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Acceptance of demand-side flexibility in the residential heating sector — Evidence from a stated choice experiment in Germany

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ABSTRACT

The growing share of renewables and the electrification of the transport and heating sectors are increasingly leading to an imbalance between electricity supply and demand in the distribution grids at the regional and local level. While the supply side is becoming increasingly flexible and volatile, the demand side is largely rigid and inflexible, especially at the household level. However, households have great potential to provide flexibility for grid stability by matching their electricity demand to supply. In this paper, we investigate whether and under which conditions households are willing to participate in so-called regional flexibility markets and adjust their electricity demand. We use a subsample of 541 observations from a large-scale online survey of private households in Germany that includes a stated choice experiment. Our results indicate that demand-side flexibility in the residential heating sector is accepted to some degree, but is mainly constrained by interventions in the own home and loss of comfort. Nevertheless, a large number of households are willing to offer flexibility, with additional services of flexibility products having a positive impact on willingness. In addition, the general willingness to participate in regional flexibility markets strongly depends on household-specific characteristics.

1. Introduction

For a comprehensive decarbonization and a slowdown in global warming, a cost-effective mitigation strategy is to shift electricity generation from conventional energy sources to renewable resources (IPCC, 2014). However, this poses numerous challenges for the electricity grids and the security of electricity supply (German National Academy of Sciences Leopoldina, 2020). The increase in the number of distributed electricity generation plants and the volatile generation of electricity from sun and wind are likely to lead to an increasing imbalance between electricity supply and demand in distribution grids at the regional and local level (International Energy Agency, 2021; Bundesnetzagentur, 2020). In addition, electricity demand in Germany is expected to increase by 11 % by 2030 compared to 2018, with the electrification of the transport and heating sectors being the main driver of electricity demand growth (Kemmler et al., 2021).

In general, there are different approaches to deal with the growing challenges associated with increasingly volatile electricity generation and growing electricity demand. On the one hand, large investments in grid expansion and storage capacities can counteract grid congestion. However, grid expansion can be economically inefficient and time- and resource-consuming, especially when peak loads occur for only a few hours a day or week (Heilmann et al., 2020). Besides grid expansion, electricity demand could also become more flexible, similar to electricity supply, and could serve for grid-balancing purposes (Stawska et al., 2021). Accordingly, electricity demand could be adjusted depending on electricity supply or vice versa. Such flexibilities in electricity demand and supply could, for example, be offered and traded on balancing markets.

While a balancing market for electricity with ancillary services providing flexibility to the transmission grids is already well established in Germany (see Bundesnetzagentur, 2021), regional flexibility markets (RFMs) involving residential households are still in a research stage (Kubli et al., 2018; Mengelkamp et al., 2017). However, households are likely to become a more important player in the future electricity system and grids. The increasing penetration of electric vehicles (EVs) and heat pumps not only increases electricity demand, but also offers potential for demand-side flexibility. Direct load control (DLC) of battery storages, heat pumps, and EVs in the residential sector could contribute to efficient grid management and grid stabilization (ENTSO-E, 2021). For example, a heat pump could be turned off when electricity demand exceeds supply, or the charging of an EV could be delayed or curtailed.

Heilmann et al. (2020) provide a framework for the design of such flexibility products based on technical and trading dimensions. In addition, they give an overview of different RFM approaches, some of which

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have been tested in pilot implementations of various research projects in Germany with interfaces to the real grid. Currently, however, grid operators at the regional or local level have only limited opportunities to trade or bundle flexibility in RFMs. One reason for this is the tight regulation of the electricity grid in Germany and the still limited technical capabilities of the operators to manage the grid efficiently. In addition, an important prerequisite for trading and bundling flexibility in RFMs is the willingness of households to offer such flexibility in their electricity consumption behavior and, if necessary, to accept an external control of their electricity demand by the grid operator or an external aggregator.

To this end, the German regulator has introduced new regulations for the management of controllable consumption devices such as heat pumps, battery storage and charging facilities for EVs at the end of 2023. The new regulations in Section 14a of the Energy Industry Act (EnWG) enable distribution system operators to reduce the output of individual systems at short notice and thus prevent a grid overload. In return for the agreement on grid-supportive control, operators of controllable consumption systems only need to pay a reduced grid fee in the form of a flat-rate discount on the grid fee or a percentage discount on the energy price. From April 2025, grid operators must also offer the option of a time-variable grid fee in conjunction with the flat-rate discount. The new regulations in Section 14a EnWG come into force on January 1, 2024 (Bundesnetzagentur, 2023).

Previous studies in the area of flexible electricity supply and demand by private households have rather focused on participation in regional or local electricity markets, i.e., trading or consuming locally produced electricity (e.g. Mengelkamp et al., 2017, 2019). Kubli et al. (2018), for example, has examined flexibility co-generation in more detail, but only as part of an electricity contract. So far, it is rather unknown to what extent and under which conditions private households are willing to opt for a contract that explicitly includes the provision of flexibility services. Our study contributes to filling this research gap. Based on a subsample of 541 households from a large-scale online survey in Germany, we investigate households' preferences for integrating their heat pump into RFMs. The residential heating sector is of particular interest in this context, as increasing electrification of this sector can significantly contribute to the decarbonization of the economy, while at the same time offering high potential for demand-side flexibility.

This study analyzes data from a stated choice experiment on the choice of flexibility contracts, including a number of contract modalities. We aim to determine the extent to which households are willing to offer flexibility and how flexibility contracts should be designed to encourage households to opt in. In addition, we aim to identify in more detail which households can be reached for demand-side flexibility by including a range of sociodemographic and attitudinal control variables in our analyses. Our results thus contribute to current research in several ways. First, we provide insight into the true potential of electricity demand flexibility at the household level and which household-specific characteristics influence this potential. Second, we provide guidance on how to design flexibility contracts to increase the likelihood that households will actually participate in RFMs.

The outline of the paper is as follows: Section 2 provides an overview of the current state of research. Section 3 describes the data collection process, the experimental design, and the estimation procedure. Section 4 presents the empirical results, and Section 5 concludes and provides policy implications.

2. Background and literature review

With the expansion of renewable energies, especially solar power, the participation of households in the electricity market has changed. Private households are evolving from rather passive electricity consumers to so-called "prosumers", who simultaneously consume and produce electricity and thus become active participants in the electricity system (Zafar et al., 2018). Furthermore, in the context of increasing electrification of the residential heating and transport sectors, the potential of households to become so-called "flexumers", i.e., to flexibly contribute to the stabilization of the grid by adjusting their electricity demand, is growing (Kubli et al., 2018). However, the utilization of demand-side flexibility at the household level has been largely untapped so far. One possibility to use this flexibility could be the implementation of RFMs, where the available flexibility of many small consumers (households) is bundled and made accessible to the grid operator. Besides various technical and legal frameworks for the successful implementation of RFMs (see Heilmann et al., 2020), it is essential that private households are willing to offer flexibility in RFMs and to use flexibility products, e.g., to opt for flexibility contracts.

