LUT University

Nation-wide projection of motivators and consumer willingness for direct load control demand response in Finland

Sridhar Araavind, Honkapuro Samuli, Ruiz Fredy, Stoklasa Jan, Annala Salla, Annika Wolff, Rautiainen Antti

This is a Author's accepted manuscript (AAM) version of a publication

published by IET

in 27th International Conference on Electricity Distribution (CIRED 2023)

DOI: 10.1049/icp.2023.0328

Copyright of the original publication:

© The Institution of Engineering and Technology 2023

Please cite the publication as follows:

Sridhar, A., Honkapuro, S., Ruiz, F., Stoklasa, J., Annala, S., Wolff, A., Rautiainen, A. (2023). Nation-wide projection of motivators and consumer willingness for direct load control demand response in Finland. In: 27th International Conference on Electricity Distribution (CIRED 2023), Rome, Italy. pp. 401-405. DOI: 10.1049/icp.2023.0328

This is a parallel published version of an original publication. This version can differ from the original published article.

NATION-WIDE PROJECTION OF MOTIVATORS AND CONSUMER WILLINGNESS FOR DIRECT LOAD CONTROL DEMAND RESPONSE IN FINLAND

Araavind SRIDHAR
School of Energy Systems
LUT University - Finland
araavind.sridhar@lut.fi

Samuli HONKAPURO
School of Energy Systems
LUT University - Finland
samuli.honkapuro@lut.fi

Fredy RUIZ
Dipartimento di Elettronica, Informazione e Bioingegneria
Politecnico di Milano - Italy
fredy.ruiz@polimi.it

Jan STOKLASA
LUT Business School
LUT University - Finland
jan.stoklasa@lut.fi

Salla ANNALA
School of Energy Systems
LUT University - Finland
salla.annala@lut.fi

Annika WOLFF
School of Engineering Science
LUT University - Finland
annika.wolff@lut.fi

Antti RAUTIAINEN
Pohjois-Karjalan Sähkö and
Tampere University - Finland
antti.rautiainen@pks.fi

ABSTRACT

The current participation of residential sector in Demand Response (DR) is low due to various factors. Understanding the consumer motivation towards DR and their preference to enroll their household loads are essential for a widespread adoption of DR. This paper focuses on the residential consumer responses on motivator preferences to DR and their Willingness To Enroll (WTE) different household loads in DR. The research is based on a survey answered by residential consumers of Finland and extrapolates the survey results to match the national statistics of Finland. The results from this paper provide valuable information regarding consumer motivators and household load preferences in DR and regarding the potential WTE in the Finnish population.

INTRODUCTION

Renewable energy is the way for a sustainable future while mitigating the ever-increasing pollution levels. Though renewable energy has been utilized in the energy system for decades, the addition of intermittent renewable energy adds some complexity by having the need for balancing and increasing volatility of the electricity spot prices.

DR is a potential solution which can help in minimizing the negative effects of adding intermittent renewable energy into the energy system. DR can be defined as the changing of the conventional consumption patterns based on either price or external signals. DR can be further divided into two groups: Implicit and Explicit DR. If the loads are changed by individual consumers based on price signals then it is implicit DR. On the other hand, if the load curtailment is activated by an aggregator, it is explicit DR, also known as Direct Load Control (DLC) DR. Residential sector is one branch of consumers who have a few flexible loads individually but when coupled together could provide adequate flexibility to the electricity system in peak hours [1].

