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GRINS
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Reducing emissions from energy consumption through tailored behavioral interventions: evidence from two randomized controlled field trials

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Executive summary

This policy brief includes two complementary research projects aimed at exploring how nudges and informational campaigns can impact consumers' behavior with respect to environmentally relevant consumption activities.

The first contribution explores innovative methods to promote sustainable energy consumption behaviors. Due to the urgency of reducing CO_2 emissions, the project considers advanced smart-meter technology and psycho-behavioral segmentation to deliver personalized, non-invasive interventions. The first phase of the study involves analyzing high-frequency smart meter data from partners in the energy sector, supplemented by consumer attitudes and motivations. The data analysis employs self-organizing maps (SOMs) and wavelet transformations to uncover consumption patterns and cluster households based on energy behaviors. Initial findings reveal distinct seasonal trends, with winter peak usage and summer efficiencies offering insights into consumer habits. Data from international energy providers will further refine these analyses. The second phase focuses on implementing randomized controlled trials to test the efficacy of targeted behavioral interventions compared to standard approaches. By tailoring nudges to specific consumer clusters, the research seeks to foster pro-environmental behavior while maintaining individual freedom of choice.

The second work investigates the direct and spillover effects of behavioral nudges aimed at promoting sustainable resource consumption, focusing on a large-scale randomized controlled trial (RCT) conducted in collaboration with an Italian multi-utility company. The study evaluates the impact of a social information program for water conservation that included comparisons with neighbors, injunctive feedback, and conservation tips. Key findings include a 1.4% reduction in water usage and a spillover reduction on a second energy resource, with a 0.5% reduction in electricity consumption over two years. We detect no significant effect on gas consumption. Notably, the intervention was more effective when targeted as a standalone nudge, emphasizing the importance of strategic program design to avoid cognitive overload or diminishing returns from overlapping campaigns. Moreover, the program improved customer retention. These results highlight the necessity of designing well-timed, targeted, and coordinated behavioral interventions to maximize their environmental and economic benefits. For utilities and policymakers, integrating these insights can ensure that nudges are effective as well as valued by consumers, delivering a dual dividend of sustainable resource use and customer loyalty.

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1. Presentation and description of the research activity undertaken

1.1 Reducing emissions from electricity consumption through tailored behavioral interventions: a randomized controlled field trial

The project aims to analyze the impact of behavioral, effective, and non-invasive (i.e., respecting individual freedom of choice) interventions on energy consumption. This initiative, motivated by the urgent need to reduce CO_2 emissions, focuses on using personalized behavioral interventions facilitated by the ability to collect and analyze data on energy consumption through smart technologies. Smart meters provide detailed, real-time information on individual energy consumption. These tools, combined with advanced consumer feedback technologies, not only play the role of monitoring devices but also become true allies in understanding and modeling more sustainable energy behaviors. However, recent studies (e.g., Adams et al., 2021) have suggested that smart meters may not significantly reduce energy consumption as initially promised. To maximize the benefit of these technologies, we propose an approach based on consumer psycho-behavioral segmentation (Engl et al., 2019). This approach allows the identification of various motivations that drive individual choices and behaviors, facilitating the design of individualized interventions. This practice aims to overcome "one-size-fits-all" interventions, which are often ineffective or even counterproductive for certain segments of the population (Kaufmann et al., 2013; Shah et al., 2023).

Working with leading energy companies, we plan to develop advanced consumer profiling based on high-frequency data on consumption and information on different environmental motivations and attitudes from a questionnaire. We will then test targeted and customized interventions in comparison with non-targeted interventions.

The first phase involves detailed data analysis from smart meters using published historical data (Quesada Granja et al., 2022) and data obtained thanks to close collaboration with partners in the energy sector.

