The impact of an energy crisis on the residential consumers' consumption behavior based on a Finnish case study

Sridhar Araavind, Honkapuro Samuli, Ruiz Fredy, Annala Salla, Wolff Annika

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Araavind Sridhar
School of Energy Systems
LUT University
Lappeenranta, Finland
araavind.sridhar@lut.fi

Samuli Honkapuro
School of Energy Systems
LUT University
Lappeenranta, Finland
samuli.honkapuro@lut.fi

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

Salla Annala
School of Energy Systems
LUT University
Lappeenranta, Finland
salla.annala@lut.fi

Annika Wolff
School of Engineering Science
LUT University
Lappeenranta, Finland
annika.wolff@lut.fi

***Abstract*—The aggression of Russia against Ukraine has had a devastating effect on people's lives and is indirectly affecting the electricity market in Europe. The electricity market has seen a drastic increase in the electricity prices as a result of limitations on the gas imports from Russia. The sudden increase in the electricity prices and the ever-increasing inflation have affected the opinions of residential consumers on their energy usage. This paper focuses on changes in consumer behavior over different time frames during the Russian aggression by means of a survey distributed to residential consumers of a Finnish distribution system operator (DSO). The results of this paper highlight the differences in consumer preferences based on the economic effects of high energy prices along with media warnings. The results of this paper also show that when the time of need arises, consumers are more than willing to adjust their electricity usage, which is essential in the transition toward a sustainable energy system in the future.**

***Index Terms*—Demand response, residential sector, load shifting, Finland**

I. Introduction

The need for renewable energy has been clear over the past decade to comply with the targets of the Paris Agreement, leading nations across the world to pledge to reduce their emissions and increase their share of renewable energy production toward a sustainable future. The addition of renewable energy has some challenges in terms of the increasing volatility of the electricity prices and the additional need for balancing and reserve power during hours of high consumption [1].

There are various solutions that can help address the challenges posed by the addition of renewable energy in the electricity system, such as Demand Response (DR). DR is a technique that provides increased flexibility in the electricity system. Load shifting falls under DR, in which consumers shift the usage of their high-consuming loads from peak hours to off-peak hours to reduce the overall system demand. The residential sector is one of the important energy consumers in Finland, accounting for roughly 28% of the national energy demand [2]. Individually, households do not have a very high demand, but when coupled together, would result in creating a significant demand, which could be useful for load shifting during the time of need.

Although there is potential for DR in the residential sector, it has not been widely implemented for several reasons: low financial returns earned by performing DR [3], concerns regarding third-party control over appliances, and the burden of tasks to check the price signals and switch loads by the consumers themselves (without the need for aggregators) [4]. The recent aggression of Russia during the Russia–Ukraine conflict has resulted in a limitation of Russian gas imports within the EU, causing the prices of electricity to be higher than usual. These high prices could raise consumers' concerns about high prices, and governments including Finland and Sweden have promoted awareness of consumer consumption and the need for consumers to reduce their consumption to help the energy system.

This paper explores differences in consumers' preferences for using energy saving techniques and willingness to shift their loads during the beginning and later stages of the energy crisis due to the Russian aggression. This paper uses a survey administered to the consumers of a Finnish Distribution System Operator (DSO) in the months of March and September 2022. The results of this paper provide important insights into changes in the consumer behavior and the effect of national media on consumers' decision-making. The results of this study could be significant for electricity suppliers, DSOs, aggregators, policymakers, and other academics.

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II. Background Data

A. Electricity price

On the Elspot market, day-ahead electricity prices are calculated by Nordpool based on the supply and demand of electricity within the Nordpool region. In this study, the historical Elspot prices in Finland were obtained from Nordpool, [5], and the price trend over the years is shown in Fig. 1. The figure represents the spot prices in Finland from 2018 to 2022. The prices usually have a seasonality pattern, where winters have high prices, and in comparison, summers have low prices, similar to the electricity demand [6]. The Elspot prices were significantly higher in the year 2022 when compared with previous years owing to the limitations of gas imports from Russia.