Within DR programs, DLC has greater assurance over quantity, location and timing of flexibility than when compared with price based DR [2]. However, the participation of residential consumers in DLC DR has not been adequate even though the programs have been available for years [2]. The main concerns for the consumers that prevent them from participating in these programs were trust and security of the service provider [3], overriding opportunities [4], compensation problems [5] and lack of control [6]. One possible reasoning for the low user acceptance is the lack of understanding of different motivators of consumers towards DR. A myriad of previous research has mainly considered financial and environmental motivators but according to Parrish et al. [7] there are other motivators which influence consumer decision-making. Sridhar et al. [8] has employed a survey considering six main motivators for consumer preferences towards DLC DR for Finnish residential consumers. The results from Sridhar et al. [8] provided valuable insights on consumer preferences, but the survey in itself did not represent the general socioeconomic composition of Finland. Along with consumer preferences regarding different motivators to DLC DR, understanding consumer WTE individual household loads in DLC DR would help to identify the preference level within different loads and can be used to build policies and programs to increase DR adoption rate. This study helps to tackle the issue of national representation of the survey data through iterative proportionate fitting. It thus draws additional conclusions regarding the Finnish residential consumer decision-making towards DR and their WTE household loads in DLC DR which is essential for widespread DR adoption.

SURVEY DATA

Survey distribution

The survey was initially developed to be shared along with residential consumers of an electricity supplier within Finland, Pohjois-Karjalan Sähkö (PKS). PKS has been one of the major electricity suppliers within Finland and has been operating for more than 75 years. The survey was shared to the consumer database of PKS, and it was kept open for 1.5 weeks time during the month of March 2022. The survey was distributed to approximately 30,000 consumers, of which 4,134 consumers started responding. A

Authorized licensed use limited to: Lappeenranta-Lahti University of Technology LUT. Downloaded on November 14,2023 at 10:38:59 UTC from IEEE Xplore. Restrictions apply.

total of 1,468 consumers answered the whole survey. At the time of survey distribution, there were no DLC DR services provided by PKS to their consumers. The survey was distributed anonymously and no personal identifiers were collected, as per GDPR regulations and the Data Protection Act in Finland [9].

DLC DR Motivators

Based on existing literature, the most common motivator for enrolling in DR programs is the financial benefit [10], followed by environmental benefit [11]. Apart from these two main factors, some studies outlined other motivators to enroll in DR [8, 10]. As a result, this study used the following motivators and their respective terminology:

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

In order to capture the consumer preferences towards different motivators, the consumers were asked to express their preference between each pair of motivators using a 5 point Likert scale. A sample of the survey question can be observed in Figure 1.

Fig. 1: Example of a survey question for the extraction of motivator preferences

WTE household loads

In order to extract the consumer WTE their household loads in DLC DR, the overall household loads have been split into three groups: appliances (washing machine, dishwasher, tumble dryer), Electric Vehicle (EV) and heating. Only the consumers having electric heating were asked regarding their preference to enroll heating, whereas all the consumers, regardless of their ownership of EV, were asked to express their WTE an EV. This is due to the fact that EV is becoming increasingly affordable, while the current ownership of EV within Finland is still low. For this purpose the consumers were asked to give their preference to enrol their household loads based on environmental and financial incentives. Specifically for environmental incentives, as it would be hard to understand the value of kilogram reduction of CO_2 emissions, a measurable value of emission reduction equivalent to travel in a standard petrol car was provided. These two motivators were the only ones easily representable by measurable quantities which can be easily understood by the consumer. Additionally, these are the main factors to consider from an electricity supplier's point of view. Again consumers were asked to choose their preference in a 5 point Likert scale ranging from fully disagree to fully agree (analogous to Figure 1).

Consumer socioeconomic features

Based on the existing literature on analyzing the effect of socioeconomic features on consumer preferences, this study utilizes the following independent variables: gender, age, education level and gross monthly income (see Table 1). The Finnish national statistics have been bought from Official Statistics of Finland for the year 2018 [12], and it provides the population data until December 2017. The national dataset contained a small subset of protected data that could not be used for the analysis and has been removed. Data-points representing "did not state" and "other" answers were removed from the sample for the purpose of the analysis.