We will proceed with implementing and rigorously testing personalized interventions, comparing them with generic interventions to assess their effectiveness. The output of this phase is an estimation of the impact of targeted interventions in supporting more sustainable energy behaviors compared to traditional interventions. We will evaluate the overall effectiveness of our approach. Our goal is to go beyond merely understanding consumer profiles. We wish to apply lessons learned from the behavioral sciences to evaluate the effectiveness of targeted interventions in shaping more sustainable energy behaviors: we aim to make a tangible contribution to global efforts to reduce carbon emissions and promote effective transformation in society's approach to energy sustainability.

1.2 Analysis of direct/spillover effects of information programs and campaigns

Promoting sustainable development practices requires fostering behavioral change in various domains, which have different impacts and costs. Behavioral interventions, such as nudges, have been used at large by governments and businesses to promote pro-environmental behaviors among citizens and customers. However, their impact is typically evaluated in a narrow sense. First, most research focuses on the outcome directly targeted by the intervention, ignoring potential spillover effects to related behaviors. Second, impact evaluations focus on consumption, but customer satisfaction and retention are equally, if not more, important outcomes from both policy and business perspectives. The impact of nudges may be reduced if they induce avoidance behavior, which is also a sign of their negative welfare effects. Finally, little evidence exists on the effectiveness of these interventions when similar ones simultaneously target their recipients. For a correct evaluation and effective design of sustainable nudges, it, therefore, matters whether the behavioral change induced in one domain has positive or negative spillovers in other domains; whether these interventions alienate customers, possibly diverting them towards companies that are less focused on promoting sustainable conservation practices; and whether the combined effect of nudges is smaller or larger than the impact of each in isolation.

In GRINS we addressed these questions in the context of a social information program for water conservation. Through a large-scale randomized controlled trial (RCT), water customers of a multi-utility company providing water, electricity and gas, receive a report with information about their water usage, social comparison with neighbors' usage, and tips for conservation. We evaluate the direct impact of the report on water consumption and the indirect impacts on electricity and gas. We also study the program's impact on customer engagement and retention to measure the implications not just for resource usage but also for customer satisfaction, which is related to individual welfare effects. We exploit the variation in customers' receipt of similar reports targeting other resources, i.e., electricity and/or gas.

2. Relationship with the existing literature on the topic

2.1 Reducing emissions from electricity consumption through tailored behavioral interventions: a randomized controlled field trial

This project fits within the existing literature from two directions. The first concerns the literature on why, how, and which interventions to incentivize pro-environmental behaviors are most effective, and this is through analysis of pre-existing historical data with the proposed methodology. This is complemented by field testing with a field experiment of the proposed instruments. The second relates to the methodology with the use of an innovative scheme for data analysis based on interweaving different tools for a better, more in-depth exploration of the time series. Unprecedented social, environmental, political, and economic challenges like pandemics and epidemics, environmental degradation, and community violence call for a review of strategies for promoting behaviors that benefit individuals and society (Albarracín et al., 2024). Reducing CO2 emissions and delaying global warming need encouraging eco-friendly behavior (Van Valkengoed et al., 2022). One of the 21st century's most urgent concerns is mitigating the effects of global warming.

Governments, businesses, and communities must implement unprecedented reforms to limit global warming to 1.5 degrees or less (Shukla et al., 2022; The Core Writing Team, 2023). By altering their habits and lifestyles, such as consuming less energy from fossil fuels, traveling more sustainably, purchasing fewer items, and switching to a plant-based diet, people can help slow the effects of climate change (Wynes & Nicholas). Individual behavior that reduces CO_2 emissions and environmental harm is generally called pro-environmental behavior (Steg & Vlek, 2009). Several published works and meta-analyses have examined programs' effectiveness in promoting pro-environmental behavior. It is still necessary to determine which interventions are most effective, when they are most effective, and why (Van Valkengoed et al., 2022). The proposed approach in this project separates individuals into groups based on energy-consuming characteristics instead of traditional data-driven clustering (Karaliopoulos et al., 2022)., implementing a novel data analysis methodology based on Kohonen or self-organizing map (Kohonen, 2001) and wavelet transformation (Farge, 1992; Sifuzzaman et al., 2009).