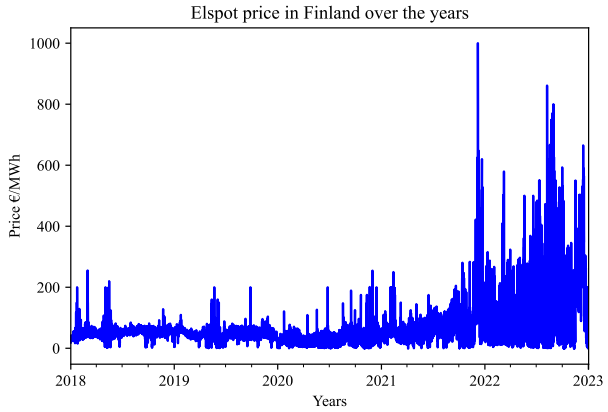


Fig. 1: Hourly Elspot Finnish prices 2018–2022 [5]

The figure shows clearly the effect of the energy crisis on the electricity spot prices. This is directly reflected in the residential consumer contracts, which are made with the electricity supplier (the DSO). Typically, a fixed price contract can be made with an electricity supplier for a maximum of two years. As a result, the contracts made during the year 2022 would have had a higher cost of electricity than the contracts made before 2022, making the consumers reevaluate their consumption during the energy crisis.

III. Survey Development

The survey was developed to be answered by residential consumers in Finland. The survey was sent out by a service company specializing in surveys, and was to be answered by residential consumers in March 2022 and September 2022 in order to grasp the changes in consumer behavior caused by the Russian aggression. The consumers were asked about their willingness to shift their major household loads (e.g., washing machine, dryer, dishwasher) from evening peak hours (17:00-20:00) to other times of the day. The consumers were given the following choices:

1) Yes, I will be willing to shift my loads from evening peaks.
2) Yes, I am willing to shift my loads, but it should be done automatically.
3) Maybe, depending on the compensation or savings.
4) No, I am not willing to shift my loads from evening peaks.
5) I do not know.

The total number of survey responses was 1000, and the respondents represented a typical Finnish consumer distribution by their age, gender, and location. Certain sociodemographic characteristics of the consumers were also collected to understand the possible differences between distinct consumer groups in their willingness for load shifting. Previous studies by [7]–[9] have shown the impact of different sociodemographic features on consumer choices regarding their participation in demand response. Therefore, for this study, the following sociodemographic features were collected from the consumers: gender, age, location, and housing conditions of the survey respondents. The characteristics of the respondents answering the survey are shown in Figs. 2, 3, and 4. It is also noteworthy that the shares of gender among the survey respondents were 50% male and 50% female.

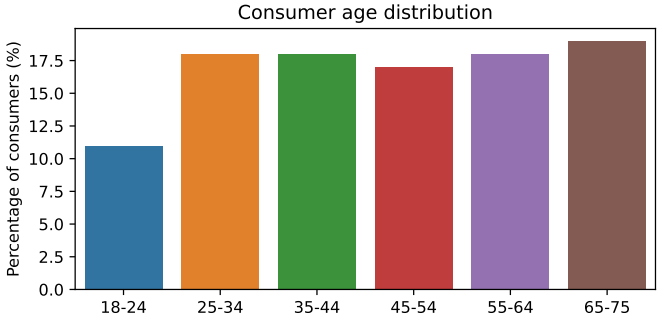


Fig. 2: Respondents' age distribution

Fig. 2 shows the age distribution of the survey respondents. The age group 18–24 is somewhat smaller than the other age groups as very few young people have electricity contracts of their own.

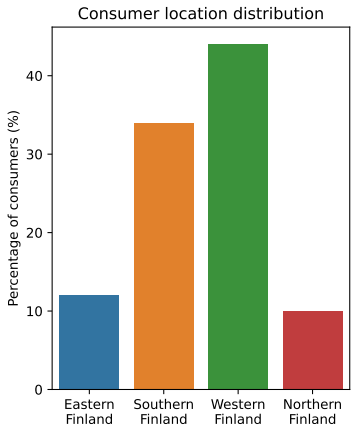


Fig. 3: Distribution of respondent locations

Fig. 3 demonstrates the distribution of respondent locations. The share of respondents from eastern and northern Finland

is lower than the shares of respondents from southern and western Finland. One possible reason for this could be the popularity of a certain electricity supplier in some regions and the presence of other local suppliers competing for the market share, but this trend is in line with the Finnish population density.