Table 1 Consumer socioeconomic features from the survey and Finnish national statistics [12]

Consumer Socioeconomic		Survey Data (%)	Finland Statistics (%)
Gender	Male	72	49
	Female	26	51
	Did not state / other	2	-
	Total	100	100
Age	19-29	1	18.6
	30-39	5	16.2
	40-49	12.7	15.2
	50-59	21.3	16.3
	60+	57.1	33.7
	Did not state	2.9	-
	Total	100	100
Education	Basic	7.9	24.2
	Upper Secondary	37.6	51.6
	Bachelors	27.6	12.3
	Masters	22.6	11.9
	Did not state / other	4.3	-
	Total	100	100
Household Income (€/month)	Low(<1000)	4.5	19.4
	Medium(1000-2500)	29.4	60.3
	High (>2500)	53.5	20.3
	Did not state	12.6	-
	Total	100	100

From Table 1, it can be observed that males, 60+ age group, people having masters education or higher and high household income are over-represented in the survey respondents when compared to the Finland national statistics. Therefore, it is essential to extrapolate the survey data adequately to mimic the Finnish national statistics to draw valuable insights from the survey results.

Authorized licensed use limited to: Lappeenranta-Lahti University of Technology LUT. Downloaded on November 14,2023 at 10:38:59 UTC from IEEE Xplore. Restrictions apply.

METHODOLOGY

Iterative proportionate fitting (IPF) is a form of survey data extrapolation which is used to calibrate the survey data to be able to represent a target composition [13]. In mathematical terms, it can be expressed as a technique to identify a matrix X which is closest to another matrix Y while subjected to the constraint that the row and column marginals of X to be (nearly) identical to a target matrix Y as expressed in equation (1).

$$X = PZQ \tag{1}$$

where P and Q are diagonal matrices which are used to transform the initial matrix Z into X in a way that the row and column marginals of X are (as close a possible to) those of the target matrix Y. Classic IPF works by alternating the elements of the target matrix to satisfy the row marginals first and then to satisfy the column marginals. Initially, the target matrix X is assigned the values of the initial matrix Z as shown in equation (2).

$$x_{ij}^0 = z_{ij} \tag{2}$$

After this, x_{ij} is adjusted to reach the target row marginals as shown in equation (3).

$$x_{ij}^1 = \frac{x_{ij}^0 u_i}{\sum_I x_{ij}^0} \tag{3}$$

Similarly, x_{ij} is adjusted to reach the target column marginals as shown in equation (4).

$$x_{ij}^2 = \frac{x_{ij}^1 v_i}{\sum_J x_{ij}^0} \tag{4}$$

Then x_{ij}^0 is set to x_{ij}^2 and the entire process is repeated until the marginals of X are identical to that of target marginals u and v.

RESULTS AND DISCUSSION

The results from the survey were first collected and then IPF has been performed on them to replicate the Finnish national statistics as shown in Table 1. IPF methodology uses the survey respondent's data but repopulates a new sample by assigning specific weights for each consumer. These weights vary individually for every consumer and the weight is higher if the consumer falls in an under-represented category and vice-versa. By performing IPF, a new sample is obtained which is as close as to the target population i.e. Finnish national statistics and hence the results from the new sample after IPF is different from that of results from the survey. With IPF attaining a possible extrapolation of results while yielding a 2 % limit, the results can be considered to be representative of the Finnish national population.

The results from the survey on consumer motivator preferences towards different motivators can be observed in Figure 2.

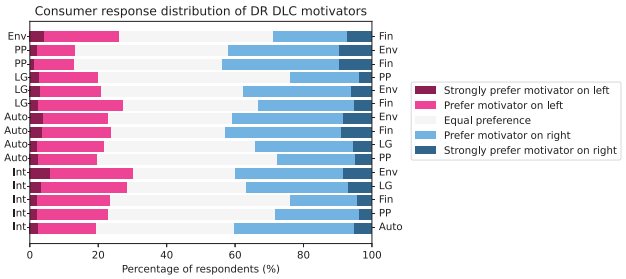

Fig. 2: Consumer response distribution from survey (before the application of IPF)

From this figure, it can be observed that the initial consumer responses had preferences which are distributed among the motivators and there is no clear distinction of consumer preferences towards the motivators. One striking fact in this figure is that the consumers had a major share neutral preference in comparison to agree/disagree shares in the figure. In contrast to this, the consumer responses after IPF can be viewed in Figure 3.

