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FLEXI

Determining the flexibilization potential of the electricity demand

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Executive summary

Solar energy production takes place at times when demand for electricity is not necessarily high. Households' electricity consumption indeed peaks in the evening, when solar production energy is at best low. This mismatch might be reduced in several ways: electricity might be transported and consumed elsewhere, it might be stored for later consumption, or households could be encouraged to align their consumption with solar energy production. While the first two solutions imply high installation costs, the latter might prove relatively inexpensive and easy to implement.

Technical studies

This technical study aimed at evaluating the potential of flexibilization of households' electricity consumption to maximize the local consumption of electricity generated by photovoltaics (PV). To simplify the analysis we consider fixed "PV production hours" (defined in our study by the period 11am to 3pm corresponding to the time window with the peak PV production) and households were asked to shift as much as possible their consumption to that period of time. The goal was to evaluate theoretically and practically the share of the consumption that could be shifted and observe the time evolution and factors influencing this change of behavior.

From a sample of ca. 300 households in Cernier (NE) equipped with smart meters to record the consumption with a 15 minute resolution, one third answered a detailed questionnaire with a description of the inhabitants, their occupation and description of the household and its equipment. These 100 households were divided in three statistically equivalent groups: A control group, a group receiving information on its consumption evolution (including comparison with similar households) and a group receiving financial incentives. Households in this latter group participated in a monthly contest with financial prices for the best behaving ones. Shift of the consumption was evaluated from the change of the ratio of the consumption between 11am-3pm to the total consumption.

For the theoretical analysis, appliances were attributed to four categories of flexibility (easily flexible, hardly flexible, flexible with technical mean and not flexible). As direct identification of appliance usage from a 15 minute resolution load curve is not possible, we developed an identification method based on Markov chain representation of the activities of the household inhabitants. Answer of the questionnaires were combined with time use budget data (from a 2005 Dutch study) and to typical appliance load curves to fit (or simulate) measured load curve of any individual household. The procedure included the separate extraction of fridge/freezer consumption and simulation of lighting consumption.

From this analysis we evaluated the share of consumption already in the PV production period, flexible, hardly flexible to be, respectively, 17-19%, 6-8%, 6-8%.

Practically, the group with financial incentives succeeded to shift up to 4% of its consumption (yearly average slightly above 2%) and such shift was also visible in the simulation. From the hourly consumption this shift (change in the ratio of consumption) was obtained both by a real shift, but also by a decrease of the consumption outside the PV production hours. No change was observed in the consumption behavior of the other groups. Within the group with financial incentive, only one third of the households achieve a significant shift. One possible reason is that households being not occupied during the day have much less possibility to shift their consumption.

Taking into account possible technical means, we estimate an addition potential of 5% by controlling freezers and 1.4% (in average for the town) by just changing the programming of boilers present in Cernier for hot water heating. Replacement of boiler with heat-pump could easily bring another 10% at least per household. Note that it is here a potential and the real value will depend on the actual PV production hours and consumption.

The shift of a certain amount of consumption during PV production hours would allow to cover this amount directly and locally with additional PV capacity without detrimental effect on the grid. In the case of Cernier we could show that flexibilization allows for a higher self-consumption of PV electricity: An PV capacity roughly equal to the amount of electricity shifted can be added for the same self-consumption value. Using hot-water heating as a storage means would allow for a much bigger PV capacity expansion.

Economic studies

In the economic part of the Flexi project, we assess the impact of two experiments that seek to influence households' electricity consumption. More precisely, we "nudge" households to shift their consumption towards the period of the day (11am-3pm) in which the production of solar energy is (supposed to be) the largest. The relevance of such a study is enhanced in the context of the energy transition, as renewable energies are bound to gain importance in the energy mix.

The first experiment consists in providing households with detailed information feedback about the evolution of their electricity consumption and the fraction they consume between 11am and 3pm. They are provided with information about the consumption of similar households. No other motivation is given to these households. The second experiment consists in a competition, in which households are ranked according to their proportion of electricity consumed between 11am-3pm and its evolution. Participating households are aware of the rules of the competition, but minimal information about their electricity consumption is provided. Each month, the best 15 households receive monetary prizes, up to CHF 50 depending on their performance.

The results of the information feedback experiment suggest that this type of "nudge" has no statistical impact on the proportion of electricity consumed between 11am and 3pm. However, the households in this experiment have globally decreased their consumption, regardless of the period of the day. This evidence seems to indicate that households understand that something is going on, and undertake actions to decrease consumption, neglecting more complex information.

The findings of the monetary incentives show that pecuniary "nudges" have sizeable impacts on the proportion of electricity consumed during the period 11am-3pm. This proportion increased by about 2.9 percentage points for households participating to this experiment, relative to non-participating households. This change is considerable given that average consumption in these 4 hours is around 20% of total consumption. The effect of this change on the national electricity supply is therefore relevant. Households achieved this outcome by reducing their consumption (mostly) in the evening while keeping their (absolute) consumption between 11am and 3pm stable.

We draw two main policy implications from our results. First, monetary incentives matter. Time-of-use tariffs can thus be expected to be an effective demand-side management tool. Second, even though our information letters did not lead to the intended shift of electricity consumption, results show that this type of tool may be used to achieve substantial electricity conservation. This finding suggests an inexpensive improvement of the current payment system, in which electricity bills are provided every two months and computed on expected consumption.

Résumé

La production d'énergie solaire a lieu à un moment où la demande en électricité n'est pas nécessairement élevée. En effet, la consommation électrique des ménages se concentre majoritairement en soirée, lorsque la production solaire est faible ou inexistante. Ce décalage peut être réduit de plusieurs façons : l'électricité peut être transportée et consommée ailleurs, elle peut être stockée pour une consommation ultérieure ou les ménages peuvent être encouragés à aligner leur consommation électrique à la production solaire. Alors que les deux premières solutions impliquent des coûts d'installation élevés, la dernière s'avère relativement peu coûteuse et facile à mettre en œuvre.

Etudes techniques

Cette étude technique vise à évaluer le potentiel de flexibilisation de la consommation électrique des ménages, afin de maximiser la consommation locale d'électricité produite par le photovoltaïque (PV). Pour simplifier l'analyse, nous considérons des "heures de production PV" fixes (définies dans notre étude par la période 11h00-15h00, ce qui correspond à la fenêtre de temps où la production PV est à son plus haut) et les ménages ont été invités tant que possible à déplacer leur consommation électrique dans cette période. L'objectif était d'évaluer, de manière théorique et pratique, la part de la consommation électrique qui pouvait être déplacée et d'observer l'évolution dans le temps et les facteurs pouvant influencer les changements de comportement.

Sur un échantillon d'environ 300 ménages à Cernier (NE) équipés de compteurs intelligents permettant d'enregistrer la consommation électrique avec une résolution de 15 minutes, un tiers a répondu à un questionnaire détaillé avec une description des habitants, de leurs occupations et la description du ménage et de son équipement. Ces 100 ménages ont été divisés en trois groupes statistiquement équivalents: Un groupe de contrôle, un groupe recevant des informations sur l'évolution de leur consommation électrique (y compris la comparaison avec les ménages similaires) et un groupe recevant des incitations financières. Les ménages de ce dernier groupe ont participé à un concours mensuel avec des prix financiers pour ceux adoptant le meilleur comportement. Le décalage de la consommation a été évalué à partir de la variation du rapport entre la consommation sur la période 11h00-15h00 et la consommation journalière totale.

Pour l'analyse théorique, les appareils ménagers ont été attribués à quatre catégories de flexibilité (facilement flexibles, peu flexibles, flexible avec un moyen technique et non flexibles). Comme l'identification directe de l'utilisation d'un appareil au moyen d'une courbe de charge avec une résolution de 15 minutes n'est pas possible, nous avons développé une méthode d'identification basée sur la représentation de la chaîne de Markov des activités des ménages. Les réponses des questionnaires ont été combinées avec des données d'emploi du temps (étude néerlandaise de 2005) et aux courbes de charge typiques d'appareils ménagers pour ajuster (ou simuler) les courbes de charge mesurées de chaque ménage individuellement. La procédure nécessitait d'extraire séparément la consommation de réfrigérateurs/congélateurs et la simulation de la consommation liée à l'éclairage.

De cette analyse a pu être évaluée la part de la consommation électrique déjà dans la période de production PV, la part de consommation flexible et la part de consommation difficilement flexible, respectivement de 17-19%, 6-8% et 6-8%.

En pratique, le groupe avec des incitations financières a pu déplacer jusqu'à 4% de sa consommation (moyenne annuelle légèrement supérieure à 2%) et un tel déplacement était également visible sur la simulation. Ce déplacement (modification du ratio de consommation) a été obtenu à la fois par un réel déplacement, mais également par une diminution de la consommation globale en dehors de la période de production PV. Aucun changement n'a été observé dans le comportement des autres groupes. Dans le groupe avec incitation financière, seul un tiers des ménages a montré un déplacement significatif. L'une des raisons est que les logements non occupés durant la journée n'ont que peu de possibilités pour déplacer leur consommation.

En tenant compte des moyens techniques possibles, nous estimons un potentiel additionnel de 5% par le contrôle des congélateurs et de 1.4% (en moyenne pour la ville) en modifiant simplement la programmation des chaudières existantes à Cernier pour le chauffage de l'eau chaude. Le remplacement des chaudières par des pompes à chaleur pourrait facilement augmenter le potentiel d'au moins 10% supplémentaires par ménage. Il faut noter que ces chiffres représentent un potentiel et que les valeurs réelles sont dépendantes des heures de production PV et de la consommation d'électricité.

Le déplacement d’une certaine quantité de la consommation électrique pendant les heures de production PV permettrait de couvrir cette consommation directement et localement au moyen d’une capacité de production PV additionnelle, sans effets néfastes sur le réseau électrique. Dans le cas de Cernier, nous avons pu montrer que la flexibilisation permet une auto-consommation plus élevée de l’électricité photovoltaïque: une capacité PV à peu près égale à la quantité d'électricité déplacée peut être ajoutée pour une auto-consommation équivalente. L’utilisation du chauffage de l’eau chaude comme moyen de stockage permettrait d’augmenter fortement la capacité PV.

Etudes économiques

Dans la partie économique du projet Flexi, nous évaluons l'impact de deux expériences, qui cherchent à influencer la consommation d'électricité des ménages. Plus précisément, nous encourageons les ménages à déplacer leur consommation électrique vers la période de la journée (11h00-15h00) durant laquelle la production d'énergie solaire est (supposée être) la plus élevée. La pertinence d'une telle étude est renforcée par le contexte de la transition énergétique, dans lequel les énergies renouvelables sont tenues de gagner de l'importance dans le mix énergétique.

La première expérience consiste à fournir aux ménages des informations détaillées sur l'évolution de leur consommation électrique et sur la part d’électricité qu'ils consomment entre 11h00 et 15h00. Ils reçoivent également des informations sur la consommation des ménages similaires. Aucune autre information n’est donnée à ces ménages. La seconde expérience est un concours dans lequel les ménages sont classés en fonction de leur part d'électricité consommée entre 11h00 et 15h00 et de son évolution. Les ménages participants sont informés des règles concours, mais reçoivent un minimum d'informations sur leur consommation d'électricité. Chaque mois, les 15 meilleurs ménages reçoivent un prix monétaire pouvant atteindre CHF 50, en fonction de leur performance.

Les résultats de l'expérience sur le retour d'information indiquent que ce type de motivation n'a pas d'impact statistique sur la proportion de l'électricité consommée entre 11h00 et 15h00. Cependant, les ménages de cette expérience ont globalement diminué leur consommation, quelle que soit la période de la journée. Ce constat semble indiquer que les ménages comprennent que quelque chose se passe et entreprennent des actions pour réduire leur consommation, délaissant les informations plus complexes.

Les résultats des incitations monétaires montrent que les motivations pécuniaires ont des effets considérables sur la proportion d’électricité consommée sur la période 11h00-15h00. Cette proportion a augmenté d'environ 2,9 points de pourcentage pour les ménages participant à cette expérience, par rapport aux ménages non participants. Ce changement est considérable étant donné que la consommation moyenne de ces quatre heures représente environ 20% de la consommation totale. L'effet de ce changement sur l'approvisionnement électrique national est donc pertinent. Les ménages ont atteint ce résultat en réduisant leur consommation (principalement) le soir, tout en gardant stable leur consommation (absolue) entre 11h00 et 15h00.

Nous retenons deux principales implications politiques de nos résultats. Premièrement, les incitations monétaires ont de l’importance. Une tarification en fonction de la période de consommation peut par conséquent être un outil efficace de gestion de la demande en électricité. Deuxièmement, même si nos lettres d’information n’ont pas conduit comme prévu à un déplacement de la consommation d’électricité, les résultats montrent que ce type d’outil peut être utilisé pour atteindre une économie substantielle d’électricité. Cette conclusion incite à une amélioration peu coûteuse du système de facturation actuel, dans lequel une facture est envoyée tous les deux mois et dont le montant est calculé en fonction de la consommation attendue.

Zusammenfassung

Gemäss der eidgenössischen Energiestrategie 2050 sollen die erneuerbaren Energien und im Besonderen die Photovoltaik substantiell ausgebaut werden und einen bedeutenden Anteil des schweizerischen Elektrizitätsverbrauchs decken. Ziel dieses Projektes ist es, das Potential für eine grössere Flexibilität im Stromverbrauch von Schweizer Haushalten abzuschätzen, um so den Anteil an lokal verbrauchter Solarenergie zu maximieren, den Einfluss auf das Elektrizitätsnetz zu minimieren und die Marktdurchdringung von erneuerbaren Energien zu verbessern.
Im technischen Teil dieser Studie wird das theoretische Potenzial für mehr Flexibilität quantifiziert, basierend auf den typischen Merkmalen eines Haushalts und den Faktoren, die die "Flexibilisierung" der Nachfrage beeinflussen. Dabei werden die technischen Elemente identifiziert, die zur Steigerung der Flexibilität beitragen. Im wirtschaftlichen Teil der Studie wird untersucht inwiefern finanzielle Anreize und Informationen die Flexibilisierung der Stromnachfrage und den Stromverbrauch beeinflussen.
Obwohl der technische Teil der Studie ein theoretisches Potenzial zur Flexibilisierung von 6 bis 8% voraussagt, zeigen die wirtschaftlichen Untersuchungen, dass es ohne finanzielle Anreize schwierig ist die Haushalte zu Verhaltensänderungen zu motivieren. Die Studie zeigt auch, dass die Charakteristika der Haushalte eine wichtige Rolle bei den real existierenden Möglichkeiten spielen, den Strombedarf zu verschieben.
Die Ergebnisse des Experiments basierend auf finanziellen Anreizen sind ermutigend. Diese haben eine signifikante Auswirkung auf den Anteil des Stromverbrauchs zwischen 11.00 und 15.00 Uhr (20% des gesamten Tagesverbrauchs). Während in einem durchschnittlichen Haushalt 20% des Stromverbrauchs auf die Mittagszeit entfallen, sind es in finanziell motivierten Haushalten 22.9%. In Bezug auf die Politik zeigt die Studie, dass zeitvariable Tarife ein wirksames Nachfragemanagement-Instrument sind um mehr Sonnenenergie ins Stromnetz zu integrieren.

Résumé

Selon la Stratégie énergétique 2050 de la Confédération suisse, le développement des énergies renouvelables, et du photovoltaïque plus particulièrement, va augmenter et représentera une part importante de la consommation électrique suisse. Ce projet vise à répondre à la question du potentiel de flexibilisation de la demande électrique des ménages, afin de maximiser la part d'énergie solaire photovoltaïque étant consommée localement, de minimiser les impacts sur le réseau électrique et d'améliorer la pénétration des énergies renouvelables.
La partie technique de cette étude vise à quantifier le potentiel théorique d'augmentation de la flexibilisation, en fonction des caractéristiques types d'un ménage et des facteurs influençant la flexibilisation de la demande. Elle identifie les éléments techniques pouvant contribuer à l'augmentation du potentiel de flexibilisation.
La partie économique de cette étude analyse comment les incitations monétaires et le retour d'information peuvent avoir un impact sur la flexibilisation de la demande et sur le niveau de consommation d'électricité.
Bien que la partie technique de l'étude montre une flexibilisation théorique potentielle de 6 à 8%, la partie économique de l'étude révèle qu'il est difficile de motiver les ménages à modifier leur comportement sans incitations monétaires. L'étude montre également que les caractéristiques des ménages jouent un rôle important dans les réelles possibilités de déplacer la demande électrique.
Les résultats de l'expérience sur les incitations monétaires sont encourageants: ces incitations ont un impact significatif et quantitativement important sur la proportion d'électricité consommée sur la période 11h00-15h00 (20% de la consommation quotidienne totale). Les ménages incités augmentent cette proportion de 20% à 22,9%, ce qui est considérable. En termes de politique, l'étude montre que les tarifs dépendants de la période de la journée peuvent être un outil de gestion de la demande électrique efficace, afin d'intégrer plus d'énergie solaire dans le réseau.

Abstract

According to the Swiss Confederation's "Energy Strategy 2050", the development of renewable energies and photovoltaics in particular will increase substantially, and will represent a significant part of Switzerland's electrical consumption. This project aims to assess the potential for more flexibility in the electrical demand of Swiss households in order to maximize the share of photovoltaic power that is being consumed locally, to minimize the impacts on the electric grid and to increase the penetration rate of renewable energies.

The technical part of this study aims to quantify the theoretical potential for increased flexibility, based on the typical characteristics of a household and the factors influencing the "flexibilization" of the demand. It identifies the technical elements that may contribute to increasing the potential for flexibility. The economic part of this study analyzes how monetary incentives and information can have an effect on the flexibilization of electricity demand and the level of electricity consumption.

Although the technical part of the study show a theoretical potential for flexibilization of 6 to 8%, the the economic part of the study reveals that it is difficult to motivate the households to change their behaviour without providing monetary incentives. The study also shows that the characteristics of the households play an important role in the real possibilities to shift the electricity demand.

The results from the experiment on monetary incentives are encouraging: these incentives have a significant and quantitatively sizeable impact on the proportion of electricity consumed during the period 11am-3pm (20% of the total daily consumption). Incentivized households increase this proportion from the average of 20% to 22.9%, which is considerable. In terms of policy, the study shows that time-of-use tariffs can be an effective demand-side management tool in order to integrate more solar energy into the grid.

Table of contents

Initial position

To ensure the security of Switzerland's electricity supply, the Federal Council adopted the Energy Strategy 2050. In this context, it is necessary to develop renewable energy, while finding solutions to:

- ensure continuous generation of electricity (cover the consumption peaks and even out short-term imbalances between supply and demand),
- increase the value of renewable energy with the control of electricity storage and transmission.

This project fits into these current major changes in the energy policy.

Main objective

This project aims to assess the potential for more flexibility in the electrical demand of Swiss households in order to maximize the share of photovoltaic power that is being consumed locally. The main objective is to precisely quantify the proportion of the demand from a household or group of households that can be covered with a local solar production plant. The influence of the use of "smart" technologies for demand flexibilization has also been evaluated.

