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Which tariff to choose? How individual attitudes and preferences explain demand for flexible electricity tariffs in Germany

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ABSTRACT

Time-variant pricing and voluntary flexibility in private energy consumption have the potential to enhance demand sensitivity in electricity markets, playing crucial roles in the transition towards a greener energy system. This paper uses survey methods to examine the determinants of the stated willingness to adopt time-variant electricity tariffs. Based on a large population sample (N = 1200) from the most populous German federal state, North Rhine-Westphalia, we differentiate between the general willingness to adopt such tariffs and specific types, including time-of-use (TOU), critical-peak-pricing (CPP), and real-time-pricing (RTP) tariffs. Additionally, participants provide information on their willingness to adjust their electricity consumption in a timely manner. Our findings reveal that the stated willingness to adopt time-variant tariffs decreases as the potential price volatility increases. Moreover, there is a strong positive correlation between the willingness to adopt time-variant tariffs and the willingness to provide energy demand flexibility. The results of our analysis further indicate that early adopters of energy-efficient technologies and supporters of climate policies are more inclined towards time-variant pricing and providing flexibility in their electricity consumption. Economic preferences, such as loss aversion and present bias, appear to be particularly relevant for adopting the RTP tariff. These insights offer valuable guidance for promoting time-variant tariffs and flexible energy consumption, facilitating the adoption of efficient and sustainable energy systems.

1. Introduction

Within the past decade, Germany has witnessed a significant increase in its installed renewable energy production capacity, more than tripling it. Specifically, the installed renewable energy production capacity has substantially risen in the past years, constituting 60 % of the total installed electricity production capacity in 2022. This trend will only intensify, as it is planned to extend the installed production capacities of onshore wind power plants by 98 %, offshore wind power plants by 275 %, and solar power plants by 216 % between 2022 and 2030 [1]. However, this rapid expansion of renewable energy sources poses new challenges to the German energy system. Compared to conventional energy sources, renewable energy production is highly volatile. Consequently, strategies to enhance demand-side responsiveness have gained prominence among scientists and government officials. One approach involves utilizing price signals to adapt private electricity consumption to fluctuations in electricity production [2,3]. Various electricity tariffs employ time-variant pricing schemes. For instance, time-of-use (TOU) tariffs set fixed prices for different time windows during the day, with higher prices during periods of low renewable production and/or high electricity demand. In contrast, critical-peak-pricing (CPP) tariffs maintain a constant price but charge higher rates on specific days characterized by low renewable production and/or high electricity demand. Contractors are notified in advance of such price spikes. Real-time-pricing (RTP) tariffs dynamically adjust their prices on an hourly basis based on the current wholesale market price of electricity [3].

Empirical research has demonstrated that dynamic pricing schemes like TOU, CPP, and RTP increase the sensitivity of electricity demand.

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Mak and Chapman [4] conducted a survey with 15 electricity suppliers in the US and found that time-variant tariffs can reduce consumption during peak times by 30 %. This finding aligns with the review conducted by Gyamfi et al. [5] on residential demand response and private energy consumption behavior. The review, which synthesizes multiple studies conducted in different countries, suggests that residential electricity tariffs with dynamic pricing schemes can effectively smooth out peaks in electricity demand. Furthermore, Guo and Weeks [6] demonstrate the benefits of dynamic tariffs for both consumers and retailers by constructing a two-stage dynamic game model. Using data from smart meters in Ireland as input, they show that appropriate market regulations decrease market efficiency but shift market gains from retailers to households, ultimately benefiting both agents. Liang et al. [7] made more nuanced observations when investigating the connection between TOU tariff usage and the adoption of different energy efficiency technologies in Phoenix, Arizona. Using a matching approach to approximate a randomized experiment, their findings suggest that TOU tariff users are more likely to install solar panel systems, but they do not exhibit an increased likelihood of using energy-efficient air conditioning devices. Yet, as Gleue et al. [8] highlight, the carbon and monetary savings from switching to a time-variant tariff will depend on the extend and timing of the consumption shift.

Demand-side response measures, such as time-variant electricity tariffs, are crucial for successfully transitioning to green energy systems. Yet, in designing such tariffs, the consumer perspective is oftentimes neglected [9] leading to ill-designed tariffs that raise distributional questions. Thus, to analyze consumer willingness to use time-variant electricity tariffs, we conducted a large online survey with 1200 respondents from North Rhine-Westphalia, the most populous federal state of Germany. Consistent with previous research, we found a high level of social acceptance of time-variant electricity tariffs (e.g., reviewed in [10]). With regards to German data, Sundt et al. [11] find that 70 % of their survey respondents would be willing to switch to a TOU tariff and shift their electricity demand. Likewise, Dütschke and Paetz [12] show that consumers are generally open to dynamic pricing, although this openness decreases with the complexity and variability of the tariff. This finding is confirmed by Gleue et al. [8], who find that 46 % of respondents would accept a TOU tariff and 26 % a CPP tariff. Similarly, Schlereth et al. [13] highlight that TOU tariffs would find some acceptance, although consumers are generally skeptical of time-variant pricing. In Verbraucherzentrale Bundesverband e.V. [14], 44 % could imagine using some time-variant tariff. Finally, also qualitative research denotes a general openness towards adopting time-variant tariffs and changing consumption behaviors in a time-variant manner [15].

This general acceptance of time-variant tariffs stands in contrast to the low actual usage rate [16–18]. A prime reason may be technological constraints. Smart metering technology is mostly required for having access to time-variant tariffs. In Germany, however, only 0.3 % of metering locations are smart metering systems [1] and the diffusion of smart technologies is generally low [19]. A second main barrier is the knowledge about time-variant tariffs. Many consumers in Germany feel badly informed about electricity tariffs with dynamic pricing schemes [12]. According to Verbraucherzentrale Bundesverband e.V. [14], 89 % of German households state to being badly or not informed at all about these tariffs. In the same representative survey, 65 % state to have never heard of time-variant tariffs before, which compares well to 68 % of our sample, who have never heard about these tariffs before.

Our study makes three primary contributions to the existing literature. First, we differentiate between different types of electricity tariffs, including a general willingness to use time- variant tariffs, TOU tariffs, CPP tariffs, and RTP tariffs. We pay attention to whether this stated willingness varies across the different offered tariffs, particular with regards to whether the willingness decreases when price volatility increases. To that end, we designed the different tariffs in such a way that price volatility increases from the TOU, to the CPP, to the RTP tariff. Such a negative relation between willingness to switch and price volatility would be consistent with the findings of Dütschke and Paetz [12], Schlereth et al. [13], and Gleue et al. [8], as described above.

Second, we identify the role of (a) economic preferences, (b) environmental and climate change policy attitudes, and (c) the use of smart technologies for the stated willingness to use these tariffs using a large and representative sample. For (a), economic preferences have often been overlooked when analyzing the willingness to adopt electricity tariffs with time-variant pricing despite their significant influence on energy consumption behavior in various contexts. With respect to general energy-saving behaviors, for example, Ghesla et al. [20] collaborated with a German electricity utility and analyzed smart metering data from 1636 German households. Their findings suggest that framing the non-monetary environmental incentive of saving electricity as a loss rather than a gain motivates households to reduce their energy consumption. Werthschulte and Löschel [21] examined a sample of 711 German respondents and highlighted the role of time-inconsistent preferences in individual energy consumption. They found that individuals with present-biased preferences tend to consume more electricity compared to those who are time-consistent. Additionally, Groh and Ziegler [22] discovered that a higher discount rate, indicating stronger individual patience, significantly reduces household energy consumption among their sample of 3700 respondents in Germany. With respect to the adoption of appliances and technologies with high energy-saving potential, Farsi [23] analyzed stated preferences data from 264 tenants of apartment buildings in Switzerland and found that risk aversion hinders the adoption of energy-efficient insulations and ventilation systems. Similarly, He et al. [24] investigated the relevance of economic preferences for the adoption of energy-efficient appliances among 235 households in rural China. Their results indicate that higher levels of risk and loss aversion are associated with lower adoption rates of such appliances. Schleich et al. [25] also identified risk and loss aversion as significant barriers to the adoption of energy-efficient appliances in a large survey across eight EU countries. Furthermore, their analysis reveals that respondents with higher discount rates are less likely to have adopted these appliances, although the role of present bias appears negligible.

Although this previous research has extensively examined the importance of economic preferences in energy economics, few studies have specifically investigated the influence of these preferences on the willingness to adopt different types of time-variant tariffs. Qiu et al. [26] investigated the role of risk aversion and time discounting in the acceptance of TOU electricity tariffs among approximately 400 homeowners in the US. Based on a choice experiment, Qiu et al. [26] computed a constant relative risk aversion parameter that is negatively correlated with TOU enrollment, indicating that higher risk aversion decreases the likelihood of using this tariff. In contrast, while time discounting is positively associated with TOU enrollment, this relationship is not statistically significant. Nicolson et al. [27] explored whether individual loss aversion influenced the willingness to switch to a smart TOU tariff using a sample of over 2000 energy bill payers in Great Britain. Their analysis provides evidence that loss aversion decreases the acceptance of the smart TOU tariff. Ziegler [28], examining the decisions of 3700 German respondents, discovered a strong correlation between time discounting and the willingness to switch to green electricity contracts. Schlereth et al. [13] explore the role of perceived risks in the willingness to switch to a TOU, CPP, or RTP tariff in a choice experiment with German electricity customers. In their experiment, risk aversion reduces the willingness to switch to a time-variant tariff, especially so for a CPP or RTP tariff. Recognizing this research gap, we incorporate a broad set of economic preferences, namely risk aversion, loss aversion, discounting and present bias, into our analysis of the willingness to use time-variant electricity tariffs in general, as well as the TOU, CPP, and RTP tariffs in particular.