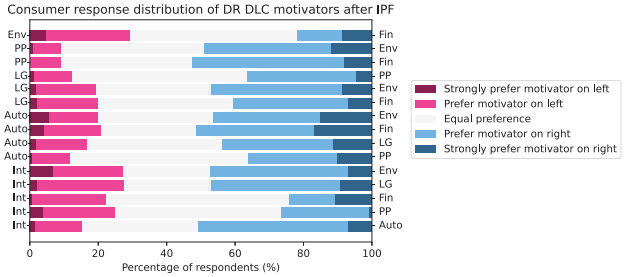

Fig. 3: Consumer response distribution from survey after the application of IPF

From this figure, the general trend can be observed that the consumer responses in the Finnish population are expected to have a lower share of having motivator preference of LG, Auto and Int than when compared to the survey respondents answers. In addition to this, consumer preference of environmental incentives over financial incentives has emerged in the whole Finnish population in comparison with the survey respondents. This is the only motivator pair in which the blue share has decreased after performing IPF.

Additionally, a k-means clustering approach has been previously performed by Sridhar et al. [8] to cluster consumers based on their motivator preferences. The clustering found that the residential consumers can be widely classified into three subgroups:

- *Adopters:* Consumers who are motivated by interest in technology and smart home automation over other motivators. This group of consumers is the ideal target for pilot phase of DR adoption within residential households.
- *Followers:* Consumers who are strongly influenced by their contacts/peer pressure and prefer local generation

Authorized licensed use limited to: Lappeenranta-Lahti University of Technology LUT. Downloaded on November 14,2023 at 10:38:59 UTC from IEEE Xplore. Restrictions apply.

over other motivators. These consumers would be willing to enroll in DR after receiving good feedback from their contacts, so targeting them after adopters is ideal for widespread DR adoption.

• *Neutrals:* Consumers who do not have a clear preference among the different motivators and would require individual targeting to satisfy their needs to enroll in DR. These are consumers who would be hard to enroll and need to be targeted after adopters and followers with specific compensation models.

The composition of these consumer groups before and after IPF can be viewed in Figure 4. From this figure, it can be observed that the initial survey respondents were dominated by neutral consumers with very few adopters in the mix. Due to this, the DR adoption would be hard and would take a significant time for widespread adoption. In addition to this, the majority of neural group corresponds to the need for more understanding of consumer needs and identifying proper compensation models individually which would result in taking significant time and work.

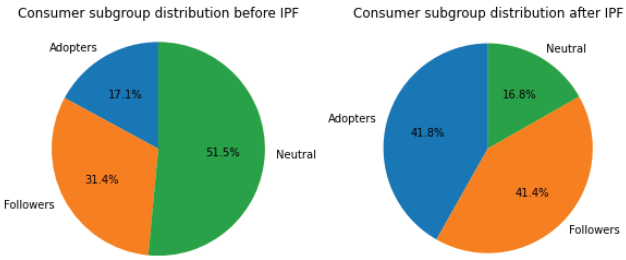

Fig. 4: Consumer subgroup distribution from survey before and after IPF

After performing IPF on the consumer subgroups, it can be observed that the distribution of consumer subgroups has been changed with the majority being almost equally distributed within adopters and followers with a minority share of neutral consumers. This results in a better distribution for widespread DR adoption as around 40 % of the consumers would be wiling to participate in the initial phase and with additional 40 % of the consumers would be willing to participate after feedback from the initial tests. Further understanding of the decision-making of the remaining 20% would be needed.