Thematic interest

The electricity supply sector is undergoing considerable changes, and the energy policy is at a turning point. In this context, the question of the flexibilization of electrical demand can provide solutions to:

- Increase the value of net metering for small solar plants: for a private producer, in many cases net metering is already more profitable than selling solar production to the grid, in part because revenues from electricity sales to Swissgrid are subject to income tax,
- Evaluate the role of decentralized storage systems (in particular batteries) and demand shifting in order to reduce the impact of high penetration rates of photovoltaic systems in domestic grids.
- Better understand the opportunities associated with very small decentralized photovoltaic plants (e.g. plants with panels and micro-inverters directly connected to the grid),
- Define coherent financial support for the electrical challenges for example by adding a bonus for local consumption into feed-in tariff structures, as is the case in Germany.

One of the main system-related problematics of an increasing penetration of renewable energies is the variability of renewable energy production. The possibility of shifting a part of the electrical demand for local usage brings the following advantages:

- Minimize the impact of photovoltaic systems on electricity grid. The integration of solar electricity into power system operations without consolidation is already causing difficulties (e.g. for Groupe E who receives lots of demands for PV electrical connections, 25 MWp in two months).
- Understand the electrical demand and the part that can be shifted in preparation for the evolutions in electricity supply technologies.
- Understand the interest of decentralized energy storage
- Maintain the reliability and stability of the overall electric power system.

Technical studies

Renewable energies and photovoltaics (PV) in particular will cover a very important part or our energy consumption in the foreseeable future. This project and the related technical studies aim at studying the potential of electric consumption shift and to study the possible role of decentralized storage systems. In this context, the goal is to identify the opportunities offered by a flexibilization of the demand to minimize the impact of PV on the electric grid and increase its penetration.

Objectives

In the first phase of this project the main goal is to evaluate the flexibilization potential of households' electric consumption to maximize the local consumption of electricity generated by PV. This potential is characterized:

- By the ratio of the consumption occurring during the "PV production hours" (defined in our study by the period 11:00 to 15:00 corresponding to the time window with the peak PV production) to the total consumption.
- For a sample of ca. 300 households (households of Cernier equipped with a smart-meter enabling the recording of the load curves with a 15 minute resolution). This ratio can be computed for a single household, a group of households or a residential area or can be extrapolated to the entire town.
- As a function of the household characteristics in order to evaluate the factors influencing the flexibilization potential (size, socio-economic profile, etc.)
- Identifying technical elements that could help improving this potential. This concerns mainly the possibility to modify the consumption time of boilers or heat pumps for domestic water heating and freezers or fridges.

This potential should be evaluated considering two cases:

1. PV installation without storage where the consumption should be maximized during PV production hours to absorb PV production.
2. PV installation with storage systems which allows an addition flexibility by storing the excess production (the one that cannot be consumed instantaneously) to be consumed at a later stage.

In the analysis or the results, flexibilization by shifting electric consumption towards PV production is similar to storage where the availability of the PV energy can be shifted. However, flexibilization offers the benefit of avoiding energy losses that any storage systems induced and of avoiding their costs. On the other hand, storage allows can provide a timely and exact supply of additional energy outside the PV production time window.

A second phase of the project is foreseen to study in more details the integration of PV systems and its effect of the consumer behavior as well as the possibility to interact with the consumer to transmit in real time information on the PV production and favorable time for electric consumptions. For the first phase the following technical studies have been designed.

Technical study content

For the analysis of flexibilization without storage (as mentioned above in the objectives), the technical study first dealt with the determination of the flexibilization potential both from a theoretical and practical point of view. As indicated above this potential is defined in relation with the consumption within the "PV production hours". The goal is to shift as much as possible consumption occurring outside this time window to that time window as shown in Figure 1.

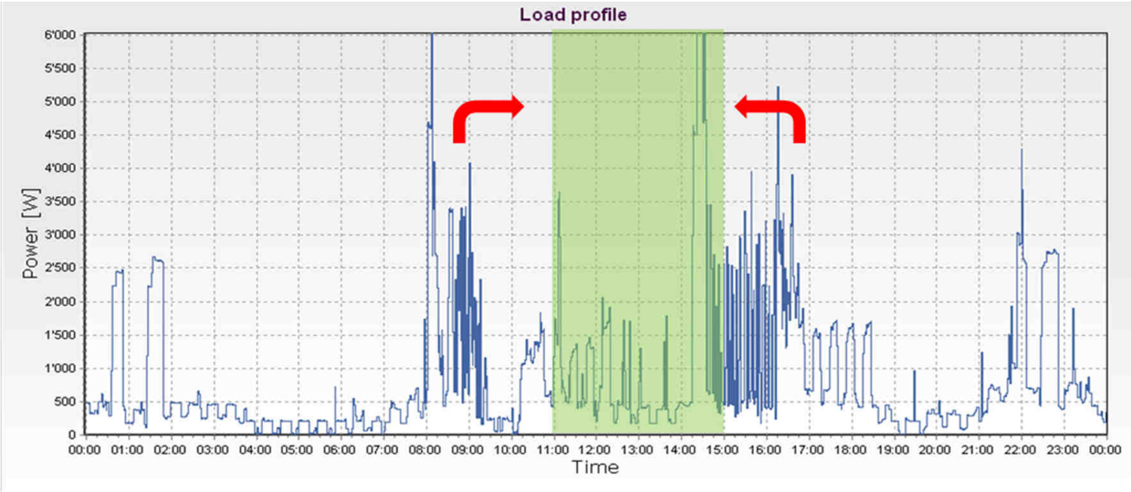

Figure 1 : Example of a 24 hours load curve of a family house: consumption should be shifted as much as possible into "PV production hours" (defined as the green area).

This technical study also aimed at evaluating how "PV coverage" could be enhanced by flexibilization with or without storage. However "PV coverage" is a notion that can take different meanings. It may indicate the part of the consumption that can be covered locally by PV. Nevertheless, Consumption is never synchronous with PV production, as both are exhibiting peaks that never balance each other. If PV produced electricity must be consumed locally then any excess in production (with respect to instantaneous consumption) is lost unless some kind of storage is available. For the present study "PV coverage" is defined as the part of the electric consumption that can be covered by PV on a yearly basis considering the grid a storage mean. A PV coverage of one will mean that the yearly total consumption can be covered by the yearly total PV production. This "PV coverage" is here analysed at different levels (household, apartment building or residential area) and we focused on how it can be enhanced by flexibilization and/or introduction of local storage.

Methodology

For the analysis, the following data were used:

- Detailed survey of participating households containing information on the number of inhabitants, age, occupation, presence in the households, type and number of appliances, etc.[1]. Among the 300 households, 124 completely answered the survey.
- Load curves of all household with a 15 minute resolution
- Additional analysis/surveys such as "time use" budget data (time of the day and duration of use of appliances, from Ref.2, especially time use survey of the Netherlands 2005, which seems the most recent one and expected to be also representative of Switzerland) and power specification of typical appliances (see Appendix 1) as derived from various sources including mainly from « Synergy Potential » of EU project Smart-A[3].
- Data and results from the literature (as mentioned in the text) as well as results from an EPFL project (financed by EOS holding) for the study of local storage of PV energy.
- High time resolution (12 second resolution) load curves of given households (not among the 300 of Cernier, data from EOS project).

[1] A complete version of the survey (in French) is reported in the Appendix.

[2] http://www.timeuse.org/information/access-data

[3] http://www.smart-a.org/D2.3_Synergy_Potential_of_Smart_Appliances_4.00.pdf

Load curve measurements

In order to determine in a reliable way the share of PV electricity that could be used locally (at the household level), the measurement of load curve with a high time resolution (better than 1 minute) is desirable. For this project the load curves are measured by smart-meters installed by Groupe E in the framework of the Prokilowatt project as well as for the purpose of the present project. This monitoring system allows the recording of load curves with a time resolution of 15 minutes only. Such a low resolution is however acceptable for the estimation of energy flux and calculation of self-consumption (auto-consumption of PV energy)[4]. However, this resolution, chosen to guaranty privacy, strongly limits the load analysis to infer what type of appliances are switched on.

Definition of «the flexibilization potential»

Flexibilization is the potential to shift consumption from a time period to another time period. In the present project, the goal is to shift consumption into the PV production hours (time window 11:00-15:00). This shift of consumption by is evaluated by the metric (also called "PV potential" in this study, as this factor represents the share of the consumption that could be covered by PV):

$$C = \frac{Cons_{11-15}}{Cons_{tot}}$$

Where $Cons_{11-15}$ is the consumption during the PV production hours and $Cons_{tot}$ is the total consumption. Such PV potential factors can be determined for one day or a longer period of time. The potential of flexibilization then is the potential to increase this factor without increasing the total consumption (shifting consumption without increasing or decreasing the total consumption).

Flexibility of appliances

In order to determine a theoretical flexibilization potential, appliances were attributed to 4 categories:

1. Not flexible
2. Flexible with technical means (usage – time and duration – controlled by hardware or software means to be implemented)
3. Hardly flexible (with an important impact on household inhabitants)
4. Easily flexible (with no or negligible impact on household inhabitants)

Technical study description

The theoretical evaluation of the flexibilization potential requires the identification of all appliances contributing to the load at any time. The total contribution of each of them over a certain period of time and their respective flexibility category allows the determination of the flexibilization potential. However, such identification (disaggregation of load curves) is not directly possible due to the 15 minute resolution of load curves. Note that, even with load curves measured at one second resolution including active and reactive power information, such identification is very difficult[5,6]. Alternative approaches are therefore necessary to determine which type of appliances is used, when and how long, and to infer their contribution to flexibilization potential. Three alternative approaches applied in this study are detailed in the next section and will be further discussed in the Results section.

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[4] N. Wyrsch, Y. Riesen, C. Ballif, Proc. of the 28th EU PVSEC, Paris (2003) 4322.

[5] A. Zoha, A. Gluhak, M. A. Imran, S. Rajasegarar, Sensors 12 (2012) 16838.

[6] P. Ferrez, P. Roduit, Proc. of the ENERGYCON 2014, Dubrovnik, (2014) 813.

For our practical study, from the sample of 124 households, 19 were discarded because they had a double tariff. Several other were discarded along the experiment for various reasons affecting the validity of the results. 5 statistically equivalent groups of ca 20 households (based on consumption and survey details) were constituted:

- 2 control groups ("Control group") receiving no information (beside the fact of being involved in a research study). One of the group involved "virgin" households not involved in any project so far.
- 2 groups ("Facture group") of households where each one would receive on a monthly basis information on its performance (aggregated performance). One of the group involved "virgin" households not involved in any project so far.
- 1 group ("Flexi group") of households participating in a contest. Each month the best performing households would receive a monetary prize.

Evaluation of the practical flexibilization potential was evaluated from the performance of the groups or individual households. A 6 month period (last 6 month of 2013) was devoted to study the behavior of all households before the actual start of the experiment (1.1.2014). Beginning of January 2014, "Facture and "Flexi" were informed and requested to shift their consumption. All households were then followed for a period of one year and the evolution of their consumption compared to previous months, to the period before the start of the experiment and to the consumption of the control groups.

Identification of loads/appliances

Three different approaches were followed for the identification of loads and load usage. They all comprise the generation of appliance inventories for each household, inventories that list appliances in 35 different types with their respective flexibility category. The list is given below in Table 1. For the first approach ("Simple consumption model") this inventory was combined with time use budget data (as mentioned at the beginning of the methodology section, Ref. 2), answers from the questionnaires and appliance power usage to generate a typical load curve. The share of consumption from the different flexibility categories can then be easily calculated. This approach is relatively similar to the one followed in J. Coquoz's master thesis at ETHZ[7] who determined the effect of demand response in the integration of PV, by simulating synthetic standard load curves (with 1 hour time resolution). However, this approach is relatively limited and does not permit to determine if one appliance is actually used or not for a particular household; it only gives statistical mean data of its usage.

Appliance type	Appliance ID	Flexibility / shiftable	Remark
Washing machine	'WASHM'	Easy	
Dish washer	'DISHW'	Easy	
Tumble dryer	'TUMBL'	Easy	
Dryer cabinet	'DRYC'	Easy	
Freezer	'FREEZ'	Not /technical	
Fridge with freezer	'FRIDG'	Not	
Fridge without freezer	'REFRIG'	Not	
Coffee / tea machine	'COFFE'	Hard	
Electric kettle	'KETTL'	Not	
Stove	'STOVE'	Not	
Oven	'OVEN'	Not	
Microwave oven	'uWAVE'	Not	
Vacuum cleaner	'VACUUM'	Easy	
Hairdryer	'HAIRDR'	Hard	
PC	'PC'	Hard	
Laptop	'LAPTOP'	Hard	
Printer / Scanner / FAX	'PRINT'	Hard	
Modem / router	'MODEM'	Hard	Not used, included in standby
Mobile phones	'MOBIL'	Hard	Not used (negligeable contribution)

[7] J. Coquoz, « Potential contribution of households' demand response for integration of distributed solar photovoltaic in Switzerland », Master Thesis EHZ, 2012.

Fixed/answering phone	'FIXNET'	Not	Not used (negligeable contribution)
Tablet computer	'TABLET'	Hard	
Photoframe	'PHOTOF'	Not	Not used (negligeable contribution)
TV set	'TV'	Hard	
TV box	'TVBOX'	Hard	
HIFI set	'HIFI'	Hard	
DVD set	'DVD'	Hard	
Gaming station	'GAMING'	Hard	
Humidifier	'HUMID'	Not	Not used
Aquarium	'AQUARI'	Not	Not used
Solarium	'SOLARI'	Hard	Not used
Sauna	'SAUNA'	Hard	Not used
Lighting	'LIGHT'	Not	
Boiler	'BOILER'	Technical	
Heat pump	'HP'	Technical	
Standby	'Standby'	Not	Continuous operating/not identified

Table 1 : Inventory of possible appliance types in households as obtained from the household survey. Flexibility categories (as chosen for this study) are also indicated.

For the second approach, in order to be able to determine the actual usage of all appliances, we adopted a Markov chain[8] method ("Markov chain model") similar to the ones used in other recent studies[9]. Household activities are described by a Markov chain defining the state (current activities) and its possible evolution as a function of time. Some activities can also be concurrent. Activities are then related to appliance usage such as cooking, vacuum cleaning, working (being out of home) or sleeping. The goal is here to approach experimental load curves with synthetic (generated or simulated) ones and therefore deduce the most probable origin of the consumption. This approach can be described schematically by the Figure 2. The Markov chain description of activities triggers load of appliances (cf. Figure 3). The model includes 14 different activities triggering the use of 23 different appliances (or appliance group). It also takes into account as much as possible interaction between household inhabitants. A validation of the approach was performed during a few days with time use budget data recorded by one EPFL researcher and load curve measured with high time resolution (5 seconds).

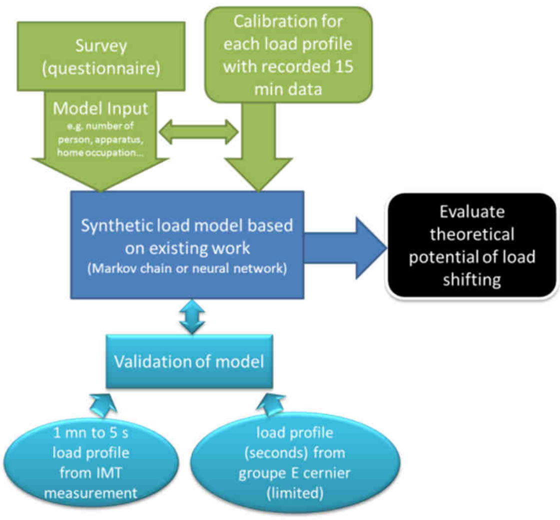

Figure 2 : Schematic description of the Markov chain approach.

[8] http://en.wikipedia.org/wiki/Markov_chain

[9] J. Torriti, Renewable and Sustainable Energy Reviews 37 (2014) 265

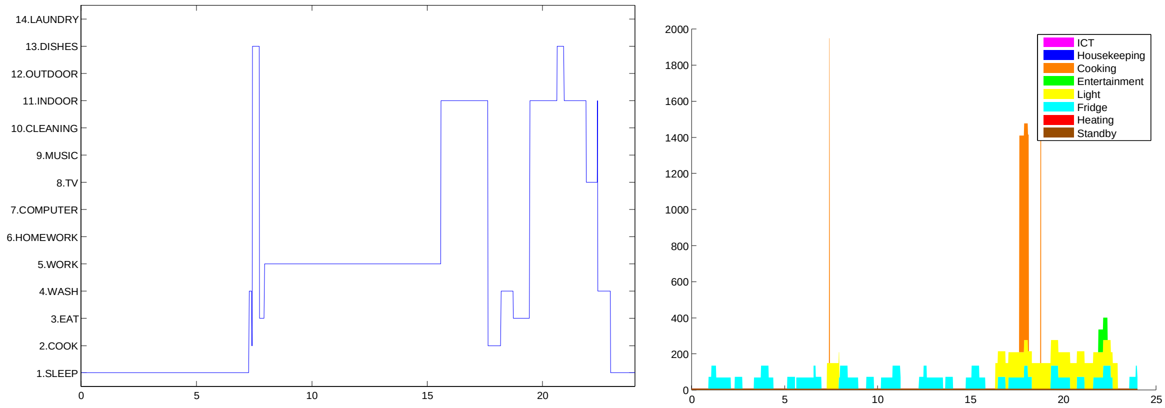

Figure 3 : The chain of activities as a function of time (over 1 day, left) results in the load curve (right). Lighting and fridge/freezer are considered separately (added to the load curve resulting from the activity chain. Note that some of the activities may be concurrent.

For this approach the following procedure was applied:

1. Establish a time use of the household activities and related used appliances based on available data from past surveys (in particular from MTU Netherlands 2005 [Ref. 2] and adjusted as a function of the knowledge on the household from the questionnaires (number of inhabitants, habits, occupations, etc.).
2. Determine standby power as the minimum power over one full day.
3. Identified fridge, freezer and hot water (if present) consumptions and subtract them from the load curves. Such identification can be done relatively easily from the periodic peaks present during night where almost no other appliances are switched on.
4. As a function of the time along the day generate possible activities from the probability given by the time use table and generate possible appliance loads curves. Select the one who best fits the load curve. Some activities may lead to the use of several appliances (cooking for example) while several activities may be occur in parallel (listening to music and using PC for example). Interaction between activities of several people living in the same household are also taken into account (cooking will occur at the same time for all people for example). Lighting consumption is defined from the occupation of the household, equipment of the household and time of the day. Note that knowledge on the exact active power is not too important as duration (and therefore energy consumed) is also fitted with time steps of 1 minute (to be able to adjust the power for each 15 minutes interval (given by the load curve).
5. Repeat step 2-4 for as many days as possible and generate a usage table (time and duration) for each appliance in the household.
6. Compute the share of total electricity consumption (as a function of flexibility categories) that can be shifted to the target time window.