Self-organizing maps are a broad category of methods called artificial neural networks (Fischer, 1998; Fischer & Gopal, 1994; Fischer & Leung, 2001), which consistently carry out dimensionality reduction and grouping (Skupin & Agarwal, 2008) and, that's why method SOM is most beneficial in the early stages of the process when the data is unclear. Because SOMs offer an intuitive representation of data, they are particularly useful in the early stages of analysis when the data relationships may be obscured or complex.

SOMs set the groundwork for more refined analysis by providing a preliminary clustering of the data. Following this initial organization, k-means clustering can further delineate the identified groups, offering a hierarchical approach that yields more precise and actionable insights (Kotyrba et al., 2021).

2.2 Analysis of direct/spillover effects of information programs and campaigns

The study on direct and spillover effects of the norm-based program adds to a growing literature that evaluates the effectiveness of social information programs and feedback on resource conservation (Allcott et al., 2011; Allcott and Rogers, 2014; Ayres et al., 2013;

Tiefenbeck et al., 2016, 2019; Fang et al., 2023). Several experimental studies have specifically looked at the direct impact of social information about water usage on water consumption, mainly in the U.S. context (Ferraro and Price, 2013; Ferraro et al., 2011; Ferraro and Miranda, 2013; Bernedo et al., 2014; Brent et al., 2015; Hodges et al., 2020). The evidence documents short-term water conservation effects of up to 5 percent. The effect can persist over longer time horizons, although it is 50 percent smaller after only one year (Ferraro et al., 2011; Bernedo et al., 2014). These effects are attributable to short-lived behavioral adjustments and more persistent changes in habits and physical capital. More recently, Jessoe et al. (2021) use high-frequency water consumption data to evaluate a home water program in California during a drought period. They find a 4–5 percent reduction in water usage, but the effect dissipates over five months.

Our research contributes to this literature in different ways. First, relatively few papers rigorously address the spillover effects of a social information report on the consumption of other resources. Jessoe et al. (2020) examine cross-sectoral spillover using one-year post-treatment data on water and electricity usage in the United States. They find that home water reports induce a 1–2 percent reduction in summertime electricity use, which disappears by 4–5 months post-treatment. Carlsson et al. (2020) find that a social information campaign on water use had a positive and sizeable spillover effect on electricity usage for households experiencing positive direct effects. Goetz et al. (2022) evaluate the effects of a hot-water-saving intervention and find persistent direct and spillover effects on dishwasher use and toilet flushing but no effect on electricity. Our paper evaluates spillover effects on a broader set of behavioral outcomes, namely electricity and gas usage, and over a more extended period (two years after treatment) allowing us to disentangle considerations of persistence of the effects from seasonality in resource usage.

Second, we evaluate the impact of the water report on customers' retention and engagement. These aspects are crucial for businesses in this sector and policymakers interested in the welfare impacts of these programs. After the liberalization of energy markets, many studies have analyzed household contract-switching choices (or lack thereof) and underlined the roles of both price and non-price attributes (Hortaçsu et al., 2017; Shin and Managi, 2017; Fontana et al., 2019; Schleich et al., 2019). Brent et al. (2015) examine whether a social comparison intervention affects other utility conservation programs, such as free home water audits and rebates for efficient toilets or irrigation controllers. They find that receiving the home water report increases program participation. Far smaller effects are found by Allcott and Rogers (2014). However, the role of customized pro-environmental information campaigns on customer retention appears unexplored, despite its importance for business and society. In our setting, reducing churn was a key objective of our partner utility, which faced yearly contract deactivation rates of 10.5 and 11.5 percent in the liberalized gas and electricity markets, respectively. Our result of lower deactivation of gas and electricity contracts following the water report provides the first experimental evidence of the role of green nudges in boosting customer experience and loyalty.

