Residential flexible electricity demand and comfort boundaries: survey evidence

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Abstract

Flexible electricity demand is crucial for the future of the electricity grid, especially as the use of variable renewable generation grows. One important area of focus is residential flexibility, which aims to better align household electricity consumption with production. However, there is limited understanding of how willing households are to participate in flexibility programs that involve turning off certain appliances during peak hours. This article presents findings from a survey of residential flexibility conducted on 3000 households, half of which were members of a renewable energy cooperative. The study examines respondents' preferences for demand response schemes and compares the responses of cooperative members, who tend to be early adopters of flexibility, to non-cooperative members. Furthermore, the paper presents the results of two choice experiments that explore how respondents make trade-offs when considering flexibility contracts for heat pumps and electric vehicles.

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1 Introduction

To decarbonise its economy, the European Union has set the goal of reaching a 32% share of renewable energy in its gross final energy consumption by the year 2030 (Council of the European Union, 2018), which is expected to result in a much higher share of renewables in the electricity sector specifically. This is the case in Belgium as well, even though its national 2030 target is only 17.5% renewables in gross final energy consumption (CONCERE/ENOVER & CNC, 2019). This shift will require a significant change in the way various actors, including consumers, interact with the electricity system. Households are expected to play a key role in this regard, by using heat pumps (HPs) and electric vehicles (EVs) to participate in demand-response programs (Elia group, 2021). Both of these assets are rapidly proliferating and represent an important share of future (flexible) electricity demand.

Demand-response (DR) programs aim to adjust electricity demand in order to match electricity production, which may come from renewable sources like wind or solar. By doing this, DR can help increase the share of variable renewables in the electricity mix and improve security of supply by reducing the risk of mismatches between production and demand. It can also reduce reliance on fossil-fuelled peak capacity, which further reduces emissions and dependence on imported fuels.

A key question for the future of the electricity grid is the extent to which electricity consumption can be shifted from peak- to off-peak hours. The flexibility potential of households, which can contribute to demand-response programs, can be expressed as being dependent on two factors:

1. The so-called extensive margin of flexibility, which refers to the number of households enrolling in demand-response programs,
2. The intensive margin of flexibility, which refers to the enrolled households' true willingness to shift electricity demand over time.

The distinction between the two margins recognizes that the comfort boundaries of households may affect the amount of load-shifting that is possible. In a DR scheme where a DR operator can remotely control the power consumption of the assets of some households and potentially turn them off during peak hours (also called "Direct load control"), comfort preferences may indeed limit the potential for flexibility. For example, a household that participates in a DR scheme and gives control of their HP to a DR operator may require that a certain minimum temperature be maintained in their home at all times. Hence, in order to consistently estimate the true potential of flexible electricity demand, behaviors need to be accounted for.

Recently, scientific literature has focused on the technical potential of flexibility in DR programs. However, this focus may not be sufficient for evaluating how users perceive the impact of these programs on their comfort and willingness to participate. In addition, the hypothetical nature of flexible electricity demand requires specific research methods to be used, such as choice experiments, in which participants may for example be asked to compare flexible electricity contracts and choose their preferred one, making it possible for the researcher to investigate the trade-offs at play.

Choice experiments are becoming increasingly popular in the context of probing customers' preferences as to innovative electricity contracts. This is probably due to their hypothetical nature, which accomodates well with schemes that do not exist yet. For example, (Richter & Pollitt, 2018), (Ruokamo et al., 2019), (Lehmann et al., 2022), (Hille et al., 2019), (Broberg & Persson, 2016) conduct choice experiments on contracts on general flexibility interventions ; such as heating or general electricity consumption curtailment. However, by focusing primarily on the extensive margin of flexibility, they do not show how flexible electricity contracts would lead to changes in respondents' daily practices, or how users take their comfort (and how it may be impacted) into account when choosing between different types of contracts. On the other hand, (Curtis et al., 2020), (Harold et al., 2021) examine the preferences for flexibility contracts on specific white goods and the latter infers quantitative estimates of money and CO_2 savings achieved by these contracts. However, we suggest that it is important to also examine larger, more energy consuming residential assets like HPs and EVs, as they are likely to play a significant role in the future of the electricity grid and may have an impact on the thermal comfort and range anxiety of households when used for DR purposes. For instance, (Yilmaz et al., 2021) and (Yilmaz et al., 2022) conduct choice experiment on contracts of flexibility interventions on HPs and EVs. Even though our approach and design is similar to theirs, we distinguish our contribution by considering an attribute that aims at offering respondents direct understanding of the way the flexibility contracts have an impact on their comfort levels. Specifically, on the EV maximum driving range or the indoor temperature in DR schemes on HPs. We also further distinguish between the behavioral patterns of early adopters of flexibility contracts (Cooperants) and the General population.

To better understand the extent to which comfort affects flexibility, we study the use of large residential assets (e.g., HPs, EVs, electric boilers) in future DR programs. The goal of this project is to study the following research questions: (i) How can flexible residential assets contribute to the future energy system?; (ii) What factors influence residential flexibility?; and specifically: (iii) How does human behavior limit the technical potential of flexibility? A large collection of data has been collected through surveys to ensure external validity of the findings. This framework allows us to examine the scale-up of flexibility in a way that incorporates real user behavior and accounts for the significant heterogeneity that exists among individuals in terms of flexible asset ownership and comfort preferences.

This paper is structured as follows: Section 2 presents the type of data collected in the surveys and choice experiments ; Section 3 presents the analysis and estimation results and discusses them and Section 4 concludes and introduces the next steps.

2 Data

2.1 Survey data

The data for this research come from a framework of two separate large-scale surveys. In order to consistently estimate the effect of DR programs on both electricity peak reduction and users' comfort levels, the survey questions targeted the following two forms of heterogeneity:

- Capability heterogeneity: As envisioned by Belgium's TSO (Elia group, 2021), EVs and HPs will both play a core role role in the future "consumer-centric market" which will allow for the scaling up of flexibility. However, not every household owns these assets or any other appliance that may be used or enable DR. Therefore, it is important to address the differences in asset's ownership across households so as to estimate how much flexibility on the electricity grid can be achieved in practice.

- User heterogeneity: Preferences and attitudes of both energy cooperative members (who may be considered as early adopters of flexibility programs) and the rest of the population must be studied and compared. Key aspects such as readiness to hand over control over specific appliances to a DR operator but also temperature and driving preferences must be estimated.

To achieve this, two large anonymous online surveys were conducted to gather information on preferences regarding residential flexibility. The surveys were similar to one another and included the following sections: (i) an overview of residential flexibility, (ii) questions about the assets owned by the household of the respondent, (iii) questions about household's energy consumption habits, (iv) questions about the willingness to participate in DR schemes with different assets, (v) two choice experiments on flexibility interventions involving HPs and EVs, (vi) questions about attitudes and preferences, and (vii) sociodemographic information. The structure and content of the surveys was refined based on feedback from previous testing with both members and non-members of energy cooperatives.

The two surveys were taken online on the website Qualtrics[1] during the months of November and December 2022.

- The *cooperants survey* ($N = 1515$ responses) was shared to members of the energy cooperatives Energent[2] (via an email that Energent sent) and Ecopower[3] newsletters' subscribers. These respondents are grouped under the label "Cooperants". In total, 86 % of the Cooperants respondents has answered the survey via Ecopower's email and 14 % via Energent's email.

- The *general population survey* ($N = 1256$ responses) was shared via Prolific[4] to respondents living in Belgium, France, The Netherlands, Germany or Luxembourg. The distribution of responses by country is shown in Table 1.

[1] https://www.qualtrics.com/

[2] Energent is an energy cooperative of approximately 2,000 members, based in Ghent, Belgium. They coordinate projects to promote the use of renewable electricity. https://energent.be/.

[3] Ecopower is a flemish energy cooperative based in Antwerp, Belgium which supplies renewable electricity to its customers. https://www.ecopower.be/.

[4] Prolific is an online platform for online research which allows surveys to be shared with a database of respondents (possibly matching some chosen sociodemographic characteristics) and pay them in exchange for taking a survey. For this survey, the data quality was checked by introducing comprehension and attention checks. https://www.prolific.co/.

General population survey ($N = 1420$)				
BE	FR	NL	DE	LU
18.59%	20.99 %	25.56 %	34.37%	0.49%

Table 1: General population survey: country distribution of the responses

2.2 Description of the respondents pool

In order to assess how the two respondents groups compare, an overview of the sociodemographic characteristics of the respondents pool is presented in Table 2, while Table 3 reports an overview of respondents' dwelling characteristics. We observe that the General population respondents are younger and have a smaller income than Cooperant respondents. In line with the findings from Table 2, we find that the General population includes a higher proportion of tenants and lives in smaller dwellings.

	Cooperants ($N = 1515$)	**General population** ($N = 1420$)
Share men (*)	75.6 %	48.4 %
Share women (*)	23.4 %	49.1 %
Share 18-34 y.o. (*)	4.4 %	73.2 %
Share > 65 y.o. (*)	28.7 %	0.6 %
Share employed full time (*)	47.7 %	47.5 %
Share retired (*)	34.1 %	1.2 %
Share net monthly household income < 2000 €	7.7 %	23.4 %
Share net monthly household income ≥ 4000 €	45.3 %	30.3 %
Share owns shares in an energy cooperative	97.2 %	2.4 %

Table 2: Sociodemographic characteristics of the survey responses. Items labeled (*) refer to the person taking the survey.