From this analysis, the flexibilization potential related to technical measures like programming hot water heating during the day (during PV production) instead of during night (when tariffs are low) or shift freezer/fridge consumptions can also be easily calculated. Contribution to hot water heating is done automatically by identifying large power peaks during night (between 0:00 and 6:00).

The third approach involved a detailed analysis of the load curves (“load profile approach”) to determine:

- Standby power (as the minimum power during night (between 0:00 and 6:00)
- “Base” consumption given by appliance switch on for a long time (> 1 hour). This contribution is evaluated by taking the hourly minimum power minus the standby power.
- “Peak” consumption given by rapidly changing load power. It is given by the load at any time minus the base and minus the standby power.

The analysis (i.e. the contribution of standby, “base” and “peak” consumption) as a function of the time of the day permits to extract the contribution of a specific type of appliance to the consumption over a certain period of time (days, weeks or months). For example “peak” consumption around noon can be attributed to cooking (stove, oven, etc.), night (between 0:00 and 6:00) to fridge and freezers (as fridge and freezer are operating in cycles with a duration which is typically of the order of 30 minutes; it will then create peaks of consumption when looking at the consumption load during one hour), “base” consumption in the evening to lighting, TV and IT, etc. A seasonal comparison should allow for further breakdown. For the purpose of this study (to be able to extract changes in consumption during “PV production hours” and to catch contribution from dish washer in particular), the following time windows were chosen:

- Night : 0:00 to 6:00
- Morning : 6:00 to 11:00
- Cooking time : 11:00 to 13:00 and 18:00 to 20:00
- Early afternoon : 13:00 to 15:00
- Afternoon : 15:00 to 18:00
- Early evening : 20:00 to 22:00
- Evening : 22:00 to 24:00

For the last part of the technical study we focused on the potential "PV coverage" (part of the electric consumption that can be covered by PV) with and without flexibilization and with and without storage. Real load curves (with 12 second and 15 minute time resolution) of individual households as well as aggregated load curve of groups of households and PV production are compared on a yearly basis to evaluate self-consumption and the gain offered by flexibilization. Maximum PV penetration in absence of any energy feed outside the considered group of households can also be estimated.

Results

The following results were obtained after 18 months: 6 months before the actual start of the experiment (triggering change in behavior) and 12 months of following the behavior evolution. Note that data from some of the households where only available 3 months before the start of the experiment. Therefore, change in the consumption habits should only be compared with the 3 months before the start of the experiment.

Flexibilization potential

Let us start by looking at the practical results. Figure 4 shows the evolution of the “PV potential” (i.e. the part that could be covered by PV with our simple definition) for both the “Facture” and “control group” of households. No significant change or differences are observed. In contrast, “Flexi group” of households were clearly able to increase the PV potential by up to 5% compared to the control group on a weekly average, from the start of the experiment on January 1, 2014 (cf. Figure 5). On a monthly average, this increase is at 3.3% maximum and is seen to decrease from mid-year to ca. 2% (cf. Figure 6).
Note that the PV potential metric exhibits no or very little seasonal dependence.

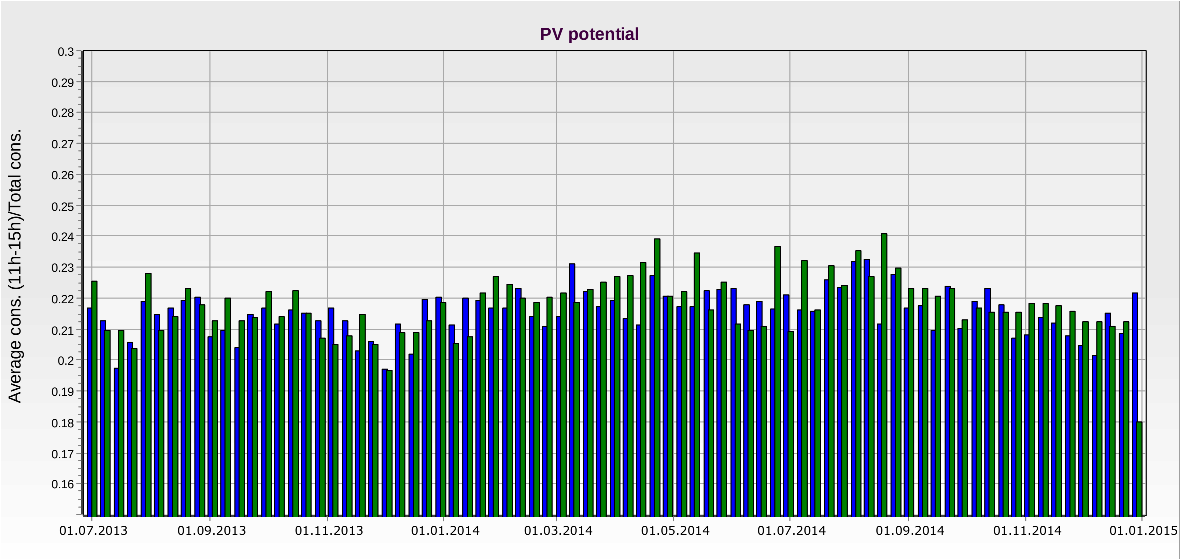

Figure 4 : Weekly evolution of the “PV potential” as a function of time (from 1.7.2013 to 31.12.2013) for the “Facture group” (green) and “Control group” (blue).

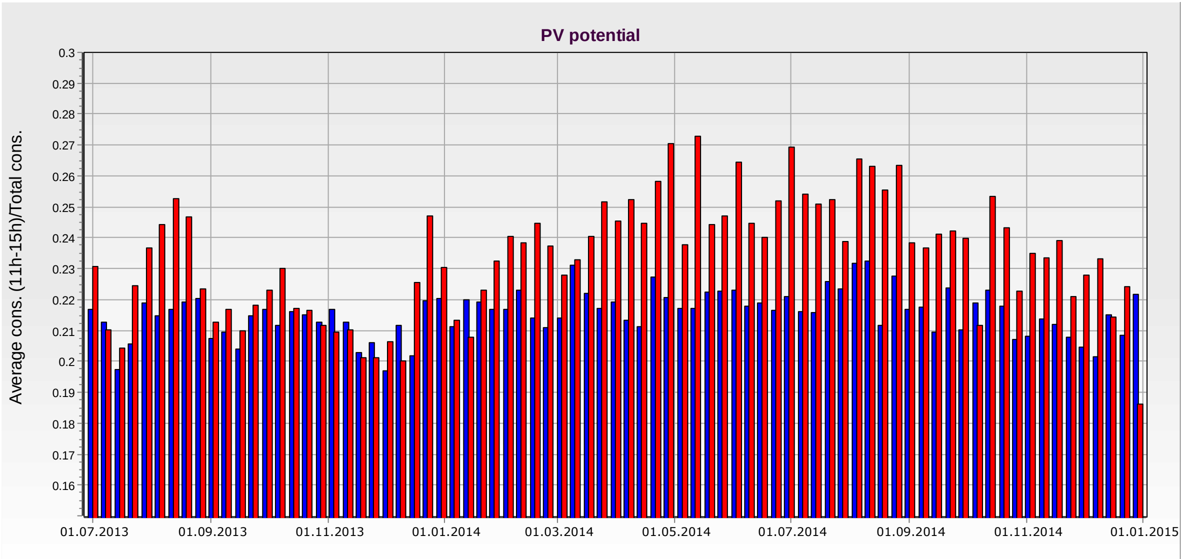

Figure 5 : Weekly evolution of the “PV potential” as a function of time (from 1.7.2013 to 31.12.2013) for the “Flexi group” (red) and “Control group” (blue).

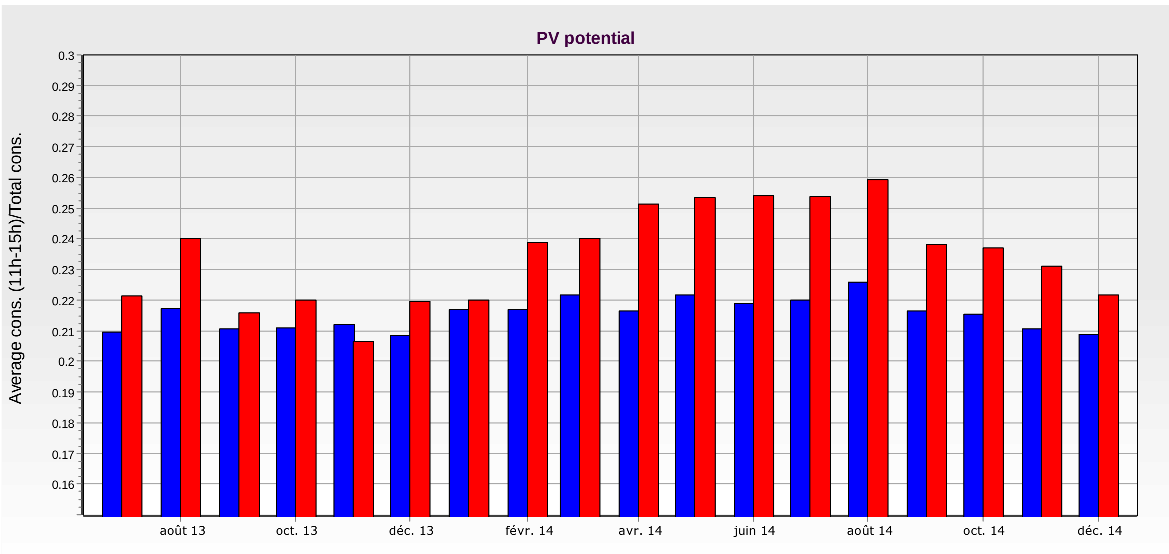

Figure 6 : Monthly evolution of the “PV potential” as a function of time (from 1.7.2013 to 31.12.2013) for the “Flexi group” (red) and “Control group” (blue).

Figure 7 shows the hourly average of the consumption as a function the hour of the day for the semester before the start of the experiment, for the first semester of the experiment and for the second one. We clearly see that consumption during "PV production hour" (11:00 to 15:00) was increased during the experiment while consumption during the late afternoon was reduced. Detailed analysis demonstrates (not surprisingly) that this shift is slightly more pronounced during week-ends (when more people are at home) than during working days. Figure 8 shows the behavior for "Control group" which exhibits a similar pattern before and after the experiment with less than 1% fluctuation can be observed. Note that, in contrast to the PV potential, the hourly consumption exhibits some seasonal dependence due to the effect of lighting. Comparisons are therefore more difficult. Nevertheless, the semester before the experiment and the second semester (as plotted in Figure 7) should be exempted of such a problem.

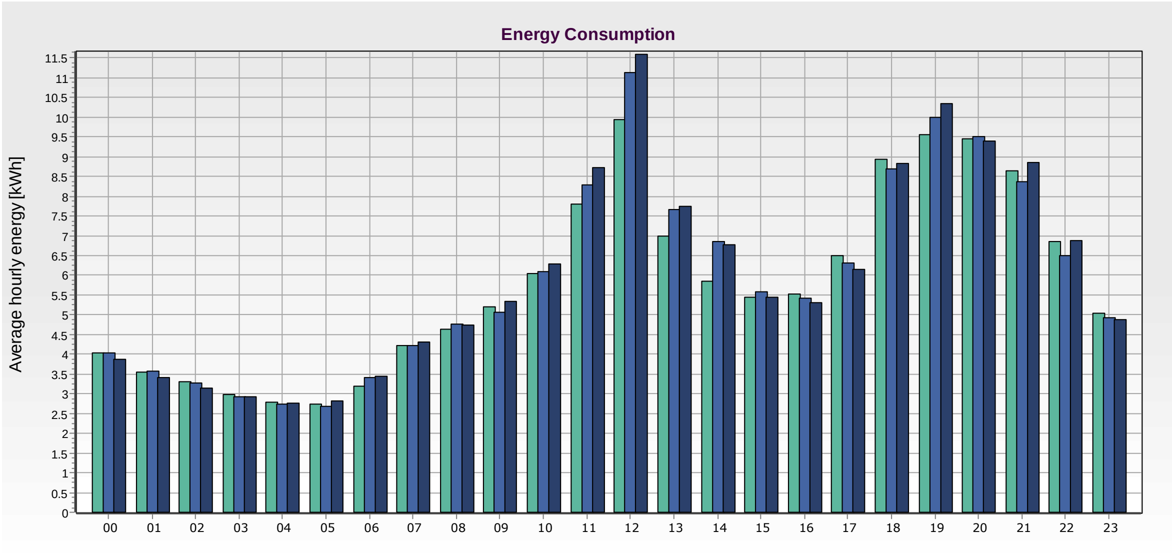

Figure 7 : Hourly average of the consumption of the "Flexi group" (20 households) as a function of the hour of the day for the semester before the start of the experiment (1.7.2013 to 31.12.2013, in light green), for the first semester of the experiment (1.1.2014 to 31.6.2014, in blue) and for the second semester of the experiment (1.7.2014 to 31.12.2014, in dark blue).

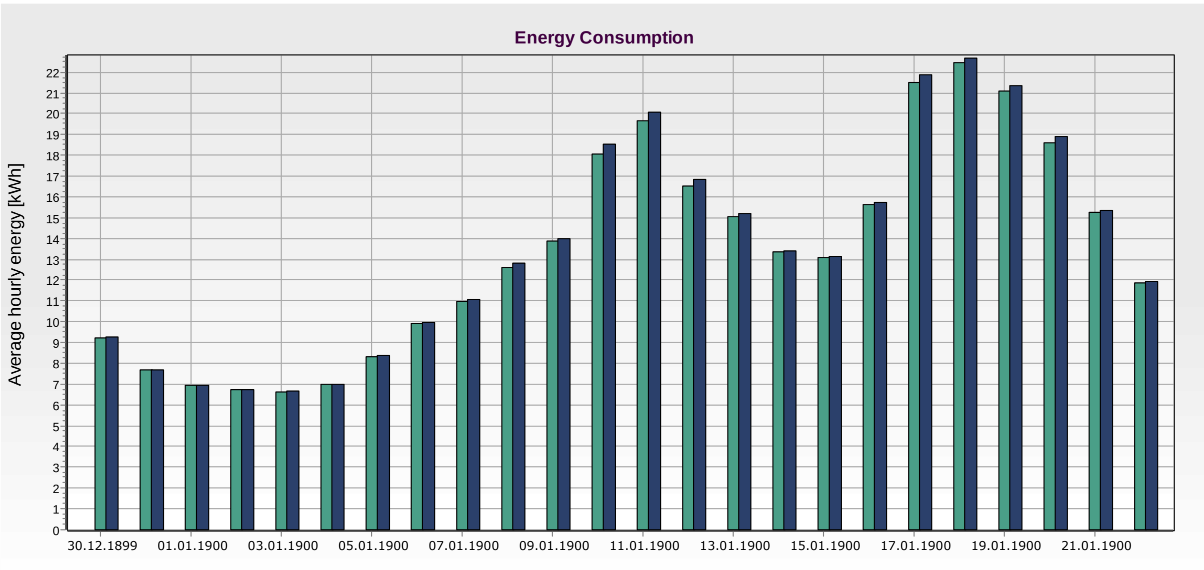

Figure 8 : Hourly average of the consumption of the "Control group" (40 households) as a function of the hour of the day for the semester before the start of the experiment (1.7.2013 to 31.12.2013, green), and for the next 12 months (1.1.2014 to 31.12.2014, in dark blue).

The change in PV potential for the best performing household is shown in Figure 9. This household exhibit a relatively high consumption in the time period 10h-14h compared to the control group, indicating that its inhabitant are indeed at home during the day and as a consequence able to shift more easily their consumption. In this case the consumption during the PV production hours for was increased by more than 10%. A clear shift of the consumption from the morning and late afternoon to mid-day is also clearly observed (cf. Figure 10).

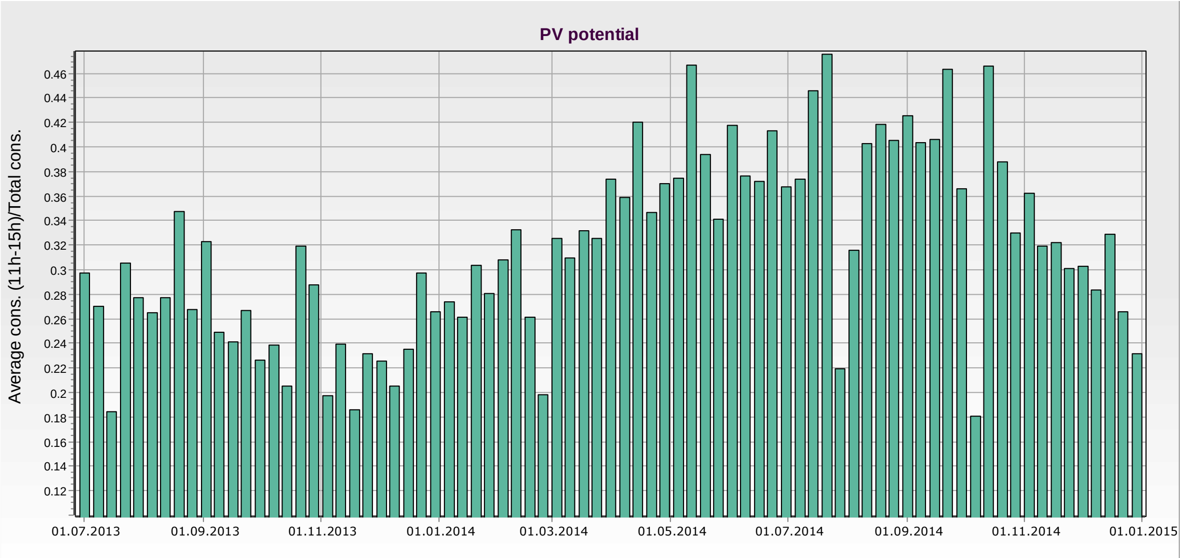

Figure 9 : Weekly evolution of "PV potential" as a function of time (from 1.7.2013 to 31.12.2014) for the best performing household.