For (b), we explore the role of individual support for climate- and environmental-related political interventions and actions (summarized as the climate and environmental policy support (CEPS) scale), individual environmental attitudes measured by a compressed version of the new ecological paradigm (NEP) scale [22,29,30], and individual interest in energy and climate politics. Empirical research has consistently shown that environmental values and norms play a significant role in explaining and predicting various energy-related behaviors and preferences. For instance, Pothitou et al. [31] found that environmental values have a significant impact on individual energy-saving behavior in Great Britain. Pro-environmental households in their study demonstrated a higher level of engagement in actively saving energy. Similarly, Liu et al. [32] examined the correlation between environmental attitudes and the acceptance of green or sustainable homes in China. Their findings indicate that individuals with pro-environmental attitudes tend to hold more positive opinions towards such homes. In the context of Germany, Merten et al. [33] investigated the relationship between pro-environmental attitudes and social acceptance of carbon pricing. They found that individuals with stronger pro-environmental attitudes exhibit greater acceptance of carbon pricing measures.

Given that time-variant electricity tariffs can contribute to a successful transition to a greener energy system, it is likely that social acceptance of these tariffs is influenced by pro-environmental attitudes, values, and norms. Accordingly, Sundt [34] investigated the drivers of individual willingness to use time-variant electricity tariffs in Germany and found that acceptance is primarily driven by climate change awareness rather than monetary benefits. Similar observations are made by Parag [35] when testing four different framings with a sample of Israeli households that use at least four energy-intensive appliances. Specifically, Parag [35] shows that the stated willingness to use a TOU tariff is driven more by the associated environmental benefits than by the economic ones. Such a finding is also obtained by Gleue et al. [8]. In an online survey among German households, they identify a greater willingness to adopt a TOU and a CPP tariff when provided with information about the environmental benefits. Given these findings, we hypothesize that a greater support for climate- and environmental-related political interventions, environmental attitudes and interest in energy and climate politics increases respondents' willingness to adopt a time-variant tariff.

For (c), we identify individuals who already utilize smart energy technologies, such as smart meters or smart lighting, as early adopters. The adoption of smart energy technologies remains limited due to concerns related to data privacy and financial investments [36,37]. Consequently, we consider users of smart energy technologies as early adopters. The role of technology adoption and usage in mitigating climate change and promoting environmental protection has gained significant attention from researchers and policymakers. Residential energy technologies, in particular, are considered crucial for transitioning energy systems towards greener electricity production [38]. Furthermore, the adoption of such technologies at an individual level has been found to encourage a more sustainable and environmentally friendly lifestyle [39,40]. However, Shirani et al. [41] discovered that residents in Wales, UK, do not necessarily associate smart energy technologies with energy savings. Instead, they express concerns about increased energy consumption and affordability. This finding aligns with the observations of Lekavičius et al. [42] in their study of Lithuanian respondents, where affordability emerges as a significant barrier to energy technology adoption. The researchers also found that policy measures, such as subsidies, appeared to be particularly effective in promoting technology adoption among higher-income households.

Furthermore, the results from Spence et al. [43] indicate that support for smart energy technologies is highest when these technologies are applied in a workplace context, as evidenced by their study involving 213 respondents from the UK. Srivastava et al. [44] show that consumers with greater usage of smart technologies were more likely to provide flexibility in a demand-response program. Parag and Butbul [45] find that a positive attitude towards smart home systems predicts a higher likelihood to provide demand flexibility and Nicolson et al. [27] show that the ownership of appliances providing demand flexibility increases the willingness to switch to a TOU tariffs. Hence, overall, it seems reasonable to believe that smart energy technologies have the potential to facilitate and enhance the effectiveness of demand-side response in the electricity market.

Third, we extend our analysis from respondents' stated willingness to adopt time-variant electricity tariffs to their stated willingness to adjust electricity consumption according to the time-variant prices. This analysis is motivated by Torriti and Yunusov [46], who argue that whether a household gains or loses from a TOU tariff mainly depends on their willingness and ability to shift consumption activities timely. Hence, in addition to investigating the correlation between the adoption of time-variant tariffs, the willingness to consume flexibly and potential differences in their determinants, we conduct an experiment involving information treatments that are designed to enhance respondents' willingness to shift consumption patterns. In the experiment, we investigate whether respondents' willingness to shift their consumption is influenced by providing environmental- or technology-related information. In addition, a control group did not receive any additional information. The environmental-related information highlights the environmental advantages of shifting electricity consumption. The technology-related information emphasizes how digital technologies could facilitate greater flexibility in shaping private electricity consumption. These treatments are motivated by the literature cited above, highlighting the role of environmental and climate change policy support and technology usage for the adoption of time-variant tariffs. Dütschke and Paetz [12] discuss both determinants and argue that consumers may be doubtful when it comes to the positive aspects of dynamic pricing, such as saving costs or environmental benefits, while smart devices are a necessary enabler of switching to time-variant tariffs. However, the role of these environmental- and technology-related factors for the willingness to provide time-variant consumption is less explored.

Overall, this study enriches our understanding of the factors driving consumers' willingness to adopt time-variant electricity tariffs and voluntary provision of flexible energy consumption. The remainder of this paper is structured as follows. The next section provides information on the sample used for the investigation, including the respondents' general demand for time-variant electricity tariffs and their stated willingness to adjust electricity consumption. It also characterizes the environmental measures, smart energy technology users, and the economic preferences of the sample. Section 3 introduces our econometric approach and Section 4 statistically identifies potential determinants of respondents' stated willingness to use electricity tariffs with time-variant pricing and their willingness to adopt flexible energy consumption patterns. Finally, in Section 5 we discuss our findings and derive policy recommendations.

2. Data collection and descriptive statistics

In collaboration with the "Virtual Institute Smart Energy" (VISE) and a market research company, we conducted a large-scale online survey including an information treatment experiment and four incentivized economic preference elicitations in the final week of December 2020, resulting in a sample of N = 1200 respondents.[1] The survey used quota sampling such that the sample is representative in terms of age and gender for North Rhine-Westphalia, the most populous of Germany's federal states.[2] The survey encompassed multiple sections, starting with respondents providing information on standard demographics such as gender, age, and education. Subsequently, participants were asked a series of questions and presented with statements related to their technology affinity, electricity tariff usage, energy consumption patterns, and environmental attitudes and values. The median time taken to complete the survey was approximately 25 min.[3]

Table 1 presents an overview of the sample's basic demographic characteristics, the stated willingness to use time-variant electricity tariffs and to shape electricity consumption more flexible, the environmental attitudes and usage of smart technologies. The sample consists of an equal proportion of female and male respondents, with no respondents identifying as diverse. The average age of respondents is approximately 43 years, and the majority of the sample, 35 %, holds a German 'Abitur', which is the higher-level of a secondary schooling degree. Another 27 % obtained the middle-level of a secondary schooling degree and 24 % of the sample completed some university degree. In addition to the standard demographics, Table 1 summarizes key measures that will be explained in detail in the following subsections.

Table 1
Summary statistics of the sample.

Variable	Mean (SD)	Range	N
Female	50.00 % (50.02)	0–100	1200
Age	42.59 (13.54)	18–65	1200
Education: no degree	0.16 % (4.08)	0–100	1199
Education: elementary school	0.33 % (5.77)	0–100	1199
Education: lower secondary school	12.76 % (33.40)	0–100	1199
Education: secondary school	27.44 % (44.64)	0–100	1199
Education: higher secondary school	34.61 % (47.59)	0–100	1199
Education: university degree	24.02 % (42.74)	0–100	1199
Education: doctorate	0.67 % (8.14)	0–100	1199
GEN Electricity Tariff	5.79 (2.91)	0–10	1046
TOU Electricity Tariff	4.96 (3.16)	0–10	1127
CPP Electricity Tariff	4.38 (3.12)	0–10	1117
RTP Electricity Tariff	3.90 (3.14)	0–10	1116
Flexible Private Electricity Consumption	4.79 (2.97)	0–10	1138
Climate and Environmental Policy Support (CEPS)	3.42 (0.85)	1–5	1020
New Ecological Paradigm (NEP)	4.01 (0.68)	1–5	1200
Interest in Climate Policy	3.47 (0.99)	1–5	1200
Smart Technologies	0.88 (1.42)	0–6	1200

Note: For Female and the education categories frequencies in percent are reported. GEN Electricity Tariff, TOU Electricity Tariff, CPP Electricity Tariff and RTP Electricity Tariff measure participants' willingness to adopt a time-variant electricity tariff on a 11-point Likert scale, where a score of 0 indicated a low willingness and a score of 10 indicated a high willingness. GEN denotes a general interest, TOU refers to a time-of-use tariff, CPP to a critical-peak-pricing tariff, RTP to a real-time-pricing tariff. Flexible Private Electricity Consumption is measured on the same 11-point Likert scale, where a score of 0 indicates a low willingness to timely defer consumption and a score of 10 indicates a high willingness. CEPS and NEP describe the average response to the items of the respective 5-point Likert scales. Interest in Climate Policy is measured on a 5-point scale. The 5-point Likert scales of the CEPS, NEP and Interest in Climate Policy range from 1 to 5 and a higher value indicates stronger pro-environmental attitudes. Smart Technologies is a count variable ranging from 0 (no smart technologies) to 6 (equipped with all surveyed smart technologies).