A few studies have already investigated preferences for flexibility options or products. Kubli et al. (2018), for example, examine the choice of and preferences for electricity contracts that include a flexibility option. They find that preferences for or sensitivity to flexibility options depend strongly on the technology considered, i.e. battery storage, heat pump, or EV. In total, however, they conclude that households are only willing to accept flexibility options in exchange for a high compensation. This can be both a monetary compensation, such as a discount in monthly electricity costs, or a higher benefit from other features, such as a higher share of renewables in the electricity mix. In the case of the heat pump, for example, they find that the required (monetary) compensation for a minor flexibility option already exceeds the average monthly electricity costs in their sample. The importance of (financial) compensation to overcome perceived discomfort related to flexibility provision or risks regarding the data provision is also highlighted in several other studies, such as in Broberg and Persson (2016), Richter and Pollitt (2018), and Parrish et al. (2020). Besides financial incentives, Harold et al. (2021), for example, find positive preferences for advance notice and opt-out options from flexibility options which can also increase the willingness to participate in flexibility programs.

In addition to contract attributes or features, Kubli et al. (2018), for example, suggest that also other factors, like personal situation and household characteristics, might be relevant for the acceptance of demand-side flexibility options. Broberg and Persson (2016) considered socioeconomic factors in their analysis of Swedish households' preferences for demand-side management. Although they conclude that it is not easy to identify general patterns, they find that, for example, controlling domestic electricity consumption plays a greater role for younger people than for older people, but older people have more concerns about data sharing and perceived risks. The relevance of data sharing concerns is also highlighted by Richter and Pollitt (2018) and is related to high compensation requirements. In addition, Yilmaz et al. (2022) analyzed the acceptance of DLC programs of EVs and heat pumps based on sociodemographic factors in Switzerland. They use gender, dwelling type, tenure, education, household type, employment, age and income to form socioecomic groups. They find that, for example, a higher educational degree or income have a positive effect on the acceptance of DLC programs for EVs. Besides sociodemographic characteristics, Stenner et al. (2017) find that a household's decision to participate in innovative DLC programs is also influenced by attitudinal characteristics, for example whether the household has trust in the competence of the energy supplier.

Overall, Parrish et al. (2020) provide a systematic, literature-based review of consumer engagement in demand response programs. They identify a total of six categories of influencing factors, namely financial aspects, familiarity and trust, perceived risk and perceived control, complexity and effort, interaction with user routines and activities, and user characteristics such as the amount of time spent at home, household size, and knowledge about technology and energy services. However, they point out that the use of such programs among households is highly heterogeneous, and results so far have been mixed.

Table 1
Summary statistics.

Variable	Mean	Std. dev.	Min	Max	N
Age	55.75	11.91	30	83	450
Male	0.91	0.29	0	1	534
High education[a]	0.60	0.49	0	1	531
High income[b]	0.78	0.42	0	1	435
Information on income	0.80	0.40	0	1	541
Household size	2.95	1.24	1	8	534
Ownership heat pump	0.50	0.50	0	1	541
Plan to install a heat pump	0.18	0.38	0	1	541
No plan to install a heat pump, battery storage, or EV	0.33	0.47	0	1	541
PV system: Financial motive	0.87	0.34	0	1	541
PV system: Independence motive	0.66	0.47	0	1	541
Environmental awareness	4.73	1.37	0	6	539
Willingness to take risks	3.08	0.96	1	5	533
Trust in others	1.30	1.00	0	3	534
Technical lifestyle	0.62	0.49	0	1	531
Local lifestyle	0.79	0.41	0	1	536

[a] High school diploma or higher degree.
[b] 3000 Euro or more per month (net income).

The studies considered so far find a rather limited acceptance of demand-side flexibility options. While most of them consider demand-side flexibility only as an additional feature of electricity contracts, Fell et al. (2015) specifically investigated the acceptance of different DLC tariffs for heating supply. They found that respondents prefer a flat DLC tariff to time-of-use (TOU) tariffs, even though the flat DLC tariff implies a loss of control. They conclude that DLC is accepted in principle, but only within tightly defined bounds, and that, complementary to Harold et al. (2021), options to override or opt out from flexibility should be included. The results of Fell et al. (2015) and the current discussions about demand response or DLC programs at the household level in Germany rather suggest to consider demand-side flexibility as an additional service and not to integrate it into the regular electricity tariff.

What is missing so far is a closer analysis of the design of such flexibility contracts and also the investigation of the willingness of households to participate in RFM, which can offer the advantage of bundling many small facilities and thus provide the grid operators with an aggregated flexibility potential. For this reason, our paper contributes to insights on the design of flexibility contracts by analyzing data from a stated choice experiment in the context of participation in a RFM. We have included a number of contract features that can be derived from the presented literature review and aim to provide a more detailed insight into the accepted bounds of DLC programs as outlined by Fell et al. (2015). In addition, we aim to contribute to the literature on heterogeneity in household preferences by considering sociodemographic and attitudinal characteristics in our analyses. We therefore follow the suggestions of Kubli et al. (2018) and Richter and Pollitt (2018) and attempt to identify target groups for the provision of demand-side flexibility.

3. Data and methodology

3.1. Data collection and sample

The data used is a subsample of a large-scale online survey conducted by the University of Kassel between January and May 2020. The survey targeted customers of a regional grid operator in northern Hesse, Germany, who own a renewable energy system such as a photovoltaic (PV) system (so-called "EEG customers").[1]

The aim of the study was to investigate the willingness of private households to participate in RFMs and to offer flexibility to grid operators. For this purpose, the main part of the survey consisted of a stated choice experiment on the hypothetical choice on flexibility contracts. Within the choice experiment, three different technologies, namely battery storage, EV, and heat pump, were considered because, according to Kubli et al. (2018), preferences and sensitivity to flexibility options vary significantly between technologies. In addition, a variety of information about the households and the respondents was collected, such as housing situation, energy and heating behavior, technical details of installed systems, or personal, environmental, political, and lifestyle preferences. Furthermore, since the topic of the survey was quite complex and it was expected that the respondents would not be familiar with RFMs, an explanatory video[2] was provided at the beginning of the survey to adequately prepare the respondents for the objective of the study and the following hypothetical decision situation.

In this paper, the choice of flexibility contracts with a heat pump is analyzed using a subsample of 541 complete observations. The subsample consists mainly of households that already own or plan to install a heat pump in the future, but also includes some households that reported not owning or planning to install or purchase any of the three technologies considered.[3] Table 1 provides summary statistics of our subsample for a set of sociodemographic and attitudinal characteristics (further details on the construction and coding of the variables can be found in Table A.1 in the appendix).

[1] The sample considered is quite specific and does not represent the average German household. However, as the provision of demand-side flexibility and participation in RFMs requires some prerequisites, we consider the chosen sample, i.e. homeowners who are familiar with renewable energies and other energy topics, to be very suitable for the topic of the study.

[2] The video is available at https://www.youtube.com/watch?v=4jKaCzM1lMg.

