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Swiss Household Energy Demand Survey (SHEDS): Objectives, design, and implementation[*]

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Abstract

The Swiss Household Energy Demand Survey (SHEDS) has been developed as part of the research agenda of the Competence Center for Research in Energy, Society, and Transition (SCCER CREST). It is designed to collect a comprehensive description of the Swiss households' energy-related behaviors, their longitudinal changes and the existing potentials for future energy demand reduction. The survey has been planned in five annual waves thus generating a rolling panel dataset of 5,000 respondents per wave. The first two waves of SHEDS were fielded in April 2016 and April-May 2017. This paper elaborates on SHEDS's general objectives, design, and implementation. It also reports a series of practical examples of how the datasets are being used in empirical analyses.

[*] The design of SHEDS has been the result of close collaboration among researchers from University of Basel, University of Neuchâtel, ETH Zurich, University of St Galen, University of Geneva and Winterthur University of Applied Sciences. In addition to the authors of this document, these researchers include: Valéry Bezençon, Julia Blasch, Tobias Brosch, Cécile Hediger, Ann-Kathrin Hess, Stefanie Hille, Massimo Filippini, Maria Lagomarsino, Bruno Lanz, Ghislaine Lang, Linda Lemarié, Jasmin Mahmoodi, Corinne Moser, Laurent Ott, Robin Samuel, Annika Sohre, Ivan Tilov, and Uros Tomic. This work has been coordinated by Sylvain Weber, Iljana Schubert, Paul Burger and Mehdi Farsi. The coding and online implementation have been conducted by Sylvain Weber, at the University of Neuchâtel. Intervista experts Michael Schrackmann and Cédric Pellet played a crucial role in fielding, which is greatly appreciated. Last not least, we acknowledge the participation of many respondents from Intervista Online Access Panel in completing the survey but also in guiding us with their helpful comments and criticisms.

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1. Introduction

The Swiss Household Energy Demand Survey (SHEDS) is carried out by the Competence Center for Research in Energy, Society, and Transitions (CREST), one of the Swiss Competence Centers in Energy Research (SCCERs).[1] It is currently hosted at the University of Neuchâtel and represents part of research the activities in SCCER CREST's Work Package 2 (WP2: "Change of Behavior"). WP2 brings together research groups from various areas such as psychology, sociology, marketing, and economics. From 2014 to 2016, members of these research groups worked towards establishing a common research agenda and framework with focus on the behavioral determinants of energy consumption of Swiss households (Burger et al. 2015). SHEDS was developed in the context of this common research agenda. As such, SHEDS gathers extensive data on psychological, sociological, marketing and economic factors expected to drive energy consumption. To date, two waves of data have been collected, providing a rich variety of information for conducting micro-level analyses and to generate insightful policy recommendations. The survey also serves as a basis for numerous collaborations among CREST's researchers.

Intended as a reference document for the users, this paper outlines SHEDS objectives, provides a concise description of the survey structure and design, and offers a quick flavor of a selection of applications. The remainder of the paper is organized as follows. Section 2 discusses the objectives of SHEDS and its main strengths compared to existing surveys. Section 3 presents the survey design, structure, and implementation. Section 4 provides a series of short practical examples to illustrate how SHEDS datasets could be used in empirical analyses. Section 5 discusses future perspectives and concludes.

2. Objectives and added values

In line with the SCCER CREST's mission, the SHEDS initiative aims at fostering interdisciplinary research in the field of energy, society and transition. The SHEDS's general purpose is facilitating empirical research by providing large-scale household data based on a comprehensive survey with a multidisciplinary design drawn from a selection of relevant research questions across a variety of fields ranging from psychology and sociology to economics and engineering.

In this context, SHEDS endeavors to achieve a twofold objective. The first objective is to provide a basis for understanding the change of energy-related behaviors at the household level, and the

[1] The formal abbreviation is SCCER CREST, but we will also use the shorter abbreviation CREST interchangeably in this paper. SCCER CREST is financially supported by the Swiss Commission for Technology and Innovation (CTI). Details are available on the website: http://www.sccer-crest.ch.

relationships among these changes across different domains of energy consumption. This will be achieved by modeling and forecasting such changes, in an effort to identify both their causes and consequences in relation to a range of socio-economic and psychological characteristics of Swiss households and the individuals living therein.

The second objective is to provide a reliable basis for the scientific assessment of new ideas and design of new initiatives in policy, business and civil society in order to influence households and individual decisions with respect to energy consumption. This objective is achieved through a series of choice experiments implemented in each wave.[2] This feature of SHEDS is especially important for testing possible measures, be they political instruments or involving technological/business innovations that are considered promising but still not widespread in the market. The resulting insights can be used not only for the development of policy and governance measures, but more importantly for identifying the promising measures and their building blocks for further evaluations such as field experiments. The complementary added value of such choice experiments is in the possibility they provide for testing theoretical hypotheses about the underlying mechanism of behavioral changes.

The added values provided by SHEDS can be summarized with respect to its five main features: longitudinal aspects, distinctive view of different energy domains and their relationships, integrated choice experiments, design efficiency and flexibility, and finally the consideration of multiple explanatory factors proposed by different scientific disciplines.

While several surveys related to energy consumption exist in Switzerland, these are usually organized as repeated cross-sections and focused on a single energy domain. A typical example is the Microcensus on Mobility and Travel Behavior, a survey organized every 5 years by the Federal Office of Statistics to investigate the evolution of behaviors related to mobility. Such surveys allow investigating specific questions in their energy domain; however, they do not offer a global view of how households consume energy. Nor do they allow to track individual behavior over time and thus to develop an understanding of the factors leading to behavioral change. Existing panel surveys like the Swiss Household Panel, currently hosted by the Swiss Centre for Expertise in Social Sciences (FORS) at the University of Lausanne, on the other hand, provide longitudinal information for a sample of Swiss households but lack detailed information on energy demand and consumption.

Keeping the same respondents allows to track changes in a genuine manner, whereas repeated cross-sections impose strong statistical assumptions to investigate evolution patterns (Deaton 1985, Ridders and Moffitt 2007). Aside from improving the ability to study the extent, determinants and consequences of individual dynamics and adjustments, panel data have the

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[2] We use the term "choice experiment" in its broad sense, to cover any type of experiment designed to elicit people's (stated) preferences. Among others, choice experiments include discrete choice experiments, contingent behavior experiments, and conjoint analyses.

advantage that they facilitate the identification of causal links between different factors and allow analysts to control for heterogeneity in unobserved or unobservable characteristics across respondents (Baltagi 1995).

By collecting extensive data on energy consumption for a representative sample of households followed over time, SHEDS seeks to fill this gap. It therefore greatly expands our ability to investigate the dynamics of energy consumption over time and across energy domains at the household level. This includes the possibility of studying the effects of macro-level economic and social changes such as policy adjustments on individual and household behavior. Towards this end, SHEDS is organized as an annual rolling panel, implying that former respondents are invited to complete the survey in consecutive years with drop-out respondents being replaced with new ones such that the total number of households interviewed in each wave can be maintained at a constant level of 5,000 respondents.