2.1. Demand for time-variant electricity tariffs

In the following, we differentiate between a respondent's stated willingness to use a time-variant tariff in general (GEN), the TOU, the CPP, and the RTP electricity tariff. Table 2 provides an overview of the time windows and prices that were mentioned as examples when introducing each tariff. As 68 % of our sample have never heard about time-variant tariffs before, such examples were necessary to illustrate the implications of each tariff.[4] By contrast, 99 individuals, comprising 8 % of the total sample, reported already using an electricity tariff with time-variant pricing.[5] We nevertheless elicited their willingness to use a time-variant tariff, as this willingness might still vary and, e.g., depend on the experience with and type of tariff currently used.[6]

To elicit the willingness to use time-variant tariffs in general (GEN), the TOU, CPP, and RTP tariffs, we included four questions in which respondents stated their willingness to use the respective tariff on a 11-point Likert scale. A score of 10 represented a high willingness to use the tariff, while a score of 0 indicated a low willingness. To avoid order effects, the order of the elicitation of the willingness to use the TOU, CPP or RTP tariff was randomized.[7]

Table 2
Examples of the time-variant electricity tariffs with time windows and prices.

Tariff	Time window of price changes	Prices
GEN	–	–
TOU	7–9 am	36 ct/kWh
	6–10 pm	27 ct/kWh
CPP	335 days	27 ct/kWh
	30 days	60 ct/kWh
RTP	Hourly changes	0–90 ct/kWh

As depicted in Fig. 1, we observe heterogeneous preferences for the investigated time-variant electricity tariffs among our respondents. Regarding the general time-variant tariff (GEN), with a median value of 6 out of 11 points, most respondents expressed a general willingness to use electricity tariffs with time-variant pricing. To categorize responses, approximately 57 % of the sample indicate a high willingness to use a general time-variant tariff (scoring 10 to 6 points), 17 % are indifferent (scoring 5 points), and 26 % indicate a low willingness (scoring 4 to 0 points).

In comparison, the willingness to use a TOU tariff is lower, as indicated by a median willingness of 5. Around 46 % of the sample show a high willingness to use a TOU tariff, 15 % are indifferent, and 39 % express a low willingness. The highest willingness, a value of 10, is only

[1] The VISE is a consortium of scientific, institutional, and private stakeholders that together shape the dialogue between science and practice in the domain of energy economics. Projects of the VISE have received funding from the European Fund for Regional Development. The VISE has already contributed to the body of scientific literature with research targeting the topics of co-benefits and regional electricity (e.g., [47,48]).

[2] Following the recommendation of the market research company, we restricted sampling, and hence survey representativeness, to individuals being up to 65 years old. The reason is the low number of individuals that are older than 65 and willing to participate in an online survey. As a consequence, participants older than 65 who select into our survey would not be representative of their age group.

[3] Appendix C provides an overview on all questions and statements that have been used for this paper in chronological order.

[4] Since time-variant tariffs are uncommon in Germany, we follow Gleue et al. [8] and use the tariffs offered by the French energy supplier EDF to motivate our examples. Our TOU-example is inspired by their Off-Peak tariff, the CPP-example by the EJP-option to the Off-Peak tariff and the RTP-example by the Tempo tariff, see, e.g., here https://particulier.edf.fr/en/home/energy-and-services/electricity/tarif-bleu.html.

[5] Of these, 35 respondents are using a TOU-tariff, 5 respondents a CPP-tariff, 31 respondents a RTP-tariff and 28 some other time-variant tariffs.

[6] As explained in Section 3, we control for these individuals in our analysis, and exclude them from the analysis in an additional robustness check.

[7] Appendix F.2 provides details on the statements used for eliciting a respondent's willingness to use a time-variant electricity tariff.

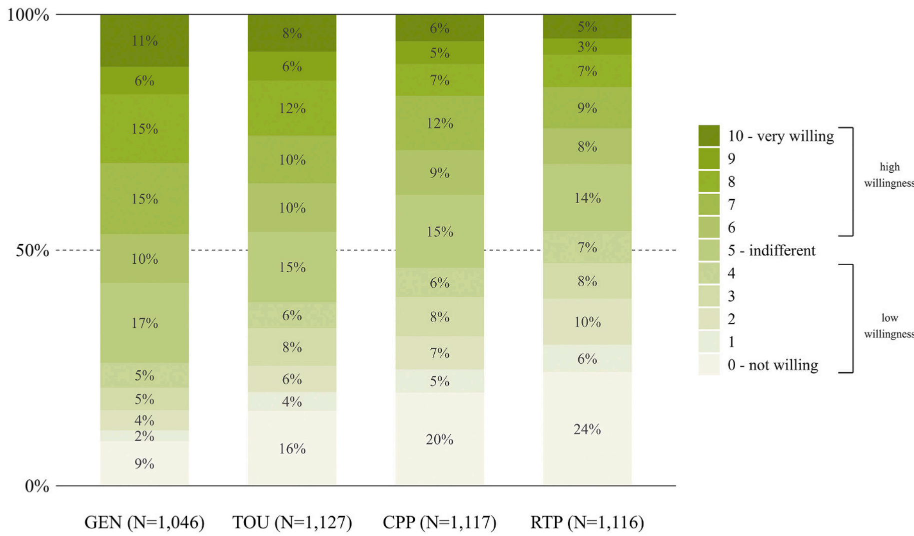

Fig. 1. Distribution of respondents' stated willingness to use electricity tariffs with flexible pricing, measured on a 11-point Likert scale.

reported by 8 %, while 16 % report a 0 and are not willing to adopt a TOU tariff. This distribution closely aligns with the findings of Nicolson et al. [27], who measured acceptance on a 7-point Likert scale for British energy bill payers. They found that 17 % of their sample was unwilling to switch to a 'smart' TOU tariff, while 8 % indicated the highest willingness to switch.

The median willingness to use a CPP tariffs is 4, reflecting that the proportion of the sample reporting a high willingness is further decreasing (38 %) and the proportion reporting a low willingness is increasing (46 %). The RTP tariff shows the lowest level of acceptance. Around 32 % of respondents show a high willingness to use such a tariff with real-time price variation, but the majority of respondents (54 %) express a low willingness.

Hence, we find a relatively high level of acceptance for using electricity tariffs with time-variant pricing in general. However, the willingness to use these tariffs substantially decreases as potential price volatility increases.

2.2. Flexibility in private electricity consumption

Time-variant electricity tariffs mainly steer private electricity consumption patterns via price signals, aiming to shift electricity usage towards times with high renewable energy production. Hence, we hypothesize that the willingness to adopt time-variant electricity tariffs is associated with a willingness to adjust electricity consumption in a flexible manner. To examine this linkage, we test whether the willingness for flexible consumption correlates with the willingness to adopt the time-variant electricity tariffs.

To that end, the survey included a question asking respondents to indicate their level of willingness to timely defer their private electricity consumption. This question was measured on an 11-point Likert scale, where a score of 0 indicated a low willingness and a score of 10 indicated a high willingness.[8] A total of 1138 out of the 1200 respondents provided an answer to this question. Fig. 2 illustrates the distribution of responses. In general, 45 % of the respondents show a high willingness to timely defer their electricity consumption, 15 % are indifferent, and 40 % indicate low willingness.

Table 3 shows a strong positive correlation between flexible electricity consumption and all four time-variant electricity tariffs, as determined by a Spearman rank correlation test. The coefficients range from 0.53 for the correlation with the RTP tariff to 0.59 for the correlation with the TOU tariff. For each tariff, the null hypothesis of independence is rejected at the 1 % significance level. These findings indicate that individuals who are more willing to use time-variant tariffs are also more likely to embrace flexible electricity consumption practices.

In a second step, we investigate how time-flexible electricity consumption may be promoted by specific information provided prior to the elicitation question. To examine this, we conducted an experiment within our survey and randomly assigned respondents to one of three groups. The first group served as the control group and received no specific information. The second group, referred to as the 'Environmental Treatment', was provided with information highlighting the environmental advantages of shifting electricity consumption. The third group, considered as the 'Technology Treatment', received information emphasizing how digital technologies could facilitate greater flexibility in electricity consumption.

