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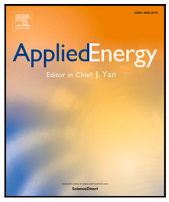

Toward residential flexibility—Consumer willingness to enroll household loads in demand response

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ABSTRACT

Consumers of the future play an important role in the energy system by leveraging their household loads to be flexible through demand response (DR) during a high network stress. This study aims to identify the consumers' Willingness To Enroll (WTE) their different household loads in DR considering consumer preferences for both financial gains and emission reductions. To study this, a questionnaire survey was administered to 1,468 Finnish residential consumers, and several statistical methodologies were used to draw key findings regarding consumer socioeconomic and demographic characteristics on their WTE their household loads in DR. The key results of the study are: First, among the household loads, heating and electric appliances have a higher consumers' willingness to enroll than EVs. Second, within the incentives, consumers preferred financial incentives to environmental incentives. Third, the expected compensations for consumers were 100 €/annum for appliances and EVs and 200 €/annum for heating. The results of this study have clear practical implications for energy flexibility in the residential sector. Further, the paper discusses the corresponding policy implications that are essential for a widespread DR adoption in the future.

1. Introduction

1.1. Overview

With the drastic increase in the renewable energy production in recent years and the current plans to reduce the dependence on fossil fuels in the energy system, it is fair to say that the flexibility of resources will play a vital role in the future. The European Union has recently updated its renewable energy targets for the future from 40% to 45% for 2030 [1]. To achieve such high targets, a rapid deployment of variable renewable energy production is required, and the need for flexibility will increase for such a huge transition. These additions to the energy system introduce many unknowns in the operations and planning of the energy system. In addition, the opportunity to have a bidirectional flow of electricity introduces many challenges and requires proper management of the distribution network [2,3]. Concerning the variable production of renewable energy, the need for demand flexibility is vital to help achieve this transition [4–6]. Demand Response (DR) is likely to play an important role in the transition toward a renewable future while aiding in the interactions on the demand and supply sides [7].

DR is defined as the changes in consumer consumption patterns in response to specific signals [8]. There are mainly two types of signals: price signals and control signals. In the first type, consumers change their consumption based on the time-varying price of electricity; this is also called as Implicit DR [9]. In the second type, consumers' consumption patterns are changed by providing the control of selected appliances to an external aggregator or utility, which, in turn, can remotely control the operation of the appliance based on the needs of the electricity system [10]. The second type is also known as Direct Load Control (DLC) or Explicit DR.

DR has been used within the energy system for a long time, with the main participation coming from commercial and industrial consumers [11,12]. The residential sector constitutes a group of consumers who have small individual load flexibility, but when aggregated together can provide adequate flexibility. Although the participation from the residential sector is relatively low, the theoretical potential to provide flexibility is still available [13]. Along with the rapid enrollment of

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smart meters to residential consumers, the residential sector represents one potential group of consumers who can help aid in the transition toward a sustainable future [14].

1.2. Literature review

When comparing DR programs, DLC has the edge over price signals owing to the higher assurances of flexibility, security, and timing [15,16]. In addition, DLC is reliable and provides quick flexibility, which is needed to involve consumers to participate in ancillary markets. Even with such advantages, the enrollment of residential consumers in DLC has been low [5,17]. Previous studies have attributed this issue to different concerns faced by consumers as explained below.

James Fell had conducted a DR study based on focus groups to study the consumer behavior regarding different tariff structures and household demand response applications based on residential consumers from Great Britain [18]. The study uses a two-way ANOVA test to analyze the results. The results from this study highlights that consumer trust in a service provider and privacy concerns are an important factor in residential DR adoption. Poilitt et al. conducted a public opinion survey in the year 2013 regarding consumer attitudes and behavior regarding smart energy use which was to be answered by the residential consumers from Britain [19]. The results from this study highlight that there is an increasing concern for sharing of private data with service provider in comparison to their previous study. Similarly, Balta-Ozkan et al. studied the smart energy systems across UK, Germany and Italy in different sectors [20]. The results from this study show that consumers have a concern regarding security and privacy of their data. Throndsen & Ryghaug studied smart grid users in Norway based on a pilot project [21]. Their results were that adoption of smart grids was accompanied by different reactions from skepticism and pragmatism to enthusiasm and concerns regarding privacy and security issues hindering its adoption in the future. Additionally, the study also suggested that if the early adopters are brought into discussions on their role as smart grid users and raising awareness leads to a performative effect in adoption of smart grid projects. Stenner et al. used a survey to capture the consumer behavior regarding their willingness to participate in DLC programs for Australian residential consumers [17]. The study proposed that consumer distrust in the service provider affected their willingness to participate in DLC programs.

Parkhill et al. had conducted an empirical study in three phases with interviews, workshops and surveys for the consumers in Great Britain regarding their attitudes and perception of the UK's energy sector [22]. The results from this study show that the public cares a lot about climate change and the need to have renewable energy solutions. Additionally, the study shows that consumers do not prioritize the supply side or demand size requiring changes and the main values consumers were concerned with were costs, energy security, climate change and control over their loads. Smale et al. studied two smart grid projects operated in the Netherlands and drew the conclusion that the overriding opportunities are an important factor to consider for the users [23]. Kobus et al. had conducted 21 interviews of consumers using an energy management system "Smart Wash" operating on their washing machine for several months to wash based on the energy market data [24]. The results from this study show that the consumers having kids had a higher need to override the program and a general concern among interviewees was the trustworthiness of the system. Fell et al. conducted a representative survey of residential consumers of Great Britain on their acceptability of different tariff systems and DLC control of their heating [25]. The results from this study show that around 30% of residential consumers from Great Britain prefer static Time-of-Use pricing and DLC on their heating loads were acceptable only with an override option. Paetz et al. studied consumer reactions to smart home energy management solutions using focus groups in Germany [26]. The results from this study showed that consumers in general had a positive impression from the energy management solutions which aids in financial savings but giving up their flexibility of usage of appliances and adapting their routines to fit the energy management schedule was considered difficult by the consumers. Murtagh et al. conducted interviews with 21 different households in England regarding their opinions on peak pricing and remote demand control during peak hours [27]. The results from this study showed that consumers from England found the peak pricing to be inequitable and affecting the less wealthy families and households and third party control of their loads were considered to contravene their rights of control within their households. Xu et al. conducted a survey on US residential consumers on their acceptance of DLC programs on their air conditioning units [15]. The results from this study shows that half of the respondents were willing to accept DLC without any incentives and an override option in the DLC program outperformed a 30 $ financial benefit per 3 months of summer which highlights the importance of control in households.

From the literature, it is clear that consumers have specific concerns regarding privacy with respect to their participation in DR programs. One potential solution to study the complex decision-making of consumers is to identify the motivators for consumers to enroll in DR. To identify and analyzing the motivators for consumers to enroll in DR could help increase the DR adoption rates. In addition, the effect of the sociodemographic features of consumers on their preferences to enroll in DR is also essential. Sridhar et al. [28] studied the different consumer motivators for DLC DR and the impact of different sociodemographic features of consumers on their motivators when dividing the consumers into different subgroups based on a survey answered by Finnish consumers. The results of the study highlight the consumers' heterogeneity of motivators for DLC DR. The authors divided the consumers into three subgroups: adopters, followers, and neutral based on their preferences of the DR motivators obtained by the survey.

