Influence of Personal Recommendations towards Electricity Consumption on Consumer Behavior

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***Abstract* – Reducing electricity consumption belongs to significant prerequisites of mitigating the negative impact of the current energy crisis in Europe. At the same time, it is a necessary condition for slowing down the environmental deterioration of the Earth. Various studies have shown that the Bidgely technology, which provides consumers with disaggregated data on individual electric appliance consumption, has proven to be a successful way of achieving savings and more responsible consumer behavior. Bidgely enables sending personal recommendations to an individual consumer, when their consumption compared to consumers within a close radius, is higher and above the benchmark. Our study examines the impact of personal recommendations by Bidgely on consumer behavior. It compares the consumption of individual appliances in a household before and after a consumer has received the recommendations.**

***Keywords* - energy efficiency, disaggregation, behavioral changes, nudge, consumer behavior**

I. INTRODUCTION

Energy is a two faces type of commodity with its bright and dark side, both of noteworthy impact on humans. Brightly, it has enabled the game changing inventions such as: internet, new ways of medical treatments, options towards universe exploration and many more. As a result, humans have become heavily dependent on energy consumption in order to maintain sustainable economic development, which leads to increase of the world's demand for energy (Benromdhane 2015; Mahi et al. 2020). The second and darker side of energy is linked to its production, which belongs to the major factors causing the Earth's deterioration as 62 % of the global energy supply origins from fossil fuels (EMBER, 2022).

Followingly, there are 2 motivators increasing the importance of changes in consumption from the long-term perspective:

1. Energy's remarkable role within preserving current society's functions and its further evolution.

2. Limited volumes of clean energy, as production from fossil fuels needs to be eliminated to slow down the climate change, but sustainable sources can be unpredictable as shown in during the year 2021 resulting into energy crisis.

70 % of carbon dioxide emissions into the environment origin from households (Wang et al., 2017). This fact linked to the knowledge that energy production is one of the major factors of Earth's deterioration is a reason strong enough to pursue investigation into ways how household consumers use electricity and to search for the moments, when it can be more efficient. Households' energy consumption has a large saving potential estimated up to 27% of current households' energy use, which can be saved through more efficient energy use (Zhou, Yang, 2016).

This study examines, if technology providing disaggregated data on household's electricity consumption has a potential to be included into set of tools nudging electricity consumers towards the sustainable change in their behavior within electricity consumption. It focuses on behavior within individual categories of electricity consumption with the aim to reveal the areas providing the best potential for remarkable and sustainable decrease in consumption as an outcome of behavioral change.

This paper is structured as follows:

- Section 2 "Current state overview" introduces various findings on the topic of sustainable behavioral change of habits. Also, it briefly describes the Bidgely technology, which currently belongs to the major disaggregation techniques and data analyzed in this study origin from there.
- Section 3 "Data and methodology" describes the dataset and approach to examining the data related to energy consumption.
- Section 4 "Results and limitations" presents our findings within behavior related to energy efficiency.
- Section 5 "Conclusion and Discussion" summarizes our study and provides the review of implementation options for the findings.

II. THE CURRENT STATE OVERVIEW

Electricity production is among major factors generating carbon footprint. It has been estimated that through the realistic implementation of already known changes in consumer behavior, the European Union (EU) could reduce its carbon footprint by about 25% (Moran et al., 2020). The most impactful are changes in the consumption pattern (28% of the total), reduced consumption (26%), switching to goods with a lower carbon footprint in production (17%) and to goods with less carbon emission during use (19%).

Electricity usage is mostly connected to daily routines or habits. As habits are one of the strongest impediments to lifestyle change, acting to 'lock in' behaviour (Marechal, Lazaric, 2011), this reality makes achievement of lasting sustainable change in consumers' behavior a complex issue with wide spectrum of opinions and suggested approaches.