Third, we assess the effect of receiving multiple nudges. Relatively few studies have tackled this issue and combined different nudges within the same intervention.6 Yet, this question is relevant for policymakers and businesses as they target a variety of information campaigns to the same behavioral outcomes, often through multiple channels (Montaguti et al., 2016). Whether the cumulative effect of multiple nudges is larger or smaller than the sum of each in isolation is an open empirical question. The marginal effect of additional energy conservation nudges may decrease if the first one has already induced a reduction in consumption. An established finding in this literature is that the impact of nudges decreases as the margins for reduction shrink, even backfiring for low users (Byrne et al., 2018; Bhanot, 2017; Bonan et al., 2020). Alternatively, recipients may be less attentive to additional nudges if cognitive constraints limit the amount of information they can absorb (Gigerenzer and Gaissmaier, 2011) or if they try to avoid the social pressure of receiving many nudges, as demonstrated by the literature on information and ask avoidance (Andreoni et al., 2017; Exley and Petrie, 2018; Adena and Huck, 2020; Serra-Garcia and Szech, 2022; Golman et al., 2022). This might lead to a backlash against the company and a societal loss arising from additional resource usage. Conversely, multiple nudges may increase individuals' awareness of existing synergies between behaviors, heighten the salience of environmental conservation motives (Bonan et al., 2021b), and reassure about firm's commitment to sustainable development rather than mere greenwashing.

Previous works have looked at the interaction of different nudges in influencing one or more outcomes within the same behavioral sphere, e.g., electricity usage (Hahn et al., 2016; Brandon et al., 2019; Bonan et al., 2020, 2021b; Fang et al., 2023). The impact of nudge interactions appears heterogeneous and increases with the ability to target relevant and consistent sources of bias effectively. We contribute to this nascent literature by providing evidence on the heterogeneous impact of a report depending on the receipt of other similar reports. Unlike previous work, we look at the impact of the same nudge targeted to different behavioral spheres, i.e., water, gas, and electricity usage. We provide evidence that multiple nudges deplete consumers' limited attention towards the different resources.

3. Research output

3.1 Reducing emissions from electricity consumption through tailored behavioral interventions: a randomized controlled field trial.

The next section will cover ongoing data analysis on historical data (C. Quesada Granja et al., 2022).

We used GoiEner smart meter data for this analysis. The dataset contains hourly time series of electricity consumption (kWh) provided by the Spanish electricity retailer GoiEner. We use the processed time series (imputation of missing samples), which is longer than one year in duration and is collected after May 30, 2021, to avoid the COVID-19 effect.

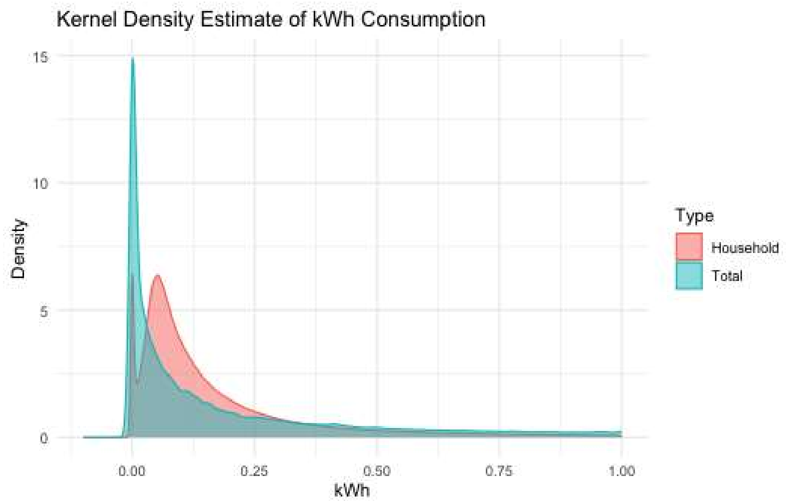
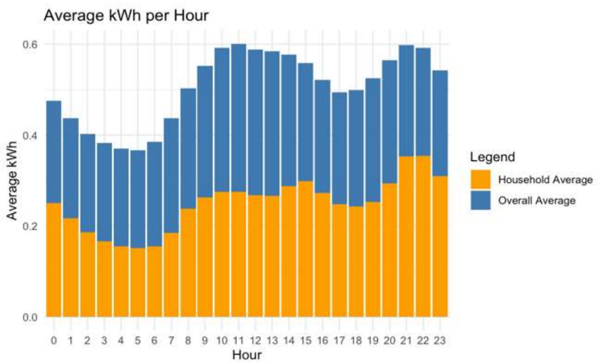


Figure 1: Kernel Density Estimate of kW

The dataset has 2949 commercial users (1.78 average kWh) and 14570 households (0.25 average kWh). Household classification was done using the dataset's National Classification of Economic Activities (CNAE-2009) values.