Fig. 2 displays the distribution of the willingness for flexible consumption by the treatment groups. We see in the control group a high willingness to shape electricity consumption more flexibly by 41 % and a low willingness by 36 % of respondents. In the Environmental Treatment, respondents exhibit a slightly higher level of willingness compared to the control group. Within this group, 44 % of the respondents show a high willingness towards consumption flexibility and 43 % express a low willingness or unwillingness. This shift is even more pronounced among the Technology Treatment group. There, 46 % of respondents demonstrate a high willingness and the 38 % express a low willingness to shape their electricity consumption more flexibly.

Despite these slight shifts, the median value of willingness to consume flexibly remains at 5 points across all treatment groups. Furthermore, based on a two-sided Mann-Whitney U test, we cannot reject the null hypothesis that the median of the control group and the Environmental Treatment group are equal ($p = 0.65$) or that the median of the control group and the Technology Treatment group are equal ($p = 0.10$). These results suggest that our information treatments may not have a significant effect on respondents' willingness to shape their

[8] Appendix F.3 provides information on the question used for eliciting respondents' willingness to shape their electricity consumption more flexible.

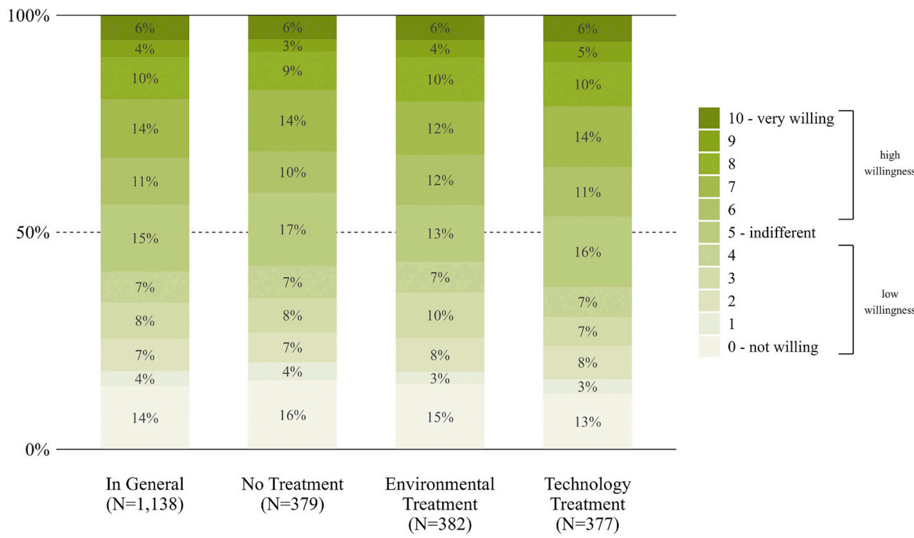

Fig. 2. Distribution of respondents' stated willingness to shape their electricity consumption more flexible, measured on a 11-point Likert scale.

Table 3
Matrix of Spearman rank correlations between stated willingness to shape private electricity consumption more flexible and to use time-variant electricity tariffs.

	CEN tariff	TOU tariff	CPP tariff	RTP tariff
Flexible electricity consumption	0.56*** (N = 1025)	0.59*** (N = 1095)	0.55*** (N = 1087)	0.53*** (N = 1089)

Note: Significance indicated by *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.

electricity consumption more flexibly.

2.3. Environmental measures

We construct three measures to account for the potential influence of environmental values and norms on the willingness to adopt time-variant tariffs and consume energy in a flexible manner. These measures capture the sample's support for climate and environmental policy, environmental attitudes, and interest in energy and climate politics.[9] First, we incorporated a set of seven statements in the survey to assess respondents' agreement with political interventions and regulatory actions aimed at mitigating climate change and enhancing environmental protection. We refer to this set of statements as the 'Climate and Environmental Policy Support' (CEPS) scale.[10] Each statement was evaluated on a 5-point Likert scale, where a score of 1 indicated low consent and a score of 5 expressed high consent. The statements included items such as whether respondents agreed that 'Germany should increase the price for emitting CO2' or 'Germany should support the development of efficient and energy-saving technologies'. The CEPS scale demonstrates good reliability in measuring respondents' attitudes towards climate- and environment-related political interventions and regulatory actions (Cronbach's alpha = 0.81). In our sample, the mean value of the CEPS measure is 3.42 (see Table 1).

Second, we followed the approach of Groh and Ziegler [22], Engler et al. [30], and Whitmarsh [29] by including a subset of six statements from the 'New Ecological Paradigm' (NEP) scale, as suggested by Dunlap et al. [50]. The NEP scale is commonly used to assess individual attitudes towards the environment and nature. Similar to the CEPS scale, respondents indicated their agreement with each of the six statements on a 5-point Likert scale. A score of 1 meant disagreement, while a score of 5 represented high consent. The statements included items such as 'Plants and animals have the same right to live as humans' or 'Nature's balance is delicate and easily disturbed'. The subset of six statements from the NEP scale show good reliability (Cronbach's alpha = 0.76). Following Table 1, the mean value of the NEP measure is 4.01 in our sample.

Lastly, we examined the extent to which our sample is engaged in climate and energy politics. Respondents indicated their general interest in this field on a 5-point Likert scale, with a score of 1 indicating no interest at all and a score of 5 representing high engagement. As displayed in Table 1, the mean value for our sample's interest in climate- and energy-related politics is 3.47.

2.4. Early adopters of smart energy technologies

As the installation of smart technologies is often an enabling factor for implementing time-variant electricity tariffs, we elicit the usage of smart energy technologies. Building upon the work of Grünewald and Reisch [36], we consider six smart energy technologies, including smart meters, smart lighting, and smart plugs, and surveyed individuals whether they use these technologies or not.[11] As Table 4 shows, the adoption of these technologies varies among our sample. While some technologies, such as smart lighting are already adopted by 27 %, other technologies such as an energy data monitor that visualizes energy consumption data are only adopted by 6 % of the sample.

These statistics reflect the situation in Germany well. The uptake of

[9] Appendix F.5 provides details on the questions and statements used for eliciting a respondent's support for climate policy, environmental attitude, and interest in energy and climate policy.

[10] The CEPS scale includes statements that have been used by the ENABLE.EU (http://www.enable-eu.com/) project to investigate European households' acceptance towards climate and environmental policy (http://www.enable-eu.com/wp-content/uploads/2018/02/ENABLE.EU-D4.1.pdf). Löschel et al. [49] use a subset of these statements to empirically identify whether income shocks caused by the COVID-19 pandemic changed individual environmental policy support.

[11] Appendix F.6 provides details on the definition of smart energy and the included smart energy technologies.

Table 4
Adoption of smart technologies.

Variable	Frequency (SD)	Range	N
Smart Meter	9.42 % (29.22)	0–100	1200
Smart Lighting	26.50 % (44.15)	0–100	1200
Energy Data Monitor	5.67 % (23.13)	0–100	1200
Smart Sockets	22.92 % (42.05)	0–100	1200
Smart Energy Products	15.08 % (35.80)	0–100	1200
Smart Home Programming	8.67 % (28.15)	0–100	1200

Note: For each smart technology adoption frequencies in percent are reported.

smart meters in Germany is among the lowest compared to the other European countries. In 2021, only 0.3 % of metering locations in Germany have been equipped with smart metering technology [1]. In response, Germany has decided by law (Act of on the Digitization of the Energy Transition (GDEW)) to not only accelerate the up-take of smart meters but to obligate electricity suppliers to offer time-variant tariffs by 2025. Likewise, according to national statistics, 10 % of German households are equipped with some smart energy management system (e.g., thermostat, electricity meter, lightning) and 13 % have some smart household appliance (e.g., robot vacuum cleaner, refrigerator, washing machine) [51].

To classify a measure of early adoption, we thus construct a variable that counts the number of adopted smart energy technologies. Hence, the higher the value of that count variable the greater the inclination to (early) adopt smart technologies. As shown in Table 1, the variable 'Smart Technologies' has a mean value of 0.88, indicating that on average less than one smart technology is adopted. By contrast, 2 % of the sample have all six technologies adopted.

2.5. Economic preferences

To examine the role of economic preferences in the choice to use a time-variant tariff and to offer flexible consumption, the online survey included four incentivized multiple price lists (MPLs).[12] In each MPL, respondents had to make choices between different small monetary stakes. Multiple switching between options within an MPL was allowed and we follow prior literature to infer individual risk and loss preferences, time discounting and biases in discounting [52–54].

Our data shows that some respondents do not satisfy the monotonicity condition, i.e., they made inconsistent choices in their set of decisions within an MPL [55–57]. Considering the MPLs used to elicit risk and loss preferences, 23 % and 19 % of the sample did not satisfy monotonicity. For the two MPLs eliciting time preferences, approximately 34 % and 35 % of the respondents made inconsistent choices. These percentages are largely in line with the existing literature [54,57,58]. We do not drop these inconsistent respondents, and, instead, as shown by Table 5, we created a factor variable for each economic preference measure consisting of the three levels A, B, and C.