The second major improvement of SHEDS is that several domains of energy consumption are considered: electricity, heating, and mobility. In each domain, information is collected about energy equipment (e.g., heating system, vehicles and electrical appliances) and their usage patterns (e.g., indoor temperature and distance traveled) as well as the related expenditures (such as electricity bill). Because the various domains of energy consumption can be linked at the individual level, SHEDS can be exploited to conduct a holistic analysis of energy determinants. It could, for instance, be used to investigate issues such as whether determinants of energy consumption are similar in different domains, or how behavioral changes in one energy domain influence what happens in other domains.

Third, in addition to collecting repeating survey questions, SHEDS encompasses choice experiments, which provide an opportunity to test causal relationships and explore potential intervention strategies. These choice experiments benefit from much more information than commonly available in similar kinds of studies, because respondents answer a large questionnaire in several consecutive years. Psychological, sociological, and economic characteristics are thus available and constitute a large pool of potential determinants for explaining the respondents’ choices in the experiments.

Fourth, SHEDS’s design follows efficiency requirements minimizing redundancy and ensuring that any single included question fulfills a specific research purpose. In particular, the questionnaire consists of core and rotating modules (details in Section 3), thus some question blocks alternate on a bi-annual or tri-annual basis. This modular structure has been devised in order to address a broader range of questions for the same basic set of respondents than with a comparatively fixed panel like the Swiss Household Panel. Efficiency is an important criterion for maintaining the costs at a reasonable level but also for increasing the quality of responses. Moreover, flexible modules allow comparatively quick reactions to new developments and research needs in each wave.

Finally, because the survey design is a joint effort by researchers from a wide range of disciplines, SHEDS offers a significantly broader perspective on each respondent than provided in standard energy surveys or household panels. This is important because it provides the possibility to combine insights from different fields of study (psychology, sociology, marketing and economics) to overcome what has been criticized as the disciplinary lock-in of energy studies (e.g., Stern 2014, van den Bergh 2008, Wilson & Dowlatabadi 2007).

3. Survey design[3]

3.1. Implementation

SHEDS is an online survey designed and implemented by researchers from SCCER CREST. It is then fielded in collaboration with the company Intervista,[4] mandated to conduct the sampling; namely, contacting potential respondents and offering them an incentive (bonus points) for answering the survey. Respondents are invited until a sample size of 5,000 is reached. Only respondents who report being involved (at least partly) in their household's expenses qualify for the survey. The final sample is constructed to be representative of the Swiss population (excluding Ticino) according to the following pre-selected characteristics and quotas:

- Age: 18-34 = 30%, 35-54 = 40%, 55+ = 30%;
- Gender: males = 49%, females = 51%;
- Region: French-speaking = 25%, German-speaking = 75%;
- Living situation: tenants = 62.5%, owners = 37.5%.

Each wave of SHEDS is planned to be 25-30 minutes long for each respondent, regardless of tenure in the survey. The average survey duration for the respondents who have filled the survey (without interruption) is around 28 minutes for the 2016 wave, and 27 minutes for the 2017 wave. Each wave undergoes a preliminary internal assessment by ad-hoc respondents and a pre-test with a limited number of respondents from the main pool. The pre-test respondents are also invited to provide open-ended comments and criticisms. The pre-test responses are used for fine-tuning the questionnaire and to correct eventual errors before launching the main survey.

The survey is first prepared in English (the common working language among SCCER CREST researchers), and then translated to German and French. Respondents have the possibility to answer in these three languages. The CREST team uses the online platform Qualtrics[5] in preparing, testing and implementing the survey prior to execution. Respondents are also re-directed to

[3] Technical documents (in English) reporting the complete questionnaire are available on the webpage dedicated to SHEDS: http://www.sccer-crest.ch/research/swiss-household-energy-demand-survey-sheds/.
[4] https://www.intervista.ch.
[5] https://www.qualtrics.com.

Qualtrics by Intervista to complete the survey. The statistical software Stata[6] is thereafter used for data cleaning and preparation prior to release to the data users.

3.2. Survey structure

SHEDS is designed as a series of modules: core modules intended to collect longitudinal data, as well as additional modules dedicated to one-time experiments. The core modules represent a major part of the survey (more than two third in time length).

Core modules

The core modules are based on the multidisciplinary framework developed by the research group (Burger et al., 2015), and are drawn from the established and cutting-edge research literature of their respective fields. The core modules are dedicated to eliciting energy-related, psychological, social context, and socio-economic information. The energy-related modules collect information about equipment and usage in three energy domains: electricity, heating, and mobility.

The psychological modules, in turn, focus on main individual predictors of behavior and include norms, attitudes, values, emotions, self- and outcome efficacy, asf. Social context modules, on the other hand, provide information on routines, lifestyles, information uptake and trust, asf. The socio-economic modules collect the usual information on household size and composition, working status, income, asf. It is also worth mentioning that some background information about the respondents, such as age, gender, or place of residence, comes directly from the survey company Intervista and therefore is not collected during the survey but is matched thereafter.

Most of the core modules are repeated in every wave of SHEDS and for all respondents, in order to collect information from the same individuals and concerning identical topics over time (e.g., annual energy expenditures). Time-invariant characteristics, however, are naturally collected only once for each respondent, at the time of first entrance in SHEDS (e.g., psychological attitudes). In addition, regarding elements which are unlikely to change on a yearly basis (e.g., cars or living situation), respondents are only asked to answer again if they experienced changes compared to what they stated in the previous wave. Finally, some of the core modules are rotated in further waves of the survey and are asked on a less frequent basis (every 2-3 years or at the beginning and end of the data collection) since they do not need to be collected on a yearly basis due to their relatively stable nature (e.g., values). The duration of core modules is thus shorter for the returning respondents, freeing up valuable survey time which can be dedicated to additional modules.

[6] http://www.stata.com.

Additional modules and structure

Next to core modules, each wave of SHEDS encompasses a series of additional modules in which various types of choice experiments are implemented. The concept and objectives of these experiments are presented in more detail section 3.3. The first wave of SHEDS (2016) included a single choice experiment. [7] Starting in the second wave (2017), more substantial choice experiments have been included, thanks to the aforementioned time that has been freed up for returning respondents. To keep survey duration within acceptable limits, only the returning respondents are included in a choice experiment. Total survey duration is intended to be similar (25-30 minutes) for new and returning respondents.