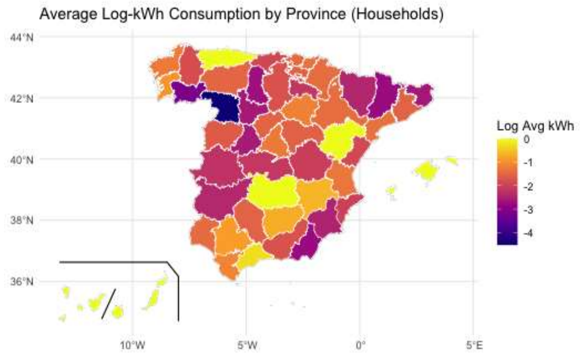


Figure 2a: Average kWh per Houre by Household consumption and Overall Consumption

Figure2b: Average Log-kWh consumption by province

Winter shows the highest average consumption at 0.299 kWh. This increase is likely to be due to higher heating energy usage during colder months. Fall follows with a mean consumption of 0.247 kWh, which may reflect increased energy needs as temperatures drop and days get shorter. Spring records a lower mean consumption of 0.236 kWh, possibly due to milder temperatures leading to reduced heating and cooling needs. Summer has the lowest average at 0.212 kWh, likely because of the efficiency of cooling systems and potentially shorter energy usage periods in longer daylight hours. Overall, the data suggests a clear seasonal trend in household energy consumption, with winter being the peak season for energy use. Understanding these patterns can be critical for energy providers in managing demand and for households in planning their energy usage strategies.

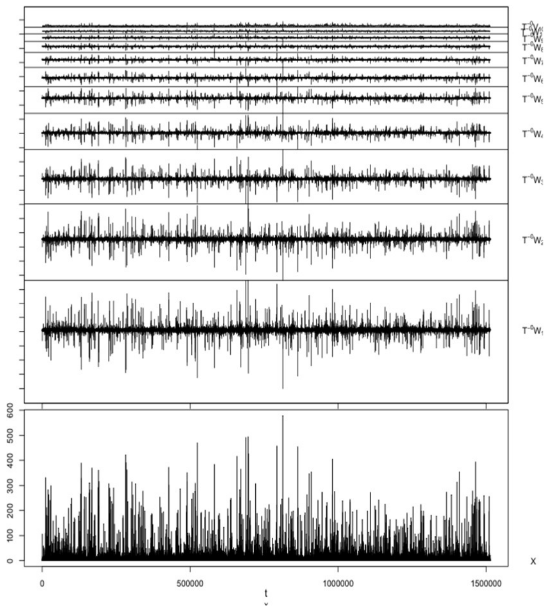


Figure 3: Example of Wavelet Plot on already available data

We will apply the SOM methodology to the raw and wavelet-transformed data, select the optimal number of clusters, and perform k-means clustering. This approach enables a direct comparison between the effectiveness of our proposed innovative methodology and the standard, widely used methods in the literature. The following section will describe the expected collaboration outputs with the energy companies. The team is defining the agreements that will grant the researchers access different providers' historical smart meter consumption data. In particular:

- Elektrizitätswerke Des Kantons Zürich (EKZ): historical electricity data from 5000 households for the last year (15 min intervals) with data on access and use of the company consumer portal.
- AGSM AIM: historical electricity data from 25000 households for the last year (15 min intervals).
- A2A Ciclo Idrico: historical data from 80000 households for the last 2 years (1 h intervals).