For all variables, level A captures respondents that have been classified as being risk neutral or seeking, loss seeking, impatient, or future biased or unbiased. This level constitutes the baseline level against which level B and C are compared in the regression analysis. Level B captures all respondents who made inconsistent choices. Level C incorporates all respondents who are risk averse, loss averse, patient, or present biased, based on their consistent choices in the four MPLs.[13]

As Table 5 shows, we consider 19 % of our sample as risk-neutral or -seeking, and 58 % as risk-averse. An even larger fraction is loss-averse, 63 %, as opposed to 18 % being loss-seeking. With regards to the time preferences, one third of the sample is impatient and another third is patient. The large majority is also unbiased or future-biased (56 %), whereas 9 % are classified as present-biased.

3. Econometric approach

To identify potential relationships between the willingness to adopt a time-variant electricity tariff as well as the willingness to shift electricity consumption and the discussed independent variables, we employ a parametric analysis using a linear multiple regression model.

The OLS estimation procedure for the willingness to use a time-variant electricity tariff follows the model as illustrated by Eq. (1), where SW_i^{tariff} captures the stated willingness of respondent i to adopt the specified time-variant electricity tariff. The vector Env_i includes the three environmental measures specified in Section 2.3. The variable SET_i represents the count variable for the number of smart energy technologies used. $Pref_i$ is a set of vectors that includes the factor variables for loss aversion, risk aversion, present bias, and patience. $X1_i$ represents a vector of a first set of control variables and $X2_i$ represents a vector of a second set of control variables. Finally, ε_i is the error term of the model, assumed to be identically and independently distributed with a conditional mean of zero, $\varepsilon \sim N(0, \sigma^2)$.

$$SW_i^{tariff} = \rho_0 + \rho_1 Env_i + \rho_2 SET_i + \rho_3 Pref_i + \rho_4 X1_i + \rho_5 X2_i + \varepsilon_i. \quad (1)$$

In total, we carried out four estimation runs where we regress our sample's willingness to use time-variant tariffs in general (GEN), the TOU, CPP, or RTP electricity tariff on the characterized independent variables contained in Env_i, SET_i, $Pref_i$, while controlling for $X1_i$ and $X2_i$. Each estimation run produces three specifications. In the first specification of the model (1), we include the first sets of variables of interest, Env_i and SET_i, as well as the first set of control variables, $X1_i$. This first set of control variables includes gender, age, education categories and the type of respondent's current electricity tariff. The second specification (2) expands the model by incorporating individual economic preferences, $Pref_i$. Finally, the third specification (3) adds a broader set of control variables, summarized in $X2_i$, to the second specification. This broader set of control variables includes the respondent's dwelling type, whether the respondent owns or rents the dwelling, the size of the household, the living space of the dwelling, the monthly electricity costs and the time when the respondent last switched his/her electricity contract.

We adopt this step-wise approach to investigate the robustness of our results. Specifically, the correlations between our main variables of interest, Env_i, SET_i and $Pref_i$, and the willingness to use a time-variant tariff might change depending on which specification is being used due to spurious correlations both among the main variables of interest and between the main variables and the different sets of control variables. However, the number of observations will also change between specifications, due to missing responses to some survey questions. To adjust for changes in the number of observations and to allow a comparison between the specifications, we hold the sample size constant. That is, across all our regressions, we restrict our sample to those

[12] Appendix F.4 provides an overview on the MPLs and their respective descriptions that have been included in the survey.

[13] The literature commonly uses discounting as a continuous variable. For this analysis, however, we decided to transform the discounting variable such that it only includes three levels, i.e. *impatient*, *inconsistent*, and *patient*. After calculating the continuous discount factor following Ziegler [28], we conducted a median split among the respondents who made consistent choices. Respondents with a discount factor larger than the median have been classified as *impatient* while respondents equal or smaller than the median were classified as *patient*.

Table 5
Operationalization of economic preference as factor variables with levels A–C for each variable.

Level	Risk preferences	Loss preferences	Discounting	Time bias
Level A	Neutral/seeking	Seeking	Impatient	Future/unbaised
(N/Perc)	(228/19 %)	(216/18 %)	(390/33 %)	(675/56 %)
Level B	Inconsistent	Inconsistent	Inconsistent	Inconsistent
(N/Perc)	(277/23 %)	(225/19 %)	(415/34 %)	(415/35 %)
Level C	Averse	Averse	Patient	Present
(N/Perc)	(695/58 %)	(759/63 %)	(395/33 %)	(110/9 %)

respondents with non-missing observations in specification (3). This implies that we lose 307 observations, i.e., 26 % of the sample. Yet, we lose most observations through their non-response to the CEPS measure (see Table 1), which is one of our main variables of interest.

The analysis of the willingness to consume electricity in a flexible manner follows a similar OLS regression approach, as illustrated by Eq. (2), with SW_i^{cons} denoting the stated willingness to shift consumption. The indicators $EnvT_i$ and $TechT_i$ denote the Environmental Treatment and the Technology Treatment, respectively. All other variables are defined as above.

$$SW_i^{cons} = \theta_0 + \theta_1 EnvT_i + \theta_2 TechT_i + \theta_3 Env_i + \theta_4 SET_i + \theta_5 Pref_i + \theta_6 X1_i + \theta_7 X2_i + \varepsilon_i. \quad (2)$$

As with the willingness to adopt time-variant tariffs, we use a step-wise approach and run four specifications of this regression model. In the first specification (1), we focus on the two treatments and investigate their respective effect on the willingness to provide flexibility in consumption. We also add the first set of control variables, which includes the basic demographics (gender, age, education) and, importantly, controls for the type of the current tariff. In the second specification (2), we start investigating the behavioral determinants of shifting consumption. To that end, as in the analysis of the willingness to adopt a time-variant tariff, we add the Env_i and SET_i variables. The third specification (3), further adds the individual preference measures, $Pref_i$, and the fourth specification (4), tests the robustness of the identified correlations by adding the second set of control variables, $X2_i$. We again hold our sample size constant across the different specifications by restricting the observations to those with non-missing data in specification (4).

We provide three main robustness checks to these estimation runs. First, specification (1) of our regressions for the willingness to use a time-variant tariff (GEN, TOU, CPP, RTP) as well as specification (1) of the regression for the willingness to shift consumption controls for the current electricity tariff of the respondent by including $X1_i$. While this current tariff is a common tariff for 92 % of the sample, the remaining respondents are customers of some time-variant tariff. Thus, in a robustness check, we do not only control for this tariff type but exclude all respondents who are using a time-variant tariff already. Second, as shown in Section 2.2, our two types of dependent variables are closely related. Specifically, the willingness to consume electricity flexibly is a strong predictor of the willingness to adopt a time-variant tariff. We adjust for this correlation in a robustness check of Eq. (1) that treats SW_i^{cons} as an additional control variable.

Third, by using a linear OLS regression model, our analysis follows Nicolson et al. [27] and implicitly assumes the dependent variable to be continuous. To test whether this assumption biases the results, we redid the estimation by applying an ordered probit regression model that is suitable for the analysis of categorical dependent variables. The results of the ordered probit regression, summarized in Appendix Table D.1 for the use of time-variant tariffs and Appendix Table D.2 for the willingness to shift consumption, exhibit minor changes in significance and no changes in the direction of the coefficients.

4. Results

4.1. Demand for time-variant electricity tariffs

Tables 6 and 7 report the regressions results of the demand for a general (GEN) time-variant tariff, TOU, CPP or RTP tariff depending on the respondent's environmental measures, their adoption of smart technologies, and their economic preferences. The first specification of the model includes environmental measures and the variable for the number of smart energy technologies adopted. The CEPS scale, the interest in climate policy, and the number of used smart technologies are found to have significant and positive correlations with the willingness to use all four types of time-variant tariffs. This indicates that climate policy interest and support acts as an enabler of time-variant tariffs. Likewise, the usage of pre-existing technologies, likely characterizing early adopters and openness to innovation, predicts a higher likelihood of adopting the novel tariffs. In contrast, the respondents' environmental attitudes, as measured by the compressed version of the NEP scale, do not show a significant correlation with the willingness to use time-variant electricity tariffs in general. For the acceptance of the TOU and CPP tariffs, the NEP variable even displays a negative, yet insignificant, sign. For the acceptance of the RTP tariff, this negative sign of environmental attitudes becomes highly significant, indicating a lower acceptance of RTP tariffs with stronger environmental attitudes. Notably, these correlations between environmental measures, the early adoption of smart technologies, and the willingness to use time-variant tariffs are robust across the different specifications. Both in magnitude and significance coefficients change little upon the inclusion of the economic preference measures (2) or the broader set of control variables (3).

In addition to environmental attitudes and smart technology usage, economic preferences have been identified as important factors in energy-related decision-making. Therefore, our second specification of the model incorporates individual economic preferences, operationalized as factor variables and included as fixed effects.[14] The inclusion of economic preferences, specifically loss aversion and present bias, reveals different correlations with the four dependent variables. Loss aversion is important for the stated willingness to use all time-variant tariffs except for the CPP tariff. For all of the other three tariffs, we estimate a negative significant correlation. This negative correlation is significant only at the 10 % level for the general willingness to use a time-variant tariff (GEN), but at the 5 % level for the TOU and RPP tariffs. Risk aversion and patience, on the other hand, exhibit no significant correlations with the stated willingness to use any tariff. In contrast, present bias plays a role in the willingness to use the RTP tariff, i.e., present-biased respondents tend to show a higher stated willingness to use tariffs whose prices vary in real-time than their time-consistent or future-biased counterparts. These findings are robust to including the broader set of control variables in specification (3).