Based on the literature, the flexibility potential of residential households has been rising with the increasing deployment of smart meters. Annala et al. [29] studied the demand-side flexibility potential of Finnish residential households. The study indicates that residential consumers are willing to allow remote control of their household appliances while not affecting their day-to-day routines. This paves the way to study the specific load control preferences of residential consumers in more depth. Ruokamo et al. [30] used a discrete choice experiment to study the consumer willingness to participate in direct load control of their electrical appliances and heating based on the time of day (morning or evening) while providing financial compensation and system-level emission reductions. The results of this study show that residential consumers in Finland have a higher preference to enroll their heating in DLC than their electrical appliances. Broberg & Persson [31] also used a similar discrete choice experiment to study Swedish households' willingness to enroll their electrical appliances and heating in direct load control based on financial compensation. The results Broberg & Persson also highlight that residential consumers prefer to enroll their heating in DLC DR over their appliances. Further, Broberg & Persson studied the effect of consumer sociodemographic features: household composition, age, gender, and income on their DLC DR preferences. The results of this study show that younger people and households with less than two people were more willing to enroll their loads in DR than older consumers and households with more than one person [31].

1.3. Research gap and contributions

Although the previous studies have attempted to identify consumers' WTE in DLC DR, they have not considered the combined effect of consumers' preferences for environmental and financial incentives to determine their willingness to enroll different households in DLC DR. Furthermore, there is a research gap in analyzing the effect of different motivators for a consumer to enroll in DR on their WTE their household loads, as well as the effect of consumer subgroups on their WTE. Therefore, the contributions of this paper are as follows:

1. Identification and quantification of residential consumers' WTE their household appliances and devices in DLC DR based on combined environmental and financial incentives.
2. Identification of the effect of consumer sociodemographic features on their WTE their household appliances and devices in DLC DR.
3. Analysis of consumers' WTE their household appliances and devices in DLC DR based on different consumer subgroups.

To this end, a survey was formulated and sent to Finnish residential consumers. Finland is one of the leading countries in terms of renewable energy production and has set ambitious targets for the coming years [32]. This makes the analysis of residential consumers' WTE different household appliances and devices essential. This study is a step forward in terms of residential DR and provides valuable insights for Distribution System Operators (DSO), policymakers, retailers, and academia to understand the consumer decision-making in residential DR.

The structure of the paper is as follows: Section 2 describes the methodology employed in this study in detail, with Section 2.1 explicating the development of the survey and 2.2 explaining the various analyses used in this study. Section 3 presents the results through different analyses, and Section 4 illustrates the implications of the results and the limitations of the study. Lastly, Section 5 concludes the study along with policy implications.

2. Methodology

2.1. Survey development[1]

In order to obtain valuable responses from actual residential consumers, a collaboration was established with an electricity supplier operating within Finland: Pohjois-Karjalan Sähkö (PKS). PKS is one of the major electricity supplier within Finland operating for more than 75 years. The consumer database of PKS was used, to whom the survey was distributed. The residential consumer database of PKS, is used as a pool of participants within which the survey was distributed. The consumer database uses email addresses of the person responsible for paying the electricity bill in the household, and this person is thus considered the main decision-maker of the household concerning electricity consumption. The survey was distributed to approximately 30,000 consumers, of which 4134 consumers started responding. At the time of survey distribution, there were no DLC DR services provided by PKS to their consumers. The survey was kept open for a week during February 2022, and 1468 consumers answered the whole survey. The survey was distributed anonymously and no personal identifiers were collected, as per the European Union GDPR (General Data Protection Regulation) and the Data Protection Act in Finland [33]. The survey was initially developed in English, and a Finnish translation was added to it to provide the respondents with a choice of their preferred language. The general composition of the consumers using services from PKS is dominated by men (67%) and the average consumer age is 57–59 years. The survey did not contain any questions to assess the previous knowledge of respondents' in DR programs and instead provided a brief description on what DR is and how consumers could participate in DR programs by selecting their household loads which will be automatically controlled. This was done to ensure the respondents understand the key concepts of the study and the possible form of implementation of the DR and DLC programs.

[1] The corresponding author is responsible for the survey data and any questions regarding data sharing should be directed to the corresponding author.

2.1.1. Dependent variables

The dependent variables in this study are divided into two groups based on their motivators to enroll and their WTE household appliances or devices in DLC DR. The survey respondents were first asked to indicate their preference for different motivators to enroll in DLC DR. Based on the literature outlined by Parrish et al. [34], six different motivators were considered:

- Financial gains **(Fin)**: Potential reductions in the electricity bill.
- Environmental gains **(Eco)**: Potential reductions in CO_2 emissions helping transition to a green future.
- Local generation **(LG)**: The preference for local production and local sustainability.
- Encouragement by contacts/Peer pressure **(PP)**: The preference to enroll based on the number of personal contacts enrolled in the same program and based on their feedback.
- Smart home automation **(Auto)**: The preference to enroll based on smart home automation, which minimizes the user's workload.
- Interest in technology **(Int)**: The preference to enroll based on personal interest in trying new programs.

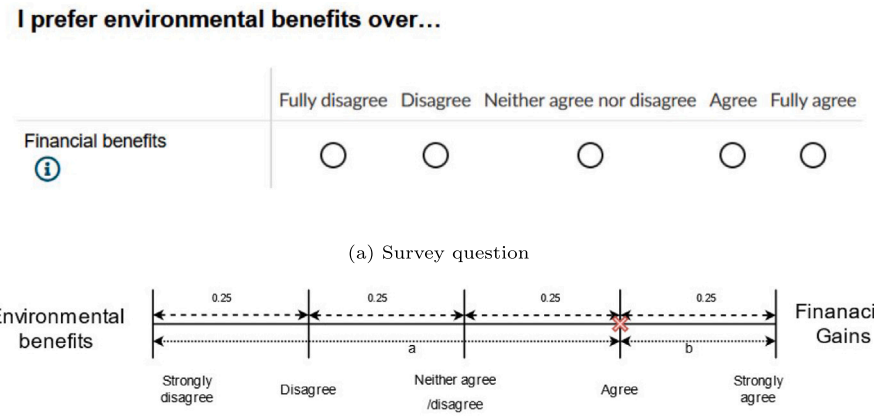
For all these motivators, the consumers were asked to choose their preferences, and the answers were collected based on a 5-point Likert scale with the following options (scale values): Strongly disagree, Disagree, Equal preference, Agree, and Strongly agree.

The second group of dependent variables considers the residential consumers' Willingness To Enroll (WTE) their household appliances in DLC DR. In order to capture the WTE, the questions were sorted into three different subgroups. The subgroups consist of the DLC DR enrollment of (1) home appliances (washing machine, dishwasher, tumble dryer); (2) heating (only analyzed for consumers having a heat pump or electrical heating as it is consumer specific and can be used in DLC DR); and (3) EVs (was asked to be answered by all consumers regardless of ownership as the current ownership among survey respondents is around 5%). The consumers were asked if they were willing to enroll their appliance/device based on potential financial gains and potential environmental gains separately on a 5-point Likert scale. A further open-ended question was asked to specify their required compensation to enroll. The overall value of the DLC DR WTE of a specific device is obtained by determining the priority of economical and environmental gains through the first group of dependent variables and multiplying it with the answers to the willingness to enroll based on financial and environmental gains, respectively, as shown in Eq. (1). In this study, the overall WTE a specific household load was formulated based on consumer preferences for financial and environmental gains as these are the two types of motivators that can be quantified in an easily understandable form. Additionally, from the electricity supplier's point of view, these are the main factors they can use to encourage consumers to enroll in DR.

$$WTE_{d,c} = w_{fin,c} * wte_{d,fin,c} + w_{env,c} * wte_{d,env,c} \quad (1)$$

In Eq. (1), $WTE_{d,c}$ is defined as the willingness to enroll the device d in DLC DR by a consumer c. $w_{fin,c}$ is the weight of financial gains, and $w_{env,c}$ is the weight of environmental gains for a consumer c; $w_{fin,c}$ and $w_{env,c}$ are calculated from the consumer's preference of environmental over financial gains by using Eqs. (2) and (3), respectively. $wte_{d,fin,c}$ is the willingness to enroll the device d based on financial gains by the consumer c, and $wte_{d,env,c}$ is the willingness to enroll the device d based on environmental emission reductions by the consumer c. The weights $w_{fin,c}$ and $w_{env,c}$ are obtained from the survey questions; the consumers were asked to choose if environmental benefits are preferred over financial benefits to enroll in DLC DR. The responses were collected on a 5 point Likert scale as shown in Fig. 1(a).