	Cooperants ($N = 1515$)	**General population** ($N = 1420$)
Share owners of their dwelling	95.8 %	34.2 %
Share dwelling < 100 m^2	12.0 %	63.6 %
Share dwelling ≥ 200 m^2	17.3 %	4.2 %
Share dwelling built > 2006	18.1 %	14.7 %
Share dwelling has been renovated	68.2 %	33.8 %

Table 3: Characteristics of respondents' dwellings

2.3 Choice experiments on EV and HP interventions

We probed participants' preferences for flexibility contracts by conducting two choice experiments for contracts of interventions on HPs and on EVs. Each respondent was presented with four choice cards for each choice experiment[5] and the choice cards were identical between the General population and the Cooperants group. Every choice card included two potential contracts and the option to opt out, i.e. to select none of the two contracts and move to the next choice card.

In order to minimize the standard errors around parameters estimates, the choice cards of both choice experiments were designed so as to reduce the so-called D_b-error by using the software NGENE (ChoiceMetrics, 2018) to generate a Bayesian D-efficient design with prior values estimated from testing surveys (Hensher et al., 2015). For each choice experiment, a total of 64 choice cards

[5]The order in which the two choice experiments were presented was randomized between the respondents.

Attribute name	Levels	Description
Range	200, 150, 100, 50 [km]	Maximal EV range during and right after an intervention.
Frequency	1, 6, 12, 52	Number of evenly spread interventions on a yearly basis.
Time	PM, Ev., Night, AM	Period at which the interventions start.
€	3, 5, 10, 20 [€]	Monetary compensation per intervention.

Table 4: Choice experiment on interventions on EVs: attributes and levels.

were designed and blocked in 16 blocks ; the respondents (regardless whether they are from the General population or Cooperants group) would be randomly assigned to one of the blocks. The survey was distributed via Qualtrics[6] and the cards were constructed via the procedure in (Weber, 2021).

Finally, to mitigate the hypothetical bias and ensure that the task is well-understood by participants, the survey included an explanatory text on the attributes of the choices respondents were asked to make.

Choice experiment on EV interventions

The different attributes and the levels they take in the EV choice experiment are shown in Table[7] 4. An example of a choice card is given in Fig. 1.

Based on your household's mobility preferences, which of these intervention contracts would you choose for your household?

	Contract A	Contract B	Opt out
Remaining autonomy	100km	150km	No interventions
Compensation per intervention	20 €	10 €	
Start of the interventions	11pm-5am	5am-11am	
Frequency of interventions	Once a week	Once a year	

Figure 1: Example of a choice card for the choice experiment on EV interventions.

Choice experiment on HP interventions

In addition to the choice experiment on interventions on EVs, respondents also took part in a choice experiment on interventions on HPs. The attributes and levels for the choice experiment on HP interventions are shown in Table 5. An example of a choice card for the choice experiment on interventions on HPs is shown in Fig. 2.

3 Results and discussion

3.1 Ownership of flexible assets

Table 6 shows the percentage of ownership of different assets that allow for flexibility among the two groups.

[6]https://www.qualtrics.com/

[7]In order to make it clearer to the respondent in the survey, the values of the attribute *Frequency* were expressed in the choice cards in the following way: "Once a year", "Once every 2 months", "Once a month", "Once a week". Similarly, the values of *Time* were expressed in the survey as: "5 a.m. - 11 a.m.", "11 a.m. - 17 p.m.", "17 p.m. - 23 p.m.", "23 p.m. - 5 a.m.".

Attribute name	Levels	Description
Temperature	19, 18, 17, 16 [°C]	Maximal indoor temperature during an intervention.
Frequency	1, 6, 12, 52	Number of evenly spread interventions on a yearly basis.[15]
Time	PM, Ev., Night, AM	Time at which the interventions start.[18]
€	1, 2, 3, 4 [€]	Monetary compensation per intervention.

Table 5: Choice experiment on interventions on HPs vehicles: attributes and levels.

Based on your household's heating preferences, which of these intervention contracts would you choose for your household?

	Contract A	Contract B	Opt out
Indoor temperature at which the heat pump restarts	17°C	16°C	No interventions
Compensation per intervention	2 €	1€	
Start of the interventions	5 p.m.-11 p.m	5am-11am	
Frequency of interventions	Once a week	Once every two months	

Figure 2: Example of a choice card for the choice experiment on HP interventions.

3.2 Comfort boundaries: thermal comfort and range anxiety

In order to investigate thermal comfort in the survey, participants were asked to report the minimum and maximum indoor temperatures that they find comfortable during the Winter and Summer seasons. The mean results are displayed in Table 7.

We find significant differences in preferences on comfort temperatures across the two groups both in Winter and on the minimum temperature in Summer. Cooperants have narrower temperature comfort boundaries than the General population respondents in Winter. This provides evidence that Cooperants may be more attached to their comfort levels.

To study the range anxiety phenomenom, we surveyed EV owners who reported using their EV as one of their primary modes of transportation (this selects a subset of the sample). We asked them to report the minimum range (in km) that they want to keep available in their vehicle at all times during and right after a flexibility intervention on their EV. The average values are shown in Table 8. We observe that the difference in the average minimum value of EV driving range to ensure comfort amongst EV owners across groups is not significant.

3.3 Attitudes and preferences

Self-assessed knowledge of flexibility-related concepts

Survey respondents were asked to report the knowledge they had over four flexibility-related concepts before starting taking the survey on a scale from 1-4 (Never heard of it - I know a lot about the concept) adapted from (Li et al., 2017). Mean values are reported in Table 9.

We observe that Cooperants report a significantly higher understanding of all of the notions compared to the General respondents, apart from the concept of "Home automation or smart homes". This may be explained by the General population being a younger group, therefore more likely to know about or to have engaged with these new technologies.

Ecological attitudes

The respondents' attitudes towards the environment and energy-saving measures were evaluated. Four items from a Likert scale (1-5: Not agree - Agree) were selected[20] from (Bauwens &

[20] "I want to feel that I am personally contributing to the protection of the environment.", "I am concerned about climate change.", "I am the type of person who cares about the environment.", "I see myself as an environmentally conscious consumer.", cf. (Bauwens & Devine-Wright, 2018).

	Cooperants ($N = 1515$)	General population ($N = 1420$)
Solar panels	68.1 %	16.0 %
Digital meter	39.3 %	50.1 %
Home automation system	24.0 %	27.7 %
Electric boiler (DHW)	22.1 %	51.1 %
HP	17.8 %	14.5 %
EV	15.6 %	5.6 %
Home battery	9.5 %	2.9 %

Table 6: Percentage of ownership of flexibility-enabling assets

(means)	Cooperants	General population	p-value of the difference
Winter, min	19.09 °C (0.04 °C)	18.00 °C (0.08 °C)	< 0.05
Winter, Max	21.65 °C (0.04 °C)	22.41 °C (0.08 °C)	< 0.05
Summer, min	19.34 °C (0.06 °C)	18.39 °C (0.10 °C)	< 0.05
Summer, Max	24.39 °C (0.08 °C)	24.19 °C (0.12 °C)	0.15

Table 7: Average minimum and maximum comfort temperatures in Winter and Summer. The p-values are reported for a two-sample t-test on the equality of the means, with unequal variances.

Devine-Wright, 2018) to assess the respondents' ecological attitudes. The mean values for these four items are shown in Table 10.

As one can expect, Cooperants respondents are significantly higher on the ecological attitudes scale than the General population respondents.

Electricity-saving habits

The respondents' electricity-saving habits were evaluated using nine items selected[21] and adapted from (Herabadi et al., 2021). The respondents were asked to report the self-assessed frequency (scale 1-5: Never - Always) at which they engage in these habits. The mean values for these nine items are shown in Table 11.

In line with the findings from Table 10, we observe in Table 11 that Cooperants report committing to electricity-savings habits more often than the General respondents.

3.4 Degree of control

Respondents were asked to report their willingness to allow a flexibility program to control some of their appliances, as adapted from (Fouad et al., 2022). Examples of flexibility interventions for seven appliances were presented, and respondents were asked to select the level of control they would be willing to hand over to the program[22]. The percentage of responses for each appliance and for each survey is shown in Fig. 3 and 4, with the appliances being grouped as "large domestic systems" and "small appliances" for the sake of clarity.

[21] "I make sure the lights are off before I leave a room.", "I use natural light as a light source.", "I use energy-saving lamps (e.g., LED lamps).", "I unplug the power plug when not in use.", "I turn off PCs/laptops when they are not in use (turned off, not in sleep mode).", "I choose electronic devices (not lighting) that use the least energy even if they are a bit more expensive to purchase.", "I make sure that the refrigerator door is not open too long.", "I set a moderate temperature for my heating system.", "I reduce the use of warm water for bathing (e.g. use cold water in warm/hot weather).", cf. (Herabadi et al., 2021).