This data will be a useful benchmark for comparing water and energy consumption clusters. The period also includes exogenous variations in water availability that can inform the empirical analysis. The second phase will use the clusters identified in the data analysis to send target messages to maximize energy consumption during the day.

3.2 Analysis of direct/spillover effects of information programs and campaigns

In October 2019 an Italian multi-resource utility launched an "Opower-style" home water report that includes a static neighbour comparison, an injunctive feedback, a dynamic comparison and water saving tips. Eligible customers were randomly assigned to a treatment group that receives the report and a control group that does not. Some customers were already familiar with this type of report as since October 2016, the utility has delivered norm-based reports targeting electricity and gas use.

We have access to administrative data provided by the multi-resource utility after being anonymized. Data on water and gas consumption are based on meter readings performed periodically, at least once per year, by the distributor for all customers, and on self-readings provided voluntarily by customers. Given the relatively low and irregular frequency of water and gas readings, we base our analysis on six-month periods, roughly corresponding to winter (November–April) and summer (May–October). On average, we employ three readings to construct the average usage value in a semester, one of which is always entirely included in the semester. Conversely, data on electricity usage relies on actual consumption, measured through smart meters every month. Usage data for the three resources are expressed at the daily level in each month normalized with respect to the control group's mean consumption in the intervention period.

Figure 4 shows normalized electricity, water, and gas consumption in our sample period, October 2018 to October 2021. The lower frequency of water and gas consumption data relative to electricity is apparent, as is the strong seasonality characterizing gas usage. In 94 percent of households, gas is used for space and water heating and for cooking. Consumption peaks in winter, given that space heating accounts for the majority of the resource use. Electricity usage is also seasonal, with a first peak during the winter months and a second in the summer, likely due to air conditioning. Water consumption is stable across the different seasons.

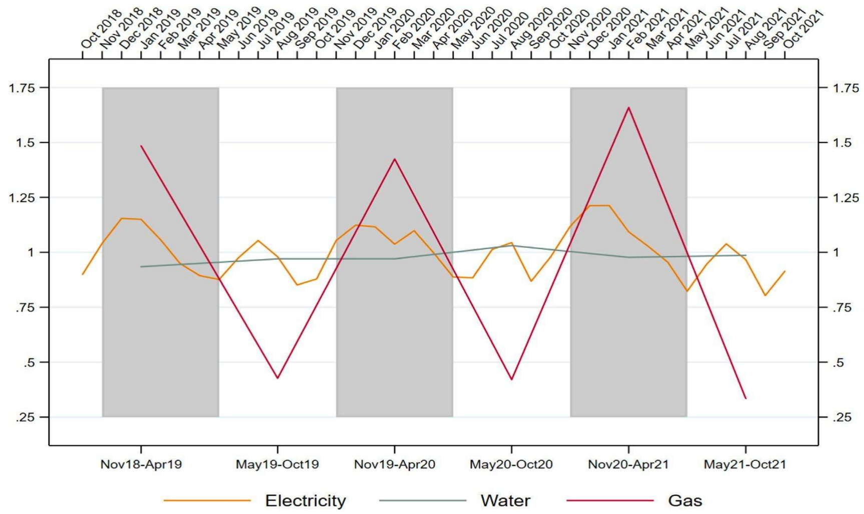


Figure 4[1]: Resource usage over the study period.

To evaluate the direct impact of receiving the water report on water consumption and the indirect effect on gas and electricity usage, we estimate the intention to treat effects (ITT), based on whether customers received the treatment, represented by the norm-based report described above on water consumption. Customers assigned to the control group did not receive any information on water consumption.

We find that the program significantly decreases water usage by 1.4 percent over the two post-treatment years. While we detect no effect on gas consumption, we find spillover effects on electricity consumption, which decreases by 0.5 percent. This spillover effect may be due to the mechanical correlation between water and electricity usage or to behavioral factors, such as the water report increasing users' motivation to save money or to preserve the environment by reducing consumption of all resources. The available data does not allow us to test the role of different mechanisms behind the spillover effects that we observe. Nevertheless, we can note that the magnitude of the spillover effect on electricity (-0.5 percent) is consistent with what we would expect, given the size of the correlation coefficient between water and electricity in our setting and of the direct treatment effect coefficient.