For example, if a consumer chooses "Agree" as their response to the statement "I prefer environmental benefits over financial gains"



(a) Survey question

(b) Extraction of consumer WTE

Fig. 1. Extraction of consumer WTE their household device/appliance from the survey questions.

(indicated by a red cross in Fig. 1(b)), then $w_{fin,c}$ and $w_{env,c}$ are obtained by Eqs. (2) and (3).

$$w_{fin,c} = b/(a+b) \tag{2}$$

$$w_{env,c} = a/(a+b) \tag{3}$$

where:
a is the distance between the left end of the scale (environmental benefits) and the consumer's response, and b is the distance between the right end of the scale (financial gains) and the consumer's response.

2.1.2. Independent variables

The independent variables in this study are the consumer data based on their socioeconomic and demographic characteristics, which are considered to influence the DLC DR enrollment. The variables considered in this study are shown in Table 1. The table provides information of the survey respondents in percentages.

From Table 1, it can be observed that the composition of the sample reflects well the composition of the customers according to the PKS customer database in terms of gender distribution and age skewed toward higher values and can therefore be utilized to provide valuable insights regarding DLC DR motivators.

2.2. Overview of the analysis

This methodology section of the paper is divided into four different analyses of the WTE of appliances based on the sociodemographics of the consumers, the DLC DR motivators of the consumers, and segmentation of the consumers into subgroups. A series of one-way ANOVA test is performed on the WTE of appliances (continuous dependent variables) implied by the sociodemographic characteristics (categorical independent variables) of the consumers, and a Tukey's post-hoc test is further performed to identify the groups having significant results. Following this, a Fuzzy Set Qualitative Comparative Analysis (fsQCA) is performed to further identify possible relationships within different consumer sociodemographic groups and the WTE of different appliances. A robust regression is performed on the WTE of appliances (continuous dependent variables) on the different DLC DR motivators (continuous dependent variables) to identify the relationship between the DLC DR motivators and the WTE of appliances. Finally, a series of one-way ANOVA test is performed on the WTE of appliances and the different consumer subgroups (categorical variable) to obtain the significance groups within each subgroup. An overview of the analysis performed in this paper is shown in Table 2.

2.2.1. ANOVA

The ANOVA test is one of the key statistical tests applied in a variety of fields. An ANOVA test is used to investigate the effect of categorical independent variables on the dependent variables. ANOVA tests have also been used in DR surveys; for instance, by Yilmaz et al. Schöne et al. Chen et al. and Wang et al. to identify consumer sociodemographic effects on DR preferences [35–38]. A one-way ANOVA test is used to compare two groups in order to identify statistical evidence of the groups being significantly different. The ANOVA test provides F and p values, which can be used to identify the presence of statistical significance. The F value checks if the variance between the means of the two populations being compared are significantly different. In addition, the F value determines the p value. The F value is defined as the ratio of the variance of the group means to the mean of the within-group variances. The p value denotes the probability of getting a result as extreme as the observation if the null hypothesis is true. The p value can be less than 10% to be significant. If there is a presence of statistical significance from the initial one-way ANOVA test, a Tukey's HSD post-hoc test is additionally carried out. By using this post-hoc test, it is possible to identify the group that had a significant result in the ANOVA test [39]. Usually, the significance level for a post-hoc test like Tukey's is set at $\alpha = 5\%$, and if the p value from Tukey's test is less than 0.05, then there is a statistically significant difference between the subgroups.

2.2.2. fsQCA

fsQCA is a type of Qualitative Comparative Analysis (QCA), a type of data analysis that does not require statistical significance to analyze the effect of different variables in a subgroup. The fundamental concept of QCA is to study the (relative) number of observations in the available dataset that provide support for a given investigated relationship formulated as an IF-THEN rule. For example, if we consider two features X and Y, they can be represented by subsets of the dataset, where each subset consists of observations that have the respective feature. Now if we consider the statement "if X then Y" denoted as $X \Rightarrow Y$, then the dataset is checked for evidence in favor of the posed relationship. In this understanding, every observation having the features X and Y at the same time is an "example" of the validity of the investigated relationship and can be used as evidence in favor of the relationship's validity. The evidence against the investigated relationship is represented by those observations that have the feature X but lack the feature Y; these observations are considered "counterexamples" to the investigated relationship. Accordingly, observations that do not possess the feature X are considered unrelated to the investigated relationship and as such do not constitute evidence in favor of the relationship or

Table 1
Independent variables for 1468 Finnish consumers.

Variable	Percentage
Gender	
Male	72%
Female	26%
Other	0.5%
DNS[a]	1.5%
Age	
19–29	1%
30–39	5%
40–49	12.7%
50–59	21.3%
60+	57.1%
DNS[a]	2.9%
Education	
Basic	7.9%
Upper secondary	37.6%
Bachelor's degree	27.6%
Master's degree or higher	22.6%
Other	4.3%
Dwelling	
Apartment	14.8%
Terraced	11.8%
Semidetached	2.9%
Detached	68.4%
Other	2.1%
Presence of children	
Yes	14.16%
No	83.65%
DNS[a]	2.19%
Number of people in household	
1	22.2%
2	59.2%
3	8.6%
4 or more	9.2%
DNS[a]	0.8%
Gross monthly income (in Euros)	
Less than 1000	4.5%
1000–2500	29.4%
2501–3500	23.9%
3501–4500	14.9%
4501–6000	9%
Greater than 6000	5.7%
DNS[a]	12.6%

[a]DNS: Did Not State.

against it. The relative number of observations supporting the proposed relationship is identified as the strength of support of the relationship in the dataset or the consistency of the relationship with the data, and the relative number of observations that are against the proposed relationship is identified as strength of evidence against the proposed relationship [40,41]. The features constituting the investigated statement can be either crisp or fuzzy and as such represented in the QCA by standard (crisp) sets or fuzzy sets [42,43]. If at least one of the features needs a fuzzy set to be represented, then the relationship becomes a fuzzy relationship and the fuzzified version of QCA, i.e., the fsQCA, should be applied. A fuzzy set can be understood as a set whose elements can belong to the set only partially, and thus can have the characteristic feature defining the set only to a certain degree. Instead of the crisp (nonfuzzy) sets where the membership is either 1 (i.e., "the element belongs to the set") or 0 (i.e., "the element does not belong to the set"), the fuzzy sets allow a full range of membership degrees from the $[0, 1]$ interval reflecting the level for which the given element has the characteristic feature of the set. In this study, $WTE_{d,c}$ was converted into a fuzzy set through a trapezoidal membership function

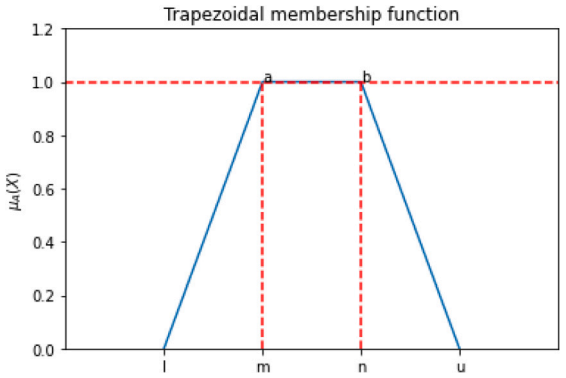


Fig. 2. Fuzzy transformation using the trapezoidal membership function.
Source: Adapted from [44].

transformation. A general shape of such a membership function is depicted in Fig. 2 obtained from [44]. The interval (l, u), the support of the fuzzy set, contains all the values (elements of the universe on which the fuzzy set is defined) that belong to the fuzzy set at least to some extent. On the other hand, the interval $[m, n]$, the kernel of the fuzzy set, contains all the elements that fully belong to the fuzzy set. The elements in $(-\infty, l] \cup [u, \infty)$ do not belong to the fuzzy set at all. To define the trapezoidal fuzzy set membership function, its user usually defines the kernel of the fuzzy set (elements that should be considered to fully belong to the set) and then the supplement to its support (the elements that do not belong to the set at all), and the membership function for elements from $[l, m]$ and $[n, u]$ is assumed to be linear at the respective interval.