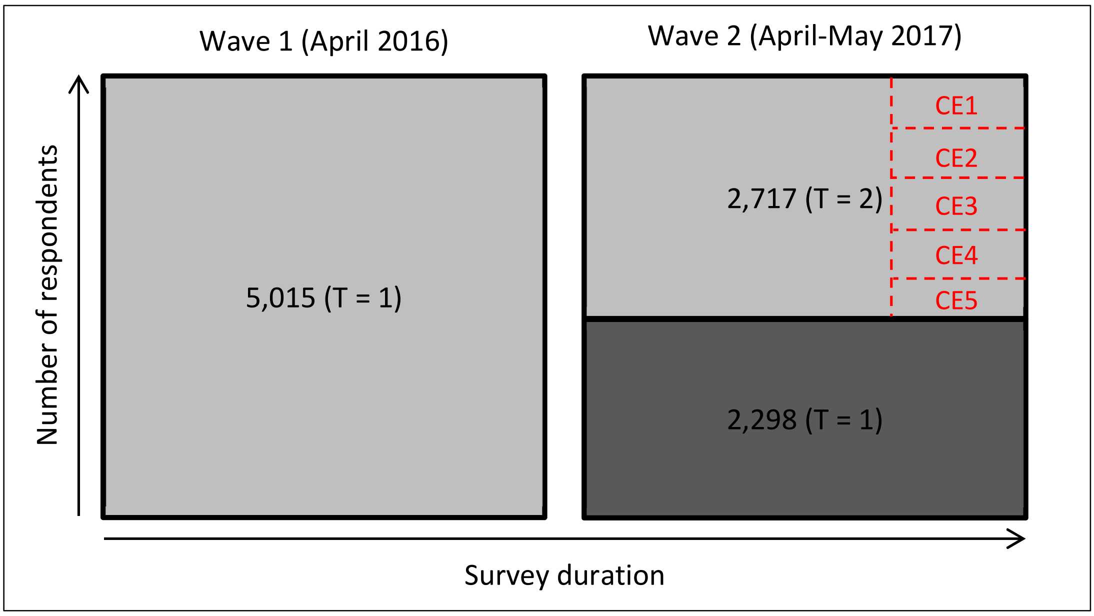
The first two waves of SHEDS are depicted schematically in Figure 1. In April 2016, 5,015 respondents completed wave 1. In April 2017, these respondents were invited to take part in wave 2. Among them, 2,717 completed the survey again, so that annual attrition rate amounts to more than 45%. In wave 2, the returning respondents have a tenure of two years (T = 2) in the survey, and each of them completed one out of five choice experiments (CE1-CE5). The allocation of respondents across these five different choice experiments was conducted randomly, while accounting for the fact that certain experiments required respondents with given characteristics. For instance, one choice experiment was designed specifically for house owners and another one specifically for tenants.

To maintain the sample size (roughly) constant across waves, new respondents were additionally invited to complete the survey in April-May 2017. A fresh sample of 2,298 respondents entered SHEDS in wave 2, and thus have a tenure of only 1 in this survey wave.[8] These new respondents answered only the core modules in wave 2. They will be contacted in wave 3 again and will then be eligible candidates for the choice experiments.

[7] This was a relatively short experiment specifically suitable for the first wave where longer experiments were not feasible because all respondents had to take the full version of the core modules.

[8] By chance, complete respondents are in exact same number in both waves 1 and 2. Their number could differ by some units in future waves.

Figure 1: Number of respondents and structure of waves 1 and 2



Source: own elaboration

The data is distributed as a set of files, each corresponding to a specific module and wave. There is, therefore, one data file "SHEDS*YEAR.ext*" for the core modules, which are repeated in every new wave.[9] Other files contain data on additional modules, i.e., responses to choice experiments. They are identified by filenames that are made up of the name of the file containing the core modules followed by an abbreviation indicating the corresponding module. For example, the file named "SHEDS2017_ODCE.*ext*" contains the answers to a discrete choice experiment dedicated to owners. Up to now, data are available in the following file formats:

- Comma-separated values (.csv)
- Microsoft Excel, version 12.0 (Excel 2007) or higher (.xlsx)
- Stata data file, versions 11 to 14 (.dta)
- SPSS System files (.sav)

Data combinations across modules and waves are straightforward. Since SHEDS is a survey of individuals rather than households, its primary unit of analysis are individuals. Consequently, the key variable by which individuals are identified is the unique individual identifier "id". This variable permits to track individual responses both across waves (i.e., across time) and modules.

[9] In the file name "SHEDS*YEAR.ext*", the italic "*YEAR*" stands for the corresponding year in which the survey was executed (e.g., "2016" for the first wave of data), and "*ext*" stands for the file extension.

3.3. Choice experiments

Choice experiments represent an important part of SHEDS.[10] The objective of these experiments is to elicit households' behaviors in areas where observational data are not readily available. Such experiments are expected to be useful to test specific hypotheses on what drives changes in energy consumption and to provide insightful recommendations related to the energy transition in Switzerland. While being limited in time length (about a third of the questionnaire), they are expected to provide significant information about the individual changes in behavior in response to pre-defined choice attributes and/or treatments. The attributes could pertain to various technological, policy and market factors as well as the decision context whereas treatments could involve various manners of priming the respondents (e.g., psychological conditions, provided information) prior to the choice task or presenting the tasks or attributes (e.g., framing).

The single choice experiment included in wave 1 was designed to test the relevance of energy literacy in the energy-related decisions of Swiss households. This example is covered in more detail in Section 4.4. Wave 2 of SHEDS contained a series of five choice experiments, all being related to heating or electricity consumption.[11] The 2,717 returning respondents (who have also answered wave 1) were distributed among these experiments. Choice experiment 4 was split into two closely related experiments conducted on the same subsample of respondents. Table 1 displays a list of these choice experiments, along with a short description and the number of respondents.

[10] As mentioned above (footnote 2), the term choice experiment should be understood in a broad sense.

[11] In wave 3, all choice experiments will be related to mobility.

Table 1: The choice experiments included in wave 2 (SHEDS 2017)

Choice experiment	Research topic	Method	Main design variables	# respondents
1. Home owners' heating system replacement decision	Effects of information and incentives, effective design of labels and carbon taxes	Discrete choice experiment with several treatment groups	Technology; Investment costs; Energy labels; Annual heating costs; CO_2 tax	511
2. Tenants' willingness to pay for new heating systems	Impact of information and incentives on tenants' contribution in energy investments	Multiple price lists with several treatment groups	Monthly rents; Energy labels; Annual heating costs; CO_2 tax	406
3. Households' participation likelihood in bottom-up energy reduction initiatives	Investigating success factors in engaging different societal segments in bottom-up energy demand reduction initiatives	Vignette experiment with conjoint analysis	Promotor/actor (e.g., peers); Channel/medium of initiative (e.g., online); Social value frame (e.g., competitive)	970
4. Consumer preferences for electricity utilities' innovative tariffs and saving plans	Decision-making processes and purchase choices; Impact of prior commitment, information and product designs	Discrete choice experiment composed of two distinct experiments (A/B), with several treatment groups	A. Reduction target; Bonus size; Bonus type; Fine size; Improved information B. Electricity consumption reduction/increase; Bonus/malus magnitude; Pre-selected default choice	574
5. Trade-offs between energy-saving and climate mitigation	Impact of perceived effort on the willingness to contribute in climate mitigation projects	Incentivized contingent behavior experiment with several treatment groups	Priming with a writing task: actions to reduce energy consumption; Willingness to donate for climate protection	256

4. Application examples

4.1. Determinants of household energy expenditures

To illustrate the analytic potential of SHEDS, this section provides an investigation of the main drivers of household energy demand in Switzerland. The results are obtained from linear regressions explaining household expenditures for electricity, heating and fuels for private mobility of the following form:

$$\ln\left(y_{i,\eta}\right) = \alpha + x_i'\boldsymbol{\beta}_{\boldsymbol{\eta}} + z_{i,\eta}'\boldsymbol{\gamma}_{\boldsymbol{\eta}} + \varepsilon_{i,\eta} \qquad (1)$$

where $y_{i,\eta}$ are household i's expenditures in energy domain $\eta \in$ {electricity, heating, mobility}, x_i is a set of respondent and household characteristics assumed to be relevant for all types of energy demand, and $z_{i,\eta}$ represents a set of domain-specific controls. Results for the estimations are given in Table 2.