[22] Options were: "I wouldn't give control.", "I'm not sure I would give control.", "I would only give control if I can still stop the interventions and be informed of the interventions 1 day in advance (e.g. with an app).", "I would only give control if I can still stop the interventions (e.g. with an app).", "I would give full control (e.g. even without an app)."

(means)	Cooperants ($N = 128$)	General population ($N = 37$)	p-value of the difference
Minimum EV autonomy	159.83 km (86.16 km)	133.38 km (85.26 km)	0.10

Table 8: Average values of the minimum remaining range (in km) that EV owners want to maintain in their vehicles during and right after a flexibility intervention. The p-values are reported for a two-sample t-test on the equality of the means, with unequal variances.

(means)	Cooperants ($N = 1514$)	General population ($N = 1256$)	p-value of the difference
"Energy transition"	3.27 (0.02)	2.53 (0.03)	< 0.05
"Home automation or smart homes"	3.08 (0.02)	3.18 (0.02)	< 0.05
"Electricity flexibility"	2.88 (0.02)	2.10 (0.03)	< 0.05
"Energy cooperatives"	3.35 (0.02)	2.02 (0.03)	< 0.05

Table 9: Self-assessed knowledge by the respondents on different concepts before taking the survey (scale 1-4: Never heard of it - I know a lot about the concept, adapted from (Li et al., 2017)). The p-values are reported for a two-sample t-test on the equality of the means, with unequal variances.

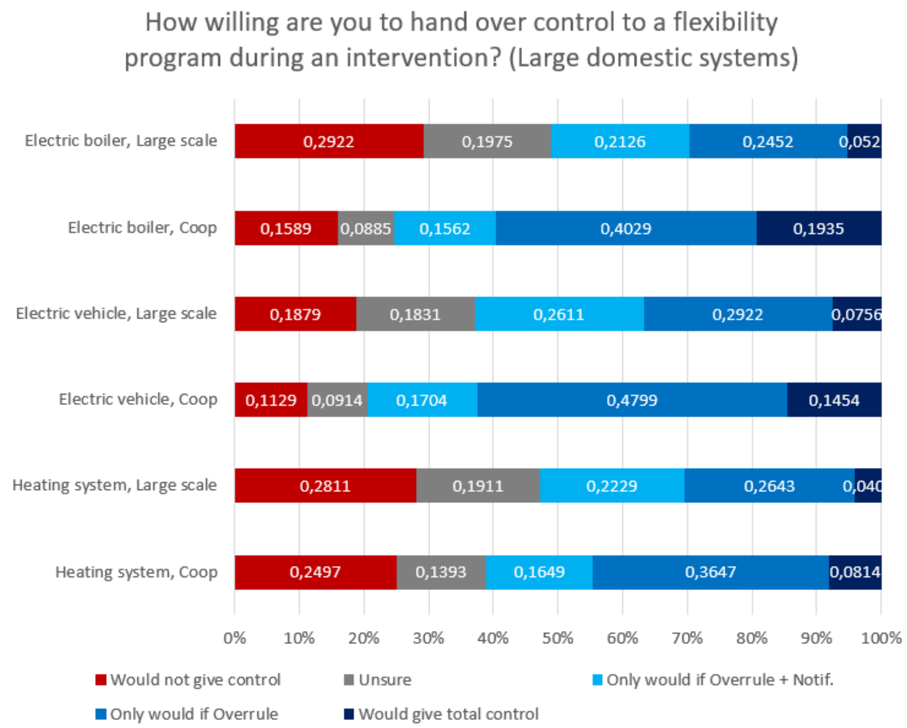

Figure 3: Willingness to cede control over an appliance (domestic systems) to a flexibility program: percentage of responses

We observe that survey respondents who are cooperative members seem to be more willing to allow a flexibility program to control their larger domestic appliances than their small appliances compared to the general population ("large scale") survey respondents. However, the opposite trend was observed for smaller appliances.

3.5 Likelihood to enroll

The study participants were asked about their willingness to enroll in a demand-response program if offered the opportunity. The frequency of responses to this question is presented in Fig. 5. A

Cooperants ($N = 1512$)	General population ($N = 1256$)	p-value of the difference
4.29 (0.01)	3.91 (0.02)	<0.05

Table 10: Measure of the ecological attitude of the respondents, based on (Bauwens & Devine-Wright, 2018). The p-values are reported for a two-sample t-test on the equality of the means, with unequal variances.

Cooperants ($N = 1514$)	General population ($N = 1256$)	p-value of the difference
4.25 (0.01)	3.90 (0.02)	< 0.05

Table 11: Measure of the frequency at which respondents perform electricity-saving habits, based on (Herabadi et al., 2021). The p-values are reported for a two-sample t-test on the equality of the means, with unequal variances.

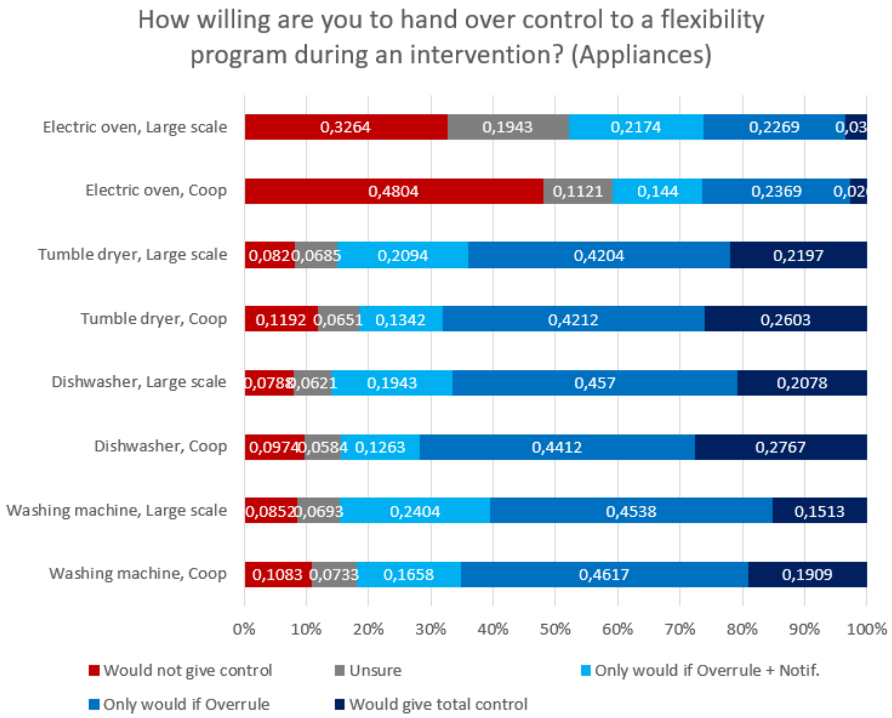

Figure 4: Willingness to cede control over an appliance to a flexibility program: percentage of responses

Fisher's exact test revealed that the responses from the two groups were significantly different at $p < 0.05$.

The responses from the two groups showed that a lower percentage of cooperative members reported being unlikely to enroll in demand-response (9.6%) compared to the general population (13.8%), while a higher percentage of cooperative members reported being likely to enroll (73.5% and 66.3%). This suggests that cooperative members may be more likely to exhibit higher flexibility potential compared to non-energy cooperative members.

3.6 Factors explaining the decision (not) to enroll

The decision-making process behind the participants' likelihood to enroll was examined through the importance that respondents assigned to certain motivating factors (Likert 1-5: Not important at all - Extremely important) adapted from (Fouad et al., 2022) and (Ferreira et al., 2022). The results, including only the data from participants who indicated that they would be "Somewhat likely" or "Extremely likely" to enroll, are presented in Table 12.

Table 13 displays the results for the motivation factors (adapted from (Fouad et al., 2022) and

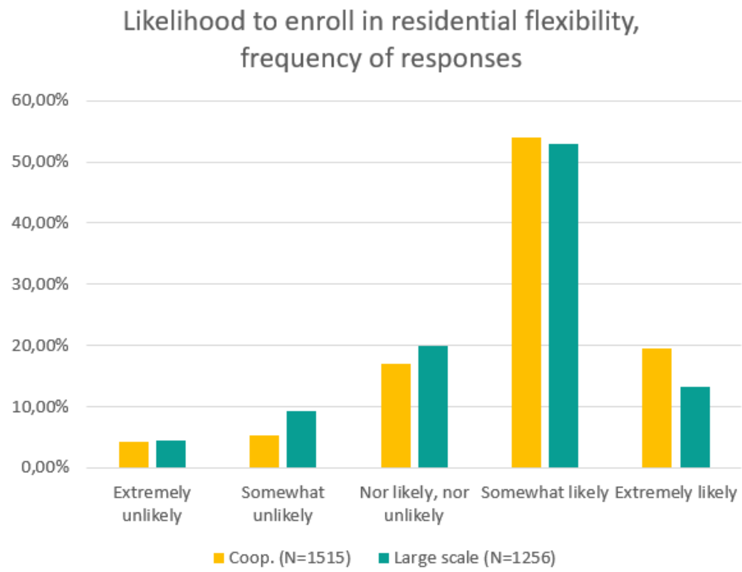

Figure 5: Frequency of responses: "If offered, how likely are you to enroll in a flexibility program?"