Appropriate timing of change initiation

A growing amount of literature points to the importance of not only how to intervene to achieve social and lifestyle change, but also when. Many interventions (e.g., information campaigns) are ineffective because they are not strong enough to disrupt habits (Verplanken et al., 1997). But, because habits are cued by stable contexts as e.g.: the same time, place and/or social group, (Wood et al., 2005), change in context disrupts habits (Verplanken et al., 2008). For example, low-carbon behavior, such as bus use, energy efficiency and waste reduction measures, have been shown to be more effectively changed using low-cost interventions in the 12 weeks after relocation (Verplanken, Roy, 2016; Ralph, Brown, 2017), as well as at other moments of change (Nicolson et al., 2017).

Also, the times of significant change or transition (Thompson et al., 2011) have been identified as key opportunities for reconfiguring lifestyles (Capstick et al., 2014; Graham et al., 2011) and identities (Devine et al., 2020).

A number of researches reveal, that disruptions either life-course (e.g. moving home) or structural events (e.g. economic downturn, extreme weather events, the COVID-19 pandemic) provide opportunities to more effectively change behavior (Birkman et al., 2010; Carroll, Conboyt, 2020; Verplanken et al., 2018; Marsden et al., 2020).

This knowledge increases actuality and relevancy of the topic of changing consumer behavior within electricity consumption due to turbulent market situation triggered by energy crisis starting in 2021 and being deepened by impact of war in Ukraine on the energy market. That only confirms humans' dependency on energy and its importance.

We prefer to be nudged in simple and encouraging manner

The implementation of policies aimed at encouraging and preserving the change in behavior includes a set of uneasy topics to be sold. Cutting down consumption in general, no matter if related to food and obesity impact on healthcare system or related to environmental goals, is unpopular among citizens as cutting down means restriction or change in a habit.

There have been a numerous studies providing various outcomes and opinions on effective way of behavioral change.

One of the strongest factors shaping behavior is social influence, yet rarely recognized by individuals themselves (Nolan, Schults, Cialdini, 2008). Adoption of low-carbon innovations, such as electric cars and solar panels, is significantly shaped by social norms and neighborhood effects (Bollinger, Gillingham, 2012; Grazziano, Gillingham 2015; Pettifor et al., 2017). According to study by Bogueva et al. (2017), social norms have a significant and positive relationship with both consumer attitudes and intention towards reducing their meat consumption related to environmental protection.

Waste separation is more simple and less financially demanding example of social influence impact. This type of behavioral change is compatible with the tendency of environmental psychologists to focus on low-impact, incremental behavior changes that are 'simple and painless' (Thøgersen, Crompton, 2009) rather than higher impact, more transformative behavior changes, such as purchasing energy-efficient or renewable energy equipment (Nielsen et al., 2021), which are necessary for lifestyle change that is in line with effective climate change mitigation (Whitmarsh, 2021).

Within area of environment protection, a positive effect on the willingness to change behavior appears to be conditioned by the link between our collective action and climate change salient. On the contrary, making salient how one's own behavior harms the climate decreases the chance of desired behavioral change (Lavallee, Di Giusto, 2019). Peifer et al. (2020) find that voluntary simplicity is positively related to perceived consequences for others and that making the link between consumption and climate change salient significantly reduces intentions to buy a new pair of shoes that is desired, but not needed.

Households usually have an economic incentive to save heating and electricity, and utilities sometimes provide additional incentives. A Swizz study found that electricity consumers generally prefer positive incentives for reducing consumption to negative incentives against increasing consumption (Mahmoodi et al., 2020).

The demographic factors have been generally seen to have small effects on acceptability. Among the stable factors, ideology seems to be a consistent predictor, while the influence of generalized and political trust is more limited and varied. Values, specifically self-transcendence or bio-spheric values, show stable positive effects on acceptability, but the association is typically quite weak. (Ejelov, Nilsson, 2020)

Most of the studies agree, that desired behavior should be presented with more of encouragement to do something with benefiting result, and less as a necessity to change something to prevent undesired outcome. They also reveal that consumer acceptance of incentive schemes depends on loss and risk-aversion as well as on how optimistic consumers are regarding their ability to meet the goal of their behavioral change.