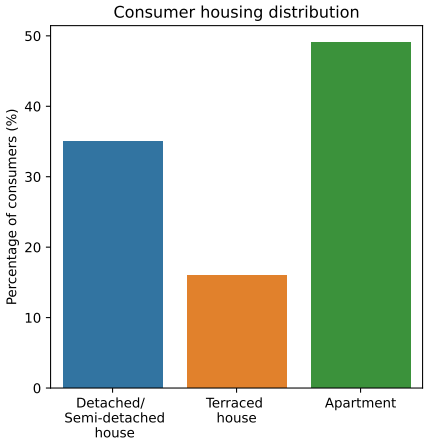


Fig. 4: Distribution of the respondents' housing types

Fig. 4 illustrates the distribution of the respondents' housing types. The proportion of consumers living in an apartment is significantly higher than the proportions of consumers living in terraced houses and detached or semidetached houses.

IV. Methodology

In order to compare the proportions of consumer responses between two different survey populations, a statistical Z test was performed in this study. This is a hypothesis statistical test used to test if two proportions are different from each other. The mathematical formula for z statistic is given by

$$z = \frac{p_1 - p_2}{\sqrt{\hat{p}(1-\hat{p})[\frac{1}{n_1} + \frac{1}{n_2}]}} \tag{1}$$

where z is the z-statistic that is compared with the standard normal deviate, p_1 and p_2 are the two sample proportions, $\hat{p}$ is the estimated true proportion under the null hypothesis equal to $(n_1 * p_1 + n_2 * p_2)/(n_1 + n_2)$, and n_1 and n_2 are the numbers of observations in the two samples.

The value of z determines if the populations are different from each other, and the value of z can be compared with different significant levels based on the obtained p value. If the p value is significant at 10% ($p < 0.1$), then *** is used along the p-value in this study. If the p value is significant at 5% ($p < 0.05$), then ** is used, and if the value is significant at 1% ($p < 0.01$), then * is used in this study.

V. Results

The overall results of the surveys can be observed in Fig. 5.

Fig. 5 shows clearly the changes in consumers' willingness to shift their loads. During the month of March, the share

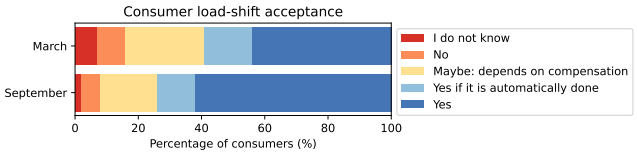
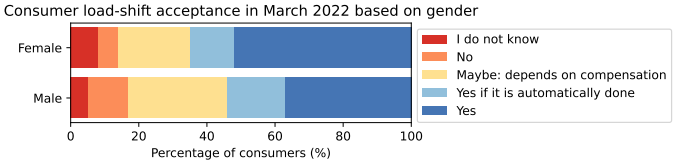
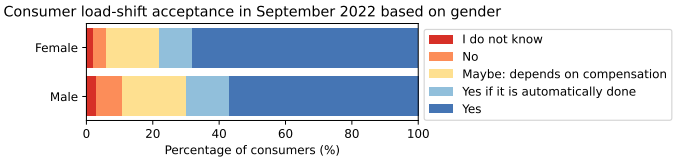


Fig. 5: Overall respondents' acceptance



(a) Responses from March 2022



(b) Responses from September 2022

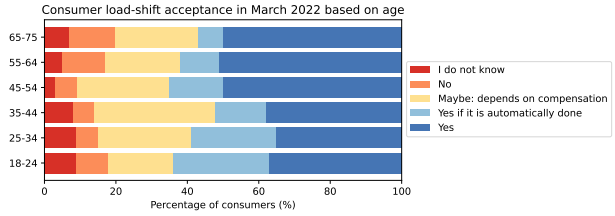
Fig. 6: Responses based on consumer gender

of consumers willing to shift loads was around 60% (self and automatic shifting), and this share increased to around 80% when the responses were collected in September, which also has a z value of -9.759 ($p < 0.001^*$). Additionally, the proportion of consumers who were reluctant to shift loads was also lower.

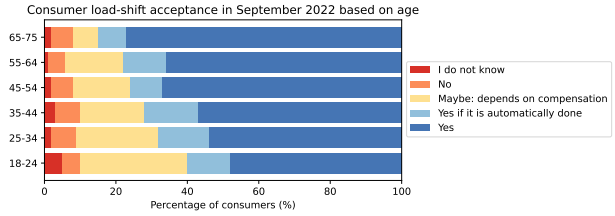
In order to observe the changes in consumer behavior based on their sociodemographic features, the responses from consumers from different groups are plotted.