The findings show that a broad number of socio-economic characteristics are associated with energy expenditures by Swiss households. Aside from a household's income and its position along the family life-cycle, it is above all structural preferences that matter. That is, household energy demand is found to depend largely on consumer decision over structural features such as the size of living quarters, the place of living along the urban-rural continuum, the ownership status of the dwelling of residence, the number and type of cars, where to live in relation to where to work, or which electronic appliances to hold. On the contrary, everyday decisions such as whether to switch off the light when leaving a room or to continuously ventilate seem to make only limited differences in energy demand. Results seem to suggest that energy demand is highest among high-income households, residing in large single-family houses outside urban areas.

Table 2: Determinants of Household Energy Expenditures

Variables	Electricity	Heating	Mobility
HH income (log)	0.0235	0.2190***	0.1974***
Age under 30	ref.	ref.	ref.
Age 30 to 54	0.1016**	0.2293**	-0.0745
Age 55 to 65	0.1982***	0.2956***	-0.1699***
Age over 65	0.1565**	0.4235***	-0.0781
Sex of head (1 if female)	0.0112	-0.0196	-0.0676**
French speaking	-0.1221*	0.0457	0.0798
Primary education	ref.	ref.	ref.
Secondary education	0.3276*	0.0049	0.1371
Tertiary education	0.3229*	0.0295	0.0989
1 person HH	ref.	ref.	ref.
2 person HH	0.1339***	0.0541	0.0668
3+ person HH	0.2536***	0.1056	0.1440***
City	ref.	ref.	ref.
Agglomeration	0.0036	-0.0012	0.1069***
Countryside	0.0843**	0.0485	0.1557***
Owner	-0.0338	-0.0595	-0.0710**
House (0 if flat)	0.3260***	0.2411***	0.0539
Size of dwelling in m^2 (log)	0.1048***	0.1404**	-0.0338
Age of house (log)	0.0320*	0.0561*	0.0087
Constant	4.4673***	1.4145*	2.2083***
Observations	2,322	1,618	2,612

4.2. A descriptive analysis of longitudinal changes in electricity usage

SHEDS is a longitudinal survey, in which the same individuals are interviewed in several consecutive years. It can therefore be used to track and investigate the evolution of energy consumption over time among Swiss households. For instance, the following two questions can be exploited to analyze electricity consumption and its evolution:

- How much do you pay for electricity (including VAT) during a one-year period?
- How much electricity do you use during a one-year period?

In principle, these two questions should give approximately identical information. Both are indeed supposed to reflect electricity consumption by the households, and even though the link between electricity usage and electricity bill should not be perfect because the price of a kWh might differ across households, we should observe a very strong correlation.

A general principle followed in SHEDS is to maximize the amount of reliable data collected. Whenever possible, different questions allowing to retrieve similar information are therefore included. Variants are also formulated in a less technical way to supplement the quantitative questions. For instance, as a complement to the two questions above, SHEDS also included simpler qualitative questions such as: How many TVs or computers do you own? How many hours of TV do you watch in a typical day? How many times per week do you use the dishwasher? … The latter questions are objectively less demanding to respondents and they provide reliable indicators that can be used ex-post by researchers to cross-check some responses to the most challenging quantitative questions.

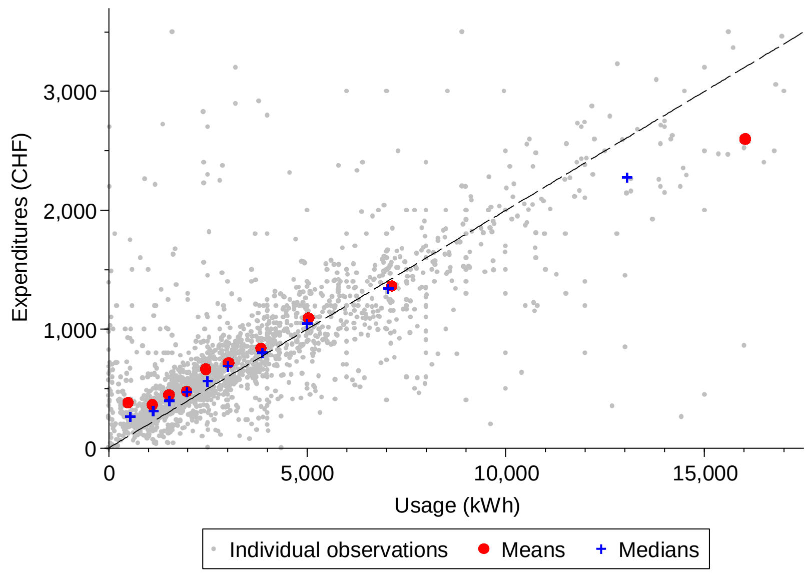
We therefore start our analysis by comparing electricity expenditures and usage stated by SHEDS respondents. Figure 2 shows a scatter plot of electricity expenditures versus electricity usage. Even though some values are clearly unrealistic, most observations concentrate around a line representing the average price of electricity in Switzerland (20 cents/kWh).[12] Moreover, the means and medians obtained for 10 percentile point bins of the electricity usage distribution show a perfectly plausible relationship.

Figure 3 shows the distributions of electricity expenditures and usage for 2016 and 2017, as well as the distribution of the individual changes between the two waves. We observe that the overall distributions obtained in SHEDS match well the amounts for typical Swiss households,[13] with the first quartile, median and third quartile being respectively close to 1,500, 2,500 and 4,500 kWh. Moreover, an important insight offered by SHEDS is that changes can be tracked over time at the individual level. In the right of Figure 3, the distributions of the changes of electricity expenditures and usage are plotted. As could be expected, we observe electricity consumption was globally stable between 2016 and 2017.

[12] https://www.prix-electricite.elcom.admin.ch/Start.aspx

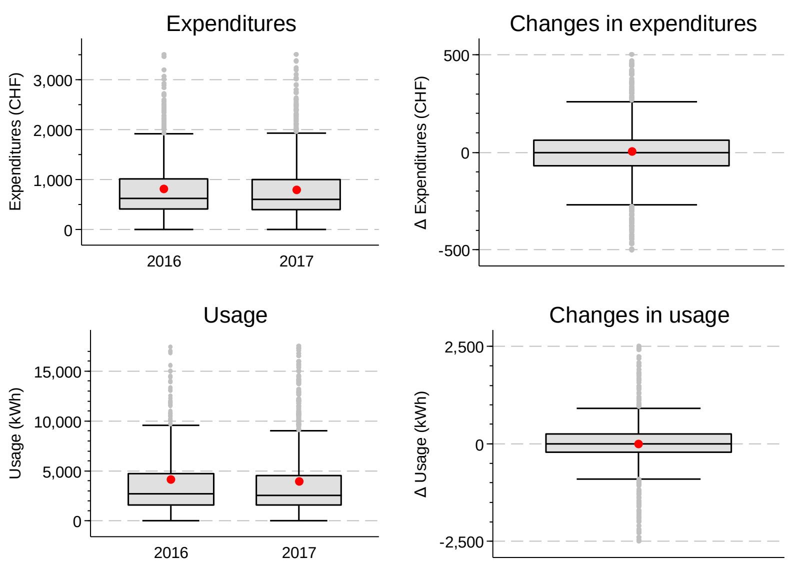
[13] See e.g., EnergieSchweiz: "Energieeffizienz imHaushalt" / SuisseEnergie: "L'efficacité énergétique dans le ménage".