[14] Each economic preference variable includes three levels. The first level A (risk neutral or seeking, loss seeking, impatient, and future biased or unbiased) serves as the benchmark and is, thus, omitted. We do not report level B (inconsistent) of the economic preferences factor variables as there is no value-added to compare inconsistent respondents only against level A.

Table 6
Estimated OLS parameters in linear regression models. General willingness (GEN) and TOU tariff as dependent variables, measured on a 11-point scale.

	(1)	(2)	(3)	(1)	(2)	(3)
Variables	GEN	GEN	GEN	TOU	TOU	TOU
CEPS	0.53***	0.54***	0.55***	0.57***	0.56***	0.58***
	(0.12)	(0.12)	(0.12)	(0.14)	(0.14)	(0.14)
	[0.29; 0.77]	[0.30; 0.78]	[0.30; 0.79]	[0.30; 0.83]	[0.30; 0.83]	[0.31; 0.85]
NEP	0.09	0.07	0.06	−0.23	−0.23	−0.22
	(0.15)	(0.15)	(0.15)	(0.17)	(0.17)	(0.17)
	[−0.21; 0.39]	[−0.23; 0.37]	[−0.24; 0.36]	[−0.56; 0.10]	[−0.56; 0.10]	[−0.55; 0.11]
Interest Climate Policy	0.64***	0.64***	0.66***	0.52***	0.52***	0.53***
	(0.11)	(0.11)	(0.11)	(0.13)	(0.13)	(0.13)
	[0.41; 0.86]	[0.42; 0.86]	[0.44; 0.89]	[0.27; 0.77]	[0.28; 0.77]	[0.28; 0.78]
Smart Technologies	0.37***	0.39***	0.38***	0.36***	0.36***	0.32***
	(0.06)	(0.07)	(0.07)	(0.07)	(0.07)	(0.08)
	[0.24; 0.50]	[0.26; 0.52]	[0.24; 0.51]	[0.22; 0.50]	[0.22; 0.50]	[0.17; 0.47]
Loss aversion		−0.46*	−0.42*		−0.64**	−0.66**
		(0.25)	(0.25)		(0.27)	(0.27)
		[−0.94; 0.03]	[−0.91; 0.06]		[−1.17; −0.10]	[−1.19; −0.12]
Risk aversion		−0.18	−0.23		−0.16	−0.20
		(0.24)	(0.24)		(0.26)	(0.26)
		[−0.65; 0.28]	[−0.70; 0.23]		[−0.68; 0.35]	[−0.72; 0.32]
Patience		0.21	0.21		−0.01	−0.01
		(0.23)	(0.23)		(0.25)	(0.25)
		[−0.23; 0.66]	[−0.23; 0.65]		[−0.50; 0.48]	[−0.50; 0.48]
Present bias		0.16	0.16		0.41	0.39
		(0.32)	(0.32)		(0.36)	(0.36)
		[−0.47; 0.79]	[−0.47; 0.79]		[−0.29; 1.11]	[−0.31; 1.09]
Constant	−2.43	−1.96	−1.86	−2.64	−2.06	−3.61
	(2.83)	(2.85)	(3.07)	(3.13)	(3.16)	(3.41)
Control Set 1	Yes	Yes	Yes	Yes	Yes	Yes
Control Set 2	No	No	Yes	No	No	Yes
Observations	893	893	893	893	893	893
R-squared	0.16	0.18	0.20	0.13	0.14	0.16

Note: Variables are not standardized. CEPS and NEP describe the average response to the items of the respective 5-point Likert scales. Interest in Climate Policy is measured on a 5-point scale. Smart Technologies is a count variable from 0 to 6. Loss Aversion, Risk Aversion, Patience and Present Bias are binary indicators. The omitted baselines are loss seeking, risk neutral/seeking, impatient and future/unbiased, respectively (see Table 5). Control Set 1: Gender indicator, age, education categories, current tariff categories. Control Set 2: Housing type categories, dwelling ownership indicator, household size, living space, monthly electricity costs, last tariff switch. Standard errors in round parentheses, 95 %-confidence intervals in square parentheses. Significance indicated by ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

In Table A.1, we display the coefficients of the different control variables used in specification (3). We observe that females are significantly more likely to select into a general and a TOU time-variant tariff. The willingness to use a time-variant tariff seems to decrease with age, although this correlation is only significant for the CPP and RTP tariffs. We further see that house owners (as opposed to tenants) are less likely to select a time-variant tariff, which is significant for the RTP tariff. A larger household size, though, predicts a significantly higher likelihood of selecting all time-variant tariffs. Finally, we see a tendency that more frequent tariff-switching behavior increases the likelihood to switch to a time-variant tariff.

With regards to our two robustness checks, Table B.1 shows that these findings are robust to the exclusion of respondents who are already using a time-variant tariff. Table C.1 investigates robustness when controlling for the willingness to provide flexibility in electricity consumption. We see a robustness of present bias predicting a higher likelihood to use the RTP tariff, and of the environmental measures and use of smart technologies predicting a higher uptake of all tariffs, except for the NEP scale. We do, however, lose significance for the loss aversion result. For the CPP tariff, where the loss aversion coefficient was negative but insignificant in Table 7, the sign flips but stays insignificant in Table B.1. This may be due to a strong correlation between loss aversion and the tariff demand on the one hand, and loss aversion and the willingness to provide flexible consumption on the other hand, as investigated in the next section.

In summary, our exploratory analysis examined the relationship between economic preferences, individual environmental attitudes, and the early adoption of smart energy technologies in the context of demand response in the electricity market. Our findings contribute to the existing literature by demonstrating that different economic preferences, in particular loss aversion, are associated with the willingness to use specific time-variant tariffs. We consistently observed a positive and significant correlation between our sample's support for climate and energy policies and the willingness to use all four types of time-variant electricity tariffs. On the other hand, our results indicate a negative correlation between environmental attitudes, as measured by the NEP scale, and some of the time-variant tariffs. Furthermore, users of smart energy technologies show a higher acceptance towards these electricity tariffs on average.

4.2. Flexibility in private electricity consumption

In this analysis, the willingness to provide flexibility in electricity consumption serves as the dependent variable in the regression model, which is to be explained by the same set of independent and control variables as in the analysis of the willingness to adopt time-variant electricity tariffs. The independent variables include our respondents' support for climate and environmental policy measures and interventions (CEPS scale), environmental attitudes (NEP scale), interest in climate and energy politics, early adopters of smart energy technologies, and economic preferences. Furthermore, as different respondents have been exposed to different information treatments regarding the environmental benefits or the role of digital technologies in providing higher flexibility in electricity consumption, we include these information treatments as additional independent variables. The control group, which received no information, serves as the benchmark in our regression analysis.

The results presented in Table 8 indicate that both, the Environmental and Technology Treatment have a positive effect on our respondents' willingness to voluntarily shape their energy consumption in

Table 7
Estimated OLS parameters in linear regression models. CPP and RTP tariff as dependent variables, measured on a 11-point scale.

	(1)	(2)	(3)	(1)	(2)	(3)
Variables	CPP	CPP	CPP	RTP	RTP	RTP
CEPS	0.57***	0.59***	0.61***	0.79***	0.78***	0.77***
	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)	(0.13)
	[0.31; 0.84]	[0.33; 0.86]	[0.35; 0.88]	[0.53; 1.05]	[0.52; 1.04]	[0.51; 1.03]
NEP	−0.19	−0.20	−0.22	−0.58***	−0.56***	−0.57***
	(0.17)	(0.17)	(0.17)	(0.17)	(0.17)	(0.16)
	[−0.51; 0.14]	[−0.53; 0.13]	[−0.55; 0.11]	[−0.91; −0.26]	[−0.88; −0.23]	[−0.90; −0.25]
Interest Climate Policy	0.45***	0.45***	0.47***	0.42***	0.42***	0.46***
	(0.12)	(0.12)	(0.13)	(0.12)	(0.12)	(0.12)
	[0.20; 0.69]	[0.20; 0.69]	[0.23; 0.72]	[0.18; 0.67]	[0.18; 0.66]	[0.22; 0.70]
Smart Technologies	0.37***	0.38***	0.35***	0.29***	0.27***	0.24***
	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)	(0.07)
	[0.23; 0.51]	[0.24; 0.52]	[0.20; 0.50]	[0.15; 0.43]	[0.14; 0.41]	[0.10; 0.39]
Loss aversion		−0.16	−0.15		−0.60**	−0.59**
		(0.27)	(0.27)		(0.27)	(0.27)
		[−0.69; 0.37]	[−0.68; 0.38]		[−1.13; −0.08]	[−1.11; −0.07]
Risk aversion		0.16	0.11		0.17	0.12
		(0.26)	(0.26)		(0.26)	(0.26)
		[−0.35; 0.67]	[−0.40; 0.62]		[−0.33; 0.68]	[−0.39; 0.62]
Patience		−0.05	−0.03		−0.25	−0.21
		(0.25)	(0.25)		(0.24)	(0.24)
		[−0.53; 0.44]	[−0.51; 0.46]		[−0.73; 0.23]	[−0.69; 0.26]
Present bias		0.39	0.34		0.85**	0.80**
		(0.35)	(0.35)		(0.35)	(0.35)
		[−0.30; 1.08]	[−0.35; 1.03]		[0.17; 1.53]	[0.12; 1.47]
Constant	2.11	1.86	0.25	−0.45	−0.54	−1.66
	(3.09)	(3.13)	(3.37)	(3.08)	(3.08)	(3.31)
Control Set 1	Yes	Yes	Yes	Yes	Yes	Yes
Control Set 2	No	No	Yes	No	No	Yes
Observations	893	893	893	893	893	893
R-squared	0.13	0.14	0.16	0.16	0.18	0.21