[3] Prior to the experiment, respondents were asked about ownership of a battery storage system, an EV, and a heat pump. Households that reported owning none of these were further asked about plans to install or purchase one. Respondents were assigned to the different experiments based on their responses to the previous questions. For example, respondents who reported owning or planning to install a heat pump were assigned to the heat pump experiment, while respondents who reported owning or planning to install a heat pump and battery storage system were randomly assigned to either the heat pump or battery experiment. All possible assignments to the three experiments are shown in Fig. A.1 in the appendix.

Table 2
Attributes and attribute levels in the stated choice experiment.

Attribute	Level 1	Level 2	Level 3	Level 4	Level 5
Monthly compensation	25 €	20 €	15 €	10 €	5 €
Guaranteed minimum room temperature in case of shutdown	21 °C	20 °C	19 °C	18 °C	17 °C
Maximum number of flexibility calls per month	10	15	20	25	30
Frequency of information provision on flexibility calls	Information anytime online or via app	Information weekly by e-mail	Information monthly by e-mail	Information yearly by e-mail	Information yearly by postal mail
Opt-out options	No opt-out option	Daily time window of 2 hours in which no flexibility can be requested. The daily time window can be changed on a monthly basis.	Daily time window of 4 hours in which no flexibility can be requested. The daily time window can be changed on a monthly basis.	Opt-out of one flexibility call per month. You will be informed about an upcoming flexibility call at least 1 hour in advance via email or (if available) app.	Opt-out of five flexibility calls per month. You will be informed about an upcoming flexibility call at least 1 hour in advance via email or (if available) app.

Compared to the general German population, our sample is overrepresented by men (91 % vs 49 %) and by persons with higher education (60 % vs 33 %) (see Statistisches Bundesamt, 2020b, 2021). However, since the survey was generally targeted to all persons in the household, this may indicate that men and higher educated persons are more interested in technology-oriented topics related to the energy transition than women and less educated persons. In addition, at first glance, households with a higher monthly net income (3,000 € or more) and with more household members also appear to be overrepresented in our sample. However, considering only homeowners, who are also primarily relevant for providing flexibility, our sample is quite representative in terms of income, household size and age (see Statistisches Bundesamt, 2020a).

Furthermore, the proportion of households owning a heat pump (50 %) or planning to purchase and install a heat pump (18 %) is quite large in our sample, mainly due to the allocation process mentioned above. Therefore, our sample also seems to be promising for investigating the acceptance of demand-side flexibility and the willingness to participate in RFMs, as these households can be considered as pioneers in the use of suitable technologies. However, 33 % of the households neither own nor plan to purchase a heat pump, an EV, or a battery storage system, indicating that these technologies need further promotion to achieve a widespread adoption.

In addition to sociodemographic characteristics, Table 1 also captures further attitudinal characteristics considered in the analyses of potential "flexibility-providers", i.e., respondents who are more likely to opt for flexibility contracts (Section 4.1). On average, respondents reported a high environmental awareness (4.73), a moderate willingness to take risks (3.08) and low trust in others (1.30). In terms of lifestyle, 62 % of the respondents identify with a technical lifestyle, and even 79 % identify with a locally oriented lifestyle, i.e., buying and consuming local products. In addition, respondents indicated that financial (87 %) and independence (66 %) motives were most important for installing their PV system in the past.

3.2. Experimental design

Choice experiments represent hypothetical decision situations in which respondents are asked to choose one option from a set of competing alternatives. The alternatives in each choice task (decision situation) are therefore described by certain characteristics (attributes) that vary at different levels. By presenting respondents with a series of choice tasks in a row, the trade-offs between the different attributes and levels can be estimated, and thus the respondents' preferences can be determined. Furthermore, if a cost or price attribute is included, the willingness to pay or the willingness to accept certain attributes and levels can be calculated. A key advantage of choice experiments is that they can be used to study behaviors that cannot be observed in real markets, such as preferences for environmental goods, policies, or new products and services. For this reason, this method is also well suited to the subject of this work, since such flexibility options or demand respond programs at the household level are not common so far.

To investigate the willingness of private households to provide demand-side flexibility, respondents were asked to choose between different flexibility contracts. Each respondent faced six choice tasks, each including three hypothetical flexibility contract options and the option to choose nothing (the "no-choice" option). The flexibility contract options were characterized by five attributes shown in Table 2.

The first attribute is the monthly compensation of the general willingness to provide flexibility. As revealed by previous studies, an appropriate compensation for the inconveniences associated with providing flexibility is mandatory (see Broberg and Persson, 2016; Kubli et al., 2018; Richter and Pollitt, 2018, e.g.). In order to provide a realistic expectation of such a compensation, a consultation with market experts was conducted and a range between 5 to 25 Euro was set. Even if the remuneration initially appears low, these values are to be expected at the distribution grid level and are in line with the recently determined reduction in grid fees in Section 14a EnWG (between 110€ and 190€ per year (Bundesnetzagentur, 2023)). The inclusion of a monetary attribute also offers the additional advantage that the willingness to pay or accept for the other attributes considered can be estimated.

A key issue in providing flexibility is that the usage capabilities of electricity consumers or generators change as they are directly controlled to stabilize the grid. Therefore, there may be inconveniences on the household side that should be taken into account. As previous studies have shown, households are very sensitive about discomfort and interventions in their home (e.g Kubli et al., 2018; Richter and Pollitt, 2018; Harold et al., 2021). In the case of the heat pump, for example, the room temperature may deviate from the usual household room temperature when flexibility is requested. Therefore, our second attribute refers to this change and describes the guaranteed minimum room temperature in case of shutdown (of the heat pump). The guaranteed minimum room temperature ranges between 17 and 21

Table 3
Sample choice task (translated).

Attribute	Option 1	Option 2	Option 3	
Monthly compensation	15 €	5 €	20 €	“I would not like to choose any of these options”
Guaranteed minimum room temperature in case of shutdown	21 °C	20 °C	18 °C	
Maximum number of flexibility calls per month	15	20	20	
Frequency of information provision on flexibility calls	Information yearly by postal mail	Information anytime online or via app	Information yearly by e-mail	
Opt-out options	No opt-out option	Opt-out of five flexibility calls per month. You will be informed about an upcoming flexibility call at least 1 hour in advance via email or (if available) app.	Daily time window of 2 hours in which no flexibility can be requested. The daily time window can be changed on a monthly basis.	
I choose:	☐	☐	☐	☐

degrees Celsius and is based on the recommended room temperature in Germany (about 20 degrees Celsius (Umweltbundesamt, 2022)).

Furthermore, similar experiments have shown that it also matters how often flexibility calls occur (e.g. Broberg and Persson, 2016; Harold et al., 2021). Therefore, the third attribute captures the maximum number of flexibility calls per month, which can range from 10 to 30 calls per month.