Figure 2: Scatter plot of electricity expenditures vs electricity usage



Source: own elaboration. Individual observations are displayed for respondents present in both waves 1 and 2 of SHEDS, only if stated expenditures are up to CHF 3,500 and stated electricity usage is up to 17,500 kWh. To compute means and medians, we bin electricity usage into ten equal-sized (10 percentile point) bins. The dashed line provides an indication of the average electricity price in Switzerland (20 cents/kWh).

Figure 3: Evolution of electricity expenditures and electricity usage



Source: own elaboration. Observations are considered in the graphs only if stated expenditures are up to CHF 3,500 and stated electricity usage is up to 17,500 kWh (levels, left graphs), or if changes in expenditures are up to CHF 500 and changes in usage are up to 2,500 kWh in absolute value (changes, right graphs). Red bullets indicate the (untrimmed) means of the distributions.

4.3. A segmentation based on a cluster analysis

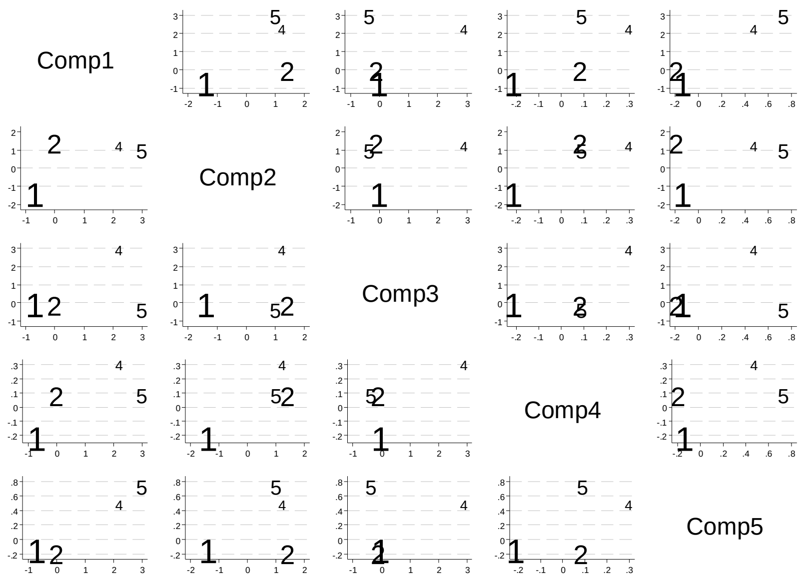
Considering the large amount of information collected in SHEDS for each respondent, it is possible to implement dimensionality reduction techniques. We here follow this line of reasoning and apply a two-step procedure using data from wave 1 of the survey. First, a principal component analysis (PCA) is conducted on a set of 25 original variables of SHEDS, representing three dimensions (equipment, usage, behavior) in three energy fields (electricity, heating, mobility).[14] Second, a cluster analysis is conducted on the principal component scores obtained from the PCA. The final objective of this analysis is to provide a (bottom-up) segmentation of households.

In a first step, we use PCA to reduce the dimensionality of the data by creating "principal components" that contain most of the variance of the 25 original variables. The optimal number of components to retain is five (Appendix Table 5 and Appendix Figure 5), and the factor loading matrix thus obtained is reproduced in Appendix Table 6. Based on the strength of the loadings, we can interpret component 1 as electricity usage, component 2 as energy used in private mobility, component 3 as energy used in air travel, component 4 as energy used in heating, and component 5 (which loads high on the number of warm meals prepared at home, the number of baths and the number of showers) as home energy usage.

In the second step, we implement a cluster analysis to partition the sample into clusters (or segments), so that the individuals in each cluster are as similar as possible, while individuals belonging to different clusters are as disparate as possible. Figure 4 summarizes the outcome of the cluster analysis, by showing the average score of each component for the five largest segments (which contain together almost 99% of all individuals, see Appendix Table 7).

[14] The 25 original variables are related to: number of electric devices, usage of dishwasher, usage of washing machine, usage of dryer, usage of TV(s), usage of computer(s)/laptop(s), usage of tablet(s), number of warm meals cooked (midday and evening), use of standby (vs switch-off), public transport tickets in HH, cars in HH, kilometers driven per year, transport mode from home to work, transport mode for leisure activities, air travel trips (short and long flights), air travel expenses, whether all rooms are heated at same temperature, whether thermostat is set to same temperature day and night, whether heating is left as usual when away, temperature in living room, number of showers, number of baths, airing behavior.

Figure 4: Average scores by cluster (only clusters with N ≥ 100)



Source: own elaboration. Size of marker proportional to the number of observations in the cluster.

The largest cluster (1) has a negative average for all components, indicating that this group consumes relatively little energy in all dimensions identified. The second largest cluster (2) has an especially high average for component 2. The individuals in this cluster thus own more cars and/or use more private transportation than all other groups. For all other components, cluster 2 scores are low. Cluster 4, which contains a relatively small number of observations (3% of the sample), contain heavy energy users with average scores being high in all dimensions. Compared to others, this cluster is especially high on component 3, which represents air travel, and component 4, which represents heating. Finally, cluster 5 scores very high on components 1, 2 and 5. Like cluster 4, cluster 5 contains a relatively small number of observations (a bit less than 10% of the sample), but it contains heavy energy users.

To summarize, this analysis shows that most of the individuals/households “behave well” in terms of energy usage. Almost half of the sample belongs to cluster 1, which is the lowest energy user. The most problematic dimension of energy usage seems to be private transportation, with three clusters (2, 4, and 5) representing half of the sample displaying a very high score on this dimension. Finally, two small clusters (4 and 5) display a high energy usage in many dimensions. The households in these clusters represent a little more than 10% of the sample and seem to be the most environmentally unfriendly. Said otherwise, the number of problematic households that should be targeted by energy saving policies is relatively small.

4.4. An example of the choice experiments in SHEDS

To illustrate the type of choice experiments included in SHEDS, this section provides an analysis of the choice experiment included in the wave 1.[15] The hypotheses behind this experiment was that (i) exposing respondents to a treatment that increases their energy literacy increases the probability that respondents carry out an investment calculation; and (ii) the performance of an investment calculation has a positive causal effect on the probability of selecting the refrigerator with the lowest lifetime costs.

As part of this choice experiment, respondents are asked to select one out of two refrigerators, which are characterized by two attributes: purchase price (upfront investment) and yearly electricity consumption – as illustrated by Appendix Figure 6. Respondents are also provided with information about unitary electricity costs and expected lifetime of the refrigerators – information that should be used to perform an investment calculation. Finally, respondents are requested to identify the fridge that minimizes the expenditure over the assume lifetime of 10 years.

On top of this choice experiment, a randomized controlled experiment (RCE) was implemented to explore whether and how investment calculations can be impacted. To this end, respondents were further divided in three groups: one control (80% of total sample) and two treatments (10% of total sample in each). In treatment 1 (Appendix Figure 7), 500 randomly selected respondents were displayed a set of "education screens" designed to improve the consumers' knowledge on how to conduct an investment analysis by comparing total lifetime costs of appliances. Four screens were presented sequentially, using a TV as an illustrative case. In treatment 2 (Appendix Figure 8), 500 randomly selected respondents were directed to an online calculator which facilitates the calculation of the lifetime costs of an appliance, requiring less mental effort from the respondent.