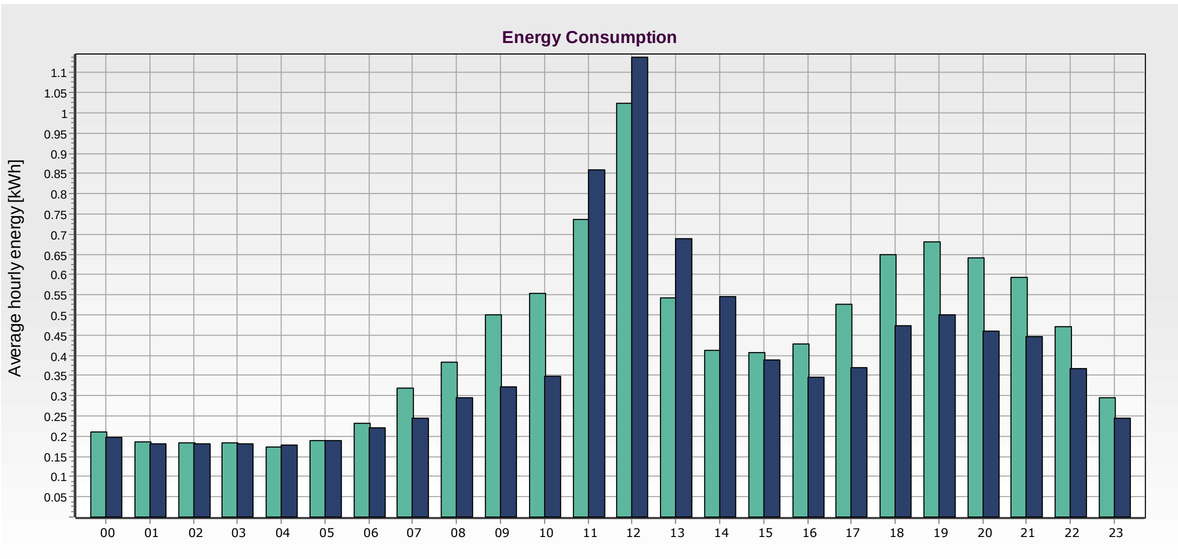

Figure 10 : Hourly average of the consumption of the best performing household as a function of the hour of the day for the semester before the start of the experiment (1.7.2013 to 31.12.2013, in green), and for the year of the experiment (1.1.2014 to 31.12.2014, in dark blue).

Simple consumption model

This approach was first checked at the beginning of the project (mid 2013) and applied to a set of 53 households for which the complete survey was available, load data were existing for a full year (from 2012 to mid-2013). The results shown in Figure 11 exhibit a relatively good correlation between simulated and measured consumptions. Simulated consumption is ca. 10% lower than the measured one with standard deviation of 44%.

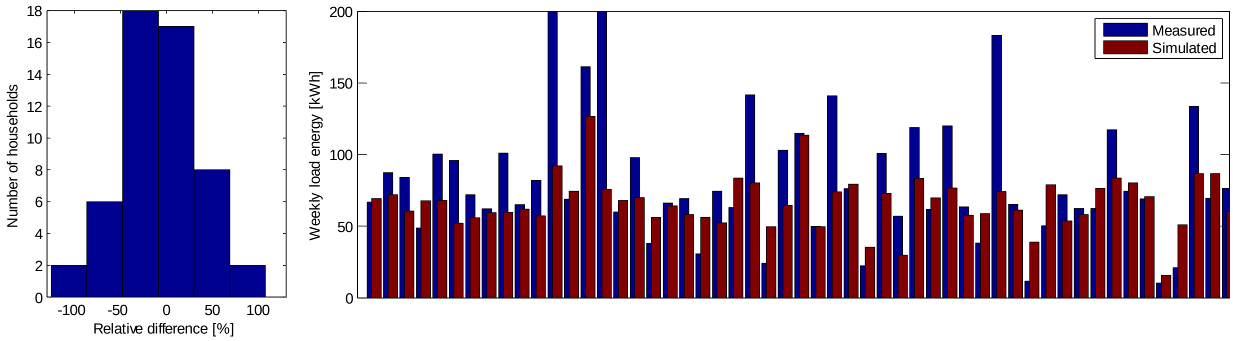

Figure 11 : Weekly simulated and measure consumption of a set of 53 households (left) and histogram of the difference between simulation and measurement (left).

This first calculation was performed without any temporal consideration (not simulating a load curve varying with time but only a weekly total consumption). From this calculation the share of consumption as a function of flexibility/shiftability category can be extracted and is given in Figure 12. The histogram of the easy shiftable energy consumption per week for the 53 households is plotted in Figure 13. Using the time use budget data, one could also infer the time of use and therefore could generate a standard load curve However, this one would only be an averaged one as in Coquoz's master thesis. It would be very difficult to reproduce reliably a load curve representative of a given household as defined by the survey data. Due to this difficulty this approach was abandoned. The amount of easy shiftable consumption seen in Figure 12 also includes the consumption which is already consumed with the PV production hours. The share of the easy shiftable consumption which is outside this time window should be much lower as we will see in the next section.

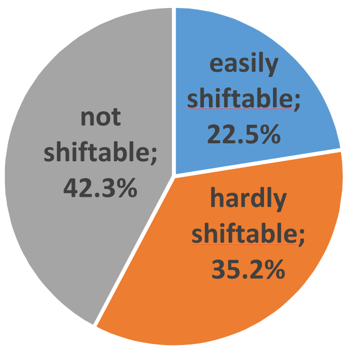

Figure 12 : Share of the total consumption as a function of the shiftability for the set of 53 households.

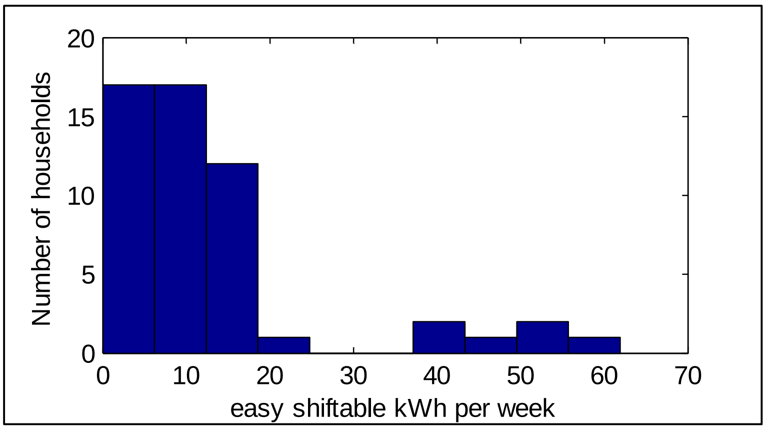

Figure 13 : Histogram of the weekly energy consumed (as plotted in *Figure 11*) that can be easily shifted.

Analysis of the consumption using synthetic load curves ("Markov chain approach")

A first example of such a simulation /fitting is given in Figure 14. The most probable activities and their related load (given by the appliances switched on during that particular activity) are chosen to best fit the measured load curve. More precisely, one chose among the most probable activities, the ones that best fit consumption peaks. The procedure is repeated for each day of a period and one expect to get a statistically correct picture of the household consumption over a long period.

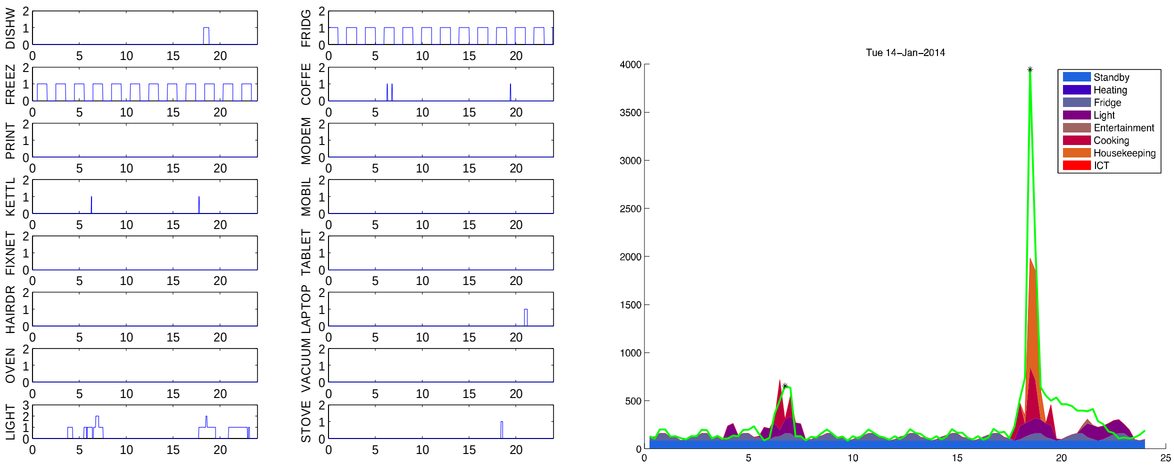

Figure 14 : Appliance loads triggered by activities (le

The shares of the total consumption as a function of shiftability for the various household groups are plotted in Figure 15. The share of the consumption for the "Flexi group" which is already within the target time window ("PV production hours) is found to vary between 18% before the start of the experiment and 20% after. The measured values, as plotted in Figure 7, are 22% respectively 24%. The simulation (Markov chain approach) while giving the correct trend, tends to underestimate the real consumption (cf. Figure 16). This fact may be due to the difficulty to fit correctly some of the consumption peak and the possibility that some appliances may be missing in the survey. The simulated time evolution of the total consumption (as a function of appliances categories) and the share of consumption as a function of shiftability are plotted in Figure 17. Finally the shares of consumption of all appliance categories for all households (all groups) are plotted in Figure 18.

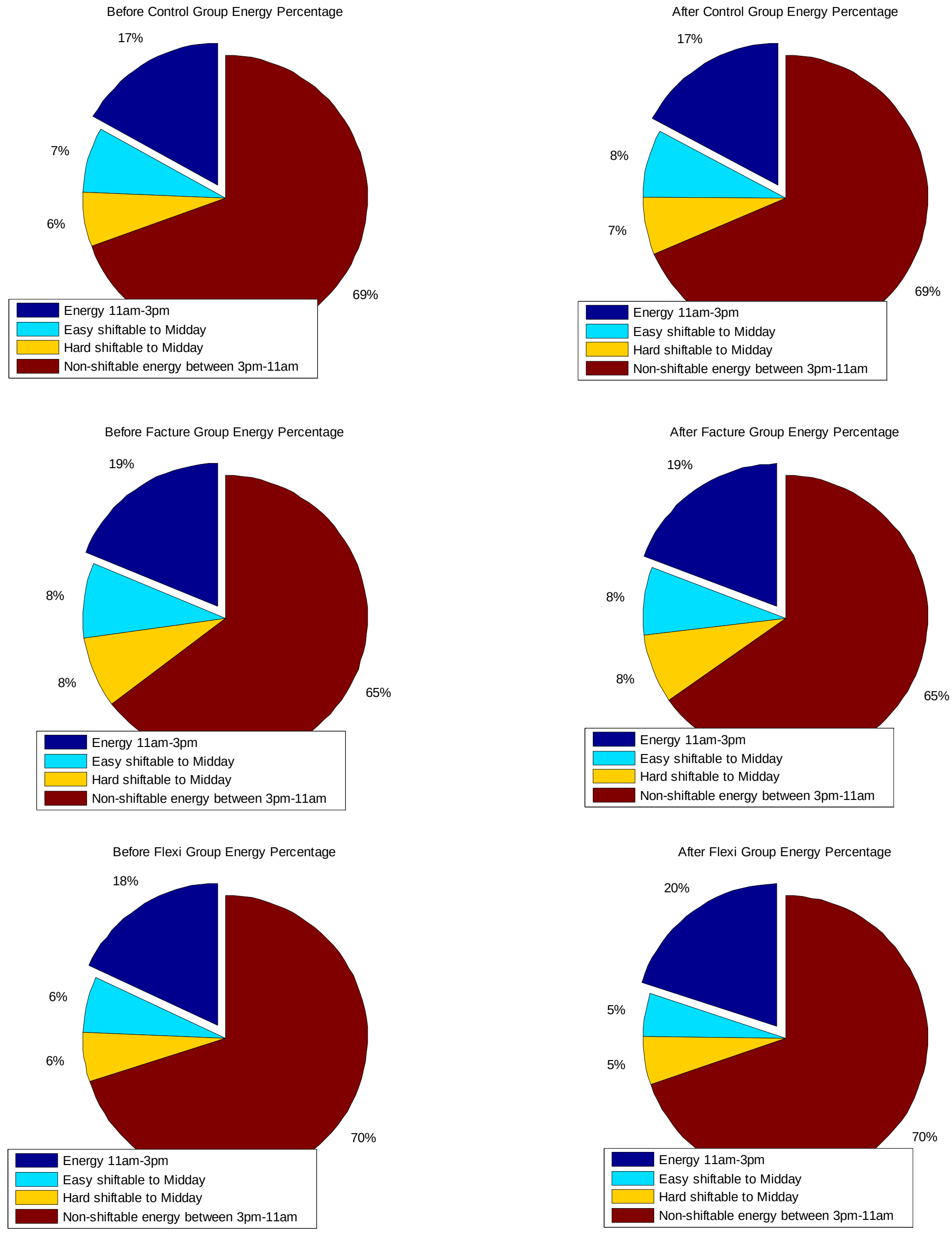

Figure 15 : Share of the total consumption as a function of the shiftability for the “Control group”, “Facture group” and “Flexi group” before the start of the experiment (1.7.2013 to 31.12.2013, in light green), and for the year of the experiment (1.1.2014 to 31.12.2014).

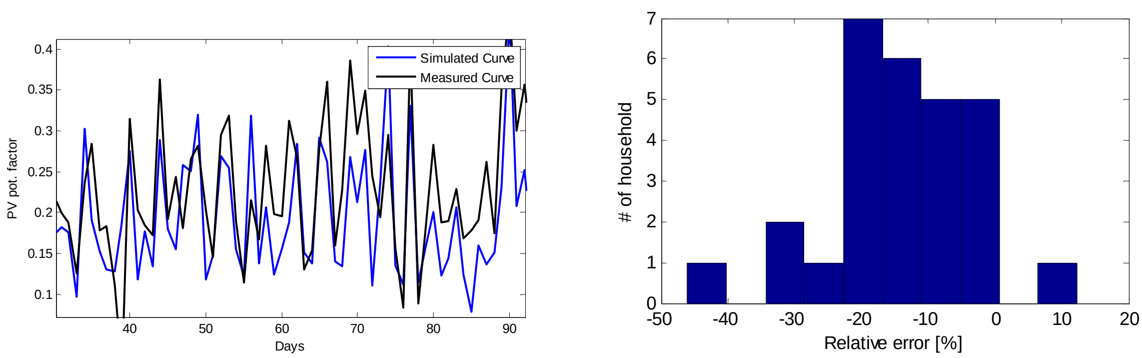

Figure 16 : Comparison of the measured and simulated values of the “PV potential” over 50 days (left) and histogram of the corresponding relative error between the measured and simulated load curves.

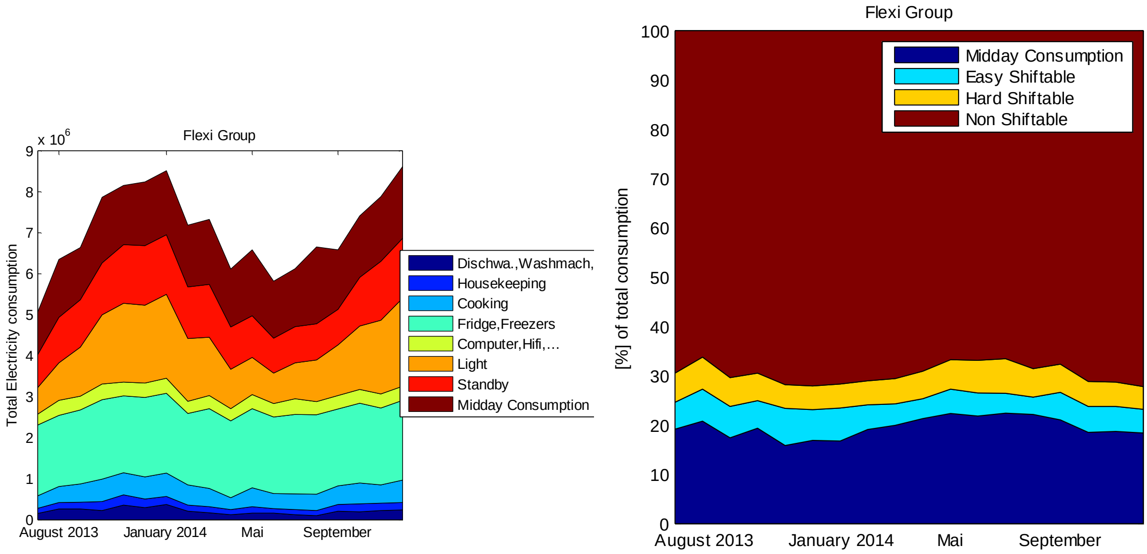

Figure 17 : Simulated time evolution of the consumption of various categories of appliances (left) and of the share of the total consumption as a function of the shiftability for the Flexi group and entire duration.

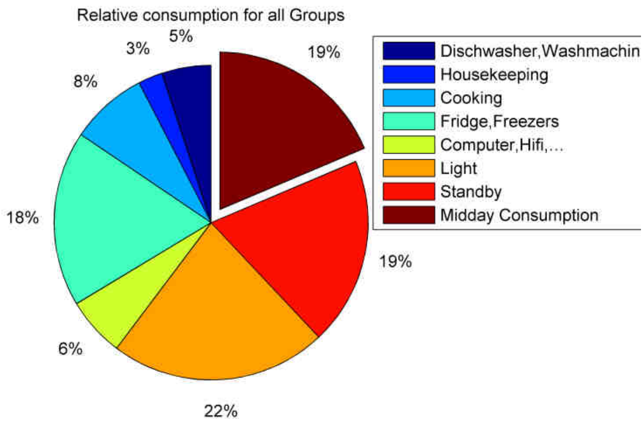

Figure 18 : Simulated relative consumption share of appliance groups (outside “PV production hours”) and consumption during “PV production hours” for all groups of households.

Detailed analysis of load curves and consumption profiles

With this detailed analysis we aim at having an independent alternative way for identifying the consumption of the various appliances and give a stronger validation to the Markov chain approach. In Figure 19, the load profiles (as defined above in the methodology section) are plotted for the “Flexi group” before and after the start of the experiment. The results reflect the behavior already observed in Figure 7 with a shift of the consumption towards mid-day (as “Mid-day base” and “Mid-day peak”). However, this analysis is here relatively misleading, both quantitatively and regarding appliance types or categories. The reason is that “peak” and “base” consumption cannot be distinguished clearly and the related appliances cannot be identified reliably. The problem is due to the 15 minute time resolution for the load curve measurement which completely blurs the peaks. When stove, oven, but especially dish washer and washing machine are used, they generate short consumption peaks which are repeated during the entire duration of the use of the appliance which span in most cases over more than one hour. These short peaks are averaged over 15 minutes intervals and the measured load curve never get to its “base” value (power value representative of the other loads in the household without the one generating peaks). For this reason, some “peak” and “base” consumption of the consumption profile are related to the same appliance and cannot be separated. This approach was therefore here not useful as a validating tool and does not give more information than the hour of day consumption breakdown of Figure 7.