QCA and its fuzzy alternative fsQCA have found various applications in fields where questionnaire data are a frequent source of information on intangible or difficult to directly measure aspects of the modeled systems. Kumbure et al. [45] used QCA and fsQCA in a strategic research context. Furthermore, it has been used in analytics for the tertiary education sector [46] and also in the analysis of cognitive structures of respondents [47]. Hence, this method has also been used here for the survey analysis of the self reported willingness to enroll in DR in this research.

In this study, $WTE_{d,c}$ was assessed by using a trapezoidal fuzzy set, where (l, m, n, u) are set to values $(2, 5, 5, 5)$, essentially representing the answer to the question "How much should the consumer be considered willing to enroll?" (this fuzzy set is denoted $\widetilde{WTE}$ further in the text). When considering a specific device, the membership degree of each consumer to this fuzzy set of "consumers willing to enroll in DR" is determined as the membership degree of the respective $WTE_{d,c} \in [1, 5]$ to the fuzzy set of "consumers willing to enroll in DR". As a result of this conversion, the consumers who had a WTE less than 2 would have a membership degree of 0 to $\widetilde{WTE}$, which means that they are considered not willing to enroll their devices in DLC DR. The consumer WTE values from 2 to 5 have a nonzero membership to $\widetilde{WTE}$, meaning that all of these consumers are considered at least partially willing to enroll in DLC DR. The consumers with WTE values of 5 are considered "willing to enroll the specific device/appliance in DLC DR", which can be observed in Fig. 3. By the use of $\widetilde{WTE}$, the study is now able to perform fsQCA to identify consumers' actual WTE their household devices and appliances in DLC DR based on their socioeconomic characteristics.

There are two main metrics that can be used to study the proposed relation in any QCA: consistency and coverage. Consistency is expressed as how strongly the proposed claim or relationship is consistent with the observations in the dataset. A high consistency would reflect the presence of a high number of cases for which the proposed relation $(X \Rightarrow Y)$ is true and very few that violate the said relationship. Coverage is defined as the proportion of the dataset for which both the

Table 2
Overview of the analysis performed.

Analysis	Purpose	Program
ANOVA - 1	Investigating the WTE of appliances based on different sociodemographic features of consumers	Stata
fsQCA	Additional investigation of the WTE of appliances based on different consumer sociodemographic features	MATLAB
Robust regression	Investigating the WTE of appliances based on different DLC DR motivators of consumers	Stata - rreg
ANOVA - 2	Investigating WTE of appliances based on different consumer subgroups	Stata

Fig. 3. Fuzzy set representation used in this study.

relations X and Y are present when compared with the size of the part of the dataset that exhibits the feature Y. For fsQCA, the interpretation of the consistency measures involves the cardinalities of the fuzzy sets instead of the actual numbers of elements, but the interpretation of these measures and their desired values remain analogous. Consistency and coverage can be expressed quantitatively, and the most recently proposed fuzzy versions of these measures can be seen in Eqs. (4) and (5), which are provided by [48].

$$Consistency(X \Rightarrow Y) = \frac{1}{2}\left(1 + \frac{\sum_{i=1}^{n}(min(X(z_i)), Y(z_i)) - min(X(z_i), Y'(z_i))}{\sum_{i=1}^{n} X(z_i)}\right) \quad (4)$$

$$Coverage(X \Rightarrow Y) = \frac{1}{2}\left(1 + \frac{\sum_{i=1}^{n}(min(X(z_i)), Y(z_i)) - min(Y(z_i), X'(z_i))}{\sum_{i=1}^{n} Y(z_i)}\right) \quad (5)$$

In the above equations, $X(z_i)$ refers to the membership degree of z_i in X, and the representation of $Y(z_i)$ is similar. Note that formula (4) defines the consistency of a fuzzy relationship in such a way that the value 1 is associated with situations when only evidence in favor of the relationship is present in the data. It gets a value of 0 when only evidence against the proposed relationship is present in the data and the consistency value of 0.5 corresponds with relationships that have as much support as they have evidence against them. Essentially, values larger than 0.5 represent more support for $X \Rightarrow Y$ in the data than for $X \Rightarrow Y'$; the higher the value is, the higher the excess support is. Values below 0.5 correspond with excess support for $X \Rightarrow Y'$ in the dataset.

2.2.3. Robust regression

Regression is a method used to identify relationships between two or more variables. It has been extensively used in energy fields in different applications. Ferreira et al. [49] used regression to access the social acceptance of DR models. Belaïd et al. [50] used regression to identify the rebound effect of consumer electricity demand based on fuel prices. Yilmaz et al. [35] used regression to identify the effect of consumer preference for different tariffs on DR acceptance. Based on the previous literature and because of its low computational demand and high effectiveness, regression can be considered a useful methodology to extract insights from the survey data. Robust regression is a form of Original Least Square (OLS) regression, while being less susceptible to outliers by minimizing absolute residuals instead of the sum of squared residuals used in OLS. The robust regression, when used in Stata, provides three main outputs: $Prob > F$ value, p value, and the coefficient between the tested variables that specifies the relationship between these variables. The $Prob > F$ value is one specific value for the whole of the regression, which is used to determine goodness of fit. If the $Prob > F$ value is less than 0.1, then there is at least one variable among all the tested variables that can be used to obtain the result (WTE in this analysis). The p value is similar to that from ANOVA and is used to check if the results from Robust Regression are statistically significant and can be used to represent a larger population. The regression is performed on two different variables, and the p value obtained from the regression is specific for the selected variables. The coefficient is also individualistic for every input and can be used to identify if there is any relationship between the input and the output variable. The equation for robust regression is as follows:

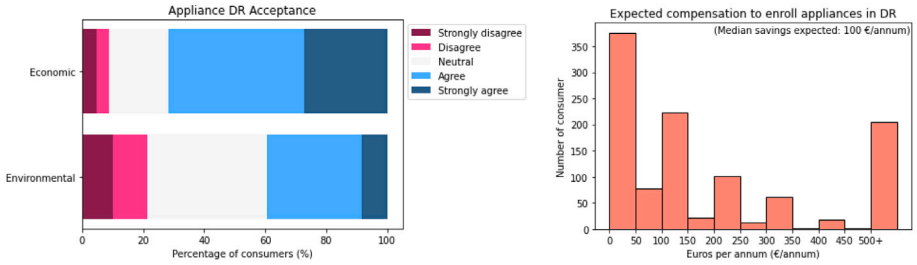
$$Y = b_0 + \sum_{i=1}^{n} b_i * x_i \quad (6)$$

In Eq. (6), Y is the predicted output, b_0 is the constant from robust regression, b_i is the coefficient for the ith input variable, and x_i is the ith input variable. The robust regression can only be studied if $Prob > F$ is less than the α value. If this is true, then there is a statistical significance in at least one of the inputs for the predicted output. When the p value of a specific variable is less than α, then that specific input is statistically significant.