Fig. 6 depicts the distribution of consumers' willingness for load shifting based on gender. From this figure, it can be seen that females have a higher acceptance to load shifting over males, and this trend seems to be evident in both the surveys. The changes in consumer willingness for load shifting (self and automatic shifting) was higher for females (from 63% to 80%; $z = -8.4209$ and $p < 0.001^*$) than for males (from 57% to 70%; $z = -6.038$ and $p < 0.001^*$). Additionally, the share of consumers who are reluctant to shift their loads is higher for males than for females.

Fig. 7 shows the responses of consumers based on different age groups. Initially, within the age groups 45–54, 55–64, and 65–75, around 50% responded with yes as their willingness for load shifting, whereas the young age groups had a lower share of roughly 35%. The trend had changed completely in the responses taken from September 2022. The trend observed then was that the older the consumers were, the higher was their willingness to enroll in load shifting. Additionally, the age group 65–75 gave the fewest responses to the choice related to compensation. In terms of percentage changes in consumer willingness for self and automatic load shifting, the age group 65–75 had the highest change, 28%, ($z = -5.8361$

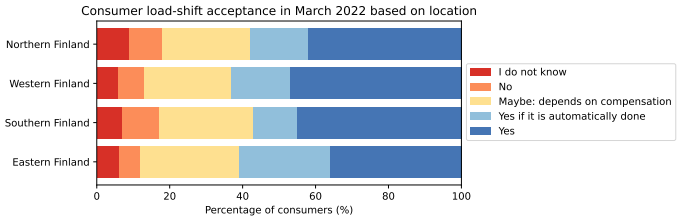


(a) Responses from March 2022

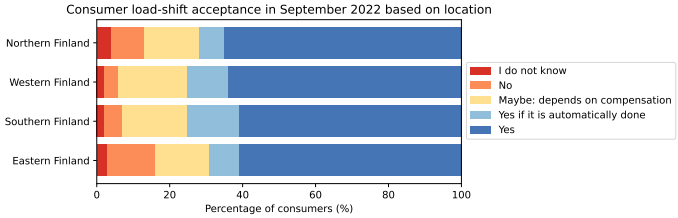


(b) Responses from September 2022

Fig. 7: Responses based on consumer age groups



(a) Responses from March 2022

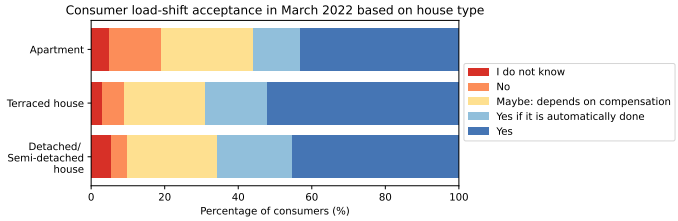


(b) Responses from September 2022

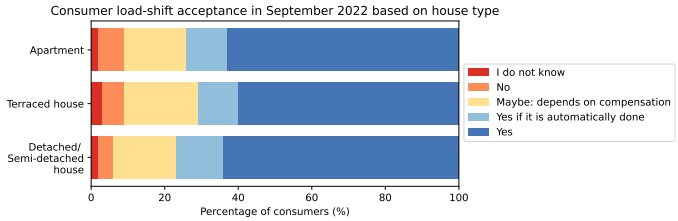
Fig. 8: Responses based on consumer location

and $p < 0.001^{*}$) which is then followed by the age group 55–65 with a 13% change ($z = -2.4524$ and $p = 0.014^{**}$). All the other age groups had minor positive changes except the age group 18–24, which had a negative change of -5%.

Fig. 8 illustrates the responses of consumers based on different housing locations. Initially, consumers in northern and eastern Finland had a slightly lower acceptance of load shifting when compared with the consumers from western and southern Finland. Additionally, in eastern Finland there was a higher share of consumers willing to shift their loads than in other regions, if the shifting is done automatically. This trend changed in the second survey sent out in September 2022, when the consumers from all the regions had almost an equal willingness to shift their loads. Similar to the results from March 2022, the consumers in western and southern Finland had a lower reluctance to shift their loads than



(a) Responses from March 2022



(b) Responses from September 2022

Fig. 9: Responses based on consumer housing type

the consumers from other locations. In terms of percentage changes in consumer willingness for load shifting (self and automatic), irrespective of the regions, all the respondents had a positive change in their willingness for load shifting. The highest change could be observed in southern Finland with a 12% ($z = -3.224$ and $p = 0.012^{**}$) change, whereas northern Finland had the least positive change of 6% ($z = 1.0731$ and $p > 0.1$).