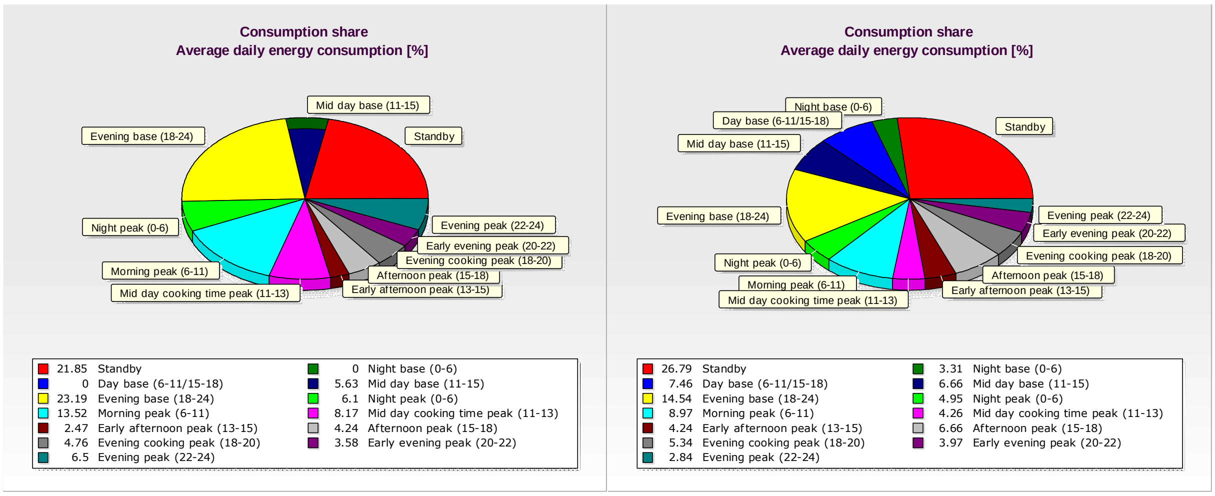

Figure 19 : Consumption profiles for the Flexi group before and after the start of the experiment.

Load shifting using technical measures

Additional flexibility could be gained by shifting some of the load by technical means. We consider here only measures that could be applied without affecting the life and comfort of household inhabitants and avoiding technically complicated measures. For this reason heating was not considered and we restrict ourselves to freezers and domestic hot water heating. Note that we did not consider fridges, because the range of temperature on which we can play to use thermal inertia is much more limited than freezers. One should also mention that, especially for fridges, modern devices operate at an optimal set-point of the compressor and operating and therefore offer almost no flexibility (on the time frame we considered). Freezer are much more flexibility (at least when not opened and not freezing additional goods).

This technical means should be relatively easy to implement without costly add-ons. Hot-water heating is a matter of modifying the programing of boilers or heat-pumps. In the case of freezers, some modern appliances already offers interface to maximize consumption when it is favourable for the grid.

Freezers: Consumption of freezers (from the simulation) is approx. 10% of total consumption. If we assume that 50% of the freezer consumption can be shifted safely (freezer temperature is lowered during PV production hours) and the freezer is then turn of for several hours playing with the thermal inertia. An additional 5% of the total consumption can therefore be shifted to the PV production hours.

Domestic hot water: Among the 1300 households in Cernier, most of them are using central heating (oil or gas based) to heat hot water. In 2014, 69 boilers (5.3% of households) and 25 heat pumps (HP) were in operation. A procedure was designed to automatically detect boiler consumption in a load curve (large peak consumption during the night) and to extract the boiler consumption. The procedure was applied on all boilers detected to determine the share of household consumption devoted to domestic hot water heating. In average, from the 18 boilers identified (in the sample of 300 households), this share was found to be 27% of the total consumption (or 1/3 of the household electric consumption, hot water not included). As a consequence, another 1.4% of total consumption could therefore be shifted in average with another programing of boilers. However, the number of boilers is vanishing and heat pumps will slowly replace some of the oil and gas central heating systems. Assuming a COP (coefficient of performance) of 3 for a HP, any new household switching to hot water heating from a HP will increase its consumption by at least 10% (hot water consumption from boiler is known to be much lower than the one from central heating due to a much large supply) and fully shiftable.

It is important to note that all the flexibilization evaluations done above (using technical means) assume a fixed PV production period and represents a potential. In reality, the PV production window changes from day to day according to insolation hours, and the amount that could practically be shifted is lower.

PV coverage and self-consumption

For the first technical study, we assume the main PV production to be between 11:00 and 15:00 or 4 hours per day. PV production over the year is equivalent to 1000 hours of full sun illumination or 3 hours per day. As a consequence, as a first very rough approximation, if one can shift x% of the total consumption, this x% of consumption could be produced by PV and consumed locally.

In the framework of an EPFL project financed by EOS Holding, a model and a simulation tool were developed to calculate the performance of PV systems with storage. Figure 20 show the self-consumption ratio of a family house (with oil central heating) consuming 5000 kWh/year as a function of the PV system size and storage capacity. If PV covers the yearly energy consumption, then the self-consumption ratio is ca. 30%, in average over the year. Self-consumption ratio is higher in winter (lower PV production) and lower in summer.

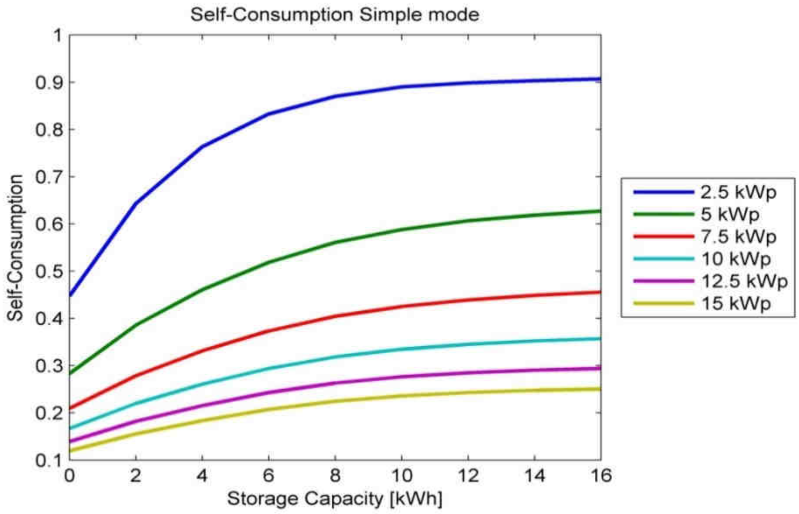

Figure 20 : self-consumption ratio of a family house (with oil central heating) consuming 5000 kWh/year as a function of the PV system size and storage capacity.

The aggregation of many loads smooth out the consumption peaks present in the load of an individual household increasing the self-consumption ratio. To evaluate this effect and the role of flexibilization on the self-consumption we calculated for years 2014 (a full year) the self-consumption ratio as a function of PV coverage for both the “Flexi group” and the “Control group”. PV production was simulated here from 2014 weather data (using Neuchâtel data, for a system with optimal orientation using PV Sunpower modules). Results are plotted in Figure 21. In this figure, the self-consumption value is also plotted for the “Control group” considering the implementation of storage capacity equivalent to 10% of the average daily consumption. If no feed outside the local grid is allowed, some energy produced from PV may be lost (excess PV production that cannot be consumed). In this case, the maximum PV coverage is then defined by the maximum allowed energy loss. In our present analysis, if we allow for 10% loss (i.e. a self-consumption value of 90%), PV coverage would be in the order of 23% without storage and 34% with storage (as seen in Figure 21).

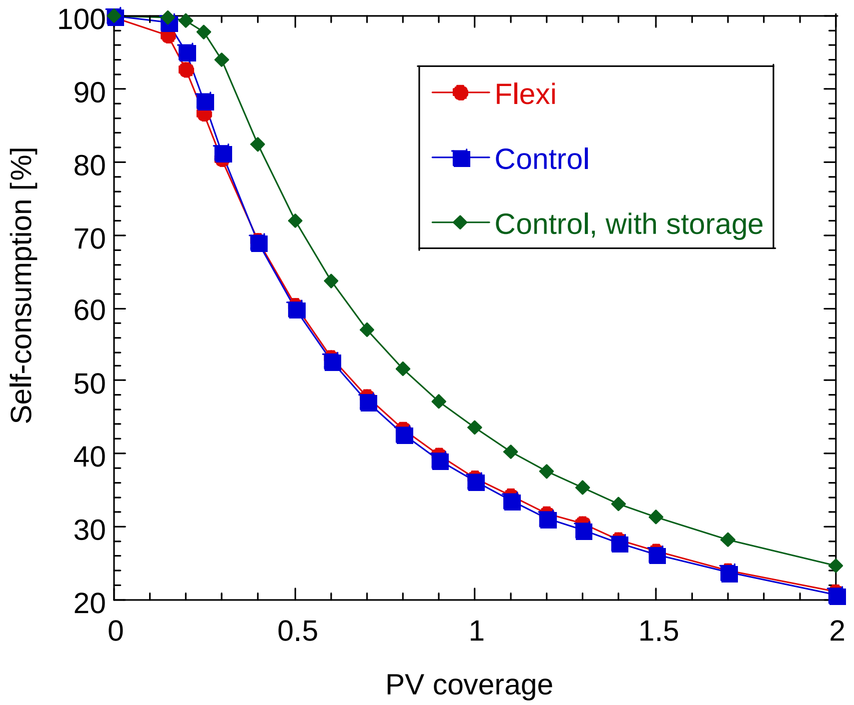

Figure 21 : self-consumption ratio (computed for 2014) for the aggregated loads of the “Flexi group”, “Control group” and “Control group” with an additional storage capacity equivalent of 10% of the average daily consumption.

Discussion / appraisal of the results / findings

Flexibilization potential

For the first technical study, the objective was just to evaluate the amount of electric consumption that could be shifted and potentially be synchronized with PV production. Even with the very basic definition of the PV production hours and metric used as a tool to promote shift of consumption and change of behavior, both technical studies shows that indeed a part of the consumption can be shifted and this shift would help increase PV coverage without detrimental effect on grid (i.e. excess PV production that cannot be consumed locally remains the same).

Change of habits to shift consumption is the least expensive measure, but the one that is probably difficult to maintain in the long term. We established that financial incentive seems (at least in this study) the only effective way to promote changes. Looking in more details, the analysis of Figure 22 demonstrates that only few households were able to change their behavior. Furthermore a certain minimum value of the total consumption seems to be needed to be able to change the consumption pattern. The shift observed in the total consumption of the “Flexi group” (see results on the flexibilization potential) is due to the change of behavior of a small number of households (approximately one third). It may also indicate (with this very small sample) that households with high consumption are less prone for a change. These observations were obtained on a small number of households and this should be validated on a larger sample. It would also be interesting to look at other potential incentives or financial schemes to trigger the shift. In this framework, owner of PV systems should probably be much more motivated to enhance their self-consumption and therefore to shift as much as possible their consumption.

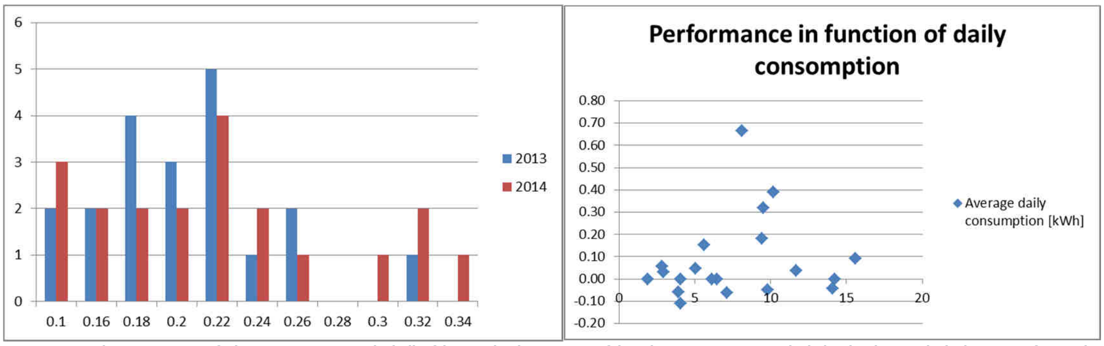

Figure 22 : Histogram of the PV potential (left) and change of in the PV potential (relative, right) as a function of the average daily consumption for the "Flexi group" of households.

We saw that from a 6-8% of the consumption (in average) that could theoretically be easily shifted, households of the "Flexi group" managed to shift 2% in average. Knowing that only a third of these households responded to the incentives, it means that these responding households managed to shift almost all they had to shift. Flexibilization of the consumption implies also to be at home during the day which is not true for many of them. Technical means are therefore also necessary to maximize shift. Programming of washing machines and dish washers are usually already available but are not yet designed in a way to consume electricity at a certain time, but just to finish the wash cycle for a given time. This could help clearly the behavior of household being out home during the day. Controlling freezers operation could also shift an additional 5% of the total consumption.

Those technical means should remain economical compared to the benefit. However, new appliance which allow to interact with a home energy system (to favor PV self-consumption) are already coming on the market, including dish-washers, washing machines and even freezers. Such modern appliances do not cost significantly more than a normal appliance and therefore the cost of flexibilization (with technical means) could be kept low.

In the future, with large penetration of HP for both heating and domestic hot water heating, an important share of the consumption could be attained equivalent to at least 10% of the household consumption.

PV coverage and self-consumption

The self-consumption of ca. 30% of Figure 20 (with a PV coverage of 1) is clearly enhanced by the aggregation of load curves. For the "Control group" (40 households) this self-consumption value increases to 36.2% and to 36.8% for the "Flexi group" (20 households with flexibilization). For all households considered in this study (ca. 100 households) the value is 36.7%. Considering that the various groups are statistically equivalent and have similar overall total consumption, both the effect of aggregation and flexibilization are observed. The "Flexi group" achieves a better self-consumption (for the same PV coverage), even with a small number of aggregated loads, than when aggregating all loads. For high PV penetration, flexibilization translates directly to an equivalent higher PV coverage with the same self-consumption.

As also observed for single households, storage capacity allows for important self-consumption gain or for higher PV coverage with the same self-consumption value. The storage capacity equivalent of 10% of the average daily consumption corresponds to the minimum consumption from a HP for domestic hot water heating. As the latter is fully flexible and can be considered as equivalent to storage[10], the computed values with storage in Figure 21 are representative of what we would be achievable in Cernier with households equipped with HP.

[10] Y. Riesen et al., Proc. of the 28th EU PVSEC, (2013) 3740.

Economic studies

Even though households have the ability to shift their electricity consumption, it is not obvious that they will actually do so. The technical part of the Flexi project examines the potential shift in energy consumption given the electric appliances owned by households. In the economic part of the project, we investigate whether households actually modify their electricity consumption when provided with incentives to do so.

In two different experiments, we “nudge” households to increase their share of electricity consumption during the solar energy production hours (i.e., from 11am to 3pm),[11] while avoiding increases in their total consumption. The first experiment focuses on the effect of information feedbacks; the second experiment implements monetary rewards. The results suggest that both treatments induce a reaction by households, even if the response is different depending on the treatment. More precisely, households exposed to information feedbacks do globally decrease their electricity consumption, regardless of the hours of the day considered. For these households, the share of consumption between 11am and 3pm does not change at all. Conversely, households exposed to monetary rewards display a significant shift of energy consumption towards the solar energy production hours, driven by a reduction in their total energy consumption. In fact, these households achieved an increase in their share of consumption between 11am and 3pm mostly by means of a decrease in consumption during the evening hours, coupled with a stable absolute consumption between 11am and 3 pm.

Research in economics displayed great interest in energy conservation in the last years. The growing concerns about environmental change, together with the decreasing reserves of fossil fuels raised the importance of renewable energy sources. There is a general agreement in identifying households as the engine behind development and one of the two major energy consumers.[12] This is the main reason why households have become the targets of different policy interventions intended to increase efficiency in the energy sector.

Electricity is a particular type of good because it is invisible and abstract. Consumers do not purchase electricity per se, but for the services (cooking, cleaning, lighting, etc.) it provides. Therefore, even though the price of a kWh might be known, it is not clear whether households are aware of the electricity cost of their actions in everyday activities. Moreover, the fact that households are billed for their electricity consumption infrequently (usually monthly or every two months) might make them insensitive to price changes. Stern and Aronson (1984) provide a humoristic illustration for this sole monthly electricity bill: in some way, it would be like shopping in a supermarket where prices are not indicated and shoppers only get the total amount they have to pay at check-out. The issue becomes of even more relevance when bills are based on consumption estimations and are thus kept constant throughout a year. A household changing its electricity consumption habits will only see a change in its bill months later.

From a general point of view, policy makers may follow two channels to support sustainable energy consumption: financial incentives and feedback information (see e.g., Groothuis and Mohr, 2013). Monetary rewards are effective if people take prices into consideration when making choices, as documented by Abrahamse et al. (2005). Such policies induce a significant reduction of consumption in the short run. However, the size of the effect depends on the amount of the rewards.[13] The long run effects remain unclear because households are usually tracked over a short period of time. In fact, evidence suggests that the effect might vanish over time (see e.g., McClelland and Cook 1980 and Allcott and Rogers 2014).

Darby (2006) finds that feedback information may reduce energy consumption up to 20%. Nonetheless, the type of information that should be released to households is still a crucial issue in the intervention’s design. Fischer (2008) and Bernstein and Collins (2014) suggest that the effectiveness of feedbacks depends on frequency and duration of information delivery, clarity of presentation, provision of normative comparisons and customized information, and supplying breakdowns of electricity use by appliance.

[11] Obviously, solar energy can be produced whenever there is sun and this period varies from day to day. The most intensive solar energy production however falls in the hours between 11am and 3pm. For simplicity (both for management of the project and for households), we define this daily slot as the solar energy production hours.

[12] According to FSO (2014), transportation is the most energy-intensive sector and accounts for 35.4% of the final energy consumption in Switzerland. Households constitute the second most important sector and are responsible for 28.4% of the final energy consumption.

[13] See for instance Hayes and Cone (1977) and Winett et al. (1978).

Smart meters combined with in-home displays can provide households with real-time information on their electricity consumption. Households involved in programs relying on smart meters obtain significant decreases in energy consumption as documented by Kahn and Wolak (2013). Not so long ago, the main drawback of smart meters was their cost (Darby, 1993). However, as noted by Jessoe and Rapson (2014), thanks to the ever-decreasing cost of information technology, the monetary cost of smart meter does no longer represent an issue. According to Baeriswyl et al. (2012), smart meters cost less than CHF 200 per device. Even though their installation costs are a bit higher than mechanical meters and their lifetime a bit shorter, they calculate that a general rollout of smart meters in Switzerland would only generate few costs, thanks to the electricity savings they would allow.

Personalized information is inexpensive to provide and it appeals to the households' conscience, either by pushing towards a more efficient behavior in terms of energy consumption, or to a more competitive one by comparing the households' behavior among neighbors, or both. Some studies[14] suggest that people like to be "seen" as green instead of greedy, so that having frequent feedback on their behavior might bring large gains in terms of energy savings. As documented by Arvola et al. (1993), Nielsen (1993) and Wilhite and Ling (1995), feedback has an important effect on people awareness of their consumption. However, people tend to underestimate the energy use and potential savings they can make by just changing some behaviors as shown by Attari et al. (2010). According to Chen et al. (2010), one of the drawbacks of this type of interventions is that people receive information about their behavior, but not ideas on how to improve it.