3. Results

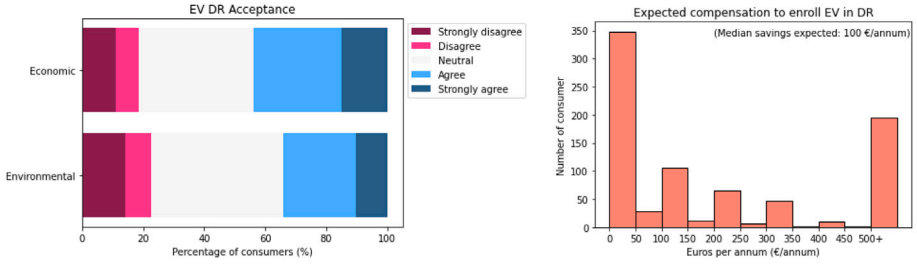
3.1. Consumer responses

The consumer responses to their WTE their household loads in DLC DR can be viewed in Figs. 4, 5, and 6. These figures are also composed of the consumers' expected financial compensation to make them enroll in DLC DR. The expected financial compensation' values are estimates of consumers expectations, given the fact that most of the respondents might not have prior experience with DR. Nevertheless, the numbers (particularly if we consider the median values of the 'expected compensations') are still useful for policy planning and for the design of campaigns for first-time adoption of DR programs. They, however, do not play an important role in the analyses performed in this paper. These figures show that the willingness to enroll the appliances in DCL DR is motivated more by economic factors than environmental ones among residential consumers. Additionally, within the household loads, EVs seem to be the least preferred load for consumers to enroll, whereas a high preference for both heating and appliances can be seen. The median financial compensation represents the median value of survey respondent's answer to their desired financial compensation to enroll the specific load in DLC DR. As some responses were significantly higher than the operating costs (more than 500 €/annum), the average value was skewed and as a result, the median value was used to represent the desired financial compensation of a typical consumer to enroll a specific load in DLC DR. The median of the expected financial compensation for appliances and EVs is 100 €/annum and that for heating is 200 €/annum.



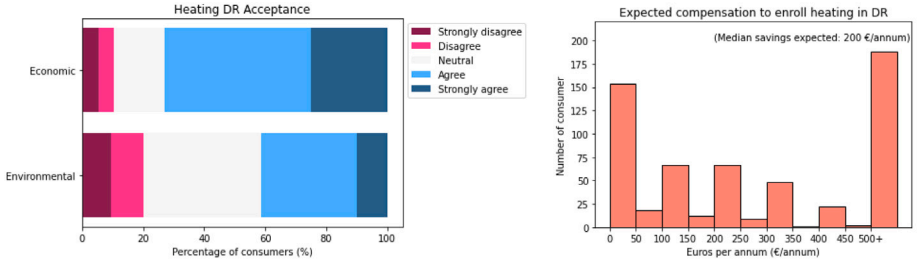
(a) Consumer response distribution (b) Consumer compensation requested

Fig. 4. Consumer responses to enrollment of appliances in DR.



(a) Consumer response distribution (b) Consumer compensation requested

Fig. 5. Consumer responses to enrollment of EVs in DR.



(a) Consumer response distribution (b) Consumer compensation requested

Fig. 6. Consumer responses to enrollment of heating in DR.

3.2. ANOVA 1

In order to find out the characteristics of consumer sociodemogrphahics having a direct effect on different DLC DR acceptance, a series of one-way ANOVA tests were performed. The results of the ANOVA test can be observed in Table 3. The results depict the different sociodemographic features of residential consumers on their WTE for different household loads. The significance level is set to 1%, 5%, and 10%, and the sociodemographic features that fall under these levels are indicated by $*$ based on the significance level (given under the table) and highlighted.

Table 3 shows that there are no significant sociodemographic characteristics for the general DLC DR enrollment of appliances. For both the enrollment of EVs and heating, age is a significant characteristic, and in addition to age, education is also a significant characteristic for the enrollment of EVs in DLC DR. Thus, in order to find the significant groups within the sociodemographics, a Tukey's post-hoc test was carried out on different age and education groups for the DLC DR enrollment of EVs and on different age groups for the DLC DR enrollment of heating. The results of Tukey's post-hoc test for the enrollment of EVs are given in Tables 4 and 5, and the results for the enrollment of heating in Table 6.

Table 3
Results from ANOVA-1.

Variables	Appliances		EV		Heating	
	F	*p*	*F*	*p*	*F*	*p*
Age	1.14	0.337	**3.99**	**0.0032*****	**2.62**	**0.0342****
Gender	0.05	0.8153	0.03	0.8605	0.22	0.6411
Education	0.73	0.5706	**5.99**	**0.0001*****	0.72	0.5762
Liv	1.78	0.1299	0.91	0.459	1.59	0.1745
Kids	0.02	0.8978	0.87	0.3509	0.29	0.5919
People in house	1.12	0.3462	0.88	0.478	0.51	0.7289
Income	1.22	0.2957	1.74	0.1231	0.17	0.9745

*/**/*** = Statistically significant at $\alpha = 10\%/5\%/1\%$.

Table 4 shows the mean and standard deviation (SD) of consumer responses to the WTE EVs in DLC DR. Significant results obtained from Tukey's test were that the consumers belonging to the age group 19–29 have a higher WTE EVs than the consumers belonging to the age groups 40–49, 50–59, and above 60 years. Similarly, the consumers within the age group 30–39 have a higher WTE EVs in DLC DR than the consumers from the age groups 40–49, 50–59, and 60+. Hence, it can be seen that consumers younger than 40 years have a higher WTE their EVs in DLC DR than older consumers.

Table 4
Tukey's post-hoc test for the age of consumers and their preference for the WTE of EVs.

Age group	Mean	SD
19–29	3.923	0.86231
30–39	3.6821	1.1743
40–49	3.31759	1.0725
50–59	3.2526	1.06
60+	3.1721	1.0474
Significant results	**19–29 vs. 40–49, 50–59, 60+ & 30–39 vs. 40–49, 50–59, 60+**	

Table 5
Tukey's post-hoc test for the education of consumers and their preference for the WTE of EVs.

Education	Mean	SD
Basic	2.93	0.99707
Upper secondary	3.14	1.0546
Bachelors	3.305	1.0709
Master's degree or higher	3.5214	1.0604
Other	2.9034	0.948
Significant results	Bachelor's degree vs. basic or other education & Master's degree or higher vs. basic, upper secondary, bachelor's degree, or other education	

Table 6
Tukey's post-hoc test for the age of consumers and their preference for the WTE of heating.

Age group	Mean	SD
19–29	4.5	1
30–39	3.94	1.17
40–49	3.66	0.9874
50–59	3.677	0.8679
60+	3.572	0.8964
Significant results	**19–29 vs. 40–49, 50–59, 60+ & 30–39 vs. 50–59, 60+**	

Table 5 shows the mean and standard deviation of consumer responses to the WTE EVs in DLC DR. Significant results obtained from Tukey's test were that the consumers having bachelor's and master's degrees or higher education have a higher WTE EVs in DR than the consumers having a basic and other type of education. In addition, the consumers having a master's degree or higher education have a higher WTE EVs in DLC DR than the consumers having upper secondary level education and a bachelor's degree.

Table 6 presents the mean and standard deviation of consumer responses to the WTE heating in DLC DR. Significant results are that the consumers in the age group 19–29 have a higher WTE heating in DLC DR than the consumers in the age groups 40–49, 50–59, and 60+. In addition, the consumers in the age group 30–39 have a higher WTE heating in DLC DR than the consumers in the age groups 50–59 and 60+.

3.3. fsQCA

As the results from the ANOVA test did not yield many statistically significant results, a fuzzy set analysis of the WTE on the DLC DR of household loads was conducted based on the sociodemographic characteristics of the residential consumers. The results of fsQCA are given in Table 7.