Fig. 9 depicts the responses of consumers based on different housing conditions. Initially, consumers living in terraced houses had a higher willingness for load shifting than the consumers living in apartments and detached / semidetached houses. In contrast to this, the results from September 2022 showed that consumers had almost an equal share of willingness for load shifting irrespective of their living conditions. In terms of percentage changes in consumer willingness for load shifting (self and automatic), respondents living in apartments had the most positive change of 18% ($z = -5.6918$ and $p < 0.01^{*}$), which was then followed by residents living in detached / semidetached houses with 15% ($z = -4.3895$ and $p < 0.01^{*}$). Respondents living in terraced houses had the least change of 3% ($z = 0.6893$ and $p > 0.1$).

VI. Discussion

This 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.

First, a distinct change in consumer behavior is evident. The aggression of Russia against Ukraine has affected the people all around the world, and the shortage of gas in Central Europe has caused high electricity prices, which are reflected also in Finland. Because of the risk of a shortage in electricity, the national media in European countries have promoted awareness about the need for conserving electricity. This is one of the major reasons that have affected the

behavior of residential consumers by significantly increasing their willingness for load shifting; this is also supported by the results of the surveys obtained by both visualization and statistical methods.

Second, it was found that the consumers' sociodemographic characteristics influence their willingness for load shifting. The results of the surveys show that females are more willing to shift their loads than males irrespective of the time of survey. This result is in line with the results reported by Yilmaz et al. (2020) and Sridhar et al. (2023) [7], [9]. Additionally, this category of consumers uses more often electrical appliances the usage of which can be shifted. Hence, the awareness due to the frequent usage of electrical appliances could also be a contributing reason for this result. In addition, the results of this paper also reveal that older age groups are more willing to accept load shifting than the younger population. One possible reason for this could be that this group of consumers belongs to the energy-vulnerable group (people exposed to adverse events and changes in the energy system), and as a result, would be more willing to reduce their electricity bill as they are sensitive to high energy prices. Sridhar et al. (2023) claimed the opposite that young consumers would be more willing to enroll in DR than older consumers. One possible reason for such contrasting results could be the time of the survey. In the present study, consumers were asked about their willingness in March and September 2022, whereas in the study presented by Sridhar et al. (2023), the consumer responses were collected in February 2022, when the aggression of Russia against Ukraine had not started yet.

Last, the changes in consumer behavior give hope for a sustainable future. When the prices of electricity skyrocketed, and the national media raised awareness to minimize consumption and save as much electricity as possible, the Finnish consumers were united and willing to shift their loads even if it was not part of their daily routine. Such a change can prove the fact that when the time comes, the people can be united and would step outside their comfort zone for the greater good. This kind of mindset is needed as the whole world is moving toward a sustainable and green future. With the increasing renewable energy shares, there is a need for households to be more flexible than before. Through this study it is evident that consumers can be motivated to be more flexible through financial incentives and collective good which can be emphasized in upcoming DR pilot programs which could increase the participation of consumers in the pilot programs.

In addition to the above-mentioned key takeaways, it is essential to understand the limitations of this study to better interpret the results. Although the survey data had populations that reflect the Finnish population demographics, in reality, there might be just one person actually involved in making an electricity contract in a household. Previous studies by Sridhar et al. (2023) had skewed gender and age demographics in their survey, which represented the actual electricity supplier database [8]. In contrast, this study considers an ideal environment where all people living in a household are responsible for their contribution toward electricity savings. Additionally, this study confirmed the changes in consumer responses through the usage of a statistical z test. Even though this statistical test is highly established, in order to draw more concrete results from this survey, additional statistical tests are recommended for the future studies using these data.

VII. Conclusion

The study is based on a survey administered to residential consumers in Finland. The survey was sent to capture the changes in consumer behavior during the aggression of Russia against Ukraine on different time frames along the energy crisis. The study used a statistical z test to compare the differences in consumer responses based on different significance levels. The results of this study highlight that the consumers were more willing to shift their loads as time progressed during the aggression. Their sociodemographic features also affected the consumer willingness. Females were more willing to shift loads than males, and the same is true for older age groups when compared with younger age groups. The study shows that with proper awareness campaigns, the majority of consumers would be willing to change their consumption patterns for the needs of the energy system. This paves the way for further flexibility programs, which could be tested among residential consumers for widespread DR adoption.

VIII. Acknowledgments

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