The last two attributes each represent a type of service attribute. As revealed by Harold et al. (2021), offering additional services can be important in flexibility contract choices and increase the willingness to participate in such tariffs. The fourth attribute is the provision of information about occurred flexibility calls, which can be available at different frequencies, e.g., anytime online or via app, weekly, monthly, or yearly by e-mail, or yearly by postal mail.[4]

The fifth and last attribute provides households with certain options to influence or prevent individual flexibility calls, so-called opt-out options. For the opt-out options, we differentiate between no opt-out option, a daily time window (2 and 4 hours) in which no flexibility can be requested, and the option to decline 1 or 5 flexibility calls per month. This will shed light on whether households prefer some predictability or short-term responsiveness. While the daily time windows can be changed monthly, flexibility calls are announced at least one hour in advance (via app or online) when opt-out options are offered for individual flexibility calls.

As in other studies, e.g. Kubli et al. (2018), we did not use specific time windows for the flexibility call. On the one hand, this reduces the complexity of the choice experiment. On the other hand, a heating system behaves inertially, so that delay effects occur between the flexibility call and the effects of the intervention in terms of change in room temperature. This inertia must be distinguished from the immediate reaction if the flexibility is provided by other devices, e.g. by switching off the washing machine or dryer.

Based on the attributes and levels presented in Table 2, a fractional, d-efficient design was created for the choice experiment using the software NGene. By entering various parameters, the software generates a d-efficient design that best represents all combinations of the specified attributes and levels. Table 3 shows an example of a choice task that was presented to the respondents. Some combinations in the choice experiment may seem irritating. However, we deliberately decided not to prohibit certain combinations of attributes and levels, as flexibility contracts in this form do not yet exist in Germany and we wanted to investigate as precisely as possible under which conditions or contract modalities private households are willing to offer demand-side flexibility. In addition, predetermined restrictions are usually at the expense of the design, which is then usually no longer balanced.

The generated design included 60 choice tasks, each with three hypothetical flexibility contract options. To avoid overloading respondents, we also used a blocked design. For this, the entire design was divided into ten blocks, each containing 6 choice tasks. Respondents were then randomly assigned to one block. As mentioned earlier, in addition to the flexibility contract options, respondents were also allowed to choose nothing (the “no-choice” option) to make the choices more realistic and to investigate the extent of voluntary flexibility provision.

Prior to the first choice task, respondents were provided with a detailed description of the decision context and contract modalities (see Appendix B). In addition, some respondents were randomly given additional information about climate and grid benefits of demand-side flexibility (treatments) to test whether this additional information had an effect on their willingness to provide flexibility. However, because we did not find any treatment effects, we combined the subgroup data into one sample for the purposes of this analysis.

3.3. Econometric approach

The collected choice data, i.e., which alternatives the respondents were presented with and what they chose in each choice task, are analyzed under the assumption of utility-maximizing decision makers (Thurstone, 1927). Accordingly, it is assumed that in each decision situation, respondents choose the alternative that provides them with the greatest utility, thus revealing the trade-offs and preferences made in each decision situation. Models derived under this assumption are called random utility models (RUMs) (Marschak, 1959).

In this paper, we consider two different RUMs using maximum likelihood estimation. On the one hand, we apply an alternative-specific conditional logit model to analyze the general willingness to provide demand-side flexibility, i.e., the extent to which participants are voluntary willing to choose one of the three flexibility contract options. Since this model is somewhat restrictive and does not account for possible heterogeneity in respondents' preferences, we additionally apply a flexible mixed logit model to determine the relative importance of the contract features under consideration and to estimate the willingness to

[4] Although at first glance it may seem strange to offer an annual update by e-mail or even by postal mail for a rather volatile intervention, we decided to include these levels in our experiment for two reasons. First, since our sample consisted of homeowners, we expected many older people to participate in the experiment who may not be very active digitally. Second, electricity bills in Germany are usually sent out once a year. An annual mailing is therefore a well-known procedure in Germany when interacting with an electricity utility.

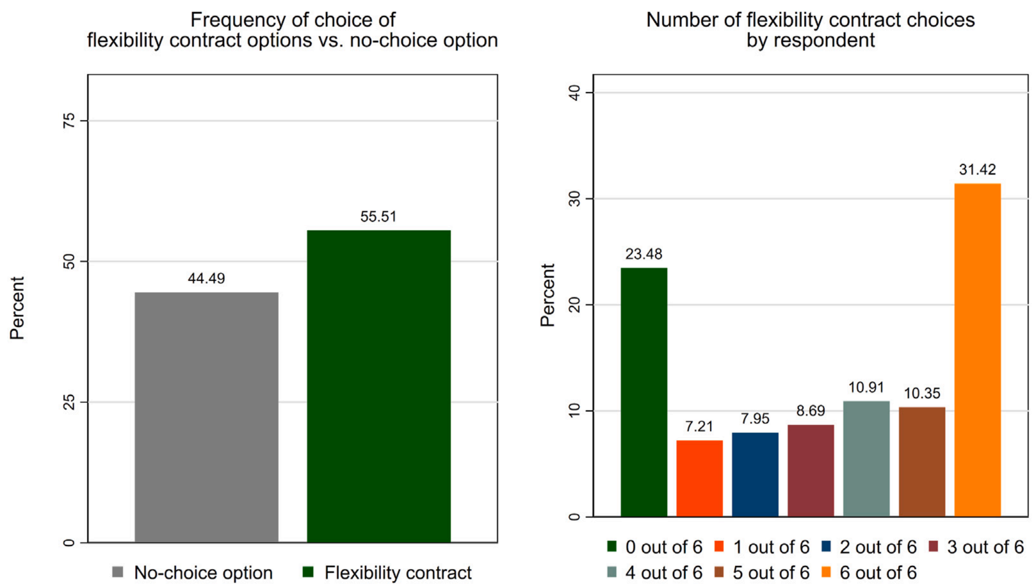

Fig. 1. Choice behavior patterns.

accept. In both models, the choice between the three flexibility contract options and the "no-choice" option is used as the dependent variable.

In the alternative-specific conditional logit model, we only consider a number of variables related to sociodemographic and attitudinal characteristics of the respondents (case-specific variables), but none of the attributes and levels, as none of these are alternative-specific. The utility U_{njt} that respondent n gets from choosing alternative j in choice task t can then be written as:

$$\begin{aligned}U_{njt} = {} & \beta_{0j} + \beta_{1,j} age_n + \beta_{2,j} male_n + \beta_{3,j} higheducation_n + \beta_{4,j} highincome_n \\ & + \beta_{5,j} infoincome_n + \beta_{6,j} hhsize_n + \beta_{7,j} heatpump_n + \beta_{8,j} PVfinance_n \\ & + \beta_{9,j} PVindependence_n + \beta_{10,j} envawarness_n + \beta_{11,j} risk_n + \beta_{12,j} trust_n \\ & + \beta_{13,j} technicalls_n + \beta_{14,j} localls_n + \varepsilon_{njt},\end{aligned} \tag{1}$$

where β_{0j} is an alternative-specific constant for alternative j. The variable age denotes the respondent's age in years. The variables $male$, $higheducation$, $highincome$, and $infincome$ are dummy variables equal to one if the respondent is male, has a high school education or higher, has a monthly net income of 3,000 € or more, and has reported income in the survey, respectively. The variable $hhsize$ represents the number of persons living in the household. The variables $heatpump$, $PVfinance$, $PVindependence$ are dummy variables equal to one if a heat pump is installed in the household, if the respondent indicated that the installation of a PV system was driven by financial motives, and if the respondent indicated that the installation of a PV system was driven by independence motives, respectively. The variables $envawareness$, $risk$, $trust$ are index variables capturing environmental awareness, willingness to take risks, and trust in others, respectively. $technicalls$ and $localls$ are dummy variables equal to one if the respondent indicated to identify with a technical lifestyle or a locally oriented lifestyle, respectively. Finally, the β_js are unknown preference parameters to be estimated and ε_{njt} is a stochastic error term.