(Ferreira et al., 2022)) behind participants' decision not to enroll, including only the data from those who indicated that they would be "Somewhat unlikely" or "Extremely unlikely" to enroll.

Why enroll? (means)	Cooperants ($N = 1113$)	General population ($N = 832$)	p-values of the difference
Contribution to the environment	**4.28 (0.81)**	**4.24 (0.81)**	**0.29**
Contribution to the energy independence of [my country]	**3.96 (0.98)**	**3.74 (0.94)**	**<0.05**
Contribution to the grid stability	**3.92 (0.87)**	**3.77 (0.85)**	**<0.05**
Experimenting with new technologies	3.19 (1.16)	3.02 (1.14)	<0.05
Increase in comfort (through automation)	2.76 (1.12)	3.08 (1.10)	<0.05
Monetary compensation	2.70 (1.02)	3.67 (0.99)	<0.05
On the advice of an acquaitance	1.91 (0.99)	2.51 (1.01)	<0.05

Table 12: Means of Likert 1-5 (Importance) assigned to factors driving enrollment in residential flexibility (excluding neutral answers), based on (Fouad et al., 2022) and (Ferreira et al., 2022). The p-values are reported for a two-sample t-test on the equality of the means, with unequal variances.

We find that both groups identified the same factors as influential in their decision to enroll, but assign statistically different levels of importance to these factors. However, there is no statistical difference in the importance assigned to monetary compensation or contribution to energy independence by the general population. This suggests that monetary compensation plays a more significant role in the decision-making process for this group, while it is less important for the cooperants group.

This indicates that both groups recognize the societal benefits of flexibility, such as the contribution to the environment, energy independence, and grid stability, but are motivated differently by the same factors. The general population shows a greater emphasis on monetary compensation.

From Table 13, we observe that both groups perceive residential flexibility as a (strong) reduction of comfort and a loss of control over their assets. We do not find any statistical difference in the importance assigned to these two factors. This can be due to the fact that by the selection of the cooperative members who do not wish to enroll, we end up considering a pool that shares more

Why decline to enrol? (means)	Cooperants ($N = 145$)	General population ($N = 173$)	p-values of the difference
Reduction of comfort	**4.30 (0.92)**	**4.40 (0.83)**	**0.31**
Loss of control over the assets	**3.72 (1.11)**	**3.90 (1.10)**	**0.14**
Concerns about the stability of the internet	**3.26 (1.36)**	**3.80 (1.29)**	**<0.05**
Lack of information	3.11 (1.30)	3.38 (1.21)	0.06
Concerns about damaging the asset, warranty or lifespan	2.86 (1.37)	3.13 (1.27)	0.07
Too low monetary compensation	2.56 (1.33)	3.25 (1.26)	<0.05

Table 13: Means of Likert 1-5 (Importance) assigned to factors driving not enrolling in residential flexibility (excluding neutral answers), based on adapted (Fouad et al., 2022) and (Ferreira et al., 2022). The p-values are reported for a two-sample t-test on the equality of the means, with unequal variances.

similar characteristics to the general population. However, the larger standard errors should be noted here, which are caused by the smaller sample size (because of this selection) than in Table 12. Both groups report a fairly large importance assigned to the concerns about the stability of the internet.

3.7 Choice experiment on interventions on EVs

3.7.1 Model specification in the Preference space

To analyze the choice experiment on EV interventions, we take the utility specification given by equation (1).

$$\begin{aligned}
U_{EV} =& \beta_{ASC} \times ASC + \beta_{€} \times €+ \\
&+ \beta_{Range_{150}} \times Range_{150} + \beta_{Range_{100}} \times Range_{100} + \beta_{Range_{50}} \times Range_{50}+ \\
&+ \beta_{Freq_6} \times Freq_6 + \beta_{Freq_{12}} \times Freq_{12} + \beta_{Freq_{52}} \times Freq_{52}+ \\
&+\beta_{Time_{Evening}} \times Time_{Evening} + \beta_{Time_{Night}} \times Time_{Night} + \beta_{Time_{AM}} \times Time_{AM}
\end{aligned} \tag{1}$$

Where the attribute $Time$ is categorical and is therefore dummy coded (with base level PM). The price attribute € is left continuous. The attributes *Range* and $Frequency$ are dummy coded (with base levels 200 km and 1 intervention a year) so as to study possible nonlinearities in preferences. The resulting utility specification in the Preference space is given by eq. (1). Finally, the alternative-specific constant ASC includes the baseline utility as well as the utility of the base levels of the parameters *Range*, $Time$ and $Frequence$: i.e. the utility derived from a contract of one single intervention a year, limiting the EV range to 200 km and starting in the afternoon, all else being equal. In other words, ASC captures the variation in utility that respondents associate with choosing any flexibility contract with a single 200 km intervention starting in the afternoon, over opting out.

The model given by equation (1) is estimated via a Mixed Logit model, a variant of the Multinomial Logit models which allows for randomly distributed parameters. That is, Mixed Logit models take heterogeneity in preferences across respondents into account by by allowing the analyst to estimate both the mean and the standard deviation of the effects of the attributes (Hensher et al., 2015). The model is estimated via a (pseudo)log-likelihood maximization in Stata 16 with the `mixlogit` command (Hole, 2007). The number of Halton draws for simulating the log-likelihood function has been set to 1,000. All parameters are assumed normally distributed but the monetary compensation parameter, which is assumed lognormally distributed[23]. The Table 14 presents the results for both the Cooperants and General population groups as well as the p-values for testing the equality of mean and standard deviations estimates across the groups.

[23]We report the mean and SD estimates of the monetary compensation coefficient itself.

(Preference space)	(1) General population				(2) Cooperants				(3) p-value of the difference	
	Mean		SD		Mean		SD		Mean	SD
ASC	2.74***	(0.29)	3.67***	(0.25)	5.74***	(0.57)	7.48***	(0.57)	0***	1.00
€	0.13***	(0.01)	0.19**	(0.06)	0.34**	(0.11)	4.23	(3.65)	0***	1.00
Range_{150}	-0.08	(0.09)	1.21***	(0.17)	-0.08	(0.09)	1.29***	(0.19)	0.40	0.99
Range_{100}	-0.37***	(0.09)	0.67**	(0.23)	-0.37***	(0.10)	0.64**	(0.22)	0.24	0.05
Range_{50}	-1.97***	(0.18)	1.94***	(0.21)	-1.68***	(0.17)	1.89***	(0.22)	0***	0.13
Freq_{6}	-0.03	(0.16)	0.97***	(0.24)	-0.07	(0.17)	1.23***	(0.25)	0***	1.00
Freq_{12}	0.44**	(0.16)	0.42	(0.31)	0.32*	(0.16)	0.04	(0.13)	0***	0***
Freq_{52}	0.45**	(0.15)	1.01***	(0.15)	0.51***	(0.14)	0.68***	(0.19)	0***	0***
Time_{Ev}	-0.13	(0.16)	0.98***	(0.25)	0.02	(0.17)	0.42	(0.67)	0***	0***
$\text{Time}_{\text{Night}}$	0.06	(0.15)	0.92***	(0.19)	0.33*	(0.15)	0.53	(0.28)	0***	0***
Time_{AM}	0.08	(0.14)	0.32	(0.25)	0.13	(0.15)	0.24	(0.34)	0***	0***
N resp.	1,420				1,515					
N obs.	17,040				18,180					
LL	-4614.84				-4571.07					
ρ	0.11				0.10					
AIC	9273.68				9186.13					
BIC	9444.04				9357.91					

Table 14: Mixed logit estimates for the choice experiment on EV interventions in the Preference space. The standard errors are clustered on respondents and shown in parentheses. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$. Column (3) shows the p-values for a two-tailed t-test Welch's test (for equality in means) and a two-tailed F-test (for equality in variances). The goodness-of-fit parameter ρ is McFadden's pseudo-R^2 where the null model is taken as the mixed logit model estimated with the mean and SD of the intercept ASC as only parameters.

Interpretation of the results in the Preference space

***ASC* intercept**

As mentioned above, as *Range*, *Frequency* and *Time* are dummy coded, the intercept captures the utility difference between a contract offering 1 intervention a year, with the intervention starting in the afternoon and limiting the EV range at 200 km, over no contract at all (the monetary compensation attribute being held constant). As a result of the base levels of the dummy-coded parameters being captured in the utility, the ASC's sign is not interpretable in terms of respondents preferences in choosing a contract (for any level of the attributes) over not choosing a contract.

€ parameter

First, we observe that the € is positive (and significant) for both groups, as is expected from economic theory. We find significant differences between the two groups. For the General population group, we find $\beta_{€} = 0.13$, which means that each additional € of monetary compensation per intervention increases the odds of the contract being selected by the respondent by approximately 14%. The marginal effect of a € is much larger for the Cooperants group, being equal to 0.34 or, similarly, increasing the odds of a contract to be selected by approximately 40%. Therefore, the Cooperants group is more money-driven than the General population group. This may be related to a higher income of the Cooperants, as shown in Table 2. As is shown by the SD estimates, the effect of one additional € varies significantly across the General population but not across the Cooperants group, which can therefore be considered homogeneous on that parameter.