The results of consumer WTE their household loads from the survey can be viewed in Figure 5. In comparison, within the different residential loads, consumers had a higher WTE their appliance over EV and heating. The least preferred load by consumers to enroll in DLC DR is the heating. A possible explanation for this trend is the fact that consumers could rather easily change their usage of household appliances but would not want to lose their comfort level with their heating. In Finland, being a Nordic country, the heating plays an important role from October to April. Another explanation for EV WTE being lower than appliances is that the majority of the survey respondents did not own an EV (95 %) and as a result, the people were asked to answer the EV WTE on assuming that they own one. Due to this, consumers might not have adequate information and knowledge about the usage and charging patterns of EV thus by making the WTE lower than appliances.

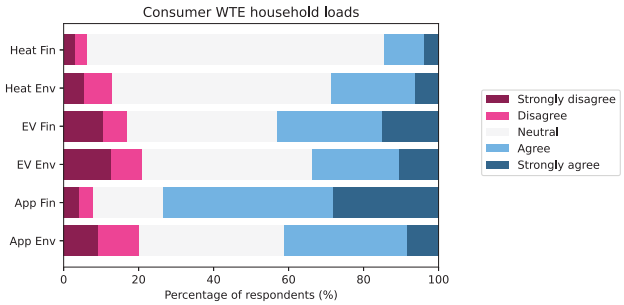

Fig. 5: Consumer WTE from survey

In addition to this, within the different incentives, consumers had a higher preference to enroll their EV and appliances based on financial incentives than environmental incentives and the contrary is true for heating. This can be attributed to the fact that consumers are mainly motivated by financial incentives over environmental reasons. Additionally, as stated before, consumers may not be willing to lose their comfort by enrolling their heating in DR and would prefer to not enroll their hating even when the financial incentives are high.

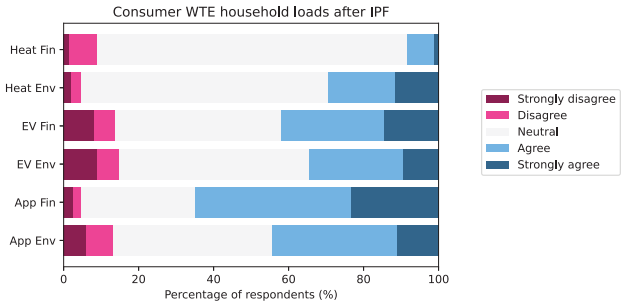

Fig. 6: Consumer WTE after IPF

The results of consumer WTE after IPF can be viewed in Figure 6. From the figure, it can be seen that the population with neutral choices have been reduced in all the different fields. In the case of financial motivations to enroll heating, consumers choosing strongly disagree have been reduced and consumers choosing agree and strongly agree have been reduced. In contrast to this, more consumers are estimated to disagree and to be neutral for heating enrollment based on financial reasons. In the case of environmental motivations to enroll heating, EV based on both financial and environmental incentives and appliance based on environmental factor we see the same trend: consumers choosing strongly disagree have been reduced and consumers

Authorized licensed use limited to: Lappeenranta-Lahti University of Technology LUT. Downloaded on November 14,2023 at 10:38:59 UTC from IEEE Xplore. Restrictions apply.

choosing strongly agree have been increased slightly. For appliance based on financial incentives, the consumers choosing strongly disagree, disagree and agree have been reduced while consumers having neutral preference have been increased.

In addition to the above-mentioned points, the study does pose some limitations which are essential to understand the results obtained. Firstly, the survey uses the responses of consumers of PKS to be repopulated to mimic the target statistic of Finland. By doing this, the study assumes that the responses of PKS consumers are representative of the whole of Finland which may not be true. But as PKS consumers are spread across the country, it can be justified that the responses from PKS can represent Finland as a whole with proper extrapolation methods employed. Secondly, the consumers' other sociodemographic features (e.g. presence of kids, number of people in the household, living condition) might affect their choices as observed from Sridhar et al. [8], but in this study, only income, gender, education level and age have been considered to repopulate the consumers to represent Finland's national statistics due to data unavailability. Thirdly, though this study has identified the national consumer preferences towards DR, it might not represent the actual situation within the country as typically there are huge shares of houses where more than one person lives and as a result only one DR preference can be extracted for the whole house irrespective of number of people living.