In contrast, in the mixed logit model, the different attributes and levels are considered as explanatory variables. The corresponding equation can be written as:

$$\begin{aligned}U_{njt} = {} & \beta_{1,n} compensation_{njt} + \beta_{2,n} flexcall_{njt} + \beta_{3,n} temp20_{njt} + \beta_{4,n} temp19_{njt} \\ & + \beta_{5,n} temp18_{njt} + \beta_{6,n} temp17_{njt} + \beta_{7,n} weeklymail_{njt} + \beta_{8,n} monthlymail_{njt} \\ & + \beta_{9,n} yearlymail_{njt} + \beta_{10,n} yearlypostal_{njt} + \beta_{11,n1} daily2h_{njt} + \beta_{12,n} daily4h_{njt} \\ & + \beta_{13,n} onecall_{njt} + \beta_{14,n} fivecalls_{njt} + \beta_{n,15} nochoice_{njt} + \varepsilon_{njt},\end{aligned} \tag{2}$$

where $compensation$ and $flexcall$ are continuous variables that represent the monthly compensation and the maximum number of flexibility calls per month. The other attributes are included as dummy variables reflecting the different attribute levels of the guaranteed minimum room temperature in case of a shutdown ($temp20$, $temp19$, $temp18$, and $temp17$), the frequency of information provision on flexibility calls ($weeklymail$, $monthlymail$, $yearlymail$, and $yearlypostal$), and opt-out options ($daily2h$, $daily4h$, $onecall$, and $fivecalls$), respectively. In addition, a dummy variable for the "no-choice" option is included. Since only the relative utility or change in utility due to a change in the attributes is estimated, reference levels are determined for the dummy-coded attributes (*21 °C guaranteed minimum room temperature, information about calls anytime via app or online, no opt-out option*). For the continuous variables, the change in utility refers to the change in the attribute by one unit.

4. Results

4.1. Potential for demand-side flexibility in the residential heating sector

First, a brief descriptive analysis of the collected data is provided. Looking at the respondents' overall willingness to participate in RFMs and to provide demand-side flexibility, we find that of the 3,246 choices in total (6 choices each from 541 households), 1,808 times one of the three flexibility contract options was chosen and 1,444 times the no-choice option was chosen. Accordingly, in the majority of decisions (56 %), respondents were voluntary willing to make their heat pump available for grid balancing. Nevertheless, even the "early adopters" considered in this study seem to be skeptical to some extent in having their energy demand externally controlled, as no flexibility was provided in 44 % of the decisions (see Fig. 1, left-hand panel).

In addition, looking at the decisions of each household, it can be seen that households tend to be either "flexibility providers", who choose a flexibility contract option for all six decisions, or "flexibility deniers", who never choose a flexibility contract option. In contrast,

Table 4
Mean parameter estimates (robust z-statistics) from the alternative-specific conditional logit model.

Case-specific variables	Option 1 *(base alternative)*	Option 2 Mean parameter estimates (z-stat.)	Option 3 Mean parameter estimates (z-stat.)	Option 4 *(no-choice option)* Mean parameter estimates (z-stat.)
Age		0.003	−0.008	0.018***
		(0.41)	(−1.29)	(3.33)
Male		0.308	0.443**	0.529***
		(1.44)	(1.96)	(2.83)
High education		0.253*	−0.107	0.080
		(1.80)	(−0.75)	(0.67)
High income		0.140	−0.049	0.167
		(0.79)	(−0.28)	(1.07
Information on income		0.347	−0.143	−0.520**
		(1.34)	(−0.60)	(−2.53)
Household size		0.016	−0.060	−0.027
		(0.28)	(−1.02)	(−0.54)
Ownership heat pump		−0.114	−0.135	−0.040
		(−0.85)	(−1.01)	(−0.34)
PV system: Financial motive		−0.056	0.216	0.137
		(−0.30)	(1.12)	(0.82)
PV system: Independence motive		−0.075	−0.097	0.238**
		(−0.54)	(−0.70)	(1.95)
Environmental awareness		−0.026	−0.072	−0.097**
		(−0.55)	(−1.50)	(−2.25)
Willingness to take risks		−0.059	0.095	−0.206***
		(−0.84)	(1.35)	(−3.38)
Trust in others		−0.081	−0.093	−0.118**
		(−1.16)	(−1.32)	(−1.92)
Technical lifestyle		0.211	0.182	−0.075
		(1.54)	(1.30)	(−0.64)
Local lifestyle		−0.165	0.319*	−0.029
		(−1.00)	(1.84)	(−0.20)
Constant		−0.326	0.295	−0.903
		(−0.52)	(0.46)	(1.64)
Number of observations		2,610		
Number of participants		435		

* (**, ***) means that the corresponding parameter is different from zero at the 10 % (5 %, 1 %) significance level. Note that 106 (636) participants (observations) are excluded from the analysis due to missing data for one or more of the case-specific variables.

only between 7 and 11 % of households chose a flexibility contract option 1, 2, 3, 4 or 5 times during the entire experiment (see Fig. 1, right-hand panel).

These results indicate both obstacles and opportunities for demand-side flexibility: although 23 % of the households surveyed (“flexibility deniers”) cannot be reached at all for the provision of demand-side flexibility, 31 % of the households surveyed, on the other hand, appear to be less sensitive to contract design and are willing to provide flexibility under any circumstances (“flexibility providers”). This high degree of willingness may of course be related to the selected target group, as the households surveyed are already familiar with energy issues (owning a renewable generation system) and may therefore be more willing to behave in a grid-friendly manner or contribute to improving the energy system. At the same time, however, our results also show that even among these “early adopters” there are still barriers to overcome, as almost a quarter of those surveyed appear to be unwilling to participate in such new markets. For the remaining 46 % of respondents, the design of the flexibility contracts appears to be decisive for their willingness to participate in RFMs, which is examined in more detail in Section 4.2.

Given the mixed patterns in choice behavior, we apply an alternative-specific conditional logit model in the first step of our empirical analysis to determine the impact of the respondents’ characteristics on their general willingness to provide demand-side flexibility. Therefore, Table 4 reports the estimated mean parameters (robust z-statistics) for the case-specific variables listed in Table 1. The estimated parameters can be interpreted as an increase or decrease in the probability of choosing an alternative over the base alternative. The base alternative is one of the three unlabeled flexibility contract options (*Option 1*).