Range parameters

As the *Range* parameters are dummy coded with base level Range_{200}, they each represent the variation in utility between a contract offering 200 km of EV range limit and a contract offering any other given level of Range, all other attributes being held constant. As the mean value of the Range_{150} parameter is not significant for both respondents groups, the average respondent is indifferent to having 150 km or 200 km range limit on their EV. There is, however, evidence of significant variation in preferences around that mean value for both groups, as is shown by the SD estimate for Range_{150}. The p-values in the third column of Table 14 show that the null hypothesis of both groups showing similar preferences and heterogeneity for the Range_{150} parameter cannot be rejected. On the opposite, the mean and SD estimates for the Range_{100} and Range_{50} parameters show significant decreases in utility as well as significant variation in tastes in both groups.

To further study the Range parameters, we follow the procedure in (Hensher et al., 2005) and conduct a Wald test on the differences in estimates across levels to determine whether Range is better specified linearly. This assesses whether the utility gain from each additional km of EV range depends on the range itself. The results of the Wald tests for both groups are shown in Table 15. As observed, the p-values of the test are < 0.0001 for both groups. This provides evidence that respondents' preferences with regard to EV range limit in the context of flexibility interventions does not evolve linearly. This may reflect the range anxiety phenomenon. Finally, we observe that the range anxiety is smaller in the Cooperants group, which might be partly explained by the larger share of EV owners in that group compared to the General population group. It may show that range anxiety is less predominant amongst EV owners.

	General population		Cooperants	
$\frac{1}{50}\left(\beta_{\text{Range}_{150}} - \beta_{\text{Range}_{100}}\right)$	0.032***	(0.003)	0.026***	(0.003)
$\frac{1}{50}\left(\beta_{\text{Range}_{100}} - \beta_{\text{Range}_{50}}\right)$	0.006**	(0.002)	0.006**	(0.002)
$\frac{1}{100}\left(\beta_{\text{Range}_{150}} - \beta_{\text{Range}_{50}}\right)$	0.019***	(0.000)	0.016***	(0.002)
$\chi^2(1)$	51.68***		36.14***	
p-value	< 0.0001		< 0.0001	

Table 15: Wald test on the linearity of the *Range* parameter ; choice experiment on EV interventions. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

Frequency **parameters**

As observed with the insignificant parameter for β_{Freq_6}, respondents in both groups are indifferent to contracts offering one or six interventions on their EV a year, all other contract's attributes being held constant. The significantly positive signs for $\beta_{\text{Freq}_{12}}$, $\beta_{\text{Freq}_{52}}$ show that respondents from both groups associate a higher frequency of flexibility interventions on their EV with a gain in utility. This can be partly explained by a strategy to maximize monetary benefits by choosing a contract with a larger number of interventions. The variations in tastes are significant for β_{Freq_6} and $\beta_{\text{Freq}_{52}}$ as the SD estimates show. On the opposite, the preferences for $\beta_{\text{Freq}_{12}}$ do not significantly vary in both groups, i.e. all respondents agreed to equally value utility derived from 1 intervention a month, all other attributes being held constant.

This provides evidence that respondents are in favor of more frequent interventions. To further study this effect, we test the counterfactual linear specification of the *Frequency* attribute via a Wald test, similarly as before. The results of the test are shown in Table **??** and allow us to reject the null hypothesis of the linear specification. Therefore, from the estimates in Table 14, we observe that the utility derived from the marginal intervention on a yearly basis diminishes with the frequency of interventions, which is consistent with economic theory.

Time **parameters**

The mean estimates for the $Time_{\text{Ev.}}$ and $Time_{\text{AM}}$ parameters are insignificant for both respondent groups, which means that the average respondent does not favor interventions starting in the evening or morning over interventions starting in the afternoon (base level for the dummy coding). The estimate for $Time_{\text{Night}}$ is significant for the the Cooperants group, with a mean value of 0.33 (i.e. an increase of 39% on the odds of selecting a contract). In other words, Cooperants significantly prefer interventions on their EV which start at night. This coincides with the moment

	General population		Cooperants	
$\frac{1}{6}\left(\beta_{\text{Freq}_{12}} - \beta_{\text{Freq}_6}\right)$	0.07851***	(0.01822)	0.06476**	(0.01889)
$\frac{1}{40}\left(\beta_{\text{Freq}_{52}} - \beta_{\text{Freq}_{12}}\right)$	0.00014	(0.00213)	0.00468*	(0.00204)
$\frac{1}{46}\left(\beta_{\text{Freq}_{52}} - \beta_{\text{Freq}_6}\right)$	0.01036***	(0.00234)	0.01252***	(0.00241)
$\chi^2(1)$	16.69***		9.23**	
p-value	< 0.0001		0.0024	

Table 16: Wald test on the linearity of the *Frequency* parameter ; choice experiment on EV interventions. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

where most EVs are likely to be connected to the electricity grid, i.e. when the flexibility potential is the highest.

3.7.2 Model specification in the WTP space

The model (1) can be estimated in the willingness-to-pay space to derive estimates which directly represent the marginal rates of substitution between a given parameter and the monetary compensation. This procedure offers the advantage of presenting WTP estimates which are more precise than taking ratios of estimates in the Preference space cf. (Hensher et al., 2015). To estimate this model, we use the command `mixlogitwtp` (Hole, 2015) on the nonlinear specification of *Range* and *Frequency*, as taken above. The results are presented in Table 17.

The specification is selected as the same one as above and, in particular, *Range* and *Frequency* remain dummy-coded.

Interpretation of the results in the WTP space

***ASC* intercept**
The *ASC* estimate captures both the inherent monetary trade-off between choosing a flexibility contract over not choosing any (all contract's attributes being else constant) as well as the marginal rates of substitution between the base levels of the dummy-coded parameters (i.e. $Range_{200}$, $Frequency_1$ and $Time_{PM}$) and the monetary attribute €. For that reason, its value cannot be clearly interpreted in terms of these different contributions separately.

€ parameter
In the WTP space, the mean and SD estimates of the monetary attribute are not expressed in terms of WTPs and have the same interpretation as in the Preference space (cf. Table 14).

***Range* parameters**
As in the Preference space, we observe that the average respondent is indifferent between having 150 km or 200 km of EV range limit, as is shown by the insignificant parameters in both groups. Further, respondents are willing to trade-off a 100 km decrease from 200 km down to 100 km of EV range limit during flexibility interventions with an average monetary compensation of 3.52 € for the General population group or 4.31 € for the Cooperants group. The trade-off is substantially larger when it comes to compensate a 150 km EV range limit decrease (from 200 km to 50 km) as respondents require on average 19.14 € of monetary compensation (General population) or 18.08 € (Cooperants group). These mean estimates are significantly different, as is shown in the third column of Table 17.

The marginal value of a km of EV driving range is estimated in Table 18 by computing the differences in the *Range* parameters estimates across levels. The marginal value of a km of driving range drops from 0.31 € (for 1 km of driving range between 100 and 150 km of range limit) to 0.06 € (for 1 km of driving range between 50 and 100 km range limit) for the General population group. Regarding the Cooperants group, this marginal value drops from 0.28 € to 0.07 €. Besides, as shown by the *p*-values for the Wald test in equality of the differences in estimates, the *Range* attribute is better specified non-linearly in the WTP space as well.

(WTP space)	(1) General population				(2) Cooperants				(3) p-value of the difference	
	Mean		SD		Mean		SD		Mean	SD
ASC	32.51***	(3.93)	39.95***	(3.34)	83.56***	(11.27)	101.28***	(11.18)	0***	1.00
€	0.16**	(0.05)	0.16	(0.10)	0.11***	(0.02)	0.07	(0.04)	0***	0***
$Range_{150}$	-0.52	(0.87)	12.11***	(1.70)	-0.71	(0.94)	14.39***	(2.24)	0***	1.00
$Range_{100}$	-3.52***	(0.83)	8.89***	(1.76)	-4.31***	(0.91)	9.19***	(1.80)	0***	0.90
$Range_{50}$	-19.14***	(1.53)	19.31***	(2.24)	-18.08***	(1.53)	22.12***	(2.23)	0***	1.00
$Freq_{6}$	0.15	(1.60)	9.19***	(1.86)	0.39	(1.82)	11.16***	(2.20)	0***	1.00
$Freq_{12}$	5.08**	(1.56)	2.80	(1.67)	4.18*	(1.77)	3.54*	(1.75)	0***	1.00
$Freq_{52}$	5.24***	(1.46)	10.16***	(1.43)	6.18***	(1.69)	7.72***	(2.04)	0***	0***
$Time_{Ev}$	-1.68	(1.54)	9.61***	(2.23)	-0.88	(1.79)	4.23	(2.57)	0***	0***
$Time_{Night}$	-0.25	(1.44)	8.96***	(1.55)	1.94	(1.73)	5.54*	(2.27)	0***	0***
$Time_{AM}$	0.22	(1.44)	1.87	(2.74)	-0.43	(1.68)	0.50	(0.93)	0***	0***
N resp.	1,420				1,515					
N obs.	17,040				18,180					
LL	-4626.78				-4603.33					
AIC	9297.57				9250.65					
BIC	9467.92				9422.43					

Table 17: Mixed logit estimates for the choice experiment on EV interventions in the WTP space. The standard errors are clustered on respondents and shown in parentheses. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$. Column (3) shows the p-values for a two-tailed t-test Welch's test (for equality in means) and a two-tailed F-test (for equality in variances).