The economic study of the Flexi project is closely related to a growing literature that focuses on managing electricity demand.[15] Our contribution is in line with several recent studies in the literature, in which high-frequency meter data are used to investigate households' reactions to different treatments. Degen et al. (2013) and Degen (2014) base their analyses on the results of an experiment conducted in the city of Zurich and that was designed to evaluate the electricity saving potentials of different types of information. Among the participating households, more than 1,000 were equipped with smart meters and in-home-displays. Real-time feedback induced households to reduce electricity consumption on average by 3 to 5%. Di Cosmo et al. (2014) analyze the impact of a large-scale randomized controlled trial where over 5,000 Irish households were exposed to a variety of time-of-use tariffs and information stimuli. They find that these measures have significant effects in reducing electricity consumption, particularly during peak hours. Jessoe and Rapson (2014) test the effects of real-time information about electricity use on the price elasticity of demand, studying the behavior of households provided with an in-home-display. Their results show that information feedbacks significantly increase the price elasticity of demand. Ito et al. (2015) analyze a randomized experiment in which they assess the impact of moral suasion (intrinsic motivation) and economic incentives (extrinsic motivation) on households' reduction of energy consumption. In their results, moral suasion leads to a usage reduction of about 8 percent. However, this effect is only observed in the short-run and vanishes over time. In contrast, households exposed to economic incentives display a persistent reduction of about 14 percent.

The goal of the abovementioned papers and that generally pursued by researchers and policy makers is to decrease electricity consumption. In contrast, in this paper, we induce households to shift their consumption across day hours, without requiring any decrease in total consumption. The ultimate objective is to align solar energy production with electricity consumption. Solar energy is produced during daylight hours. Households, however, consume electricity mostly in the evening. This mismatch constitutes an impediment for the large-scale usage of solar energy and might thus be an issue for the energy transition that will cause Switzerland to rely more on renewable energies. Despite the importance of this topic, we are not aware of any study having conducted experiments with a similar goal.

[14] See for instance Steg and Vlek (2009) and Dolan and Metcalfe (2013).

[15] The special report on Energy and Technology by the Economist (2015) shows that the new business models focus on the demand side of the electricity market.

Objectives

The economic study assesses the impacts of two experiments (information feedback and monetary grants) on households' behavior. The interventions are designed so as to "nudge" households in shifting their electricity consumption towards the solar energy production hours, without increasing (nor necessarily decreasing) their total consumption.

Experiment 1

The first experiment deals with the effects of information feedbacks. Households are frequently provided with paper letters, which can be seen as detailed bills. The letters include personalized information about the household's consumption (current consumption and its evolution) and the household's consumption pattern. In order to generate competition among households, consumption information relating to comparable households is also included. During the first month of the experiment (January 2014), households received a letter every week. From the second month, households received one letter per month.

Experiment 2

The second experiment implements a competition where households can earn monetary prizes. The ranking is based on the share of consumption during the solar energy production hours (11am-3pm) and its evolution, controlling for total consumption. Monetary prizes are awarded to the 15 top-ranked households (out of 22) on a monthly basis.

Methodology

The Design

The timing of the activities undertaken during the project is described in Figure 23, from its beginning to its end. The project started with a pre-program evaluation where the participating households received an invitation letter, which, besides information about the program's structure and goals, asked them to fill an online survey.[16] Each household was provided with a unique code to access the online survey. To foster participation, the invitation letter mentioned that one person chosen at random among the respondents would be awarded CHF 200 in cash.[17]

The survey consisted of about 60 questions related to households' characteristics (family size, education, income, etc.), family's routine (days people eat at home, number of working days, days when family does laundry, etc.), apartment features (size, number of rooms, type of heating system, electrical devices, etc.), and the respondent's environmental concerns (preferences for appliances that save energy, use of led bulbs, interest in environmental topics, etc.).[18]

Based on Groupe E's customer data,[19] 387 households were contacted on April 25, 2013. By May 16, 52 had answered the survey. In order to increase the sample size, a reminder letter was sent to the households who had not answered the survey.

[16] Households without internet access were asked to contact us in order to receive a printed version of the survey.

[17] The winner of the CHF 200 award has been selected among households who completed the survey by May 16, 2013.

[18] A complete version of the survey (in French) is reported in the Appendix.

[19] From the original dataset provided by Groupe E, we dropped households not living in Cernier, as well as public buildings, shops, and businesses.

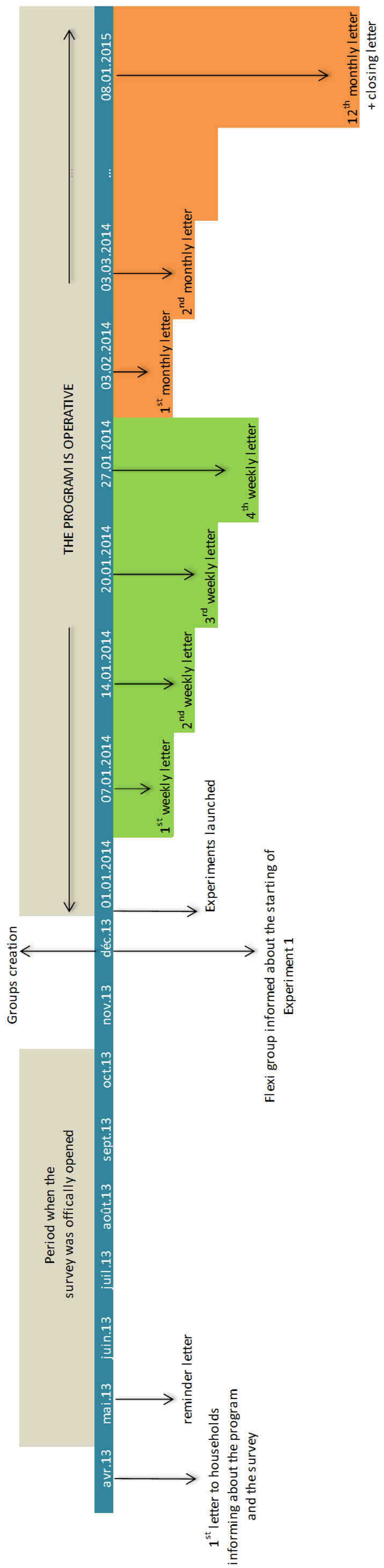

Figure 23 : Timeline of the project

By December 17, 2013, 131 households had completed the survey. Among the respondents, households facing a non-uniform pricing scheme in their electricity bill were discarded.[20] This cleaning process left 105 households eligible to participate in our experiments. This corresponds to a final response rate of more than 27%, a very high figure for this type of project. In comparison, Ito et al. (2015) obtained a response rate (after cleaning the data) of about 1.7%. In Degen et al. (2013) the overall response rate is 8.73%. While Jessoe and Rapson (2014) sent 60,000 e-mails, they used in their analysis only 437 of them (0.73%). Because of potential self-selection, it is important to consider the external validity of the experiments, although internal validity is guaranteed by random assignment to treatment and control groups. Our response rate being relatively large, we argue that this issue is less critical in our experiment than in most of the literature.

It is important to mention that two projects are already ongoing in Cernier since 2011.[21] Among the respondents to our survey, there are households involved in these projects. Therefore, at the moment of the creation of the treatment and control groups for the experiments of the Flexi project, they have been considered with caution because their behavior in terms of electricity consumption could have been already affected. Nevertheless, not every household participating in *Solution* and *Smart Solution* are aware of their participation (the so-called "passive" households), which make them comparable to untreated households. The status of the households in our final sample is detailed in Table 2.

Participation in:	# Households
No project	23 (+1)
Solution:	
Active	12
Passive	23 (+1)
Visited	9
Smart Solution:	
Active	20
Passive	18
Total	105 (+2)

Table 2 : Households status at the time of the group creation

Note: the numbers in parentheses indicate households who completed the survey after the stratification was already done.

Households labelled as "active" or "visited" have received different treatments in the context of *Solution* and *Smart Solution*. The "active" households have access to an online platform administered by Groupe E, in which they can obtain real-time data about their electricity consumption. The "visited" households received the advice of a specialist (who came to their home) about ways to reduce their electricity consumption. Hence, under the effect of these treatments, these households may already have changed their behavior. Including them in our experiments will make it difficult to disentangle the effects of former treatments from those tested in Flexi. As a consequence, we handle the "active" and "visited" apart from the other households.

The households labelled as "passive" are free from any previous treatment. Even though their dwelling

[20] Households with a double tariff pay less for a kWh during the night than during the day. Such households can obviously not be included in an experiment where the objective is to shift consumption toward the daily hours, as this could inflate their electricity bill.

[21]The project SOLUTION aims to demonstrate that the use of available local resources can achieve energy independence in the area of buildings for thermal energy and electricity needs. http://www.solution-concerto.org

The Smart Solution project aims to identify the most effective ways to reduce electricity consumption of households. The measures analyzed are based on the large-scale application of smart meters. Activities include analysis components, testing and deployment. http://www.bfe.admin.ch/prokilowatt/04370/06031/index.html?lang=fr (see: Deuxièmes appels d'offres publics pour l'efficacité électrique 2011 – Descriptif des programmes acceptés 2011)

was equipped with a smart-meter before the Flexi project was launched, they did not receive any additional information. Hence, they are comparable to households that have not previously participated in any project. Households in the "no project" (23+1) and "passive" categories (18) can be freely used in any experiment. On the contrary, the 41 households in the different "active" and "visited" categories can only be employed under certain conditions. More precisely, we include these households in the information feedback experiment, as this does not impact other households. However, it was not possible to include them in the monetary incentives experiment: the surplus of information available to them would make the competition with other households unfair.
To generate the treatments and control groups, we ran a stratification process. More precisely, the stratification mechanism consists in separating the households into groups that appear as similar as possible in terms of selected characteristics. Specifically, we focus on pre-intervention electricity consumption per person, dwelling size, and highest education level achieved by a member of the household. In order to avoid mixing different types of households, we ran two separate stratifications. In the first one, we split the 64 households in the "no project" and "passive" categories into three groups: Control 1, Facture 1, and Flexi. In the second stratification, we divided the 41 households into two groups: Control 2 and Facture 2.

Group	Used as	Contains HH	# HH
Control 1	Control for experiments 1 and 2	No project / Passive	22 (+2-1)
Facture 1	Treatment in experiment 2	No project / Passive	20 (-1)
Flexi	Treatment in experiment 1	No project / Passive	22
Control 2	Control for experiment 2	Active / Visited	20 (-1)
Facture 2	Treatment in experiment 2	Active / Visited	21 (-1)

Table 3 : Groups composition

Note: the numbers in parentheses indicate late respondents (who answered the survey after the stratification) and were included in the control groups (+) or movers who quit the experiment at some point during its progress (-).

Experiments details

Experiment 1

Households are provided with information feedback on their electricity consumption and on their similar households' electricity consumption.[22] The goal of the experiment is to influence the daily pattern of electricity consumption by providing households with detailed information that, in our intention, should encourage them to increase the share of electricity consumption between 11am and 3pm, without increasing total consumption.
More precisely, the monthly letters[23] sent to the 41 households belonging to the Facture groups report information about:

1. The household's electricity consumption in the last three months, along with the average consumption of similar households.
2. The household's average hourly consumption, highlighting consumption between 11am and 3pm.
3. The proportion of consumption between 11am and 3pm and its evolution over the last three months. For the last month, the proportion for similar households is also provided as a benchmark.

To facilitate understanding, the letters include a didactical interpretation of the household's consumption under the form of smileys. Green smileys are printed to signal a "good behavior", yellow neutranies

[22] The similar households are those included in Control 1 with a comparable number of people (1, 2, or 3+).

[23] An anonymized sample letter can be found in the Appendix. During the first month of the experiment, letters were sent every week in order to draw households' attention on the experiment and ensure that the letters would not go unnoticed.

represent a “neutral behavior”, and red frownies represent a “bad behavior”. The number of smileys/frownies varies with distance to the previous and average proportion.[24] Every month, a tip allowing for increasing the proportion of consumption between 11am and 3pm is given.

Experiment 2

Every month, the 22 households included in the Flexi group are ranked on the basis of their electricity consumption behavior and its change. Precisely, the following criteria are used:

1. Household i is included in the classification in month t only if the change in its electricity consumption with respect to that in previous month does not exceed the average consumption change of all households in the Flexi group by more than 10 percentage points[25] :

$$\frac{\Delta C_{i,t}}{C_{i,t-1}} \leq \frac{\Delta C_{average,t}}{C_{average,t-1}} + 0.10$$

   This criterion is intended to exclude households who would increase their proportion of consumption between 11am and 3pm simply by consuming (much) more electricity during these hours without decreasing their consumption in other periods of the day.[26] We tolerate a 10 percentage points deviation to account for relatively small variations due for instance to holiday periods.

2. For households satisfying the first criterion, we compute the share of electricity consumption between 11am to 3pm with respect to their total consumption. A higher proportion implies a better position:

$$proportion_{i,t} = \frac{C_{11-15,i,t}}{C_{total,i,t}} \rightarrow Classification\ R_1$$

3. For the same households, we compute the change in their own proportion with respect to the last period:

$$\Delta proportion_{i,t} = proportion_{i,t} - proportion_{i,t-1} \ \rightarrow Classification\ R_2$$

4. The final ranking is calculated by using a weighted average between R1 and R2 classifications:

$$Final\ ranking: 0.25 * R_1 + 0.75 * R_2$$

The monetary grants are distributed to the first 15 households, as detailed in Table 4.

Position	Prize (CHF)
1–5	50
5–10	30
11–15	10

Table 4 : Prizes

[24] Appendix 4 Table provides detailed information about the thresholds defining the number of smileys/frownies shown.

[25] More precisely, we use a trimmed mean to compute the average change by removing the 2 households with the largest and smallest (most negative) variations of consumption. The average is thus computed on 18 households.

[26] Note that a simpler criterion that would exclude all households who increase their consumption above some threshold cannot be implemented due to seasonality. Electricity consumption is higher in winter than in summer, and it gradually increases from July to December (see Figure 24). This is the reason why we use a relative benchmark.

On January 1, 2014, a letter about the program's launch was sent to the participating households. It briefly described the project by mentioning the starting date; the rules for ranking the monthly classification, and the fact that the monetary prizes were function of the positions in the ranking.
Starting in February 2014, each household in the group received a personalized letter indicating their monthly position. If a household was included among the top 15, it also received the monetary prize (inserted in cash in the letter). In addition, the letter enclosed a link to the website www.unine.ch\flex-irank. On this website, households had the opportunity to check the entire ranking, as well as the information of the other participant households. Households were identified by a code provided in the letters (i.e., they could only identify themselves).[27]

Descriptive Statistics

Data

Groupe E provided households' electricity consumption. For each household, consumption is available in 15-minute intervals. Because this study focuses on the share of electricity consumed between 11am and 3pm, we aggregate data on a daily basis.
We completely discard data from September 2013 because several smart meters have been installed in October 2013. In addition, in order to improve identification of the treatment effects, we exclude from the sample January 2014 data, due to several events occurred during this period, which could interfere with the experiences.[28] The final dataset contains almost 45,000 observations: 106 households observed over 11 months, 426 days.
As already discussed above, households characteristics have been obtain by the mean of an online survey.
Weather information (temperature, rain precipitation, sunny hours) has been obtained from MeteoSwiss. The data are reported at the hour or day level and refer to Chaumont station. It is only 6 km away from Cernier, exactly at the same elevation. Therefore, this information is certainly a good proxy for weather conditions in Cernier. Finally, we obtained the information about holidays' periods from the official scholar calendar of the Canton of Neuchatel,[29] and from the official holidays' calendar of the Canton of Neuchâtel.[30]

Average differences

We allocated the households to treatment and control groups through a stratification procedure, in order to ensure that the characteristics of the groups are similar (i.e., on average the groups are comparable to each other). Table 5 reports the average comparisons of the variables of interest between each treatment group and its corresponding control group. In all cases, the results show no significant differences among groups, not only for the variables used in the stratification process, but also for households' characteristics such as the number of people living in the households, environmental feelings, and energy saving feelings. This indicates that the stratification procedure was successful.

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[27] The website can be accessed by the administrator password "FlexiAdmin". An anonymized sample letter can be found in Appendix.

[28] In December 2014, Flexi group households received a letter announcing the beginning of the competition on January 1, 2014. However, release of the first monthly ranking only took place at the beginning of February 2014. Moreover, households in the Facture groups received information on their electricity performance on a weekly basis in January 2014.

[29] http://www.ne.ch/themes/enseignement-formation/Pages/calendrier-scolaire.aspx

[30] http://www.ne.ch/themes/travail/Pages/jours-feries.aspx

Variable	Groups	Control	Treated	Δ	t-stat	p-value
Total consumption	Control 1 vs Facture 1	232.33	277.5	-45.17	-0.82	0.42
	Control 1 vs Flexi	232.33	226.36	5.97	0.15	0.88
	Control 2 vs Facture 2	275.02	272.38	2.64	0.07	0.95
Monthly consumption (p.c.)	Control 1 vs Facture 1	100.74	110.85	-10.11	-0.54	0.59
	Control 1 vs Flexi	100.74	96.98	3.76	0.27	0.79
	Control 2 vs Facture 2	109.31	108.92	0.39	0.03	0.98
Monthly consumption (p.c.) classes	Control 1 vs Facture 1	0.91	1.09	-0.18	-0.74	0.46
	Control 1 vs Flexi	0.91	1	-0.09	-0.36	0.72
	Control 2 vs Facture 2	0.95	1.05	-0.1	-0.38	0.7
Square meters > 100	Control 1 vs Facture 1	0.55	0.5	0.05	0.3	0.77
	Control 1 vs Flexi	0.55	0.55	0	0	1
	Control 2 vs Facture 2	0.84	0.8	0.04	0.33	0.74
Number of people in HH	Control 1 vs Facture 1	2.64	2.68	-0.04	-0.1	0.92
	Control 1 vs Flexi	2.64	2.36	0.28	0.63	0.53
	Control 2 vs Facture 2	2.68	2.75	-0.07	-0.17	0.86
Education level	Control 1 vs Facture 1	1.86	1.86	0	0	1
	Control 1 vs Flexi	1.86	1.91	-0.05	-0.17	0.87
	Control 2 vs Facture 2	2.26	1.95	0.31	1.04	0.3
Environment feelings	Control 1 vs Facture 1	3.62	4.05	-0.43	-1.69	0.1
	Control 1 vs Flexi	3.62	3.59	0.03	0.09	0.93
	Control 2 vs Facture 2	4.21	4.05	0.16	0.65	0.52
Energy saving feelings	Control 1 vs Facture 1	3.82	4	-0.18	-0.55	0.59
	Control 1 vs Flexi	3.82	3.73	0.09	0.3	0.77
	Control 2 vs Facture 2	3.95	4.05	-0.1	-0.37	0.71

Table 5 : Descriptive statistics, by group

Note*: For each group pair, the average values, the difference in the average values, the corresponding t-statistics and p-values are reported. Consumption variables refer to the period 01.09.2013-30.11.2013, i.e., the period on which the stratification was conducted.*

Descriptive Evidence

Figure 24 illustrates the monthly average electricity consumption by group. Figure 25 is equivalent, but shows consumption per person in the household, ratio that was used in the randomization. Globally, these Figures reveal the seasonality patterns of electricity consumption.[31] Average annual consumption is close to 2,900 kWh per household in the sample. This value is slightly larger than the figures reported by Degen et al. (2013) for their sample (2,300 kWh) and the city of Zurich (2,600 kWh). However, this only represents around one fourth of the electricity consumption by an average US household, which is larger than 11,000 kWh (see Allcott and Rogers, 2014).