The fsQCA results can be interpreted based on the consistency values as described in Section 2.2.2. A high consistency value ($\gg 0.5$) would show evidence in favor of a specific group of consumers having a high acceptance rate of the DLC DR enrollment of a particular appliance. On the other hand, low consistency values ($\ll 0.5$) would denote that the given group of consumers does not exhibit a high WTE in DLC DR. Consistency values around 0.5 would denote that there are equal chances of consumers willing to enroll and not willing to enroll in DR. The key findings from fsQCA are:

- Consumers in the age group 19–29 have a high WTE in DLC DR for appliances (consistency 0.655) and EVs (consistency 0.611). The evidence of a high WTE is the strongest for appliances in this age group.
- Consumers in the age group of 30–39 have the highest consistency for a high WTE their heating in DLC DR (0.65) compared with the other appliance types.
- Consumers having 'other' as their education level have a low consistency for a high WTE their EVs (0.314) and heating (0.346) in DLC DR. The evidence in the data suggests that the WTE in DLC DR of EVs and heating is not high in this group.
- Consumers with basic education have a low consistency for a high WTE their heating (0.364) and EVs (0.347) in DLC DR. The data suggest that this group does not exhibit a high WTE for these types of appliances.
- Consumers living in semidetached houses have a high consistency for WTE their appliances in DLC DR (0.614). There is evidence suggesting that this group of consumers might have a high WTE in DLC DR for appliances.
- Consumers who gave 'other' as their living condition have a low consistency for a high WTE their EVs (0.339) and heating (0.384) in DLC DR.
- Consumers with a household income greater than €6000 have a high consistency for their WTE heating in DLC DR (0.65). High-income households thus have a high WTE their heating in DLC DR.

Some additional insights include the following:

- *Gender:*
  - Female consumers' WTE their appliances, EVs, and heating in DLC DR is more supported by the data than the male consumers'.
- *Age:*
  - Age is inversely proportional to the consumer WTE their appliances and EVs in DLC DR, i.e., with a higher age, the high WTE appliances and EVs is less supported by our data, which is in line with the results of the previous ANOVA test.
- *Education:*
  - Higher-educated consumers (bachelor's, master's, or a higher degree) show a higher support for a high WTE their household appliances, EV, and heating in DLC DR than the rest of the education groups in the data, which is in line with the results of the previous ANOVA test.
  - For consumers who gave 'other' as their education level, the level of evidence would suggest that they have a high WTE their appliances, EV, and heating is the lowest across all the education categories, which is then followed by consumers having a basic education level.
- *Living:*
  - Consumers living in semidetached houses have the highest evidence of their WTE appliances, EV, and heating in DLC DR being high across all the considered housing types.
  - Consumers who stated that they were living in other types of households have the lowest evidence of a high WTE appliances, EV, and heating in DLC DR.

Table 7
fsQCA results on the sociodemographic characteristics of consumers on the WTE of household appliances.

Parameters		High DLC DR of App		High DLC DR of EVs		High DLC DR of Heat	
		Consistency	Coverage	Consistency	Coverage	Consistency	Coverage
Gender	Male	0.542	0.706	0.438	0.712	0.455	0.732
	Female	0.567	0.268	0.442	0.260	0.466	0.239
Age	19–29	0.655	0.012	0.611	0.013	0.578	0.008
	30–39	0.579	0.053	0.557	0.063	0.650	0.063
	40–49	0.555	0.129	0.462	0.538	0.463	0.139
	50–59	0.548	0.213	0.440	0.213	0.465	0.199
	60+	0.542	0.566	0.422	0.549	0.437	0.565
Education	Basic	0.493	0.072	0.347	0.063	0.364	0.046
	Upper secondary	0.535	0.368	0.411	0.353	0.417	0.300
	Bachelors	0.569	0.287	0.461	0.289	0.465	0.330
	Master's degree or higher	0.562	0.232	0.508	0.262	0.526	0.298
	Other	0.490	0.042	0.314	0.034	0.346	0.026
Living	Apartment	0.523	0.141	0.456	0.154	0.479	0.055
	Terraced	0.552	0.119	0.410	0.111	0.423	0.080
	Semidetached	0.614	0.386	0.505	0.033	0.494	0.039
	Detached	0.549	0.686	0.438	0.683	0.458	0.802
	Other	0.446	0.021	0.339	0.661	0.384	0.024
Kids	Yes	0.529	0.137	0.469	0.152	0.487	0.179
	No	0.547	0.453	0.433	0.828	0.447	0.797
People in house	1	0.539	0.220	0.415	0.211	0.410	0.146
	2	0.550	0.598	0.444	0.601	0.465	0.629
	3	0.558	0.088	0.447	0.088	0.446	0.107
	4 or more	0.513	0.087	0.450	0.095	0.489	0.112
Income in Euros	<1000	0.576	0.048	0.447	0.046	0.474	0.031
	1000–2500	0.527	0.283	0.407	0.272	0.410	0.215
	2500–3500	0.560	0.244	0.438	0.237	0.441	0.245
	3500–4500	0.591	0.160	0.415	0.211	0.483	0.191
	4500–6000	0.559	0.092	0.530	0.108	0.557	0.138
	>6000	0.510	0.053	0.455	0.059	0.650	0.063

- *Kids:*
  - Consumers who have kids in their households have a lower evidence in the data in favor of a high WTE appliances in DLC DR than the consumers who do not have kids.
  - On the other hand, the consumers who do not have kids in their household have a higher evidence in favor of a high WTE their heating and EVs when compared with consumers having kids in their households.
- *People in the house:*
  - Consumers who had four or more people living in their house had the lowest evidence in favor of a high WTE appliances in DLC DR compared with the other groups.
  - Consumers who were living with three people in the house had the highest evidence in favor of having a high WTE appliances and EVs together.
  - Consumers who were living by themselves in the house (one person in the house) had the lowest WTE their EVs and heating when compared with the rest of the groups.
- *Income:*
  - Consumers who had a gross monthly income between €3500 and €4500 had the highest support for a high WTE appliances in the data, which is then followed by consumers having less than €1000 as a gross monthly income.
  - Consumers who are having a gross monthly income between €4500 and €6000 had the highest support for a high WTE EVs compared with the consumers in the other income groups.
  - Consumers who have a gross monthly income between €1000 and €2500 € had the lowest evidence in favor of a high WTE EVs compared with all the consumers in the other income groups.

3.4. Robust regression

In order to identify the relationship between consumer motivators to enroll in DLC DR and willingness to enroll a specific device/appliance in DLC DR, a robust regression was performed. The results of the robust regression are given in Table 8, and the $Prob > F$ value is 0.000 for this regression.

The results of Table 8 show the p value for different variables used in the analysis, and the significant results are indicated by $*$. The number of $*$ depends on the significance level. The following conclusions can be drawn from the results:

- *Appliances:*
  - Consumers who are motivated more by an interest to participate in DLC DR than by the influence of contacts/peer pressure have a lower WTE their appliances in DLC DR.
  - Consumers who are motivated more by smart home automation than by the influence of contacts/peer pressure toward DLC DR have a higher WTE their appliances in DLC DR.
  - Consumers who are motivated more by local generation than by the influence of contacts/peer pressure toward DLC DR have a higher WTE their appliances in DLC DR.
  - Consumers who are motivated more by environmental emission reductions than by financial gains achieved by participating in DLC DR have a lower WTE their appliances in DLC DR.
- *EVs:*
  - Consumers who are motivated more by an interest to participate in DLC DR than by local generation have a lower WTE their EVs in DLC DR.
  - Consumers who are motivated more by an interest to participate in DLC DR than by environmental emission reductions have a higher WTE their EVs in DLC DR.

Table 8
Robust regression results.