	General population		Cooperants	
$\frac{1}{50}\left(\beta_{\text{Range}_{150}} - \beta_{\text{Range}_{100}}\right)$	0.313***	(0.032)	0.275***	(0.030)
$\frac{1}{50}\left(\beta_{\text{Range}_{100}} - \beta_{\text{Range}_{50}}\right)$	0.060**	(0.017)	0.072***	(0.020)
$\frac{1}{100}\left(\beta_{\text{Range}_{150}} - \beta_{\text{Range}_{50}}\right)$	0.0186***	(0.017)	0.174***	(0.016)
$\chi^2(1)$	43.55***		28.28***	
p-value	< 0.0001		< 0.0001	

Table 18: Wald test on the linearity of the *Range* parameter ; choice experiment on EV interventions in the WTP space. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

Frequency **parameters**

The estimates for the *Frequency* parameters in the WTP space reflect the tendencies observed in the Preference space. First, the average respondents from both groups are indifferent to a contract offering 1 or 6 interventions in a yearly basis as is shown by the insignificant WTP estimate for $Freq_6$. Second, WTP estimates for $Freq_{12}$ and $Freq_{52}$ are significant and positive, which provides evidence that respondents are ready to trade-off a lower monetary compensation in exchange for a higher number of interventions.

To further study these trade-offs, Table 19 shows the differences in the *Frequency* parameters estimates across levels. The average value of a marginal intervention equals 0.82 € (General population) or 0.63 € (Cooperants) between six and twelve interventions a year. The value drops to 0 € (General population) or 0.11 € (Cooperants) between 12 and 52 interventions a year. This is in line with respondents adopting a strategy to maximize yearly revenues (from DR schemes) which reveals diminishing returns. Furthermore, the *p*-values for the Wald test of the equality in the parameters differences in Table 19 confirm the non-linear specification for *Frequency*.

	General population		Cooperants	
$\frac{1}{6}\left(\beta_{\text{Freq}_{12}} - \beta_{\text{Freq}_{6}}\right)$	0.8224***	(0.1753)	0.6321**	(0.1864)
$\frac{1}{40}\left(\beta_{\text{Freq}_{52}} - \beta_{\text{Freq}_{12}}\right)$	0.0040	(0.0218)	0.0499*	(0.0233)
$\frac{1}{46}\left(\beta_{\text{Freq}_{52}} - \beta_{\text{Freq}_{6}}\right)$	0.1107***	(0.0262)	0.1259***	(0.0251)
$\chi^2(1)$	20.33***		8.79**	
p-value	< 0.0001		0.0030	

Table 19: Wald test on the linearity of the *Frequency* parameter ; choice experiment on EV interventions in the WTP space. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

Time **parameters**

Table 17 shows that WTP estimates for the *Time* parameters are insignificant in both groups. This is in line with what is observed in the Preference space: the respondents' comfort is largely unaffected by the different starting times of flexibility interventions on EVs. As a result, respondents do not need any money to compensate for potential utility losses from one timeslot to the other. In the WTP space as well, the Cooperants group acts as one homogeneous group, with no variation in the WTP estimate for interventions starting at night (as shown by the SD estimate for $Time_{\text{Ev.}}$).

3.8 Modeling WTP in the population: integrating users' preferences in EV DR schemes

The estimates in Table 17 can be conditioned on a respondent's particular choice patterns so as to obtain them at the level of a specific individual (Hensher et al., 2015). This is done in Stata via the `mixlbeta` post-estimation command (Hole, 2015). The individual estimates for the *Range* and *Frequency* are plotted in Fig. 6 and 7 using the Epanechnikov kernel density to visualize the variations in WTPs in the population.

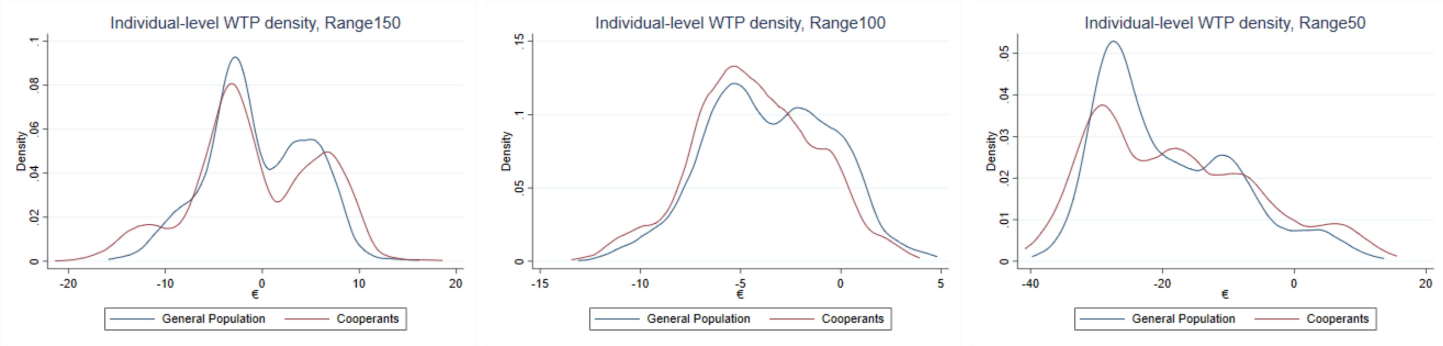

Figure 6: Individual-level WTP density, Range parameters (choice experiment on EVs)

Fig. 6 represents the distribution of the WTP estimates for the $Range_{150}$ parameter. It is found to be insignificant in Table 17. We indeed observe that the density is centered around 0 €, with some respondents showing positive $Range_{150}$. This may be because some respondents might be relatively insensitive to this level of EV range limitation[24] and would therefore see it as a way of receiving money without being affected. The WTP density for Cooperants is slightly more skewed to higher positive WTPs than the General population density. The WTP densities for $Range_{100}$ and $Range_{50}$ are more skewed to negative WTPs, in line with that behavior.

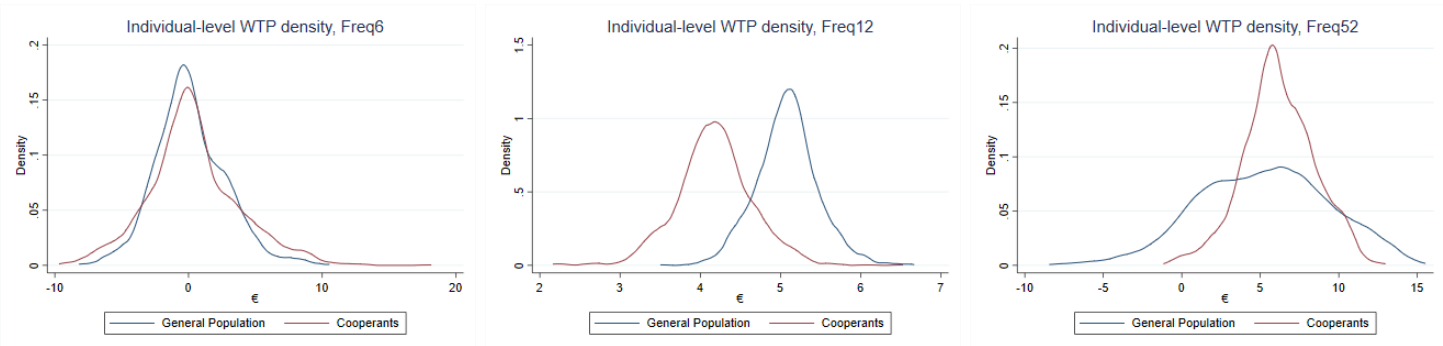

Figure 7: Individual-level WTP density, Frequency parameters (choice experiment on EVs)

Fig. 7 shows the WTP densities for the levels of the *Frequency* attribute. The density for $Freq_6$ is clearly centered around 0 €, which is consistent with the insignificant parameter in Table 17. The WTP estimates for $Freq_{12}$ substantially differ across the two groups with the General population respondents ready to trade-off more money for a higher number of interventions in a flexibility contract. This conclusion does not hold when considering the WTP densities for $Freq_{52}$, as the variation in preferences for the General population group is much larger than for the Cooperants group.

3.9 Choice experiment on interventions on HPs

3.9.1 Model specification in the Preference space

As similarly to the model specification of the choice experiment on EVs, we analyze the choice experiment on HP interventions using the utility specification given by equation (2) in the Preference space. All the parameters are dummy-coded but the monetary compensation attribute € and the intercept *ASC*. The base level of *Temperature* is set to 19 °C and the base levels of *Frequency* and *Timing* are the same as for the choice experiment on EV interventions (i.e. respectively 1 intervention a year and interventions starting in the afternoon).