In Table 4, columns 1 to 3 refer to the three unlabeled flexibility contract options, and column 4 refers to the no-choice option. As expected, most of the estimated parameters for options 2 and 3 are not statistically different from zero, which is due to the fact that there are no alternative-specific attribute levels in any of the three flexibility contract options. For the no-choice option, we find that males, respondents with higher age, and respondents with an intention to be independent of future electricity price increases are more likely to choose the no-choice option compared to the base alternative. On the other hand, respondents who provide information about their monthly net income, who have a strong environmental awareness, who indicate that they take risks, and who generally trust other people are less likely to choose the no-choice option over the base alternative.

To determine the marginal effect of the statistically significant variables on the choice probabilities, we further take a look at the probabilities of respondents choosing the no-choice option. Accordingly, the probability of choosing the no-choice option is only 32 % for the 30-year-olds, while for the 40-year-olds and the 80-year-olds the probability increases to 41 % and 55 %, respectively. In contrast, the probability of choosing the no-choice decreases from 50 % to 42 % as the level of environmental awareness increases from 0 to 6. Similarly, the probability of choosing the no-choice option is 54 % if respondents are completely unwilling to take risks (=1), while the probability decreases to only 34 % if respondents are very willing to take risks (=5). The negative parameter for *Trust* can probably be

Table 5
Simulated maximum likelihood estimates (robust z-statistics) and WTA estimates.

Variable	Mean parameter estimates (z-stat.)	Std. dev.	WTA estimates
Monthly compensation	0.088***	–	–
	(11.13)	–	–
No-choice option	1.130***	4.140***	–
	(3.58)	(15.17)	–
Maximum number of flexibility calls per month	−0.020***	0.046***	0.232
	(−2.90)	(−4.30)	–
Guaranteed minimum room temperature in case of a shutdown (reference level: 21 °C)			
20 °C	−0.618***	1.340***	7.019
	(−4.27)	(6.95)	–
19 °C	−1.921***	1.972***	21.823
	(−9.12)	(8.39)	–
18 °C	−2.313***	1.681***	26.271
	(−10.20)	(−6.08)	–
17 °C	−3.469***	1.985***	39.405
	(−12.27)	(7.66)	–
Frequency of information provision on flexibility calls (reference level: anytime online or via app)			
weekly by email	−0.317**	0.986***	3.605
	(−2.20)	(4.61)	–
monthly by email	−0.404***	0.243	4.589
	(−3.06)	(−0.72)	–
yearly by email	−0.911***	0.980***	10.345
	(−5.84)	(−4.18)	–
yearly by postal mail	−0.851***	0.084	9.666
	(−6.32)	(−0.12)	–
Opt-out options (reference level: no opt-out option)			
daily time window of 2 hours	0.963***	0.813***	−10.94
	(6.64)	(3.81)	–
daily time window of 4 hours	1.184***	1.415***	−13.444
	(7.60)	(−7.16)	–
opt-out of one flexibility call	0.457***	0.692**	−5.193
	(3.25)	(2.64)	–
opt-out of five flexibility calls	0.618***	0.594**	−7.025
	(4.29)	(2-43)	–
Number of observations		3,246	
Number of participants		541	

* (**, ***) means that the corresponding parameter is different from zero at the 10 % (5 %, 1 %) significance level. Note that willingness to pay is only estimated for statistically significant parameter estimates.

explained by the fact that people who generally trust other people may also trust their grid operator and are therefore more likely to have their electricity demand externally controlled. However, the marginal effects for *Trust* are not statistically significant.

We did not calculate marginal effects for *Male* and *Information on income*. However, similar to *Trust*, the negative parameter for *Information on income* can probably be explained by the fact that people who are willing to disclose sensitive information such as income are also more likely to share other data such as electricity consumption data (which would be required to provide demand-side flexibility), and are therefore more likely to participate in RFMs. As seen in the debate on smart meter deployment as well as by results from previous studies (e.g. Broberg and Persson, 2016; Richter and Pollitt, 2018), data protection concerns are important and can be a major barrier.

4.2. Attribute importance and willingness to accept

In the second step of our analysis, we are interested in how respondents valued the included attributes and levels when choosing a flexibility contract in order to provide insights in the design of demand respond options and the accepted bounds (see Fell et al., 2015). As mentioned in Section 3.3, we therefore use more flexible mixed logit models, since they overcome some restrictive assumptions of the alternative-specific conditional logit model and can account for heterogeneity in respondents' preferences. Table 4 shows the corresponding estimated mean parameters (robust z-statistics), standard deviations, and willingness to accept values from the maximum likelihood simulation.

Consistent with economic theory and results of previous studies, the estimated mean for our monetary attribute ("monthly compensation") indicates that households generally prefer a higher monthly compensation for providing flexibility. The estimated mean parameter is statistically significant at the 1 % level. Since the parameter is assumed to be fixed, it is assumed that preferences for the monthly compensation are homogeneous among households.

For the non-monetary attributes, the estimated mean parameters and standard deviations are also statistically significant at common levels. We find that the relevance of the different contract modalities for the decision process varies, with the guaranteed minimum room temperature being the most important, followed by opt-out options and information provision, and the number of flexibility calls per month being the least important.[5] The latter is particularly interesting because if households are willing to opt for a flexibility contract (i.e., all other contract modalities meet their preferences), there is a high potential for demand-side flexibility, as it does not seem to matter whether flexibility is requested five or 30 times per month. However, since the estimated standard deviation is significantly different from zero at the 1 % level, household preferences are heterogeneous (see Table 5).

Regarding the guaranteed minimum room temperature in case of a shutdown, households clearly prefer higher room temperatures to lower temperatures, as shown by the highly negative mean parameters for 17-19 °C compared to the reference level of 21 °C. This suggests, in line with previous studies, that private households are highly sensitive to potential discomfort and intervention in their homes (e.g. Kubli et al., 2018; Richter and Pollitt, 2018). However, since the estimated standard deviations are significantly different from zero at the 1 % level, household preferences for minimum room temperatures appear to be heterogeneous.

Complementary to the findings of Harold et al. (2021), households also seem to prefer higher frequency and availability of information on requested flexibility. Compared to the availability of information anytime via app or online, the estimated means for all other attribute levels are highly negative at the 1 % and 5 % significance level. In contrast to minimum room temperature, the standard deviations are statistically significant only for the “weekly by e-mail” and “yearly by postal mail” attribute levels, indicating that preferences for information provision seem to be less heterogeneous compared to room temperature. This is also somewhat intuitive, as room temperature or comfort temperature is probably much more individual than information needs.

For the last attribute, personal options to override flexibility calls, the estimated mean parameters are positive and also statistically significant at common levels, indicating that households prefer any form of override options to the no opt-out option. This also supplements the findings of Harold et al. (2021). In addition, a tendency for daily time windows in which no flexibility can be requested is observed. This suggests that households seem to prefer some predictability to short-term opt-out options from flexibility calls. However, similar to the previous attributes, the estimated standard deviations are different from zero at the 1 % and 5 % levels, suggesting that preferences are again heterogeneous among households.