Motivators	WTE appliances		WTE EVs		WTE heating	
	p	Coefficient from robust regression	*p*	Coefficient from robust regression	*p*	Coefficient from robust regression
Int vs. Aut	0.2772	0.036	0.169	0.041	0.5295	−0.000018
Int vs. PP	0.0325**	−0.009	0.215	−0.026	0.7248	0.00093
Int vs. Fin	0.174	0.0482	0.458	−0.0375	0.9788	−0.01657
Int vs. LG	0.8777	−0.037	0.0061***	−0.03213	0.7068	−0.09628
Int vs. Env	0.2989	−0.0026	0.0419**	0.0816	0.092*	0.059713
Auto vs. PP	0.0001***	0.072	0	0.188	0.1401	0.0437
Auto vs. LG	0.2436	−0.1033	0.0782	−0.1412	0.6249	−0.0415
Auto vs. Fin	0.9195	−0.027	0.365	−0.0646	0.8372	−0.0614
Auto vs. Env	0.1531	0.00073	0.114	0.05104	0.67	0.01178
LG vs. Fin	0.4373	0.0012	0.0435**	0.006	0.7538	0.0096
LG vs. Env	0.2124	−0.02859	0.374	−0.0729	0.3091	−0.0322
LG vs. PP	0.0186**	0.02138	0.2651	0.08905	0.2459	−0.0037
PP vs. Fin	0.7947	−0.0654	0.9059*	−0.04814	0.7277	−0.0116
PP vs. Env	0.1547	−0.008	0.2523	−0.087	0.5304	−0.057
Env vs. Fin	0.0038**	−0.0531	0.0137**	0.1597	0.0746*	−0.01714

*/**/*** = Statistically significant at $\alpha = 10\%/5\%/1\%$.

  - Consumers who are motivated more by local generation than by financial gains achieved by participating in DLC DR have a higher WTE their EVs in DLC DR.
  - Consumers who are motivated more by the influence of contacts/peer pressure than by financial gains achieved by participating in DLC DR have a lower WTE their EVs in DLC DR.
  - Consumers who are motivated more by environmental emission reductions than by financial gains achieved by participating in DLC DR have a higher WTE their EVs in DLC DR.

- *Heating:*
  - Consumers who are motivated more by an interest to participate in DLC DR than by environmental emission reductions have a higher WTE their heating in DLC DR.

3.5. ANOVA-2

From the previous study by Sridhar et al. [28], the survey respondents were clustered into different subgroups based on their motivators to enroll in DLC DR. A k-means clustering was previously performed, and the ideal cluster number was 3 with a silhouette score of 0.28. The consumer subgroups were identified as [28]:

- Adopters: The consumers falling into this subgroup had a high interest to participate in DLC DR and preferred smart home automation. These are the consumers who would be willing to enroll in DLC DR in the pilot phase and should be initially targeted. This consumer subgroup corresponds to roughly 20% of the total respondents.
- Followers: The consumers falling into this subgroup were strongly influenced by contacts/peer pressure and had a high preference for local generation. These are consumers who would be willing to enroll in DLC DR after getting some feedback from their contacts, and should be targeted after the adopters have enrolled. This consumer subgroup corresponds to roughly 30% of the total respondents of the survey.
- Neutral: The consumers falling into this subgroup had no specific preference for different motivators. These are the consumers who would not be willing to enroll in DLC DR and would need significant incentives and nudges to enroll in DLC DR. These are consumers who should be finally targeted after adopters and followers and are the hardest to accept DR. This consumer subgroup corresponds to around 50% of the total survey respondents.

Table 9
ANOVA results of different consumer groups on the WTE in DLC DR of different loads.

Variables	Appliances		EVs		Heating	
	F	*p*	*F*	*p*	*F*	*p*
Consumer subgroups	8.77	**0.0002*****	5.71	**0.0034*****	2.38	0.1028

*** = Statistically significant at $\alpha = 1\%$.

Table 10
Results of Tukey's post-hoc test for different consumer groups for the WTE appliances and EVs.

Consumer	Appliances		EVs	
groups	Mean	SD	Mean	SD
Adopters	3.697769	0.7837396	3.243665	1.001685
Followers	3.692234	1.066372	3.331497	1.153455
Neutral	3.290476	0.887868	3.125	0.9944675
Significant results	Neutral vs. Adopters, Followers		Neutral vs. Followers	

The consumer subgroups obtained from the previous research can be used to study the relationship between the different consumer subgroups and the WTE housing appliances in DLC DR. A series of one-way ANOVA test was performed, and the results of this test are given in Table 9.

The results of the ANOVA test show the presence of a statistical significance in the consumer subgroups and the WTE appliances and EVs in DLC DR. In order to understand the groups within which the significance was obtained, a Tukey's post-hoc test was performed. The results of this test are shown in Table 10.

The significant results of Tukey's post-hoc test show that the neutral consumer group has a lower WTE their appliances in DLC DR than that of the consumer groups of Adopters and Followers. Similarly, the consumer group Neutral had a lower WTE their EVs in DLC DR than the consumer group Followers.

4. Discussion

The presented study could identify several key findings, which might be of particular interest to retailers, utility companies, DSOs, and policymakers. A summary and discussion of the findings are provided below.

Firstly, the distribution of survey respondents was clearly different from the Finnish national statistics. This study was aimed at the person in the household who has made the electricity contract with the electricity supplier, who is thus considered the main decision maker within

the household. In addition to this, several previous studies had studied the consumer preferences through surveys which were sent out to the general population [30,31,35]. Though the results from these studies are valid, there could only be one electricity contract per household. With the majority of the households in Finland having more than one person living therein, the results from this paper provide the actual consumer preference toward enrolling their household loads in DLC DR which helps in formulating policies and DR programs for the future. In other words the study presented here focuses on those members of the household who are actually responsible for paying the electricity bills and would thus be the recipients of potential monetary savings. In this sense this study provides more focused responses than the studies that do not distinguish between the contract bearers and the other members of the households.

Secondly, the willingness to enroll consumers' household loads in DLC DR based on economic and financial gains was investigated by analyzing their responses to the survey. The responses suggest that consumers, in general, would prefer to enroll their loads based on economic reasons over environmental benefits. One possible reason for this could be the fact that the reductions in CO_2 emissions are not significant enough to motivate consumers to enroll them in DR. A further reason could be the low CO_2 emissions of the energy production, which consumers might already consider environmentally friendly. Within the household loads, it can be observed that both appliances and heating have a high WTE when compared with EVs based on economic reasons. This could be explained by the fact that only 5% of the survey respondents owned an EV, and the majority of the respondents might not have sufficient information or would fall into the high income group (where owning an EV is possible) to enroll in DR. The requested median compensation for household appliances, EVs, and heating are 100, 100, and 200 €/annum, respectively. Although this compensation is not very high, the current theoretical savings that can be obtained in Finland for household appliances and EVs together is slightly over 200 €/annum based on day-ahead electricity prices [14]. With the current increasing electricity prices and the increasing need for flexibility, it would be possible for consumers to gain their expected financial compensation by enrolling in DR. Comparing these values with previous studies, Ruokamo et al. [30] stated that consumers would require a compensation of 170–220 €/annum for electric load control for evening times and 60–100 €/annum for heating load control in evening times. Similar to these results, Broberg & Persson [31] reported that consumers would require around 60 €/annum for heating control and 140 €/annum for electricity control in the evenings. The results of the present study show that consumers would require more compensation for heating than for electric loads (without EVs), which is against the results of the previous studies [30,31]. One possible reason behind this could be the fact that the present study considers only electric source heating types, whereas the previous studies have not mentioned the heating source type. Furthermore, with the increasing electricity prices (in comparison with the time of previous studies; 2016 and 2019), the cost of using electrical heating would be higher, thereby making their required compensation higher.

Thirdly, a clear dependency of consumers' WTE their different household appliances and devices in DLC DR on their socioeconomic and demographic was highlighted. The study applied a statistical ANOVA test, which identified education and age as important sociodemographic characteristics influencing consumers' WTE in DLC DR. The results of this study show that young people would more likely be willing to enroll their EVs and heating in DLC DR than old people. In addition, the test also showed that the people with a higher education would be more willing to enroll their EV in DLC DR than people with a lower education. These results are in line with the general information that higher-educated people are aware of the climate change and that the need for flexible resources will increase in the future. In terms of age, the results of this paper are in line with the results reported by Broberg & Persson [31], according to which younger people are more likely willing to enroll their household loads in demand response than older people.