Working ways of delivering the motivation

Often used informational approaches appear to be generally less effective than other types of intervention (Abrahamse, Matthies, 2012). Informational campaigns may raise awareness and concern but do not always produce behavioral change (Staats et al., 1996). Their effectiveness could be supported by respecting a few principles as e.g.: tailor messages to audience values and beliefs (Whitmarsh, Corner, 2017); target times and locations of decision-making (WRAP, 2020; Kaiser et al. 2020); promoting self-efficacy instead of, or in addition to appealing to fear (Hunter, Röös, 2016), encouraging and

setting specific and realistic goals to motivate action (Abrahamse et al., 2005).

Disaggregated data on electricity consumption presented in a user friendly and simplified way meet the above listed preconditions, which makes it a potential tool to support the behavioral change within electricity consumption. Therefore, it has been selected to be a subject of this study. One of the current major disaggregation technologies is Bidgely technology, which provides household electricity consumers with regular reports on household's consumption; and recommendations on the household management areas such as: space heating, refrigeration, lighting, always on appliances.

Disaggregated information itself has two major impacts (Gupta, Chakravarty, 2013):

- increased consumer engagement,
- reduced energy usage.

The technology addresses a combination of particular behavioral principles towards nudging consumers to change their behavior within energy consumption. It can help effectively shape energy efficiency policies and campaigns (Dawnay, E., Shah, H.; 2005):

a) **Habits**. It is more difficult to change daily routines requiring little or no cognitive efforts, which is of significant relevancy in case of electricity use.

b) **Rewards**. The change is conditioned by reward, ideally shortly after the action. Energy is not a sugar. We cannot see, how much have we saved by implementing some change in usual behavior. Therefore, in case of energy efficiency an example is an easy access to the data on consumption, which is now available thanks to disaggregation technologies analyzing the aggregate household main power measurement in the house, and disaggregating this into individual appliances (Devlin, Hayes, 2019).

c) **Consequences**. The consequences of the change are important to us. In this field, the No. 1 is an electricity bill. The first-hand output from smart meters is disaggregated data presented in the kilowatt-hours (kWh) consumed.

d) **Involvement**. People need to feel involved and effective to make a change. In case of electricity consumption, a level of accessibility of information and its complexity can lead to feelings of helplessness and inaction. Currently, there have been applications linked with disaggregation technology, which are able to produce the user-friendly regular report on consumption.

e) **Approval**. Humans' behavior is strongly influenced by other people's behavior. An example of the tool enabling common natural influence among consumers is benchmarking to similar consumers to present the effective level of consumption and support the feasibility of recommendations.

III. DATASET DESCRIPTION AND METHODOLOGY

A. Dataset description and processing and hypothesis

The database examined consists of two datasets containing electricity consumption data of approximately 30 000 consumers within the household segment in Slovakia. The data contains consumers meeting the legislative criteria for the obligatory installment of smart meters, which has been proceeding sequentially in Slovakia since 2014. These consumers are primarily households using electricity for heating or equipped with electric water boilers. Free application Bidgely has been offered to consumers with smart meters and the dataset includes the ones, who have activated it.

The first dataset "peer.insight" contained more than 3 760 million rows in 14 columns with monthly electricity consumption of consumers during 3 years: from 2018 until 2021. Electricity monthly usage (in kWh) of consumers is disaggregated according to following appliances (areas):

- Air conditioning
- Always on
- Lighting
- Pool
- Refrigeration
- Space heating
- Water heating
- Z-Other
- EV
- Cooking

The second dataset named "bidgely_recommendations" has more than 11 091 million rows in 10 columns with messages (text recommendations – tips or advice), which consumers receive to reduce the consumption in a specific area or as an advice for a particular appliance. Customers have been receiving notifications from January 2020. Some examples of recommendations are presented in Table 1.

