (5 points Likert scale)
trust: mean across all 7 categories **trust in national policy**: mean of category 2 and 3	*How much do you trust the following actors in your country to make good decisions regarding district heating?* *1. energy supplier,* *2. local authorities,* *3. national authorities,* *4. European Commission,*	1 not at all - 5 completely (5 points Likert scale)

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	5. landlord, *6. industry,* 7. *neighbour*	
value mix: mean of self-centered aspects ./. mean of altruistic aspects	*no efforts (self-centered)*	1 fully unimportant - 5 fully important (5 points Likert scale)
	new and accepted technology (meso level: peers)	
	low cost (self-centered)	
	high autonomy (self-centered)	
	no changes (self-centered)	
	high comfort (self-centered)	
	reliable heat (self-centered)	
	clean heat (altruistic)	
	economy (altruistic)	
relevance of restrictions (see Appendix 4)	*1. group: restriction & costs;* *2. group: comfort & for others;* *3. both groups;* 4. *none of the groups*	selection of one option
importance (see Appendix 3)	*1. constraints & needs (self-centered)* *2. peers & community (meso-level peers)* *3. economy & environment (altruistic)* 4. *transparency & fairness (self-centered)*	1: least important 5: most important
evaluation of heating options (see Appendix 5)	*low cost (fossil, biomass, solar thermal, DH, HP)*	1 fully agree - 5 fully disagree (5 points Likert scale)
	climate friendly (fossil, biomass, solar thermal, DH, HP)	
	low price risks (fossil, biomass, solar thermal, DH, HP)	
	reliability of technology (fossil, biomass, solar thermal, DH, HP)	
	high dependency (fossil, biomass, solar thermal, DH, HP)	
	high transactions (fossil, biomass, solar thermal, DH, HP)	
socio-demographic	*sex*	categorical: 1-4
	age	numeric: 17-67
	education	1 primary, 2 high school, 3 training, 4 academic
	country	11 CZ, 12 DK, 14 FR, 15 DE, 19 IT, 21 LT, 24 NL, 25 PL, 28 SK, 30 ES, 31 SE
	location	< 2000, 2000-19999, 20000-199999, 200000-1 mio, >1 mio
	ownership	own house, own apartment, rented house, rented apartment

Appendix 3: Importance of self-centered (hedonic or egoistic) versus altruistic aspects

Which of these aspects do you consider as the most important and the least important when choosing a new heating system? Please select the least and the most important aspect.

Most or least important:	**nature of aspects**	**caring for**
My specific needs comprising comfort, heating needs, the technical features of my housing, expenditures for heating, heating technology, autonomy in heating	egoistic, hedonic	oneself

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The heating systems most often used in my community or neighborhood or promoted by the local municipality	hedonic	oneself
Impacts that my purchase decision has on economic growth, employment, national income distribution, global environment and climate change	altruistic	others
That there are mechanisms in place that ensure fair pricing of my heat, e.g. price controls, obligation to publish prices or costs	hedonic	oneself

Appendix 4: Relevance of constraints and preferences

Please select one (or both or none) of the two groups that include in your view the most decisive topics when choosing a new heating system:

Relevance of constraints and preferences	factor level	relevance of ...	caring for ...
Group 1:			**constraints - caring for oneself**
Low total expenditures of the heating system (incl. funding opportunities)	micro	preference (egoistic)	
Availability of money to pay for the heating system		constraint	
Appropriate technical features of the building or grid connection required for the new heating system			
Qualified and reliable information or recommendation about the heating technology e.g. from experts (professionals)			
Group 2:			**preferences - caring for oneself and others**
High heating comfort that the system provides	micro	preference (hedonic)	
High degree of autonomy I get with this heating technology			
Low effort and work needed to install the new heating system			
Low emissions of air pollutants, particles and CO_2	macro	preference (altruistic)	

Appendix 5: Influencing factors and values when choosing a new heating system (values)

Which factors are very important, less important or unimportant for you when choosing a new heating system? (Selection 1-5; not important at all - very important):

Ratings of ...	**impact or factor level**	**nature of aspects ...**	**caring for ...**
Low investment expenditures and low operating expenditures	micro	egoistic (financial)	**oneself**
Secure supply of heat and certain energy prices for many years	micro	hedonic partly egoistic (financial)	
High autonomy and independency of supplier, e.g. from fuel supplier or service supplier	micro	hedonic partly egoistic (partly financial)	

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Ratings of ...	impact or factor level	nature of aspects ...	caring for ...
Efforts needed to adopt the new system should be low (e.g. no additional constructions or extensive paperwork)	micro	hedonic partly egoistic (non-financial)	
No or minor changes e.g. in the heating technology, energy supplier, system control	micro	hedonic	
High comfort of the heating system (i.e. pleasant space heat and hot water, and convenient handling, low maintenance)	micro		
Novelty of the heating technology and acceptance by friends	meso		
Clean and environmentally friendly heat e.g. low emission of CO_2, low air pollutants	macro	altruistic biospheric	**others**
Support of national employment when deciding for a locally produced heating technology	macro	altruistic	