CONCLUSION

This study helps to project the national consumer respondents towards DR and their willingness to enroll household loads in DLC DR. The study used iterative proportionate fitting methodology to extrapolate the survey respondents to mimic the Finland's national statistics in terms of age, gender, education and income levels. The study showed that when comparing the IPF results with the survey results, consumers preferred environmental incentives more than financial incentives and have a lower preference towards interest in technology and smart home automation. In terms of consumer subgroups, adopters and followers have an almost equal share of 40 % making Finland an ideal place for widespread DR adoption. Finally, the study provided additional insights to consumer WTE their household loads in DLC DR. Consumers were more motivated by environmental incentives over financial incentives and preferred to enroll their household appliances over other loads. The residential consumers had the least WTE heating. The results from this paper paves the way to perform additional research such as developing DR policies and programs, estimating realistic residential flexibility and simulating DR acceptance across Finland can be performed which are essential to for widespread DR adoption.

REFERENCES

[1] A. Sridhar, S. Honkapuro, F. Ruiz, S. Annala, and A. Wolff, "Assessing the economic and environmental benefits of residential demand response: A finnish case study," in 2022 18th International Conference on the European Energy Market (EEM), pp. 1–6, IEEE, 2022.

[2] S. Nolan and M. O'Malley, "Challenges and barriers to demand response deployment and evaluation," Applied Energy, vol. 152, pp. 1–10, 2015.

[3] M. J. Fell, Taking charge: perceived control and acceptability of domestic demand-side response. PhD thesis, UCL (University College London), 2016.

[4] R. Smale, B. Van Vliet, and G. Spaargaren, "When social practices meet smart grids: Flexibility, grid management, and domestic consumption in The Netherlands," Energy research & social science, vol. 34, pp. 132–140, 2017.

[5] N. Murtagh, B. Gatersleben, and D. Uzzell, "A qualitative study of perspectives on household and societal impacts of demand response," Technology Analysis & Strategic Management, vol. 26, no. 10, pp. 1131–1143, 2014.

[6] X. Xu, C.-f. Chen, X. Zhu, and Q. Hu, "Promoting acceptance of direct load control programs in the united states: Financial incentive versus control option," Energy, vol. 147, pp. 1278–1287, 2018.

[7] B. Parrish, P. Heptonstall, R. Gross, and B. K. Sovacool, "A systematic review of motivations, enablers and barriers for consumer engagement with residential demand response," Energy Policy, vol. 138, p. 111221, 2020.

[8] A. Sridhar, S. Honkapuro, F. Ruiz, J. Stoklasa, S. Annala, A. Wolff, and A. Rautiainen, "Residential consumer preferences to demand response: Analysis of different motivators to enroll in direct load control demand response," Energy Policy, vol. 173, 2023.

[9] P. Korpisaari, "Finland: A brief overview of the gdpr implementation," Eur. Data Prot. L. Rev., vol. 5, p. 232, 2019.

[10] T. Broberg and L. Persson, "Is our everyday comfort for sale? preferences for demand management on the electricity market," Energy Economics, vol. 54, pp. 24–32, 2016.

[11] E. Georgarakis, T. Bauwens, A.-M. Pronk, and T. AlSkaif, "Keep it green, simple and socially fair: A choice experiment on prosumers' preferences for peer-to-peer electricity trading in The Netherlands," Energy Policy, vol. 159, p. 112615, 2021.

[12] "Official statistics of Finland (OSF): Grid database 2018."

[13] S. E. Fienberg and M. M. Meyer, "Iterative proportional fitting.," tech. rep., CARNEGIE-MELLON UNIV PITTSBURGH PA DEPT OF STATISTICS, 1981.

Authorized licensed use limited to: Lappeenranta-Lahti University of Technology LUT. Downloaded on November 14,2023 at 10:38:59 UTC from IEEE Xplore. Restrictions apply.