Note: Variables are not standardized. CEPS and NEP describe the average response to the items of the respective 5-point Likert scales. Interest in Climate Policy is measured on a 5-point scale. Smart Technologies is a count variable from 0 to 6. Loss Aversion, Risk Aversion, Patience and Present Bias are binary indicators. The omitted baselines are loss seeking, risk neutral/seeking, impatient and future/unbiased, respectively (see Table 5). Control Set 1: Gender indicator, age, education categories, current tariff categories. Control Set 2: Housing type categories, dwelling ownership indicator, household size, living space, monthly electricity costs, last tariff switch. Standard errors in round parentheses, 95 %-confidence intervals in square parentheses. Significance indicated by ***$p < 0.01$, **$p < 0.05$, *$p < 0.1$.

a more flexible manner, compared to the control group. However, this effect becomes significant at the 10 % level only for the Technology Treatment and when controlling for environmental measures and the smart technology variable, as seen in the second model specification. This effect then remains robust to the further inclusion of economic preferences and additional control variables. The coefficient of the Environmental Treatments stays positive, but insignificant across all model specification. Hence, our experimental variation provides some evidence supporting the idea that the promotion of the support of digital devices can foster the willingness to consume electricity more flexibly. We do not see this supporting evidence for promoting the environmental benefits.

In the second model specification, positive and significant correlations are found between the CEPS scale, interest in energy and climate politics, and the smart technology variable with the willingness to shape electricity consumption more flexibly. Similar to the analysis of time-variant electricity tariffs, the NEP scale is negatively correlated with the willingness to shape electricity consumption more flexibly. This suggests that there may be diverging influences between personal support for climate and environmental policy measures (as measured by the CEPS scale) and individual attitudes towards environmental topics (as captured by the NEP scale). The usage of smart technologies is positively correlated with the willingness to consume electricity in a flexible manner, consistent with the findings for adopting time-variant electricity tariffs. These correlations remain robust to the inclusion of economic preferences in specification (3) and the broader control variables in specification (4).

The third model specification includes economic preferences. While patience and present bias do not exhibit any significant correlation with the dependent variable, risk and loss averse respondents show a systematically lower stated willingness to shift electricity consumption in a timely manner, compared to their neutral and risk-/loss-seeking counterparts. This result is in line with the estimated negative correlation between loss aversion and the stated willingness to use time-variant tariffs in general (GEN), the TOU and RTP electricity tariffs. This finding does not change when including additional control variables in specification (4). Further, in Table B.2, we provide a robustness check by excluding respondents that are already using a time-variant tariff from the analysis. Our findings are robust, only the significance of the loss aversion coefficient decreases from the 5 % level in Table 8 to the 10 % level in Table B.2.

In Table A.2, we spell out the results reported in specification (4) of Table 8 with respect to the control variable coefficients. The only significant control variable is the household size, which is positively related to the willingness to consume flexibly. Both the gender and age coefficients display the same sign as in the tariff demand analysis, but are not significant. Interestingly, and contrary to the tariff demand analysis, the coefficients of the education categories are all negative, though not significant. This finding contradicts the common understanding in the literature that higher education is associated with greater willingness to engage in pro-environmental behavior (e.g., [59,60,61]). It is possible that there are other unobserved factors that are correlated with both education and willingness to provide energy consumption flexibility, leading to this unexpected result. On the other hand, this finding mirrors a conclusion drawn by Torriti and Yunusov [46]. In their analysis of households gaining and losing from a TOU tariff by shifting consumption patterns, socio-demographic characteristics play only a minor role.

Table 8
Estimated OLS parameters in linear regression models. Flexibility in private electricity consumption as dependent variable, measured on a 11-point scale.

	(1)	(2)	(3)	(4)
Variables	Flexible Private Electricity Consumption	Flexible Private Electricity Consumption	Flexible Private Electricity Consumption	Flexible Private Electricity Consumption
Environmental treatment	0.26 (0.24) [−0.21; 0.73]	0.26 (0.22) [−0.17; 0.69]	0.31 (0.22) [−0.13; 0.74]	0.29 (0.22) [−0.14; 0.73]
Technology treatment	0.25 (0.24) [−0.22; 0.72]	0.39* (0.22) [−0.04; 0.82]	0.42* (0.22) [−0.01; 0.85]	0.41* (0.22) [−0.02; 0.84]
CEPS		0.68*** (0.12) [0.44; 0.92]	0.68*** (0.12) [0.44; 0.92]	0.68*** (0.12) [0.44; 0.93]
NEP		−0.32** (0.15) [−0.62; −0.03]	−0.34** (0.15) [−0.64; −0.04]	−0.35** (0.15) [−0.65; −0.05]
Interest Climate Policy		0.79*** (0.11) [0.56; 1.01]	0.79*** (0.11) [0.57; 1.01]	0.80*** (0.11) [0.57; 1.02]
Smart Technologies		0.32*** (0.06) [0.20; 0.45]	0.33*** (0.06) [0.20; 0.46]	0.31*** (0.07) [0.18; 0.45]
Loss aversion			−0.52** (0.25) [−1.00; −0.04]	−0.51** (0.25) [−0.99; −0.02]
Risk aversion			−0.40* (0.24) [−0.86; 0.07]	−0.41* (0.24) [−0.88; 0.06]
Patience			−0.00 (0.23) [−0.45; 0.44]	0.01 (0.23) [−0.43; 0.46]
Present bias			0.25 (0.32) [−0.37; 0.88]	0.26 (0.32) [−0.37; 0.89]
Constant	6.79** (3.00)	1.42 (2.82)	2.09 (2.84)	1.56 (3.08)
Control Set 1	Yes	Yes	Yes	Yes
Control Set 2	No	No	No	Yes
Observations	893	893	893	893
R-squared	0.02	0.19	0.20	0.21

Note: Variables are not standardized. Environmental Treatment and Technology Treatment are indicators for the respective treatment group. The control group is the omitted reference group. CEPS and NEP describe the average response to the items of the respective 5-point Likert scales. Interest in Climate Policy is measured on a 5-point scale. Smart Technologies is a count variable from 0 to 6. Loss Aversion, Risk Aversion, Patience and Present Bias are binary indicators. The omitted baselines are loss seeking, risk neutral/seeking, impatient and future/unbiased, respectively (see Table 5). Control Set 1: Gender indicator, age, education categories, current tariff categories. Control Set 2: Housing type categories, dwelling ownership indicator, household size, living space, monthly electricity costs, last tariff switch. Standard errors in round parentheses, 95 %-confidence intervals in square parentheses. Significance indicated by $^{***}p < 0.01$, $^{**}p < 0.05$, $^{*}p < 0.1$.

5. Discussion and policy implications

This study differentiates time-variant electricity tariffs into four types and provides insights into individuals' general willingness to use such tariffs, as well as their preferences for specific pricing schemes, namely TOU, CPP, and RTP schemes. The findings from our large population sample (N = 1200) are threefold. First, we observe a relatively high willingness to use time-variant tariffs in general or with fixed time-of-use pricing rates (TOU). In contrast, tariffs with greater potential price volatility or uncertainty, such as the CPP or RTP tariff, appear to be less popular. Accordingly, the sample's willingness to use a tariff with fixed time-of-use pricing rates (TOU) is higher compared to the willingness to use an electricity tariff with an CPP or RTP scheme. This finding is consistent with other studies using German data [8,12,13].