Blasch et al. (2017) conduct an empirical analysis of this choice experiment. In a nutshell, three hypotheses are confirmed: individuals who indicate (in a follow-up question) that they have carried out an investment calculation have a higher probability of correctly identifying refrigerator with the lowest lifetime costs, and both treatments increase the probability of carrying out a correct investment calculation. A direct policy implication of these findings is that increasing financial literacy has the potential to improve energy efficient decisions. Such implications contribute to the energy transition in Switzerland and are at the core of CREST's goals.

[15] A detailed description and analysis is provided in Blasch et al. (2017).

5. Further perspectives

The Swiss Household Energy Demand Survey (SHEDS) has been implemented by the Competence Center for Research in Energy, Society, and Transition (SCCER-CREST) for the first time in 2016, with the intention of running the survey on a yearly basis from then on. To date, two waves have been collected, and the survey will continue at least until 2019. A rolling panel of 5,000 respondents is thus being constructed, and while some attrition naturally occurs, there is a good probability to retain several hundreds of respondents over all waves planned.

The major improvements SHEDS offers compared to existing datasets can be summarized as follows. First, the same respondents are contacted year after year, thereby creating genuine panel data. That permits analyses of the evolution of energy-related behaviors beyond what can be done with other existing surveys. Second, several domains of energy consumption (heating, electricity, and mobility) are considered, rendering analyses of mutual influences across domains possible. Third, SHEDS encompasses several choice experiments in each wave, and these benefit from an unusually large pool of potential explanatory variables collected in the core modules of the survey. Fourth, thanks to its modularity, SHEDS is very flexible and adaptations are feasible in the short run, for instance to accommodate recent policy or technological changes. Fifth, SHEDS is a joint effort by researchers from a wide range of disciplines so that it offers a significantly broader perspective on each respondent than usually provided in surveys.

While the core modules of the survey remain similar wave after wave to record individual changes, the additional modules (choice experiments) focus on a different energy domain in every wave. In wave 2 (2017), the emphasis has been placed on heating and electricity. Choice experiments will be dedicated to investigations in the domain of mobility in wave 3 (2018), and heating will once again be the main center of interest in wave 4 (2019).

SHEDS currently constitutes the basis for numerous collaborations among CREST's multidisciplinary researchers. Further joint activities are expected to develop around SHEDS in the coming years, which can certainly be considered a success.

6. References

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7. Appendix

7.1. Further details on the example of Section 4.1

The dependent variables used in the empirical analysis of Section 4.1 are the ones measuring annual household expenditures on heating (heat5_1) and electricity (elec7_1), and monthly expenditures on fuels for private transport (seco6_1). For simplicity, the analysis is restricted to data from the 2016 wave.[16]

In order to deal with implausible values (outliers), we have trimmed all observations whose reported expenditures lie outside an interval of 1.5 times the interquartile range to the left of the 25th percentile and to the right of the 75th percentile (Tukey 1977). Summary statistics for the remaining observations are given in Table 3. They show that an average Swiss household in 2016 spent around CHF 662 on electricity, CHF 1,348 on space and water heating and CHF 1,014 on private mobility.

Table 3: Description of dependent variables

Variable	Electricity expenditures	Heating expenditures	Mobility expenditures
Mean (SD)	661.94 (407.11)	1348.54 (810.52)	84.51 (84.71)
Min	0	0	0
Max	1925	3800	375
# Obs.	3294 (3289 non-zero)	2105 (2086 non-zero)	4707 (3395 non-zero)
Measurement	Electricity expenditures in CHF over the last year	Heating expenditures in CHF over the last year	Fuel expenditures in CHF over the last month
Original variable	elec7_1	heat5_1	seco6_1

Source: SHEDS 2016, own calculations.

[16] Equivalent information is also available in the 2017 wave, in variables heat5a_1, elec7_1, and mob7b.

Table 4: Determinants of household energy expenditures (full table)

Variables	Electricity		Heating		Mobility	
	(1)	(2)	(3)	(4)	(5)	(6)
HH income (log)	0.0858**	0.0235	0.2593***	0.2190***	0.2280***	0.1974***
	(0.0375)	(0.0410)	(0.0609)	(0.0646)	(0.0549)	(0.0539)
Age categories						
under 30	ref.	ref.	ref.	ref.	ref.	ref.
30 to 54	0.1107***	0.1016**	0.2148**	0.2293**	-0.0441	-0.0745
	(0.0426)	(0.0493)	(0.0924)	(0.1046)	(0.0556)	(0.0494)
55 to 65	0.2017***	0.1982***	0.2964***	0.2956***	-0.1641**	-0.1699***
	(0.0506)	(0.0603)	(0.0949)	(0.1081)	(0.0663)	(0.0592)
over 65	0.2226***	0.1565**	0.4398***	0.4235***	-0.1236	-0.0781
	(0.0549)	(0.0623)	(0.1112)	(0.1232)	(0.0776)	(0.0779)
Sex of head (1 if female)	0.0008	0.0112	-0.0106	-0.0196	-0.0678**	-0.0676**
	(0.0256)	(0.0260)	(0.0398)	(0.0430)	(0.0331)	(0.0318)
French speaking	-0.1222*	-0.1221*	0.1387	0.0457	0.0906	0.0798
	(0.0692)	(0.0706)	(0.1087)	(0.1014)	(0.1109)	(0.0965)
Primary education	ref.	ref.	ref.	ref.	ref.	ref.
Secondary education	0.2755	0.3276*	0.0408	0.0049	0.1762	0.1371
	(0.1758)	(0.1893)	(0.1100)	(0.1157)	(0.1495)	(0.1417)
Tertiary education	0.2388	0.3229*	0.0554	0.0295	0.1101	0.0989
	(0.1783)	(0.1893)	(0.1093)	(0.1160)	(0.1481)	(0.1424)
Household size categories						
Single	ref.	ref.	ref.	ref.	ref.	ref.
2 person HH	0.1882***	0.1339***	0.0800	0.0541	0.0789	0.0668
	(0.0356)	(0.0408)	(0.0541)	(0.0610)	(0.0480)	(0.0445)
3+ person HH	0.4062***	0.2536***	0.1579***	0.1056	0.1793***	0.1440***
	(0.0468)	(0.0513)	(0.0607)	(0.0742)	(0.0553)	(0.0558)
City	ref.	ref.	ref.	ref.	ref.	ref.
Agglomeration	0.0485	0.0036	-0.0056	-0.0012	0.1961***	0.1069***
	(0.0320)	(0.0343)	(0.0475)	(0.0483)	(0.0420)	(0.0396)
Countryside	0.1083***	0.0843**	0.0096	0.0485	0.2770***	0.1557***
	(0.0341)	(0.0363)	(0.0538)	(0.0532)	(0.0482)	(0.0438)
Owner	-0.0347	-0.0338	-0.0755**	-0.0595	-0.0853***	-0.0710**
	(0.0237)	(0.0237)	(0.0367)	(0.0391)	(0.0309)	(0.0290)
House (0 if flat)	0.3556***	0.3260***	0.0791	0.2411***	0.0899**	0.0539
	(0.0337)	(0.0374)	(0.0500)	(0.0577)	(0.0448)	(0.0400)
Size of dwelling in m^2 (log)	0.2046***	0.1048***	0.1976***	0.1404**	-0.0017	-0.0338
	(0.0379)	(0.0382)	(0.0601)	(0.0602)	(0.0503)	(0.0478)
Age of house (log)	-0.0175	0.0320*	0.1223***	0.0561*	-0.0182	0.0087
	(0.0131)	(0.0168)	(0.0199)	(0.0312)	(0.0176)	(0.0160)
Constant	3.7432***	4.4673***	1.5871**	1.4145*	2.7228***	2.2083***
	(0.4100)	(0.5406)	(0.6932)	(0.8444)	(0.5996)	(0.6114)
Head controls	Yes	Yes	Yes	Yes	Yes	Yes
Family controls	Yes	Yes	Yes	Yes	Yes	Yes
Dwelling controls	Yes	Yes	Yes	Yes	Yes	Yes
Electricity equipment	No	Yes	No	No	No	No
Electricity-related behavior	No	Yes	No	No	No	No
Heating equipment	No	No	No	Yes	No	No
Heating-related behavior	No	No	No	Yes	No	No
Mobility equipment	No	No	No	No	No	Yes
Mobility-related behavior	No	No	No	No	No	Yes
Cantonal FE	Yes	Yes	Yes	Yes	Yes	Yes
Observations	2,628	2,322	1,750	1,618	2,612	2,612
Adjusted R2	0.280	0.328	0.123	0.150	0.0972	0.247
BIC	5286	5240	4221	4277	6649	6402