[24]It could be the case if, for example, the respondent drives on average over less distance or shows less range anxiety due to being more accustomed to the use of an EV.

(Preference space)	(1) General population				(2) Cooperants				(3) p-value of the difference	
	Mean		SD		Mean		SD		Mean	SD
ASC	2.45***	(0.28)	3.55***	(0.24)	2.32***	(0.31)	5.18***	(0.34)	0***	1.00
€	0.48***	(0.07)	1.13*	(0.52)	0.36	(0.24)	1.33	(3.44)	0***	1.00
Temp_{18}	-0.42***	(0.08)	0.89***	(0.19)	-0.47***	(0.11)	1.40***	(0.21)	0***	1.00
Temp_{17}	-1.07***	(0.12)	1.17***	(0.17)	-1.27***	(0.16)	1.51***	(0.22)	0***	1.00
Temp_{16}	-1.90***	(0.16)	1.52***	(0.20)	-2.26***	(0.27)	1.60***	(0.30)	0***	0.98
Freq_{6}	0.31	(0.17)	0.85**	(0.26)	0.29	(0.18)	0.76*	(0.31)	0***	0***
Freq_{12}	0.49**	(0.16)	0.65*	(0.26)	0.50**	(0.18)	0.65	(0.35)	0.01*	0.36
Freq_{52}	0.78***	(0.15)	0.89***	(0.15)	0.77***	(0.17)	0.93***	(0.19)	0.01*	0.96
Time_{Ev}	-0.34*	(0.16)	0.87**	(0.28)	-0.23	(0.18)	0.76*	(0.31)	0***	0***
$\text{Time}_{\text{Night}}$	0.27	(0.14)	0.42	(0.33)	0.93***	(0.16)	0.97***	(0.21)	0***	1.00
Time_{AM}	0.10	(0.14)	0.88***	(0.16)	0.36*	(0.15)	0.62*	(0.30)	0***	0***
N resp.	1,420				1,515					
N obs.	17,040				18,180					
LL	-4788.73				-4994.50					
ρ	0.08				0.09					
AIC	9621.45				10033.00					
BIC	9791.8				10204.78					

Table 20: Mixed logit estimates for the choice experiment on HP interventions in the Preference space. The standard errors are clustered on respondents and shown in parentheses. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$. Column (3) shows the p-values for a two-tailed t-test Welch's test (for equality in means) and a two-tailed F-test (for equality in variances).

$$\begin{aligned} U_{EV} = & \beta_{ASC} \times ASC + \beta_{€} \times € + \\ & + \beta_{Temp_{18}} \times Temp_{18} + \beta_{Temp_{17}} \times Temp_{17} + \beta_{Temp_{16}} \times Temp_{16} + \\ & + \beta_{Freq_6} \times Freq_6 + \beta_{Freq_{12}} \times Freq_{12} + \beta_{Freq_{52}} \times Freq_{52} + \\ & + \beta_{Time_{Evening}} \times Time_{Evening} + \beta_{Time_{Night}} \times Time_{Night} + \beta_{Time_{AM}} \times Time_{AM} \end{aligned} \tag{2}$$

The estimation proceeds as before, with 1,000 Halton draws to simulate the log-likelihood function and all parameters being assumed normally distributed but the price coefficient that is assumed lognormally distributed. The `mixlogit` (Hole, 2007) estimation results in the Preference space and for both respondents groups are presented in Table 20.

Interpretation of the results in the Preference space: nonlinear specification

Temperature **parameters**

We first examine the *Temperature* parameters. The signs for all *Temperature* estimates is consistent with what to be expected: as all estimates are negative, the average respondent associates the indoor temperature decrease from 19 °C (base level) to 18 °C, 17 °C or 16 °C as a decrease in utility, i.e. a comfort loss. All estimates for the mean parameters are significantly different across the two groups. This is consistent with the significant differences observed for the temperature preferences in Winter in Table 7: Cooperants prefer higher minimum temperatures. There is signification variation in preferences for all *Temperature* estimates and it cannot be rejected that they are similar in magnitudes across the two groups.

Analogous to the analysis performed on the estimates of the choice experiment on EV interventions, Table 21 conducts a Wald test on the equality of the differences in parameter estimates. Namely, the linearity of the *Temperature* parameters is being assessed by testing whether the utility variation between 17 °C and 18 °C is statistically equivalent to the utility variation between 16 °C and 17 °C. As the p-values in Table 21 show, we fail to reject the null hypothesis of a linear specification of the $Temperature$ parameters of both groups.

	General population		Cooperants	
$\beta_{\text{Temp}_{18}} - \beta_{\text{Temp}_{17}}$	0.656***	(0.103)	0.801***	(0.127)
$\beta_{\text{Temp}_{17}} - \beta_{\text{Temp}_{16}}$	0.829***	(0.118)	0.983**	(0.175)
$\frac{1}{2}\left(\beta_{\text{Temp}_{18}} - \beta_{\text{Temp}_{16}}\right)$	0.743***	(0.071)	0.892***	(0.112)
$\chi^2(1)$	1.03		0.77	
p-value	0.31		0.38	

Table 21: Wald test on the linearity of the *Range* parameter in the Preference space ; choice experiment on HP interventions. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

$Frequency$ **parameters**

The survey takers' response to the $Frequency$ parameters is in line with what was observed for the same attribute in the choice experiment on EV interventions. First, $Freq_6$ being non significant for both groups means that respondents are indifferent to a yearly number of interventions of 1 or 6. Second, both other $Frequency$ parameters estimates are significant and positive.

To further examine how the marginal value of an intervention evolves with the frequency of interventions, we compute in Table 22 the differences in $Frequency$ estimates across levels. We observe from the p-values of a Wald test on the differences across levels that the differences across two levels of $Frequency$ cannot be rejected to be equal. In other words, and for both groups, a linear specification of $Frequency$ is capable to retain respondent's choice patterns just as good.

	General population		Cooperants	
$\frac{1}{6}\left(\beta_{\text{Freq}_{12}} - \beta_{\text{Freq}_{6}}\right)$	0.0293	(0.0173)	0.0361	(0.0185)
$\frac{1}{40}\left(\beta_{\text{Freq}_{52}} - \beta_{\text{Freq}_{12}}\right)$	0.0075***	(0.0021)	0.0067**	(0.0025)
$\frac{1}{46}\left(\beta_{\text{Freq}_{52}} - \beta_{\text{Freq}_{6}}\right)$	0.0103***	(0.0021)	0.0105***	(0.0024)
$\chi^2(1)$	1.40		2.20	
p-value	0.24		0.14	

Table 22: Wald test on the linearity of the $Frequency$ parameter in the Preference space ; choice experiment on HP interventions. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$.

As $Temperature$ and $Frequency$ are found to be just as well specified linearly, we estimate the model specification given by equation (3) which is more parsimonious while retaining as much information as equation (2). This is a fundamental difference in respondents' behavior between choice experiment on EV and HP interventions. The results for this preferred specification estimated via a Mixed Logit model with the same number of draws and distribution assumptions are shown in Table 23.

$$\begin{aligned} U_{EV} = &\beta_{ASC} \times ASC + \beta_{€} \times € + \beta_{Temp} \times Temp + \beta_{Freq} \times Freq + \\ &+\beta_{Time_{Evening}} \times Time_{Evening} + \beta_{Time_{Night}} \times Time_{Night} + \beta_{Time_{AM}} \times Time_{AM} \end{aligned} \tag{3}$$

Interpretation of the results in the Preference space: linear specification

€ parameter

The marginal effect of a € of monetary compensation significantly varies across groups. Cooperants associate each additional € of monetary compensation with an average utility gain of 0.33 (i.e. an increase in odds of selecting the contract by approximately 39 %), the average gain is

(Preference space)	(1) General population				(2) Cooperants				(3) p-value of the difference	
	Mean		SD		Mean		SD		Mean	SD
ASC	-6.83***	(0.70)	3.35***	(0.21)	-6.58***	(0.71)	4.79***	(0.26)	0***	1.00
€	0.49***	(0.07)	1.65*	(0.70)	0.33***	(0.07)	4.76	(4.31)	0***	1.00
Temp	0.51***	(0.04)	0.00	(0.01)	0.48***	(0.03)	0.01*	(0.01)	0***	1.00
Freq	0.01***	(0.00)	0.04***	(0.00)	0.02***	(0.00)	0.03***	(0.00)	0***	0***
Time_{Ev}	-0.38**	(0.14)	0.86***	(0.22)	-0.10	(0.14)	0.80***	(0.22)	0***	0***
$\text{Time}_{\text{Night}}$	0.13	(0.14)	0.77***	(0.16)	0.73***	(0.13)	0.84***	(0.14)	0***	1.00
Time_{AM}	0.02	(0.13)	0.59***	(0.16)	0.38**	(0.12)	0.42*	(0.20)	0***	0***
N resp.	1,420				1,515					
N obs.	17,040				18,180					
LL	-4745.55				-4994.5					
ρ	0.09				0.09					
AIC	9519.11				10033.00					
BIC	9627.51				10204.78					

Table 23: Mixed logit estimates for the choice experiment on HP interventions in the Preference space. The standard errors are clustered on respondents and shown in parentheses. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$. Column (3) shows the p-values for a two-tailed t-test Welch's test (for equality in means) and a two-tailed F-test (for equality in variances).

higher for the General population group at 0.49 (i.e. approximately + 63 % in the odds of selecting the contract). In other words, the average General population respondent is equally as satisfied with a lower monetary compensation as the Cooperants group. This may be explained by the Cooperants being on average better off, cf. Table 2. As is observed in the choice experiment on EV interventions in the Preference space (Table 14), there is significant heterogeneity in the marginal value of a € in the General population group, yet the Cooperants group can be considered as homogenous on that parameter.