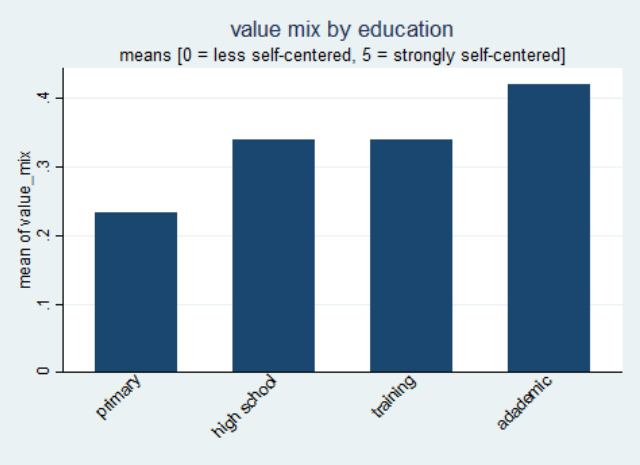

Figure 6: Value mix by education

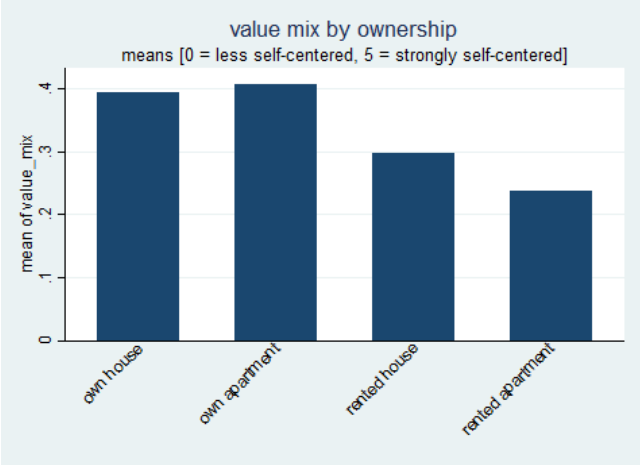

Figure 7: Value mix by ownership

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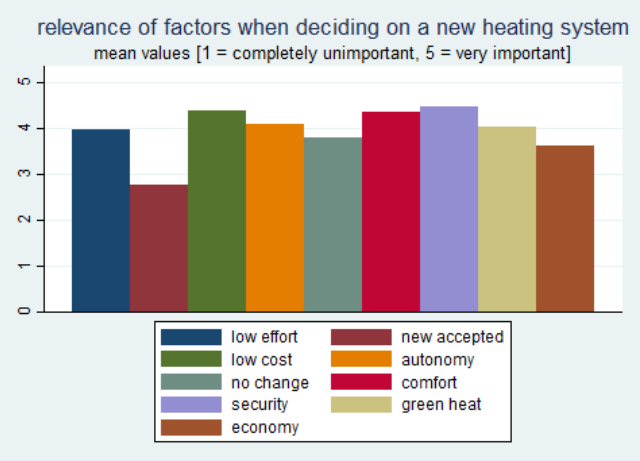

Figure 8: Preferred factors when deciding for a heating option

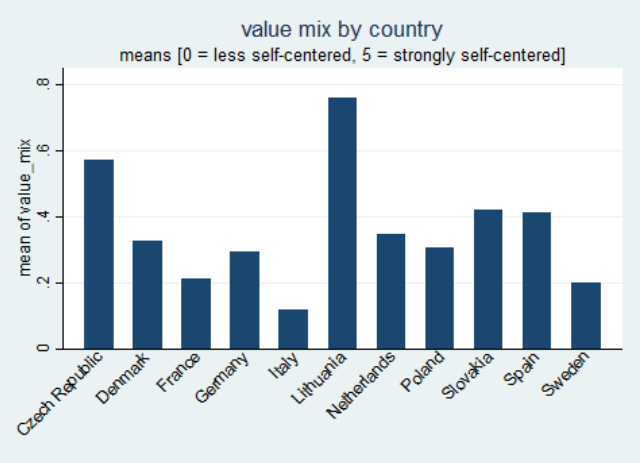

Figure 9: Value mix by countries

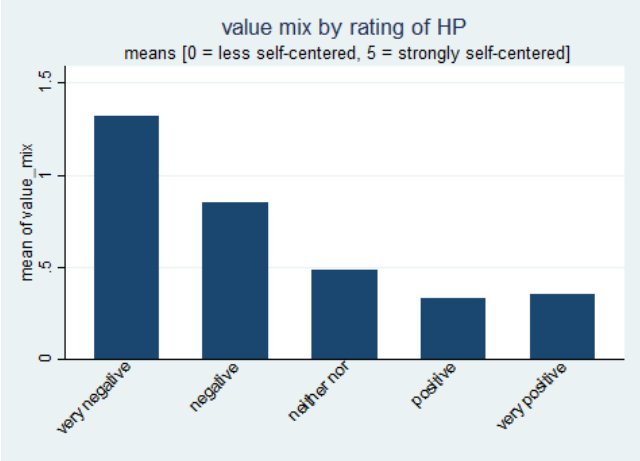

Figure 10: Value mix by rating of HP

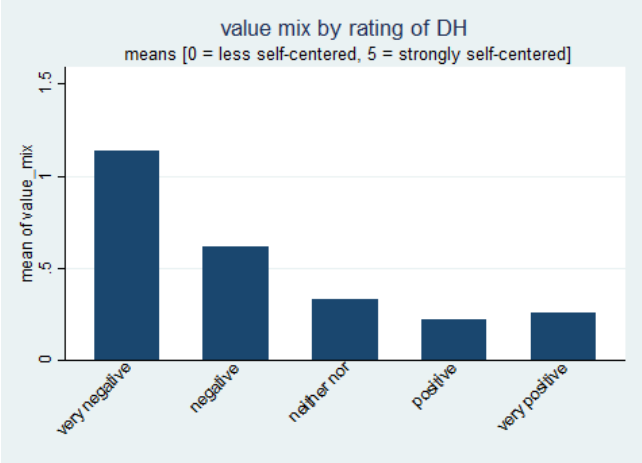

Figure 11: Value mix by rating of DH

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