Source: SHEDS 2016, own estimations. Robust standard errors clustered at the level of the ZIP code in parentheses.
*** p<0.01, ** p<0.05, * p<0.1

7.2. Further details on the example of Section 4.3

Table 5: Principal components, eigenvalues and variance explained

Component	Eigenvalue	Difference	Proportion	Cumulative
Comp1	4.04251	1.61183	0.1617	0.1617
Comp2	2.43069	.449336	0.0972	0.2589
Comp3	1.98135	.286713	0.0793	0.3382
Comp4	1.69464	.468081	0.0678	0.4060
Comp5	1.22656	.0186756	0.0491	0.4550
Comp6	1.20788	.0233843	0.0483	0.5033
Comp7	1.1845	.124356	0.0474	0.5507
Comp8	1.06014	.0508805	0.0424	0.5931
Comp9	1.00926	.112404	0.0404	0.6335
Comp10	.896855	.043268	0.0359	0.6694
Comp11	.853587	.0768324	0.0341	0.7035
Comp12	.776755	.0254728	0.0311	0.7346
Comp13	.751282	.0745612	0.0301	0.7646
Comp14	.676721	.0157544	0.0271	0.7917
Comp15	.660967	.0479162	0.0264	0.8181

Figure 5: Scree plot after PCA

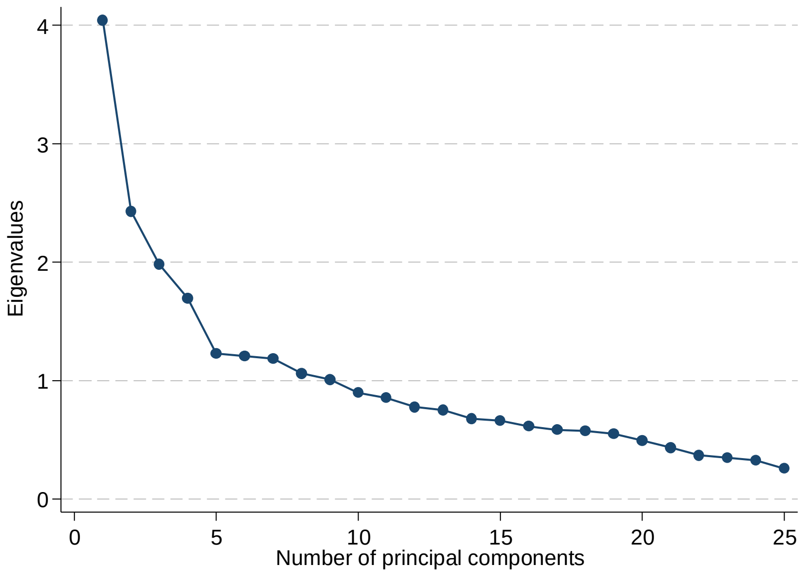


Table 6: Rotated factor loadings obtained in the PCA

	Comp1	Comp2	Comp3	Comp4	Comp5
Electric_devices	0.44	0.07	0.05	0.00	-0.04
Dishwasher	0.37	-0.04	-0.02	-0.05	0.17
Washing_machine	0.41	-0.03	-0.01	-0.13	0.09
Dryer	0.38	0.03	0.02	-0.10	0.02
TV	0.17	0.10	-0.13	0.17	-0.04
Computer/laptop	0.20	-0.16	-0.04	0.17	0.00
Tablet	0.31	-0.07	0.04	0.10	-0.08
Warm_meals_midday	0.13	-0.06	-0.05	-0.06	0.47
Warm_meals_evening	0.09	-0.07	0.15	0.02	0.32
Standby	0.33	0.03	0.04	0.19	-0.21
Pub_tickets	-0.04	-0.24	0.09	-0.04	-0.28
Cars	-0.05	0.50	0.02	-0.03	-0.11
Km_year	0.06	0.40	0.05	-0.07	0.04
Home-work	0.01	0.48	-0.04	0.02	0.00
Leisure	0.03	0.47	0.03	0.05	0.05
Long_flights	0.02	-0.04	0.52	0.04	-0.01
Short_flights	-0.03	0.02	0.55	0.00	-0.02
Air_travel_expenses	0.04	0.03	0.57	-0.03	0.00
Heat_AllRooms	-0.06	-0.07	0.04	0.48	0.11
Heat_DayNight	0.09	0.01	-0.09	-0.48	0.04
Heat_WhenAway	0.05	0.05	-0.10	0.52	-0.01
Temp_LivingRoom	0.07	0.04	-0.05	0.30	-0.05
Showers	0.05	0.00	0.08	-0.00	-0.46
Baths	-0.08	0.01	0.07	0.12	0.42
Airing	0.12	-0.09	-0.10	-0.08	-0.28

Note: colors are assigned as follows: dark green if loading ≤ -0.30, light green if loading $\in [-0.30; -0.15]$, light gray if loading $\in [-0.15; +0.15]$, light red if loading $\in [+0.15; +0.30]$, dark red if loading $\geq +0.30$.

Table 7: Number of observations by cluster

Clusters	Freq.	Percent	Cum.
1	1,887	47.38	47.38
2	1,493	37.48	84.86
3	53	1.33	86.19
4	114	2.86	89.05
5	385	9.67	98.72
6	17	0.43	99.15
7	5	0.13	99.27
8	1	0.03	99.30
9	11	0.28	99.57
10	1	0.03	99.60
11	9	0.23	99.82
12	4	0.10	99.92
13	2	0.05	99.97
14	1	0.03	100.00
Total	3,983	100.00	

7.3. Treatments of choice experiment discussed in Section 4.4

Figure 6: Screenshot of the refrigerator choice presented to respondents

Assume that you need to replace your fridge. You expect that you live in your current residence for another 10 years. In a shop you find the following two fridges which are identical in terms of size and cooling service.

	Fridge - A	Fridge - B
Purchase Price:	3300 CHF	2800 CHF
Electricity Consumption:	100 kWh/year	200 kWh/year

Assuming that one kilowatt hour (kWh) of electricity will cost about 20 Rappen on average during the next 10 years and that the value of 1 CHF in 10 years is the same as the value of 1 CHF today:

Which of the two fridges minimizes your expenditure for cooling food and beverages during the lifetime of 10 years?