Second, using a comprehensive parametric approach, we observe different statistical associations between the elicited economic preferences and the stated willingness to use some of the time-variant tariffs. Existing literature on the relationship between individual economic preferences and time-variant electricity tariffs or flexibility in energy consumption is scarce. Reis et al. [62] found no significant correlation between loss aversion and the willingness to use time-variant tariffs. However, similar to Nicolson et al. [27], we find a negative significant correlation between loss aversion and the stated willingness to use the TOU electricity tariff. While providing further evidence on the association between loss aversion and this specific tariff, we moreover find negative significant correlations of loss aversion with the stated willingness to use time-variant electricity tariffs in general and the electricity tariff with a RTP scheme. The negative significant correlation with the RTP scheme seems particularly relevant, as this tariff may be perceived as potentially causing higher costs, or in other words, high potential losses compared to other types of tariffs. In turn, economic preferences did not play a significant role in the stated willingness to use the CPP tariff. This could be attributed to the different framings and characteristics of this tariff. The presentation of CPP as a pricing scheme with higher prices on specific days, with advance notification, may have mitigated the influence of loss aversion. In addition, in contrast to Schlereth et al. [13], we do not find significant correlations between tariff choice and risk aversion. A potential reason may be our inclusion of both loss and risk aversion providing a more granular look into the association between risk attitudes and tariff choice than the analysis of risk aversion alone. We further find that RTP tariffs are systematically preferred by respondents exhibiting present-biased preferences. As present-biased individuals undervalue future consequences [63], they may underestimate the potential negative financial impact due to the price volatility inherent in the RTP scheme.

The positive correlation between our respondent's support for climate policy, as measured by the CEPS scale, and the acceptance of time-variant electricity tariffs is consistent with the broader public sentiment on climate change and policy measures. For example, the Eurobarometer study conducted by the European Commission has shown that a majority of EU citizens perceive climate change as a significant threat and express strong support for ambitious policy measures to address it [64]. Given this context, it is understandable that individuals who support climate policy and are concerned about climate change are more inclined to use time-variant tariffs and embrace flexibility in energy consumption. They may view these measures as part of the larger effort to transition to a greener and more sustainable energy system. Similar evidence for Germany is provided by Sundt et al. [11] and Gleue et al. [8]. Finally, our finding of a strong positive relation between using smart technologies and adopting time-variant tariffs, likely due to lower financial and psychological barriers as early adopters of smart technologies, is consistent with the majority of existing literature [27,44,45].

Our third main finding concerns the willingness to provide time-variant electricity consumption. Our study confirms existing literature [46], that heterogeneity in our individuals' acceptance of time-variant electricity tariffs aligns with their willingness to consume electricity in a flexible manner, as there is a large and highly significant positive correlation between both measures. Furthermore, our parametric analysis reveals similar determinants of the willingness to consume electricity in a flexible manner and the acceptance of time-variant tariffs. Individuals who are highly engaged in climate and energy politics and support climate policy are more willing to embrace higher flexibility. Similarly, those who show a strong interest in environmental and climate topics are inclined to shape their private energy consumption in a more flexible manner. The same positive correlation is observed for the use of smart technologies. Further, as for the results on tariff demand, loss averse individuals are less likely to consider consuming electricity in a flexible way. A treatment highlighting the technological support in shifting consumption can weakly increase the willingness to provide such flexibility. This result is particular in line with Dütschke and Paetz [12], who raise doubt towards the effectiveness of information highlighting the benefits of time-variant pricing but suggest that smart devices will be a necessary enabler. Yet, in Parag and Butbul [45], greater perceived societal benefits of time-variant tariffs predict larger demand flexibility, which is at odds with the insignificance of the 'Environmental Treatment' in our study.

However, these findings come with certain limitations, especially those usually applying to survey methods (e.g., reviewed in [65]), including the disregard of insights obtained through qualitative methods, such as emotions towards time-variant tariffs [66]. Further, the generalizability of our findings is tight to our specific study population (the state North Rhine-Westphalia in Germany) and our specific design of the eliciting tariff adoption. While it was necessary to provide respondents with some examples of the time-variant tariff they were asked to adopt, the examples provided likely influenced choices. Participants might have indicated a different willingness to use a certain tariff, if this tariff involved a different electricity price than we exemplified. To ensure the relevance of our findings, we designed the provided examples to closely mimic existing time-variant tariffs.

Further, we only observe stated tariff demand and stated flexibility in electricity consumption. As the widely studied Intention-Action-Gap shows (e.g., [67]), individuals' (stated) intentions often deviate from their actual behavior. However, in our context, the limited diffusion of time-variant tariffs in Germany inhibits observing actual adoption decisions. Notably, we share this limitation with other studies on tariff choice in the German context [8,11–13]. A question however is, to what extent our stated intentions are generalizable to the actual adoption of time-variant tariffs. Our study was designed to understand the (behavioral economic) determinants of tariff choice and flexible consumption. Since stated intentions are highly positively correlated with actual behaviors, as documented in numerous review papers [67], we expect the same correlations as we observe between our independent variables and stated tariff choice to exist for actual tariff choice.

Another point of discussion is the unexplained variation in tariff adoption. The R-squared in our regression models of Tables 6 and 7 ranges between 16 and 21 %, indicating that between 79 and 84 % of the variation in tariff choice is unexplained. We view two angles to this finding. First, while the low explanatory power of our regression inhibits the reliability of our findings, such R-squared values are commonly observed in similar studies. For example, the variables used in Parag and Butbul [45] are able to explain 31.4 % of the variance of providing demand flexibility, leaving around 70 % unexplained. Nicolson et al. [27] explain 10 % of the variation to switch to a TOU tariff. Second, adding more control variables might on the one hand increase the R-squared, but on the other hand may take away variation that would be explained by our main variables of interest. More specifically, in Table C.1, we control for the willingness to provide flexible consumption in our tariff adoption regressions. As both flexibility choices are highly correlated, the R-shared increases to up to 41 %. However, in Table C.1 we lose the significance of the loss aversion parameter. A likely reason for that loss of significance is that loss aversion also predicts a lower likelihood of providing flexible consumption. Hence, once controlling for this mediator, no variation linking loss aversion to tariff adoption persists.

Very related to this discussion is the risk of potential multicollinearity between the different variables. An analysis of the variance inflation factors of the specifications (3) of Tables 6 and 7 and of specification (4) of Table 8 indicates low multicollinearity between variables (factors below 5), except for the education categories. Yet, our coefficients of interest, the environmental measures, the early adoption of smart technologies, and the economic preferences, stay robust and change little in magnitude and significance whether or not education is included in the regression models. Further, Table E.1 indicates that our main variables of interest, the environmental measures, the adoption of smart technologies and the economic preferences only weakly correlate, with the strongest correlation between the different environmental measures.

Our analyses offer valuable insights for public decision- and policymakers responsible for enhancing demand-side sensitivity in the electricity market. We identify three main implications concerning various aspects of the investigated time-variant tariffs, namely monetary risk, environmental benefits, and the technological complexity associated with these tariffs. Firstly, our regression analysis indicates that loss-averse individuals exhibit a lower willingness to use time-variant tariffs. A promising strategy to mitigate concerns regarding potential excessive cost increases involves implementing safety mechanisms. These mechanisms might include price caps, time-limited trials, or predefined budgets. Such measures could particularly enhance the demand for the most volatile tariffs, which are currently the least favored due to their perceived high potential for 'losses'. Secondly, individuals who support policies aimed at environmental preservation and climate change mitigation are more inclined to adopt the investigated time-variant tariffs. Therefore, emphasizing the environmental advantages of these tariffs could help boost adoption rates and improve demand-side sensitivity. However, this implication needs to be taken with caution as the effects of the treatment highlighting environmental benefits are insignificant. Thirdly, another experimental variation included information on how digital technologies can facilitate the demand-response to time-variant electricity tariffs in households. The findings suggest that this information enhances consumers' willingness to use such tariffs. This is further in line with our estimation results, which show that individuals using smart energy technologies are significantly more likely to be willing to use time-variant tariffs. Hence, promoting and educating the public about technologies supporting the implementation of time-variant tariffs may increase their adoption rates. Leveraging these three recommendations will further increase the willingness to use time-variant tariffs in the German population. To the extent that the willingness, and its determinants as explored in this study, are linked to the actual adoption of time-variant tariffs, these recommendations provide guidance to policy-makers on how to enable demand-side responsiveness that accommodates the fluctuating supply of renewable energy resources and, hence, the required energy system change.

Overall, this paper contributes to our understanding of individual preferences and attitudes towards time-variant electricity tariffs and flexible energy consumption and draws an encompassing picture of individuals showing a relatively high acceptance of demand-side response strategies. The analysis reveals that economic preferences, environmental measures, and smart technology usage play significant roles in shaping individuals' willingness to adopt demand-side measures in the electricity market. We find that individuals with a stronger interest in climate and energy issues, as well as those who support environmental policies, are more inclined to adopt time-variant electricity tariffs and engage in flexible energy consumption. Additionally, individuals with a higher affinity for smart energy technologies are also more willing to use electricity tariffs with time-varying pricing and consume electricity in a more flexible manner. Thus, this paper sets the stage for future research to explore how the promotion of smart energy technologies and a clear communication of climate, energy, and environmental policies can further enhance acceptance and adoption of demand-side measures in energy markets.

CRediT authorship contribution statement

Vincent Weidenbörner: Writing – review & editing, Writing – original draft, Visualization, Validation, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Marvin Gleue:** Writing – review & editing, Writing – original draft, Supervision, Project administration, Methodology, Investigation, Conceptualization. **Christoph Feldhaus:** Supervision, Project administration, Methodology, Conceptualization. **Madeline Werthschulte:** Writing – review & editing, Validation, Formal analysis.

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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.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.erss.2025.103978.

Data availability

Data will be made available on request.

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