Temperature **parameter**
In the linear specification, it is found that each additional degree of temperature increases utility by approximately 0.5, with significant differences in the mean estimates across the two groups. Conversely, an intervention that decreases the indoor temperature from 19 °C to 18 °C is associated with a utility decrease of approximately 0.5, all else being held constant. In logit terms, a contract with a maximum temperature that is 1 °C than another one (all else being held constant) has approximately 61 to 67 % higher odds to be selected by an average respondent. While the General population group can be considered as having homogeneous preferences for the *Temp* parameter (as is shown by the insignificant SD estimate), it is not the case of the Cooperants group, for which we observe small but significant heterogeneity ($p = 0.035$).

Frequency **parameter**
As similarly to the choice experiment on EVs, respondents associate a larger number of interventions on a yearly basis as a utility gain, as is shown by the positive estimate for the mean *Frequency* parameter. The magnitude of the effect is small as each additional intervention increases the odds of this contract to be selected by approximately 1 % (General population) or 2 % (Cooperants). Both groups show significantly different tastes and heterogeneity on the marginal effect of an intervention in a yearly basis. The Cooperants group associates each additional intervention with a higher gain, as expected given that Cooperants are likely more eager to participate in DR schemes.

(WTP space)	(1) General population				(2) Cooperants				(3) p-value of the difference	
	Mean		SD		Mean		SD		Mean	SD
ASC	-17.74***	(2.15)	11.69***	(1.32)	-40.24***	(6.72)	33.28***	(6.32)	0***	1.00
€	0.37***	(0.05)	0.22*	(0.09)	0.14***	(0.03)	0.00	(0.19)	0***	0***
Temp	1.44***	(0.13)	0.06	(0.05)	3.04***	(0.51)	0.01	(0.31)	0***	0***
Freq	0.04***	(0.01)	0.12***	(0.01)	0.10***	(0.02)	0.17***	(0.03)	0***	1.00
Time_{Ev}	-0.84*	(0.43)	2.59***	(0.61)	-0.43	(0.91)	5.49**	(1.92)	0***	1.00
$\text{Time}_{\text{Night}}$	0.52	(0.41)	1.74**	(0.60)	4.83***	(1.18)	5.68***	(1.31)	0***	1.00
Time_{AM}	0.20	(0.39)	1.78**	(0.53)	2.59**	(0.92)	1.92	(2.99)	0***	1.00
N resp.	1,420				1,515					
N obs.	17,040				18,180					
LL	-4774.68				-5015.52					
AIC	9577.37				10059.04					
BIC	9685.77				10168.35					

Table 24: Mixed logit estimates for the choice experiment on HP interventions in the Preference space. The standard errors are clustered on respondents and shown in parentheses. Significance levels: *: $p < 0.05$; **: $p < 0.01$; ***: $p < 0.001$. Column (3) shows the p-values for a two-tailed t-test Welch's test (for equality in means) and a two-tailed F-test (for equality in variances).

Time **parameters**

The results for the *Time* parameters show opposite trends across the two groups. The average General population respondent disfavours HP interventions starting at night compared to intervention starting in the afternoon) and is indifferent to other starting times. The average Cooperant respondent is indifferent to interventions starting in the evening but significantly prefers interventions at night or in the morning over interventions starting in the afternoon. The SD estimate for $Time_{\text{Night}}$ is, however, substantial.

3.10 Model specification in the WTP space

The results for the preferred linear specification in the WTP space are shown in Table 24. They are obtained using the `mixlbeta` command in Stata 16 (Hole, 2015).

Interpretation of the results in the WTP space

€ parameter

As explained above, the € parameter in the WTP space has the same interpretation as in the Preference space.

Temperature **parameter**

The results in Table 24 indicate that the average respondent is willing to trade-off one extra degree of indoor temperature with a loss of 1.44 € (General population) or 3.04 € (Cooperants). These results are in line with the interpretation of the € parameter in the Preference space (see Table 23). Moreover, both respondent groups have homogeneous preferences regarding the *Temp* parameter, as shown by the insignificant SD estimates.

Frequency **parameter**

As a finding similar to the choice experiment on EV interventions, the significant and positive estimates for the mean of the *Frequency* parameters show that respondents are willing to trade-off on average 0.04 € (General population) or 0.10 € (Cooperants) for one additional intervention on a yearly basis. The variations around the mean *Frequency* estimates are significant but not significantly different in magnitudes across the two groups.

Time **parameters**

Consistent with the findings in the Preference space, the behaviors from the two groups are significantly different. On the one hand, the average respondent in the General population group requires money (on average 0.84 €) to compensate for interventions starting in the evening instead of in the afternoon (the other estimates are insignificant). On the other hand, we observe that the average Cooperant is willing to trade-off 0.38 € (0.73 €) for interventions starting in the morning (at night).

4 Conclusions

The large scale surveys conducted in this research revealed a significant inclination among both the General population and Cooperants respondents to engage in DR schemes. Both groups share similar motivations, primarily centered around contributing to the environment, to the country's energy independence and to the electricity grid stability. Remarkably, a higher proportion of Cooperants expressed willingness to participate in DR schemes. This is in line with their more pronounced pro-environmental traits and attitudes we observe.

While both groups present significant motivations and willingness to enroll in DR schemes, their potential for flexibility might differ. Cooperants present a greater willingness to give a DR scheme control over major appliances, such as EVs or heating systems. These appliances typically offer the most potential for shifting electricity consumption. In contrast, the General population respondents seem more disposed to give a DR scheme control of smaller appliances and white goods. One plausible reason for this is that the share of Cooperants who own major appliances like EVs is higher. The higher usage may lead Cooperants to develop habits and patterns that are not widespread in the General population.

Furthermore, even though Cooperants are more inclined to adopt DR schemes for their HPs, they present significantly narrower comfort temperature ranges. This suggests that they may be more sensitive to flexibility interventions than the General population respondents, who seem more tolerant of larger temperature variations. This observation may be explained by the older population in the Cooperants group.

By focusing on the specific ways flexibility interventions affect comfort levels, the choice experiments have revealed fundamentally different behavioral patterns in DR schemes on EVs and on HPs. While comfort boundaries appear largely linear in the HP choice experiment - meaning each additional degree of indoor temperature provides the same comfort - that is not the case in the choice experiment on EVs. The observed behavior aligns with the so-called range anxiety phenomenon: respondents display a significant opposition to lower EV range limits. Respondents' estimated willingness-to-accept for a reduction in EV range from 200 km to 100 km is around 4 €. This estimate jumps to approximately 18 € for a decrease from 200 km to 50 km. Therefore, the value of a marginal km of EV driving range varies: it equals about 0.06 € between 50 and 100 km and 0.30 € between 100 and 150 km. Meanwhile, the perceived value of a one-degree decrease in indoor temperature varies between 1.44 (General population) and 3.04 € (Cooperants).

An important observation in the choice experiments is how preferences regarding the timing of interventions differ between groups. While the General population respondents seem indifferent to the starting time of interventions on their EV, Cooperants favor nighttime interventions and are willing to pay 1.94 € to shift an intervention from the afternoon to the night. Besides, Cooperants also prefer the interventions on their HP to begin either at night or in the morning, whereas the General population respondents mainly disfavour HP interventions starting in the evening. The starting time of interventions is a large source of heterogeneity which could pose challenges for future DR schemes.

The high share of respondents expressing a high likelihood to participate in DR schemes aligns with the findings of the choice experiments. Specifically, our results show that respondents are in favor of a larger number of interventions. When monetary compensation is offered for these interventions, households are willing to accept one additional intervention annually for a reduction in their compensation by up to 0.8 € (HP interventions) or 0.08 € (EV interventions).

We have identified the following limitations to this study. First, while the surveys were rich and comprehensive, there may always be a potential for differences between the stated and the revealed preferences. For instance, findings regarding the linearity and nonlinearity in the choice experiments may not be reflected as such in actual settings. In practical scenarios, external factors, such a household suddenly prioritizing higher temperatures due to a sick child, may play a key role. To delve deeper into these effects, we are currently conducting a field experiment on HP flexibility. Another limitation to this study relates to accurately capturing the heterogeneity within groups. There may be other sources of heterogeneity. To address and mitigate this, our approach throughout this research has been to consistently compare two distinct groups and and to estimate differences in tastes preferences each group.

In conclusion, we have identified sources of substantial heterogeneity both in the extensive and intensive margins of flexibility. This suggests that future DR schemes will need to accommodate different preferences on the households' electricity consumption patterns. The fundamental insights derived from this research will advise policymakers in consistently estimating the potential that DR offers.

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