- ◯ The fridge for 3300 CHF
- ◯ The fridge for 2800 CHF

Figure 7: Education screens for treatment 1

(slides were presented sequentially, not at the same time)

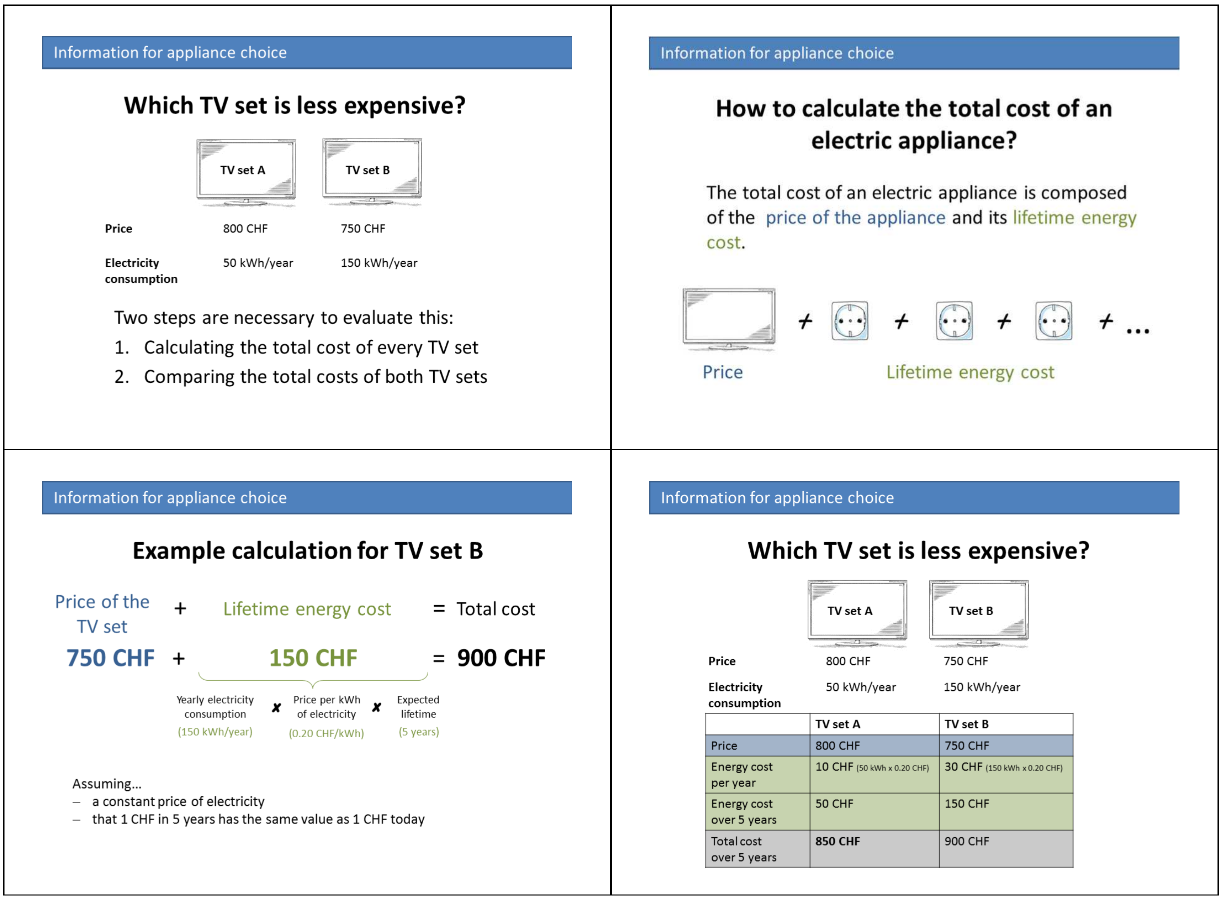
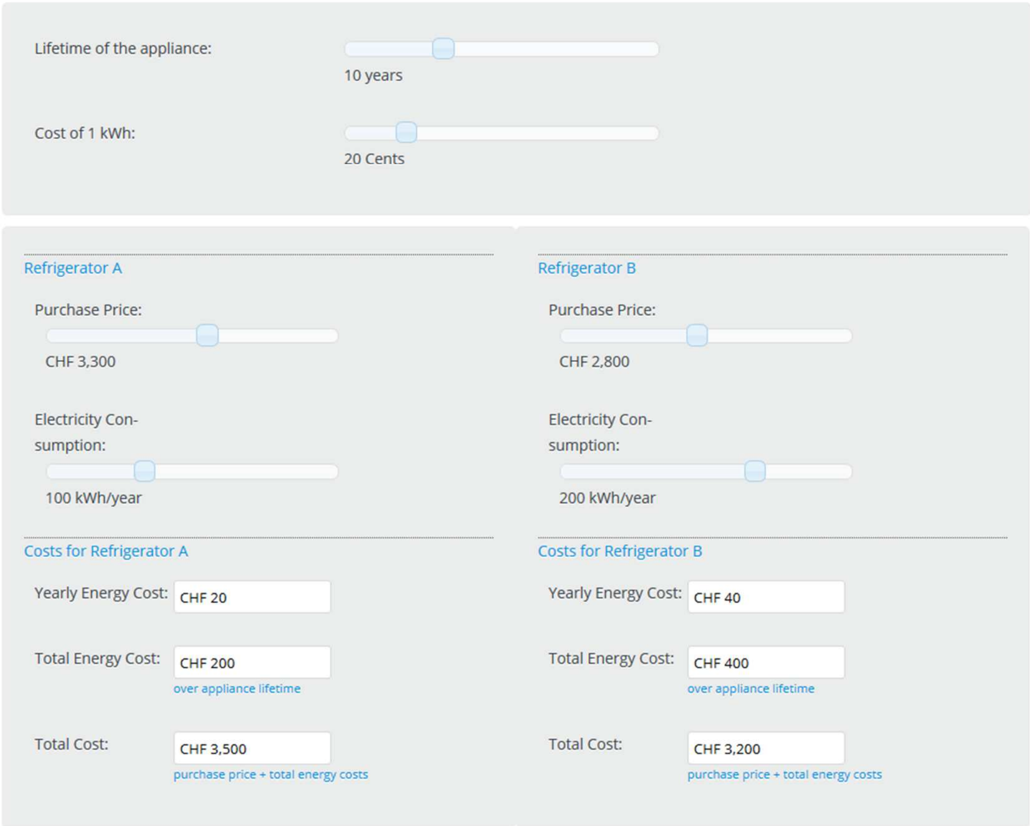


Figure 8: Online calculator for treatment 2
(the values provided in Figure 6 are used)

With this online calculator you can calculate and compare the energy costs and total costs of two different models of refrigerators. This will help you in making an informed choice between the two appliances.

You can vary the electricity price and the characteristics of the refrigerator (purchase price, electricity consumption and expected lifetime) and calculate the cost. It is assumed that a refrigerator is used 24 hours a day. For simplicity, it is also assumed that the price of electricity will remain constant and that the value of 1 CHF in 10 years is the same as the value of 1 CHF today.



* Note that java needs to enabled within your browser to see the calculator on this page. If you are unable to see or use the calculator above, you can still return and continue with the survey as usual.