TABLE I. SAMPLE OF DATASET BIDGELY_RECOMMENDATIONS

user_id	start_date	end_date	id_recommendation	title	Description
5000047068	2020-02-01	2020-03-01	R180	Look for ENERGY STAR when shopping for audio and video equipment	ENERGY STAR certified equipment is up to 50% more efficient than conventional models.
5000047068	2020-02-01	2020-03-01	R160	Don't want to keep unplugging?	Use a Smart Plug! These compact devices allow remote control and scheduling to avoid unnecessary energy use.
5000047068	2020-02-01	2020-03-01	R340	Improve your insulation	Repairing or replacing your insulation and weatherstripping can save you 20 percent or more on heating and cooling costs.

5000504793	2020-01-01	2020-02-01	R360	Avoid the night sweats	Set your thermostat between 65 and 68 degrees before going to bed to reduce heating costs by up to 10 percent.
5000901823	2020-02-01	2020-03-01	R590	Consider task lighting	Why light an entire room? Light only what you need.
5000841845	2020-05-01	2020-06-01	R700A	Adjust your fridge temperature settings	An ideal fridge temperature is 33°F to 39°F.
5000185210	2020-04-01	2020-05-01	R710A	Adjust your freezer temperature settings	An ideal freezer temperature is 0°F to 5°F.
...	...	...	...	...	...

Source: Own processing

The first step in data pre-processing was to aggregate recommendations to ten groups according to a type of area consumption (appliances).

TABLE II. NUMBER OF RECOMMENDATIONS IN PARTICULAR AREAS OF CONSUMPTION

IS_appliance	Name (area)	Number of recommendations
1	Air conditioning	272025
2	Always on	2893344
3	Lighting	1475221
4	Pool	8213
5	Refrigeration	2084255
6	Space heating	1164120
7	Water heating	1819720
8	Z-Other	373313
9	EV	4817
10	Cooking	996351

Source: Own processing

R-Studio was used in following work with datasets. Some unnecessary columns were deleted from both datasets. Our research focused on five consumptions areas: Space heating, Refrigeration, Lighting, Always on, and Air conditioning. There were filtered the unique consumers, who obtained relevant recommendations from the dataset "bidgely_recommendations" for every area of consumption. The resulting sub-dataset was joined with the dataset "peer_insight". A new dataset with monthly electricity usage of consumers was obtained from June 2018 to August 2021 in the filtered area (appliance). Finally, the monthly customers' average electricity consumption was calculated. Each of the resulting five datasets consists of the monthly average usage (kWh) of consumers from June 2018 to August 2021. Values before January 2020 represent the average consumers' electricity consumption before receiving recommendations, and values after January 2020 represent the average consumers' electricity consumption after they have started to receive recommendations.

The study examines 5 hypotheses:

HYPOTHESIS 1: The average electricity consumption of customers in the area of Space heating will not statistically significantly change after sending recommendations for its decrease.

HYPOTHESIS 2: The average electricity consumption of customers in the area of Refrigeration will not statistically significantly change after sending recommendations for its decrease.

HYPOTHESIS 3: The average electricity consumption of customers in the area of Lighting will not statistically significantly change after sending recommendations for its decrease.

HYPOTHESIS 4: The average electricity consumption of customers in the area of Always on will not statistically significantly change after sending recommendations for its decrease.

HYPOTHESIS 5: The average electricity consumption of customers in the area of Air conditioning will not statistically significantly change after sending recommendations for its decrease.