Figure 24 (panel A) shows the monthly average consumption for the treatment groups Facture 1 and Flexi and their control group (long dash, small dash and solid lines respectively). The vertical line in January 2014 indicates the periods before and after the launch of the experiments. Before the beginning of the program, the average consumption of group Facture 1 lies above the average consumption levels of the two other groups.[32] In contrast, since the beginning of the experiment, we observe a decrease in average consumption relatively to the control group, so that during the experiments the series come closer. This pattern is even more apparent in panel A of Figure 25, in which the evolution over time of the average consumption per person is documented.

The situation is different in panel B of Figure 24, in which we compare treatment group Facture 2 and its control group. The patterns clearly show that the two curves do not diverge after the beginning of the program.

[31] Electricity consumption seasonality is related to weather conditions. In particular, when weather is warmer and sunnier, people tend to stay more outside, to eat lighter and colder, to use less artificial lighting, and to wear lighter clothes. These behaviors lead to lower electricity consumption in the period of the year when weather conditions are mild/temperate.

[32] Even though average consumption seems largely different between groups Facture 1 and Control 1 before the start of the experiment, the difference is not significant as documented in Table 5.

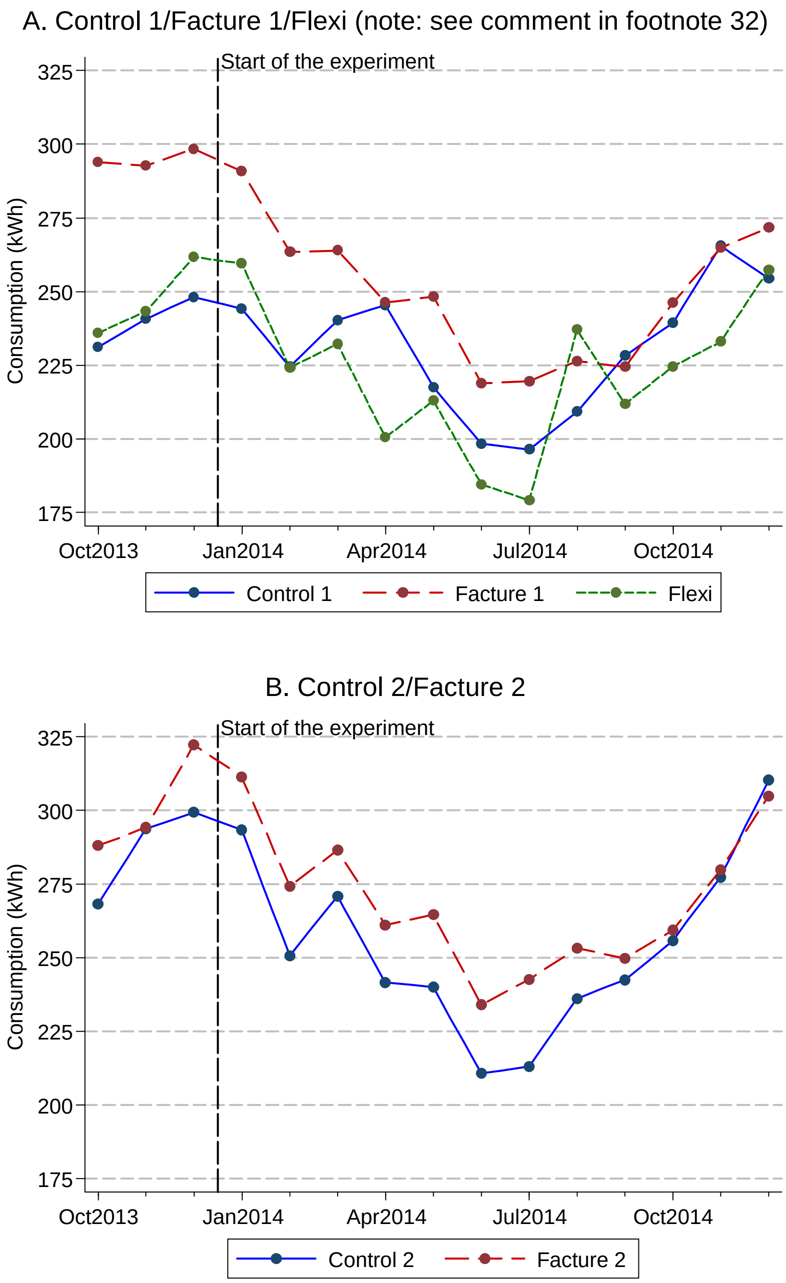


Figure 24 : Average consumption

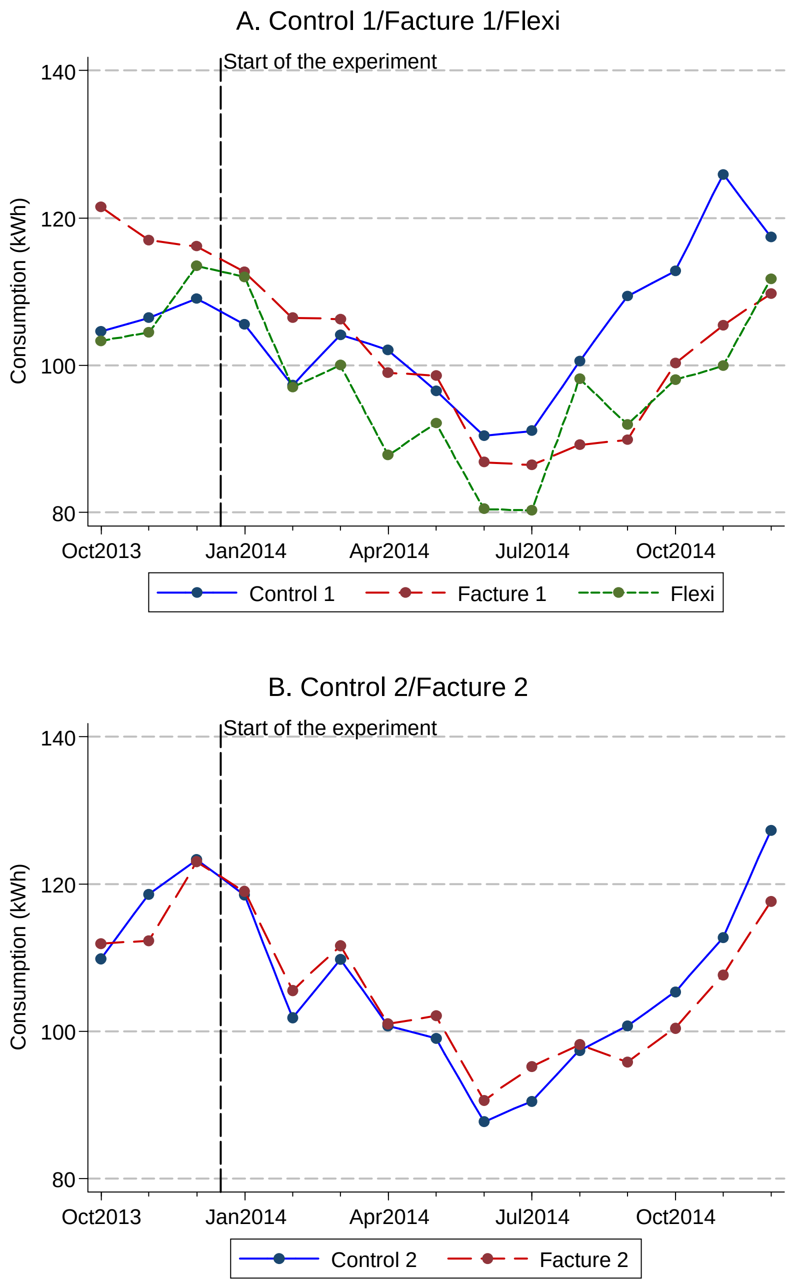


Figure 25 : Average consumption per person

Figure 26 displays the proportion of electricity consumption between 11am and 3pm for each group. From panel A, we observe that for the treated groups (Facture 1 and Flexi), there is an increase in the proportion once the experiment starts, while the control group displays smaller variation over time. Moreover, for both treated groups, the maximum proportion is reached after four and six months respectively, then it decreases eventually returning to the initial level prior the beginning of the experiment.

We observe that households in group Flexi performed particularly well (i.e., maximized their proportion of electricity consumption between 11am and 3pm) from April and August. Two alternative (but not necessarily exclusive) explanations might underlie this outcome. The first explanation is linked to the timing of the experiment: after its start in January, households have gradually changed their habits, which allowed them to improve their performance in the first months of the experiment. In this context, the reversal after July may be explained by some weariness related to the duration of the experiment. The second explanation is related to seasonal effects. The months between April and August are likely to be those when the weather is the most temperate of the year. In that period, people have the possibility to stay longer outside, to eat lighter and colder, and to use less artificial lighting. These behaviors may lead to a decrease in electricity consumption. This is especially true during the evening hours, and

this pattern appears more strongly for the Flexi group households. One may infer from these observations that increasing the proportion of consumption between 11am and 3pm might be easier in that period of the year.
Because our experiment lasted 12 months (January-December 2014), we have no way to assert which of these two explanations is correct. In order to test for this, one should either conduct a similar experiment over at least two complete years, or repeat the same experiment but starting at a different period of the year to identify if the pattern is aligned with calendar year or with experiment duration.
Figure 26 (panel B) shows the average proportion of consumption during the solar energy production hours for the groups Facture 2 and Control 2. In this case, the evidence in favour of the treatment is weaker: the proportion reaches its maximum after eight months, and then suddenly decreases.

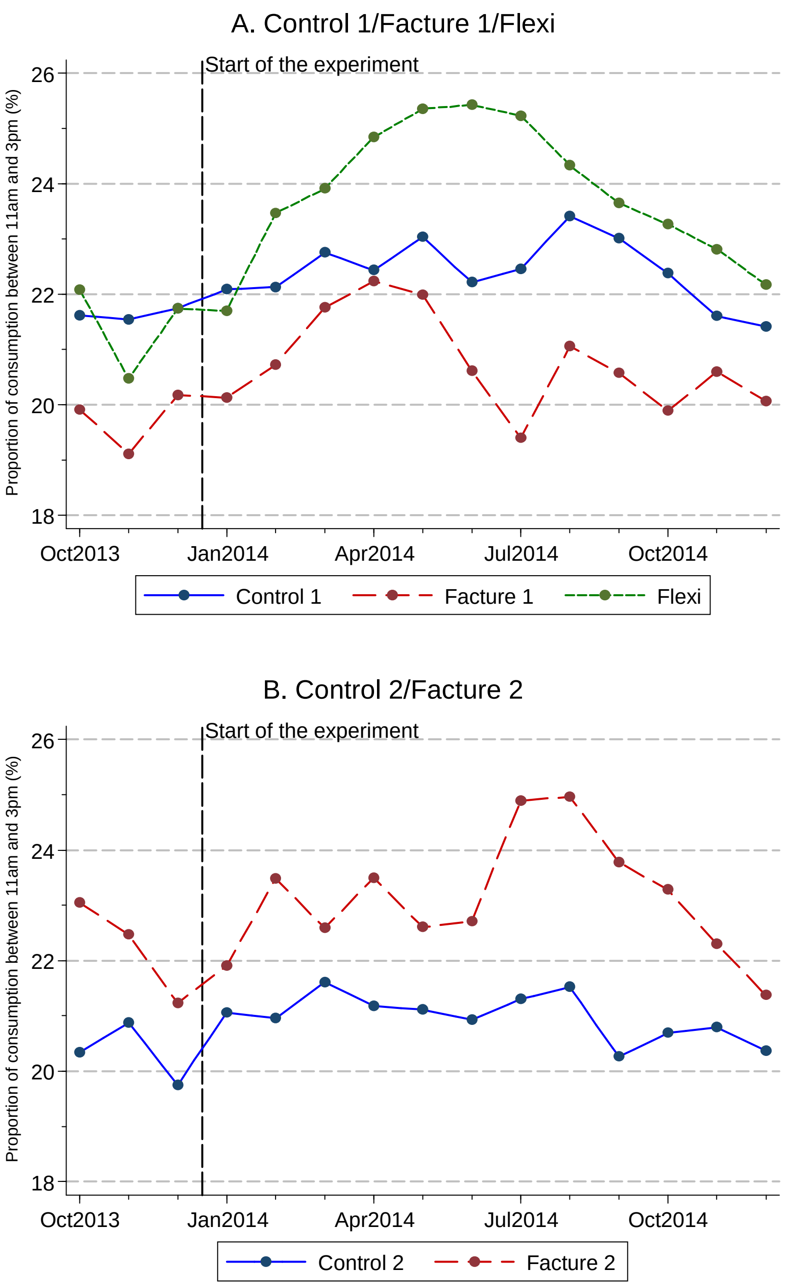
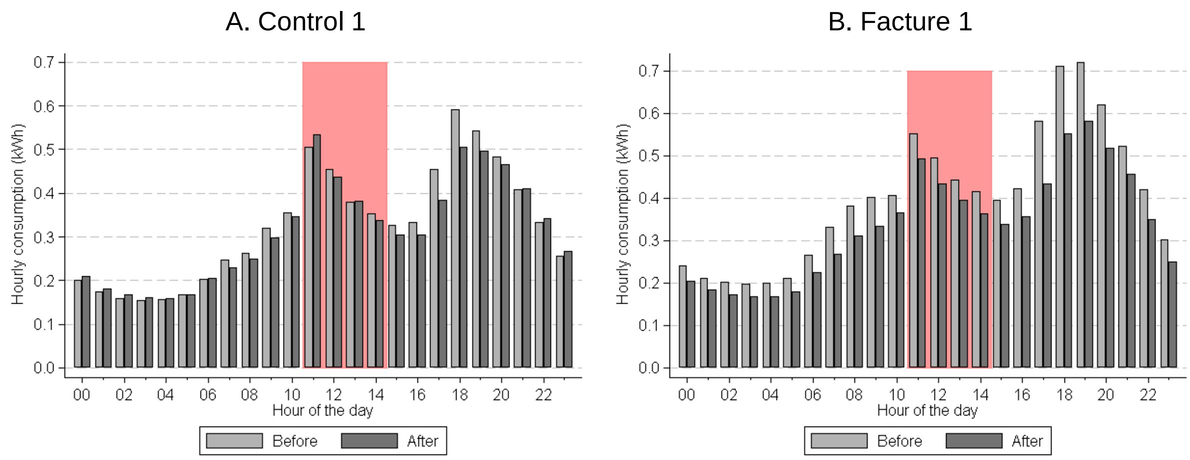


Figure 26 : Proportion of consumption between 11am and 3pm

By increasing the frequency of the data, and working at hour level, we can assess which strategy has been adopted by different groups of households to achieve an increase in the proportion of consumption between 11am and 3pm. To reach this goal, households could (i) increase their consumption in these hours, (ii) decrease their consumption outside this period of the day, or (iii) (ideally) do both, i.e., actually shift their consumption towards the solar energy production hours.[33] Still, ex ante, we had no means to ascertain that the households would correctly interpret the letters.

Figure 27 shows the average consumption profile by hour of the day for each group, separating data before (light bars) and after (dark bars) the start of the experiment. If the treatments were effective, we should observe an increase in the consumption between 11am and 3pm (highlighted by the shaded area) for the treatment groups and/or a decrease of consumption in the hours outside this period. Interestingly, we observe only minor changes for Control 1 (panel A). Consumption increased in some hours and decreased for some others, with no obvious pattern. For Facture 1 (panel B), we observe a global decrease: in every hour, consumption is lower after the start of the experiment. This might indicate that our monthly letters were not interpreted exactly as we intended. What households might have understood from receiving frequent letters is that they should decrease electricity consumption, which is the usual message transmitted by actors of the energy sector.[34] For households in Flexi (panel C), we do observe clear decreases of consumption in the morning and (mostly) evening hours, while consumption in 11am-3pm remained relatively constant. These households thus succeeded in increasing the proportion of consumption in the solar energy production hours. The econometric analysis will provide formal evidence of these observations. Looking at the consumption patterns of Control 2 and Facture 2 (Figure 27, panels D and E), we see that consumption decreased for both groups in every hour. Our fears concerning the alternative projects ongoing on these household might thus well be grounded: the objective of *Solution* and *Smart Solution* was to decrease electricity consumption, and this is what we observe, even for Control 2, which did not receive any treatment in our project.



[33] In the monthly letters sent to the treated household, we tried to avoid solution (i) by highlighting that increases in consumption were to avoid as much as possible. At the same time, tips were provided so as to shift consumption (for example: program the dish washer so that it starts at 11am) or sometimes to decrease electricity consumption outside of the period 11am-3pm (for example: unplug your TV box during the night instead of leaving it on standby).

[34] Some anecdotal evidence also goes in that direction: over the course of the experiment, we received several e-mails from households who wished to be removed because they considered our letters as too general and not useful for *decreasing* electricity consumption.