Fourthly, the study proposed the use of an additional data analysis technique – fsQCA – which used a fuzzy set representation of a "high WTE" of consumers to then provide additional insights into the dependencies of sociodemographic feats and consumers' WTE their household appliances and devices in DLC DR. The results of fsQCA were in line with the results of the previous ANOVA test and could be considered a valid approach to provide additional insights. The results of fsQCA provided additional insights into consumer age, education, living conditions, and income, and their connection with the WTE in DLC DR. The results show that people having a basic education showed the least WTE their heating and EVs, which is in line with the fact that higher-educated people are more aware of the need for flexibility and have a higher acceptance rate. It was also shown that semidetached houses with young people (younger than 40 years) are the ideal target groups for the appliance DR, and young people with a high income level are the ideal target groups for the heating DR. In terms of gender, the results of fsQCA showed that female consumers' WTE their appliances, EVs and heating in DLC DR is more supported by the data than male consumers. Within the living conditions, consumers who stated "other" (unknown living situation corresponding to 2% of the sample size) as their living conditions have the lowest WTE across all loads. Additionally, consumers who stated having kids in the households had a lower WTE their heating and EVs than consumers without kids, similar to the results from the study by Kobus et al. where consumers with kids had a higher need to override the automatic control of their appliance [24]. The data does not show any significant relationships between WTE and the number of people in the household, but comparing among consumers based on the number of people in the household, consumers who were living by themselves had the lowest WTE their EVs and heating and consumers who had four or more people living in the household had the lowest WTE their appliances whereas consumers who were living with 3 people in the household had the highest WTE their appliances and EVs in DLC DR.

Fifthly, the study analyzed the influence of motivators for DLC DR and consumer WTE their household appliances and devices through a statistical robust regression method. The results of this test resulted in the identification of important motivators that influence consumers' WTE in DLC DR. Consumers who are motivated more by an interest to participate in DLC DR than by environmental benefits have a higher WTE their EVs and heating in DLC DR. Consumers having a higher preference for environmental benefits over financial gains have a lower WTE their appliances and heating, whereas they have a higher WTE their EVs in DLC DR.

Sixth, the study analyzed the consumers' WTE based on different consumer subgroups as defined in [28]. The analysis was performed using a statistical ANOVA test, and the test result confirmed the correct categorization of consumers and affirmed the result that consumers falling into the neutral group had a lower WTE their EVs and appliances than when compared with the other groups. The results of this test highlighted the relevance of categorization (proposed by Sridhar et al. [28]) of consumers based on motivators to then develop DR programs that would suit the specific consumer groups to maximize the DR adoption rate.

Lastly, the survey was sent out to be answered by the consumers before the aggression of Russia during the Russia–Ukraine conflict. Since then, the prices of electricity have increased due to limitation on imports of Russian gas and more awareness has been spread among the consumers regarding their electricity usage and the current situation of the electricity system, also the awareness of the prices of electricity and their development has thus increased in the general population. As a result, it could be possible that the consumers WTE could have been increased due to the nation-wide awareness regarding electricity consumption and the higher financial returns reflecting the high electricity prices. In other words the willingness to enroll reported in this paper might be representing a lower estimate of the current actual willingness to enroll in DR given the geopolitical situation and the development of the prices of electricity.

4.1. Limitations

In this study there are a few limitations that must be acknowledged to better understand and correctly interpret the results. The study used the responses of consumers who may or may not own an EV. As a result of this, some proportion of the survey respondents may not have adequate information on EV charging which might hinder their WTE in DR. In addition to this, the survey also used only electric heating consumers for their WTE. In contrast to this, there is a vast share of consumers using district heating within Finland who could also contribute to the system flexibility. Since the survey was focused on WTE based on financial incentives and emission reductions it was not possible to obtain the same using district heating.

5. Conclusion and policy implications

This study helps to bridge the gap in the literature by quantifying consumers' WTE their different household appliances in DLC DR. The study proposed different statistical and data analysis methods to identify the underlying characteristics among different consumers and their WTE of their appliances and devices in DLC DR. The study used a series of one-way ANOVA tests to identify the effect of consumer sociodemographic features on their willingness to enroll their household appliances, EVs, and heating in DLC DR. The study showed the consumer willingness to enroll their household appliances in DLC DR based on environmental and financial incentives. The results of the statistical test showed that age and education were the important influencing factors for the consumer willingness to enroll in DLC DR of EVs and heating. In addition, Tukey's post-hoc test was performed to identify the statistically significant subgroups. Within the age groups, younger consumers (<30) would be more willing than older consumers to enroll in DLC DR of EVs and heating. Finally, highly educated people (with a university-level degree) had a higher willingness to enroll their EVs in DLC DR.

Additionally, the study used a data analysis approach through the usage of a qualitative analysis approach: fsQCA was proposed. The results of this method were in line with the results of an ANOVA test and provided additional insights: young (<40 years), high-income consumers living in apartment houses are the ideal type of consumer to increase the DR adoption rate.

The study also identified the relationship between different motivator preferences of consumers for the consumer WTE their household appliances and devices in DLC DR by applying a statistical robust regression methodology. The results show that the consumers who preferred environmental benefits to financial gains had a lower WTE their appliances and heating and a high WTE their EVs. Further, the consumers having a higher preference for an interest to participate over environmental gains had a higher WTE their EVs and heating in DLC DR.

Lastly, the study proposed to identify the relationship between consumer subgroups and consumer WTE by a statistical ANOVA test. The results show that the consumers in the neutral group have the least preference to enroll in DLC DR compared with the other consumer subgroups, adopters and followers, making adopters and followers the ideal target group for the DR adoption.

5.1. Policy implications

From the perspective of designing demand response programs, the study helps in identifying the important appliances within a household that can be easily targeted to encourage consumers to enroll in DLC DR. In addition, programs can be targeted at consumers based on their sociodemographic characteristics, as was highlighted in this study. Essentially, in the initial phase, the programs should be designed for areas where the level of education is high, and the population is young. In addition, the programs can also be targeted at regions with a high prevalence of semidetached houses, as the demand for this housing type has increased in Finland in recent years [51]. With the WTE being high with adopters and followers, the demand response programs should ideally target adopters first, who are to be then accompanied by followers as suggested by Sridhar et al. [28].

From the viewpoint of policymakers, the study helps in estimating realistic WTE of household devices and appliances for residential consumers. The study highlights the preference level among different household appliances through economic and environmental incentives based on consumer sociodemographics, and this knowledge must be used by the policymakers to identify the flexibility available through the residential sector for DR. Additionally, the study also shows that in different consumer subgroups, the consumers' WTE their devices and appliances varies. The policymakers should acknowledge the disparity in WTE among consumer subgroups, which might affect the overall adoption of the residential DR, and policymakers should account for the extra time to implement DR when setting targets for the future. The policymakers should also contribute to spreading awareness about residential DR and the need for it in the future, and thus increase the DR adoption rates.

CRediT authorship contribution statement

Araavind Sridhar: Conceptualization, Methodology, Software, Formal analysis, Data curation, Writing – original draft, Writing – review & editing. **Samuli Honkapuro:** Conceptualization, Methodology, Supervision, Funding acquisition, Writing – review & editing. **Fredy Ruiz:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Jan Stoklasa:** Methodology, Software, Formal analysis, Writing – original draft, Writing – review & editing. **Salla Annala:** Conceptualization, Methodology, Supervision, Writing – review & editing. **Annika Wolff:** Conceptualization, Methodology, Supervision, Writing – review & editing, Proof reading. **Antti Rautiainen:** Writing – review & editing.

Declaration of competing interest

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

Data availability

Data will be made available on request.

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