B. Methodology of analyzing trend in electricity consumption

The analysis compares consumers' average electricity consumption before and after receiving recommendations. Graphical presentation was used to show the trend of average consumers' electricity consumption for each use case. To confirm the Hypotheses, the data was divided into two sets - before and after January 2020. The Shapiro-Wilk test at 0.01 level of significance was used to test the normality of the data. After the confirmation, that the data is normally distributed, the F-test was used to test whether two samples have equal variances. If the data samples have equal variances, the t-test was performed to determine if both population means are equal. (Hudec, Liptáková, 2018)

IV. RESULTS AND LIMITATIONS

A. Results

This research has focused on influence analysis of personal recommendations to customer behavior related to electricity use in individual areas of electricity consumption: space heating, refrigeration, lighting, always on, and air conditioning. Five hypotheses were examined. Each hypothesis was set to each case of electricity consumption and supposed that consumption would not change statistically significantly after sending recommendations.

TABLE III. SHAPIRO-WILK NORMALITY TEST

	Before recommendations	During recommendations

	W	p-value	W	p-value
Space Heating	0.88031	0.02174	0.90898	0.0709
Refrigeration	0.92582	0.145	093441	0.2087
Lighting	0.93875	0.2503	0.9667	0.7092
Always On	0.96794	0.7345	0.96794	0.7345
Air Conditioning	0.92803	0.3913	0.96796	0.8834

Source: Own processing

Firstly, the data were divided into two datasets - before and during receiving recommendations within each category of electricity consumption. Shapiro-Wilk normality test was used to test data for each sub-dataset at the significance level $\alpha = 0.01$. The results shown in Table 3 determine, that data within all sub-datasets are normally distributed, that is the presumption to test if two samples within each category have equal variances by using F-test and therefore, if variances of average consumer consumption differ between periods before and during receiving recommendations.

TABLE IV. F-TEST RESULTS

	p-value	results
Space heating	0.461	p value > 0,05 , two samples have equal variances
Refrigeration	0.218	p value > 0,05 , two samples have equal variances
Lighting	0.241	p value > 0,05 , two samples have equal variances
Always on	0.479	p value > 0,05 , two samples have equal variances
Air conditioning	0.251	p value > 0,05 , two samples have equal variances

Source: Own processing

We have used F-test to confirm that the two samples have equal variances. Calculations of the results are shown in Table 4. As by the F-test results, the variances between datasets within all the categories are equal, T-test is used to test if a means of average consumer consumption differ between periods before and during receiving recommendations.

TABLE V. T-TEST RESULTS

	p-value	results
Space Heating	0.0029	$H1_0$ was rejected. There exists difference between values before and after at the significance level $p<0.05$
Refrigeration	0.9876	$H2_0$ was confirmed. There exists no difference between values before and after at the significance level $p<0.05$
Lighting	0.5593	$H3_0$ was confirmed. There exists no difference between values before and after at the significance level $p<0.05$
Always On	0.1123	$H4_0$ was confirmed. There exists no difference between values before and after at the significance level $p<0.05$
Air Conditioning	0.0015	$H5_0$ was rejected. There exists difference between values before and after at the significance level $p<0.05$

Source: Own processing

The results of the T-test are shown in Table 5. For categories Space heating and Air conditioning means of average consumer consumption differ between periods before and during receiving recommendations. For the categories Refrigeration, Lighting, and Always on there are no differences between periods before and during receiving recommendations.

Space heating and Air Conditioning

Due to the results, there are statistically significant differences between consumption before and during receiving recommendations in the categories Space heating and Air conditioning.