Overall, we find that almost all non-monetary attributes seem to be relatively more important for the decisions (with the exception of the number of flexibility calls per month) than the monthly compensation for the willingness to provide flexibility. In this regard, we also find in line with previous studies that, when weighting the estimated mean parameters of the non-monetary attributes by the mean parameter of our monetary attribute, households are willing to accept losses in comfort, information, and opt-out options but only for high compensation. The last column in Table 4 therefore reports the willingness to accept (WTA) estimated for all attributes. The WTA estimates for guaranteed minimum room temperature and frequency of information provision, for example, suggest that households accept restrictions only for high compensation, with the highest WTA for a minimum room temperature of 17 °C being almost 40 € per month. In contrast, households are willing to accept a reduction in monthly compensation between 5 € and about 13 € if override options for flexibility calls are offered, confirming the findings of Harold et al. (2021). Again, WTA estimates also illustrate the minor importance of the number of flexibility calls per month in the decision process, as the increase in WTA for an additional call is less than 1 € per month.

Finally, the positive, statistically significant mean parameter for the no-choice option emphasizes that households are to some extent not willing to be restricted or controlled in their home environment, i.e., all else being equal, households are more likely to choose the no-choice option than any of the three flexibility contract options. However, the estimated standard deviation is large and different from zero at the 1 % significance level, indicating that household preferences are highly heterogeneous in this regard. In summary, it can therefore be said that although the acceptance of demand response and DLC programs is limited according to our findings, on the other hand the compensation demanded is significantly lower than in previous studies. Additionally, we were able to show that preferences are very heterogeneous and therefore a focused recruitment of suitable and willing households should be addressed.

5. Conclusion and policy implications

While a rapid expansion of renewable energies is urgently needed for the success of the energy transition in Germany, the volatile generation from solar and wind power also poses challenges to the electricity grids. Increasing the flexibility of electricity demand as well could help to counteract volatile and decentralized generation from renewable energies. However, the flexibility potential of private households, which account for a large share of electricity demand, is not yet available to grid operators for optimal grid management. The implementation of RFMs could, for example, enable the bundling of many small facilities and to utilize them for grid balancing.

This paper therefore investigates to what extent and under which conditions private households would accept and offer demand-side flexibility and voluntarily participate in RFMs. Our analysis is based on a subsample (541 households) of a large-scale online survey with a stated choice experiment regarding the choice between different flexibility contract options. Besides analyzing the modalities of flexibility contracts, we also focus on which households are more likely to participate in RFMs based on household-specific characteristics.

Although the hypothetical decision situation was quite complex and unfamiliar, respondents were willing to voluntarily choose a flexibility contract option in 56 % of all decisions. In addition, the share of respondents who were not willing to provide demand-side flexibility at all (i.e., chose the no-choice option for all decisions) is rather small (23 %), while on the other hand, a surprisingly large share of respondents (31 %) were even always willing to opt for a flexibility contract. However, in line with previous studies, our analysis shows that the general willingness to provide demand-side flexibility of private households is rather mixed and strongly dependent on their respective characteristics. We find that young, open (in terms of data sharing, risk and trust), and conscious (in terms of the environment) people are more likely to contribute to the stability of the electricity system by flexibly adapting their electricity demand.

With regard to the analysis of contract modalities, we find that inconvenience and interference with the respondents' home environment, i.e., external control of the heat pump, are still the most important. In our case, this means that households are only willing to have their room temperature restricted in exchange for high compensation. However, compared to previous studies, the requested compensation in our studies is much lower. In addition, offering opt-out options or information about flexibility calls may increase the likelihood of signing a flexibility contract. Somewhat surprisingly, the number of flexibility calls per month seems to be only of little importance. This would be useful because it suggests that if respondents are willing to offer demand-side flexibility at all, the potential for stabilizing the grid is high, as flexibility could even be called on a daily basis.

The flexibility contract can be signed in addition to the electricity supply contract. It has been shown that the potential of demand-side

[5] Note that the rating and importance of the attributes are interdependent and relative. Individually, the attributes and levels may be more important, but in the experiment, respondents were presented with certain combinations so that they had to trade off between the attributes and levels. This enables us to determine a ranking of the attributes.

flexibility can be increased through an attractive contract design on a cost-efficient basis. Easy-to-implement features such as the frequency of information provision and opt-out options can counteract compensation for restrictions and interventions. These measures can help to motivate the willingness of households to provide flexibility and at the same time keep the cost framework for grid operators low.

Overall, we find a greater potential for demand-side flexibility at the household level compared to previous studies. This could be due, for example, to the sample selected — which on the one hand could represent a limitation of the study, but at the same time also a strength. In our study we consider pioneers or early adopters in the field of renewable energies and other large electrical consumers. Therefore, a large proportion of households in our study already own a heat pump (50 %) or plan to install a heat pump, battery storage or EV in future (18 %). Therefore, while our sample may not represent the average German household, the households considered in our study are more likely to represent the target group eligible for demand-side flexibility, i.e. homeowners with suitable technical prerequisites and with pioneer-like characteristics. For this reason, we also expect our respondents to be in a better position to understand the experiment and the implications of their choices. In this context, it is promising that the share of voluntary flexibility provision is quite high in our study.

Based on our results, the implementation of mechanisms or regulations that enable grid operators to access flexibilities in household electricity demand may be helpful to limit grid expansion measures or at least to bridge them in the short and medium term. Whether this has to be a RFM or could be other DLC measures is beyond the scope of this study. However, we were able to demonstrate a general willingness to participate in such markets and to provide flexibility. Our results do, though, suggest a number of important prerequisites for the design of flexibility options or products in line with previous studies. For example, transparent information about an intervention in electricity demand is very important. Since households tend to be skeptical of comfort losses or external control, transparent information can help to reduce these barriers. However, it should be noted that the estimated monetary compensation for such interventions is still quite high and may also indicate that the actual willingness is somewhat lower than the willingness identified in our study (revealed vs. stated preferences). In particular, it remains to be investigated or compared in this context which costs could actually be saved if the monetary compensation were set in relation to the costs of the grid expansion measures. In this regard, information and education campaigns might also be useful to alleviate households' fears about DLC and interference in their homes, thereby also lowering barriers to acceptance.

CRediT authorship contribution statement

Jonas Bender: Formal analysis, Writing – original draft, Writing – review & editing. **Larissa Fait:** Formal analysis, Writing – original draft, Writing – review & editing. **Heike Wetzel:** Formal analysis, Writing – original draft, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Additional figures and tables

See Table A.1.
See Fig. A.1.