[1] The figure shows normalized usage of water, gas, and electricity over the study period for customers with active gas and electricity contracts at time of treatment. Water and gas consumption are given at the semester level, and electricity consumption is at the monthly level. Shaded regions denote winter periods.

We also analyze how the report's impact on usage varies depending on whether the customer already receives other reports (electricity, gas, or both) at baseline. For water and electricity consumption, the program is significantly more effective among customers for whom the water report is the only one received. The program reduces water and electricity usage in this group by 2.4 and 1.7 percent, respectively. Conversely, the program does not affect water and electricity use for those already receiving other reports. Finally we study the program's impact on customers' engagement with the utility. We find that the water report leads to higher customer retention. Our results indicated that customers value the water report. If we consider customer loyalty and engagement as indicators of users' utility from the program, these results suggest positive welfare effects of the water nudge.

4. Policy implications

4.1 Reducing emissions from electricity consumption through tailored behavioral interventions: a randomized controlled field trial

The project has extensive policy implications. The first phase involving the innovative methodology of analysis applied to smart-meter high-frequency historical data, both pre-existing and obtained from collaboration with leading companies in the industry, allows, in contrast to what has been done so far, to highlight consumer profiles from their consumption clusters then interpreted with other socio-demographic measures. This innovative segmentation is very important at the policy level because it allows a clear direction for implementing subsequent nudge measures in favor of pro-environmental behaviors, engaging different clusters of consumers specifically on the aspects perceived most important by those particular consumers.

Then, we move from historical data analysis to actual implementation to test the innovative methodology's assumptions. The second part of the project is devoted precisely to conducting a field experiment to test different nudges (in the form of messages) to different identified clusters. In this phase, the potential policy implications hypothesized in the first phase will be field-tested with many subjects so that we can provide clear guidance on what elements are important to focus on to help and support individuals and households in reducing energy waste.

The analysis of consumption profiles and their relationship to sensitivity to different types of messages aims to increase our understanding of individuals' consumption choices. We expect this scientific contribution to provide the basis for further studies on energy demand and environmentally impactful consumption choices in other domains. In this way, the proposed research aims to promote sustainable consumption practices indirectly through the accumulation of knowledge and its transfer from the domain under study to other domains.

The proposal stands out for its strong innovation from the state of the art, introducing new perspectives in understanding human behavior related to energy consumption. The project results may directly influence the design of more focused, incisive, cost-effective policies to address energy sustainability challenges.

4.2 Analysis of direct/spillover effects of information programs and campaigns

The considerations related to the spillover effects of the program and its effect on customers' engagement and satisfaction are timely and relevant, given policymakers' and firms' expanding use of behavioral nudges and the resulting increase in the likelihood that consumers are exposed to multiple, possibly overlapping interventions.

Customers in our study seem to value the water report. If we consider customer loyalty and engagement as indicators of users' utility from the program, these results suggest positive welfare effects of the water nudge. The benefits of the report accrue not only to the customers who value it and pay lower bills but also to the utility in the form of higher customer retention. The industry knows that winning a new customer costs several times more than retaining an existing one and engages in expensive retention campaigns. Therefore, well-designed, communicated, and timed pro-environmental campaigns can deliver a double dividend from both a private and a collective perspective.

These results have important policy and business implications for energy and water companies' design of conservation nudges. Policymakers and businesses should carefully design the first nudge targeted at a given population. Initial interventions are likely to have the greatest direct and indirect impacts. They should also be aware of the potential diminishing effects of additional nudges. Policymakers should reduce the cognitive efforts of attending to multiple stimuli, for instance by administering them together. Additional research is needed to understand how nudges should be designed, combined, and implemented for different resources to maximize companies' goals while ensuring societal well-being.

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