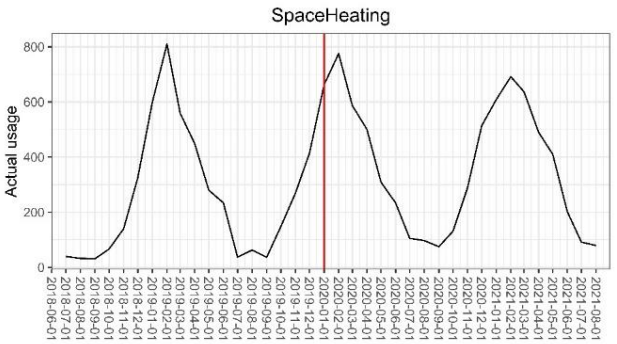

Figure 1. Monthly average electricity consumption for Space heating

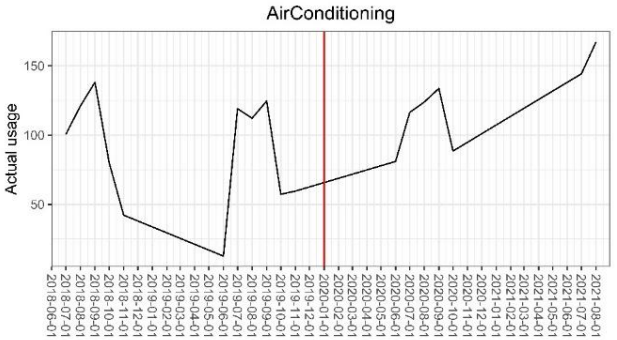

Figure 2. Monthly average electricity consumption for Air Conditioning

Figure 1 and Figure 2 represents a graphical view of the monthly average consumption for the categories. The periods before and during receiving recommendations are split by red lines. The results present, that in case of heating and air conditioning the average consumption of a household increases. As the electricity consumption within these categories are strongly related to weather situation, further research needs to reflect this aspect to specify the impact of disaggregation in these two areas. The same pattern applies to air conditioning and number of days with summer temperatures. The positive impact of disaggregation should not be rejected as abovementioned specific conditions require further research.

Refrigeration, Lighting and Always on

Based on the results, refrigeration consumer electricity consumption has not changed after they started receiving the recommendations. The reason links to the way this appliance works within household and its consumption is permanent. In this area the usefulness of monitoring its consumption links to the malfunctions of refrigerator,

when significantly increased consumption suggest that the appliance should be changed or repaired.

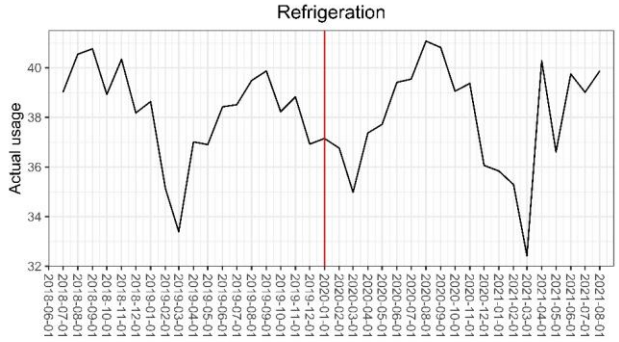

Figure 3. Monthly average electricity consumption for Refrigeration

Based on the results, Lighting consumer electricity consumption has not changed after they started receiving the recommendations. The reason should be, that lightning is area with the lowest electricity consumption. Quantified financially, this area doesn't provide sufficient motivation to change habits.

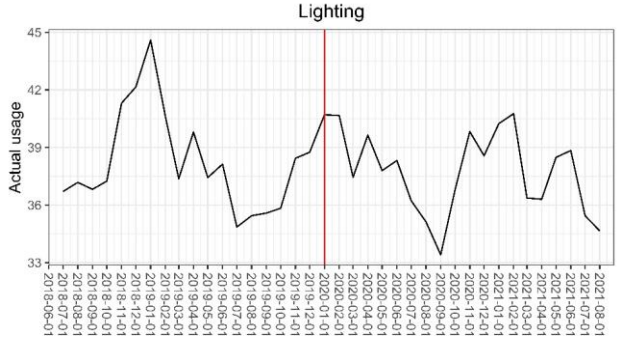

Figure 4. Monthly average electricity consumption for Lighting

Based on the results, Always on consumer electricity consumption has not changed after they started receiving the recommendations. The reason would be similar to lightning category, providing not attractive trigger to change a consumer behavior.