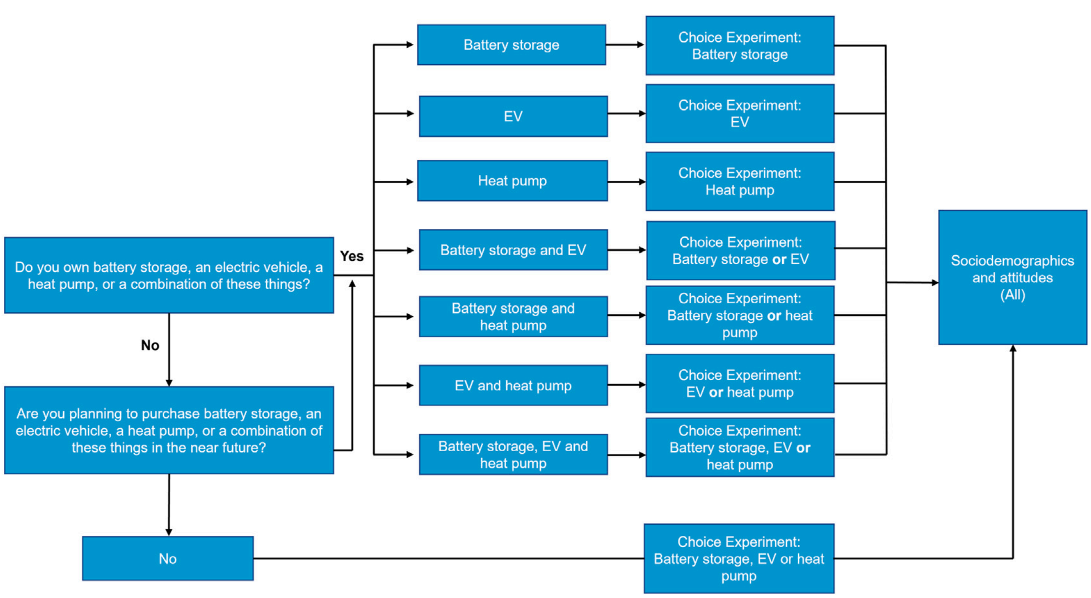

Fig. A.1. Assignment of respondents to the choice experiments.

Table A.1
Description of explanatory variables.

Explanatory variable	Definition
Age	= the respondent's age in years.
Male	= one if the respondent is a man, zero otherwise.
High education	= one if the respondent has a high school diploma or higher degree, zero otherwise.
High income	= one if the respondent's net monthly income is 3000 Euros or more, zero otherwise.
Information on income	= one if the respondent reported income, zero otherwise.
Household size	= number of persons living in the household.
Ownership heat pump	= one if a heat pump is installed, zero otherwise.
Plan to install a heat pump	= one if respondent indicated to plan to install a heat pump in the future, zero otherwise.
No plan to install a heat pump, battery storage, or EV	= one if respondent indicated not to own nor to plan to install or purchase a battery storage system, electric vehicle or heat pump, zero otherwise.
PV system: Financial motive	= one if the respondent indicated to rather or totally agree that the purchase of a PV system was for financial reasons.
PV system: Independence motive	= one if the respondent indicated to rather or totally agree that the purchase of a PV system was to be independent from future electricity price increases.
Environmental awareness	= index variable that ranges between zero and six. To construct this measure, the respondents were asked to indicate their agreement to the following six statements: "Humans have the right to modify the natural environment to suit their needs", "Humans are severely abusing the planet", "Plants and animals have the same right to exist as humans", "Nature is strong enough to cope with the impacts of modern industrial nations", "Humans were meant to rule over the rest of nature", and "The balance of nature is very delicate and easily upset". On this basis, we constructed a dummy variable for each statement. In case of positively worded statements (i.e., statements 2, 3 and 6), each dummy variable takes the value one if the respondent selected "totally agree" or "rather agree" and zero if the respondent selected "undecided", "rather disagree", or "totally disagree". In case of negatively worded statements (i.e., statements 1, 4 and 5), each dummy variable takes the value one if the respondent selected "totally disagree" or "rather disagree" and zero if the respondent selected "undecided", "rather agree" or "totally agree". The variable "environmental awareness" is the sum of these six dummy variables.
Willingness to take risks	= index variable that ranges between one and five. The respondents were asked to indicate their willingness to take risks on a symmetric scale with five ordered categories: "completely unwilling to take risks", "rather unwilling to take risks", "undecided", "rather willing to take risks", and "very willing to take risks".
Trust in others	= index variable that ranges between zero and three. To construct this measure, the respondents were asked to indicate their agreement to the following three statements: "In general, one can trust people", "These days you cannot rely on anybody else", and "When dealing with strangers, it is better to be careful before you trust them". On this basis, the first dummy variable takes the value one if the respondent selected "rather agree" or "totally agree" and zero if the respondent selected "undecided", "rather disagree", or "totally disagree". The other two dummy variables are constructed in reveres; i.e., they take the value one if the respondent selected "rather disagree" or "totally disagree" and zero if the respondent selected "undecided", "rather agree", or "totally agree". The variable "trust" is the sum of these three dummy variables.
Technical lifestyle	= one if the respondent rather or totally agreed with the statement "I like to experiment with new information technologies." The respondents were asked to indicate their agreement on a symmetric scale with five ordered categories: "totally disagree", "rather disagree", "undecided", "rather agree", and "totally agree".
Local lifestyle	= one if the respondent rather or totally agreed with the statement "It does cost me more in the long run, but I prefer to buy products that are locally made or produced." The respondents were asked to indicate their agreement on a symmetric scale with five ordered categories: "totally disagree", "rather disagree", "undecided", "rather agree", and "totally agree".

Appendix B. Description of the choice experiment [translated]

Now please imagine that you own a heat pump and that you can provide a certain extent of demand-side flexibility with it. For this, you sign a contract with a marketer who bundles the demand-side flexibility of many households and offers it to the grid operator on a regional flexibility market. For this purpose, your heat pump is switched on or off by the grid operator during selected hours. In the case of a switch-on, a room temperature of 23 ° C is not exceeded. A flexibility call lasts up to one hour. You do not incur any costs or income from a flexibility call. However, you receive a compensation for the availability of your heat pump.

In the following, we show you six times in a row four different contract modalities that you can compare with each other.

The contracts differ in terms of:

- the monthly compensation,
- the maximum number of flexibility calls per month,
- the guaranteed minimum temperature in case of a shutdown,
- the frequency of information provision on flexibility calls
- as well as your personal influence on the interruption of flexibility calls (opt-out option).

Please assume that the contracts do not differ in any other criteria (e.g. cancellation period, customer support, etc.).

The information collected with this survey will be used to make recommendations for political decision-making processes and to develop concrete proposals for legal framework conditions. Therefore, it is essential that your decisions reflect your personal situation. Please therefore consider your personal economic situation as well as your personal comfort level.

Climate treatment: By providing demand-side flexibility, you personally contribute to the use of more renewable energies and low-emission heating and mobility technologies. In this way, you actively contribute to a better CO_2 *balance of the energy system and to climate protection.*

Grid treatment: By providing demand-side flexibility, you personally contribute to a better use of the existing grid capacity. In this way, you actively contribute to a reduction of the necessary grid expansion and the grid costs for the society in general.

Control group: No additional information.

Please make each choice as if you were actually entering into a flexibility contract.

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