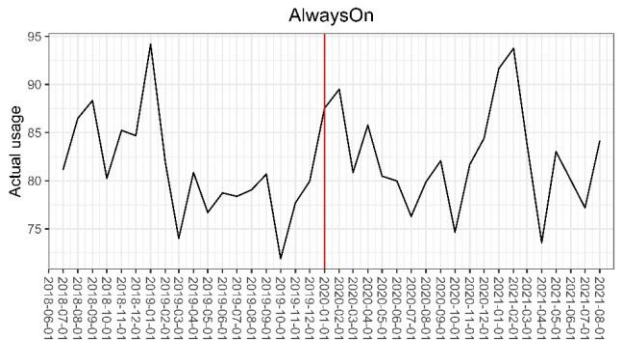

Figure 5. Monthly average electricity consumption for AlwaysOn

B. Limitations

Our current research has been accompanied by a few limitations, that need to be taken into account within interpretation of the results:

- For the purpose of the further use of these results, we have worked with average values, which do not reflect the seasonality of energy consumption.
- The level of energy consumption and efficiency is a complex topic influenced by the group of factors. We focused on the impact of an individual tool based on behavioral principles. Its impact could be intensified when combined e.g. with campaigns by state authorities.
- The personalized report on a particular household consumption has, within this database, been send through only one tool, an e-mail message without reminder notification. Therefore, deliverability of the message would have an impact on effectivity as well and way how to increase it, is another topic with the potential of improvement the total outcome.

V. CONCLUSION AND DISCUSSION

Behavior change is often narrowly conceived as individual-level consumer action (e.g. buying a low carbon product, recycling, reducing meat-eating), but is more appropriately understood as extending across the many roles and contexts humans occupy: as members of communities, participants in organizations, and as citizens who can influence policies (Nielsen et al., 2021).

The aim of this research is to study human motivations to proceed long term and sustainable change in behavior and apply them when creating policies to reach a globally beneficial outcome. As some studies show, favorable conditions towards change in habits are provided by the times of significant social change or transition, such as current tough global political and economic situation shaped by recent Covid pandemic as well as ongoing energy crisis and war in Ukraine.

The research has pointed at households, but they are persons, who can be decisions makers in their professional lives. When they change their behavior towards electricity consumption at home, it will become natural to them to transfer behavioral pattern it into professional life and behave same towards the decision at work, which expands the impact of households' behavioral change into company sector.

Disaggregation of electricity consumption and simple approach to user friendly and easily understandable data on consumption is among the tools with potential to support the behavioral change thanks to reflecting a number of behavioral principles such as: habits, rewards, consequences, involvement and approval (Dawnay, Shah, 2005)

This study has pointed at examining the particular areas of electricity consumption within households. The results show, that areas with low consumption levels and therefore also low costs on electricity appear to provide insufficient motivation to change behavior towards changing habits and consequently the electricity consumption.

The results provide an outcome, that in case of heating and air-conditioning the average consumption of a

household increases. But the amount of electricity used in these areas is significantly influenced by the weather. Therefore, further methods need to be applied to reflect the weather conditions in the period examined. In other words, average consumption of a consumer related to heating would be higher during a year when winter temperatures appear from December till January in comparison to for example a period when winter temperatures start in December but last till end of March. The same pattern applies to air conditioning and number of days with summer temperatures. The positive impact of disaggregation should not be rejected as abovementioned specific conditions require further research.

The study investigates changes in consumers' behavior triggered by comfortable access to user friendly reports containing disaggregated data related to their energy consumption. Consumers included in the dataset receive the report on their e-mail therefore the impact of recommendations on behavioral changes is strongly influenced by delivery of the message to a consumer. Therefore, open rates of the e-mails containing reports need to be reflected in more detail within further research.

Lowering energy consumption through permanent and lasting behavioral change is a complex topic requiring involvement of different subjects such as policy makers, schools, professionals and other authorities. It is also conditioned by combining a set of tools and choice of appropriate and inspiring contents. As explained in the study, disaggregation technology delivered to a consumer in a simplified and easily understandable way meets a number of preconditions to support the desired behavioral change.

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