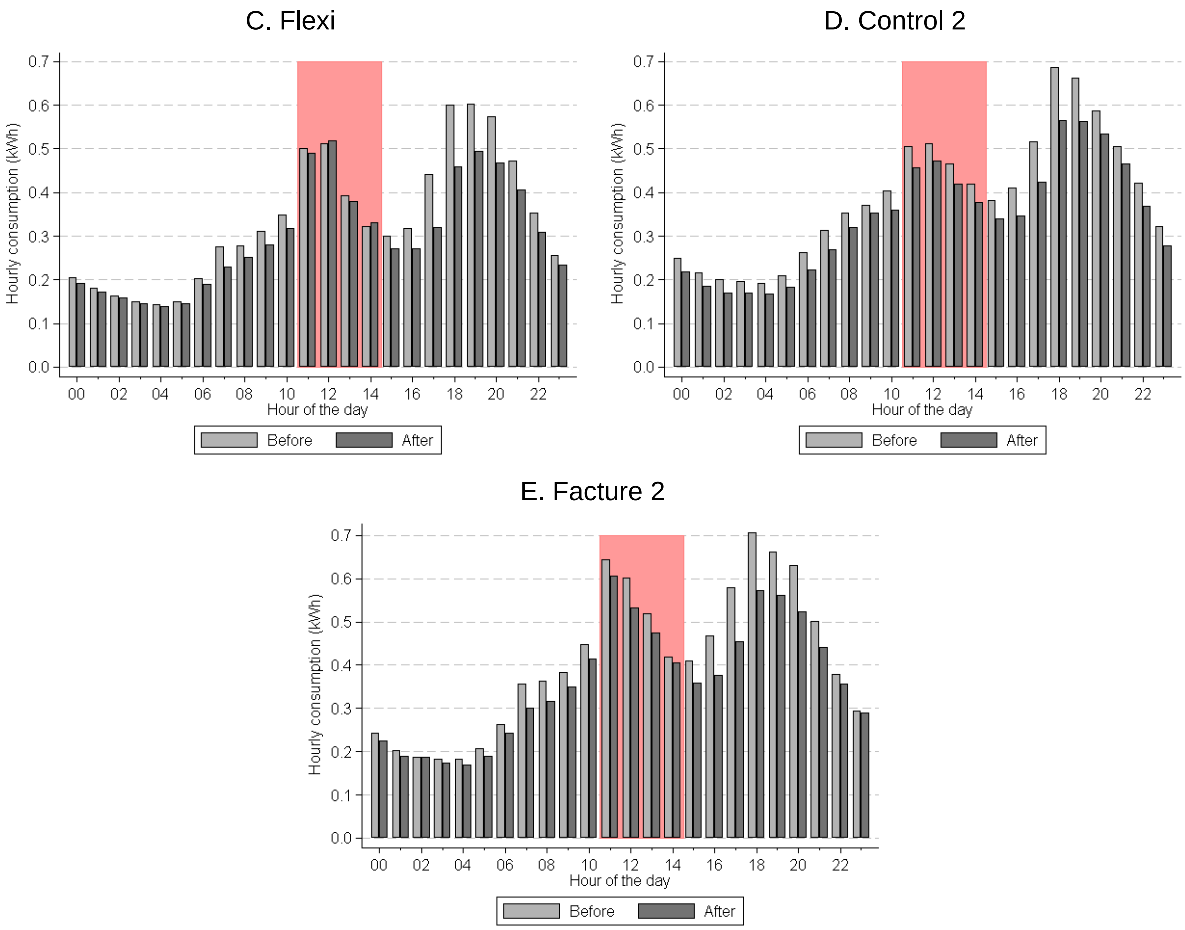


Figure 27 : Consumption daily profile (Before = Oct2013-Dec2013, After = Feb2014-Dec2014)

Econometric strategy

In order to assess the impact of the information feedback and monetary incentive on households' electricity consumption, we estimate the following specification:

$$Y_{it} = \alpha + \beta_1 D_t + \beta_2 T_{1i} + \beta_3 T_{2i} + \beta_4 (T_{1i} * D_t) + \beta_5 (T_{2i} * D_t) + \sum_{k=1}^{K} \gamma_k X_{kit} + \varepsilon_{i,t} \quad (1)$$

Y_{it} is the household's proportion of electricity consumed between 11am and 3pm, of household *i* at period *t*.[35] D_t is a dummy variable controlling for the before/after period of the intervention.[36] T_{1i} and T_{2i} indicate whether household *i* participates in experiment 1 or experiment 2. Vector $\sum_{k=1}^{K} \gamma_k X_k$ includes households' characteristics, flat characteristics, weather conditions, and holidays. More precisely, we control for education level, age of the respondent, number of people in the households, presence of solar panel in the house, usage of ecological bulbs, weather conditions, holiday periods, and weekend days.[37] We also include month (from October 2013 to December 2014) and week (we include the 52 weeks of the year) dummy variables.

[35] The unit of time in the baseline regressions is the day. As robustness checks, we ran estimations using hourly data and the main findings (not reported) are similar. Theoretically, the best strategy would be to exploit data at the 15-minute interval as in Jessoe and Rapson (2014) study on U.S. data. However, consumption being much lower in our sample of Swiss households, zeros are very common in 15-minute interval data, implying a dependent variable very asymmetric and that we cannot transform using logarithms.

[36] In our baseline estimations, the before period is defined as the period from October to December 2013, while the after period includes observations from February to December 2014. To check our result in the robustness part, we use alternative definitions to define the after period (see Figure 29).

[37] In Appendix 3, we report the precise definition of the variables included in the estimations and we provide descriptive statistics.

Since Y_{it} is a proportion (consumption 11-15 / total consumption), the interpretation of the coefficients can be done in percentage points. The average treatment effect (ATE) is calculated by difference-in-difference estimation, where the coefficients of interest are given by β_4 (or β_5) as documented in Table 6.

	Treated	Not Treated	Difference
After	$\alpha + \beta_1 + \beta_2 + \beta_3 + \beta_4$	$\alpha + \beta_1$	$\beta_2 + \beta_3 + \beta_4$
Before	$\alpha + \beta_2 + \beta_3$	α	$\beta_2 + \beta_3$
Difference	$\beta_1 + \beta_4$	β_1	β_4

Table 6: Interpretation of the coefficients of the difference-in-difference estimation
Note: these effects concern treatment T_1

Table 7 reports the results for groups Control 1, Facture 1, and Flexi. We estimate several versions of eq. (1) by OLS, with robust standard errors clustered at household level. The columns differ in the number of controls included in the estimation. Column (1) reports the basic difference in difference regression by only including the treatment condition of the households. Each subsequent column includes additional blocks of covariates (household characteristics (2), environmental attitudes (3), weather conditions (4), holidays and weekends (5)).

The coefficients indicating the effects of the two experiments (*Facture* × *After* and *Flexi* × *After*) display a positive sign. This implies that being part of the treatment leads to an increase in the proportion of the electricity consumed between 11am and 3pm. However, the magnitude of the coefficients is considerably different. For the information feedback experiment, the impact is negligible (0.1 percentage point) and insignificant. In contrast, the effect of the monetary incentives is larger (2.9 percentage point increase) and close to significant at the 10% level. Households participating to this experiment have thus increased their share of consumption between 11am and 3pm from 20% to around 23%, everything else being constant. The estimates are very stable across all the specifications.[38]

[38] The impact of the additional covariates are discussed later, based on the results of Table 12.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	0.202***	0.137***	0.137***	0.137***	0.137***	0.135***	0.137***
	(0.009)	(0.011)	(0.011)	(0.011)	(0.011)	(0.012)	(0.014)
After	0.008*	0.007	0.007	0.006	0.006	0.002	0.001
	(0.005)	(0.005)	(0.005)	(0.004)	(0.004)	(0.005)	(0.005)
Facture	-0.019	-0.016	-0.013	-0.013	-0.013	-0.013	-0.013
	(0.012)	(0.012)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Facture X After	0.000	0.001	0.001	0.001	0.001	0.001	0.001
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Flexi	-0.000	-0.007	-0.007	-0.007	-0.007	-0.007	-0.007
	(0.014)	(0.012)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Flexi X After	0.028	0.029	0.029	0.029	0.029	0.029	0.029
	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)	(0.019)
Education level		0.018	0.015	0.015	0.015	0.015	0.015
		(0.020)	(0.018)	(0.018)	(0.018)	(0.018)	(0.019)
Age: 40-49		-0.002	-0.001	-0.001	-0.001	-0.001	-0.001
		(0.012)	(0.013)	(0.013)	(0.013)	(0.013)	(0.013)
Age: 50-64		0.020*	0.021*	0.021*	0.021*	0.021*	0.021*
		(0.011)	(0.011)	(0.011)	(0.011)	(0.011)	(0.011)
Age: 65+		0.088***	0.088***	0.088***	0.088***	0.088***	0.088***
		(0.023)	(0.022)	(0.022)	(0.022)	(0.022)	(0.022)
Number of people in HH		0.016***	0.013*	0.013*	0.013*	0.013*	0.013*
		(0.005)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Solar panels			0.017	0.017	0.017	0.017	0.017
			(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Ecological bulbs > 50%			0.011	0.011	0.011	0.011	0.011
			(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Temp out of 11am-3pm				0.002***	0.002***	0.003***	0.003***
				(0.001)	(0.001)	(0.001)	(0.001)
Temp in 11am-3pm				-0.002**	-0.002**	-0.002***	-0.002***
				(0.001)	(0.001)	(0.000)	(0.001)
Holidays					-0.001	0.002	0.001
					(0.002)	(0.002)	(0.003)
Sunday						0.014**	0.014**
						(0.006)	(0.006)
Saturday						0.012**	0.012**
						(0.006)	(0.006)
Month FE	No	No	No	No	No	Yes	No
Week FE	No	No	No	No	No	No	Yes
# Obs.	27,477	27,477	27,477	27,477	27,477	27,477	27,477
R-squared	0.026	0.121	0.124	0.125	0.125	0.129	0.130

Table 7 : OLS estimations for Control 1/Facture 1/Flexi (dependent variable: proportion 11am-3pm)

*Note: * p<0.1, ** p<0.05, *** p<0.01. Standard errors, robust and clustered at household level, in parentheses.*

Table 8 reports the results about the information feedback experiment when using households already involved in alternative projects ongoing in Cernier. Also in this case we report the results of the basic difference in difference estimation (column (1), and then, column by column, we augment the set of covariates. Regardless of the specification, the impact of the treatment on the proportion of consumption between 11am and 3pm is zero and not significant. This result may be due to the type of experiment (also when using households not yet exposed to ongoing projects the impact was limited) or because these households were also influenced by the alternative projects in which they are involved.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Constant	0.195***	0.213***	0.217***	0.219***	0.218***	0.227***	0.237***
	(0.008)	(0.026)	(0.027)	(0.028)	(0.028)	(0.030)	(0.032)
After	0.006	0.006	0.006	0.006*	0.006*	0.001	0.001
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Facture	0.024*	0.031**	0.029**	0.029**	0.029**	0.029**	0.029**
	(0.014)	(0.013)	(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Facture X After	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)	(0.006)
Education level		0.005	0.005	0.005	0.005	0.005	0.005
		(0.017)	(0.017)	(0.017)	(0.017)	(0.017)	(0.017)
Age: 40-49		-0.042	-0.044	-0.044	-0.044	-0.044*	-0.044*
		(0.025)	(0.026)	(0.026)	(0.026)	(0.026)	(0.026)
Age: 50-64		-0.025	-0.028	-0.028	-0.028	-0.028	-0.028
		(0.024)	(0.024)	(0.024)	(0.024)	(0.024)	(0.024)
Age: 65+		0.020	0.020	0.020	0.020	0.019	0.019
		(0.030)	(0.030)	(0.030)	(0.030)	(0.030)	(0.030)
Number of people in HH		-0.002	-0.001	-0.001	-0.001	-0.001	-0.001
		(0.007)	(0.007)	(0.007)	(0.007)	(0.007)	(0.007)
Solar panels			-0.011	-0.011	-0.011	-0.011	-0.011
			(0.015)	(0.015)	(0.015)	(0.015)	(0.015)
Ecological bulbs > 50%			-0.002	-0.002	-0.002	-0.002	-0.002
			(0.014)	(0.014)	(0.014)	(0.014)	(0.014)
Temp out of 11am-3pm				0.002**	0.002**	0.002***	0.003***
				(0.001)	(0.001)	(0.001)	(0.001)
Temp in 11am-3pm				-0.002**	-0.002**	-0.002***	-0.003***
				(0.001)	(0.001)	(0.001)	(0.001)
Holidays					0.002	0.002	-0.001
					(0.003)	(0.003)	(0.004)
Sunday						0.007	0.007
						(0.009)	(0.010)
Saturday						-0.002	-0.002
						(0.009)	(0.009)
Month FE	No	No	No	No	No	Yes	No
Week FE	No	No	No	No	No	No	Yes
# Obs.	17,326	17,326	17,326	17,326	17,326	17,326	17,326
R-squared	0.012	0.052	0.054	0.054	0.054	0.057	0.058

Table 8 : OLS estimations for Control 2/Facture 2 (dependent variable: proportion 11am-3pm)

*Note: * p<0.1, ** p<0.05, *** p<0.01. Standard errors, robust and clustered at household level, in parentheses.*

From a general point of view, OLS estimations lead to partially satisfactory results: for the monetary incentives experiment, we find the expected impact of the treatment on households' behavior. However, this effect is not significant at conventional level (albeit it is at 15%). This weak statistical significance may potentially be explained by our sample size (despite a high response rate, we deal with groups of around 20 households), the econometric techniques (given the structure of the dataset we later account for its panel dimension), or some specific features of the series (electricity consumption series could be affected by autocorrelation).

	(1) FE	(2) RE	(3) GLS	(4) PCSE-AR1	(5) PCSE-PSAR1
Constant	0.187***	0.142***	0.142***	0.137***	0.147***
	(0.010)	(0.011)	(0.005)	(0.008)	(0.008)
After	0.002	0.002	0.001	0.002	0.001
	(0.005)	(0.005)	(0.003)	(0.003)	(0.003)
Facture		-0.013	-0.013***	-0.013***	-0.008***
		(0.013)	(0.003)	(0.003)	(0.003)
Facture X After	-0.000	-0.000	0.001	0.001	0.002
	(0.006)	(0.006)	(0.004)	(0.004)	(0.003)
Flexi		-0.007	-0.007**	-0.007**	0.006*
		(0.013)	(0.003)	(0.003)	(0.003)
Flexi X After	0.029	0.029	0.029***	0.029***	0.014***
	(0.019)	(0.019)	(0.004)	(0.004)	(0.004)
Education level		0.014	0.015***	0.015***	0.011***
		(0.018)	(0.002)	(0.002)	(0.002)
Age: 40-49		-0.000	-0.001	-0.001	0.004**
		(0.013)	(0.002)	(0.002)	(0.002)
Age: 50-64		0.022**	0.021***	0.021***	0.018***
		(0.010)	(0.002)	(0.002)	(0.002)
Age: 65+		0.089***	0.088***	0.088***	0.095***
		(0.022)	(0.002)	(0.003)	(0.003)
Number of people in HH		0.013**	0.013***	0.013***	0.011***
		(0.006)	(0.001)	(0.001)	(0.001)
Solar panels		0.016	0.017***	0.016***	0.013***
		(0.014)	(0.002)	(0.002)	(0.002)
Ecological bulbs > 50%		0.010	0.011***	0.011***	0.012***
		(0.014)	(0.002)	(0.002)	(0.002)
Temp out of 11am-3pm	0.003***	0.003***	0.003***	0.003***	0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Temp in 11am-3pm	-0.002***	-0.002***	-0.002***	-0.002***	-0.002***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Holidays	0.001	0.001	0.001	0.003	0.003
	(0.003)	(0.003)	(0.003)	(0.003)	(0.003)
Sunday	0.014**	0.014**	0.014***	0.013***	0.013***
	(0.006)	(0.006)	(0.002)	(0.002)	(0.002)
Saturday	0.012**	0.012**	0.012***	0.012***	0.011***
	(0.006)	(0.006)	(0.002)	(0.002)	(0.002)
Week FE	Yes	Yes	Yes	Yes	Yes
# Obs.	27,477	27,477	27,477	27,477	27,477
R-squared	0.016			0.089	0.197

Table 9 : Panel estimations for Control 1/Facture 1/Flexi (dependent variable: proportion 11am-3pm)

Note*: * p<0.1, ** p<0.05, *** p<0.01. Standard errors, robust and clustered at household level, in parentheses. Autocorrelation across the households is assumed in columns (3) and (4). Autocorrelation across and within the households is assumed in column (5).*

In order to address these potential concerns, in Table 9, we report the results of estimating eq. (1) for the groups of households not involved in ongoing projects, by using panel fixed effects (FE), panel random effects (RE), panel generalized least square (GLS), panel-corrected standard error (PCSE AR1) without autocorrelation within the panel, and panel-corrected standard error (PCSE PS AR1) with autocorrelation within the panel. On the one hand, the results confirm the findings of the OLS estimations for the information feedback experiment. The treatment coefficient is negligible in size (less than 0.3 percentage points) and not significant. Moreover, the sign is not stable to the approach employed. On the other hand, results about the monetary incentive experiment are encouraging. First, the treatment coefficient does not change (2.9 percentage points) with respect to the OLS estimations when estimating the model by using panel fixed or random effects. When using fixed or random effects, the coefficient of interest is still not significant at conventional levels. Second, however, when we take into account the particular structure of the dataset (the time dimension is larger than the panel dimension), and we estimate the model using a panel GLS, PCSE AR1 and PCSE PS AR1, the treatment parameter becomes significant. These approaches allow us to control for autocorrelation across and within the panels, as well as for heteroscedasticity.[39] The drop in the size of the treatment coefficient from 2.9 to 1.4 percentage points is due to the fact that in the last column we control for panel (i.e., household) specific autocorrelation. The main message to retain is that the monetary feedback experiment does exert an impact: treated households increase their proportion of electricity during the period 11am-3pm. This impact is significant when controlling for autocorrelation, heteroscedasticity and for the particular features of the panel (longer than larger), and it is sizeable.

Table 10 displays the results of estimating eq. (1) using the same approach to assess the information feedback treatment on households that are already involved in ongoing projects. The results confirm the findings of the OLS regressions: in none of the cases the treatment has an impact on the electricity consumption proportion 11am-3pm, regardless of the approach employed.

[39] Various tests show that our series are affected by heteroscedasticity and autocorrelation. More precisely, the presence of heteroscedasticity was tested by means of likelihood ratio tests. The model was estimated by GLS once using a homoscedastic error structure and once using a heteroscedastic one. The former model being nested in the latter, a likelihood ratio test thus constitutes a test for heteroscedasticity at the panel-level. Such tests clearly reject homoscedasticity at any conventional significance level in our data.

The presence of autocorrelation has been assessed in different ways. Wooldridge's (2002) test, implemented in Stata by Drukker (2003), provides a direct way to check for autocorrelation at the panel-level. This test does not detect any autocorrelation (F-statistic = 0.06, p-value = 0.81) when applied to a specification similar to that in equation (1) with time-varying covariates only (the test rests on an estimation in first-differences), in which the dependent variable is the daily proportion of electricity consumption between 11am and 3pm. However, when it is applied to the components of the proportion, it clearly indicates autocorrelation both for consumption between 11am and 3pm (F-statistic = 5.56, p-value = 0.04) and total consumption (F-statistic = 12.50, p-value = 0.00). Alternatively, we conducted a series of (more standard) Durbin-Watson tests on each individual household. In the majority of the cases, we detect first-order serial autocorrelation. Serial correlation is even stronger when a higher-order serial correlation (in particular AR(7)) is considered. This finding suggests that households are more likely to follow a weekly routine than a daily one.

	(1) FE	(2) RE	(3) GLS	(4) PCSE-AR1	(5) PCSE-PSAR1
Constant	0.227***	0.218***	0.219***	0.220***	0.210***
	(0.011)	(0.029)	(0.007)	(0.009)	(0.009)
After	0.001	0.001	0.001	0.001	0.002
	(0.004)	(0.004)	(0.003)	(0.004)	(0.003)
Facture		0.029**	0.029***	0.029***	0.030***
		(0.014)	(0.004)	(0.004)	(0.004)
Facture X After	0.001	0.001	0.000	0.000	0.001
	(0.006)	(0.006)	(0.004)	(0.004)	(0.004)
Education level		0.005	0.005***	0.005**	0.009***
		(0.017)	(0.002)	(0.002)	(0.002)
Age: 40-49		-0.043*	-0.044***	-0.044***	-0.021***
		(0.026)	(0.003)	(0.003)	(0.003)
Age: 50-64		-0.028	-0.028***	-0.028***	-0.014***
		(0.024)	(0.003)	(0.003)	(0.003)
Age: 65+		0.020	0.019***	0.019***	0.042***
		(0.030)	(0.003)	(0.004)	(0.004)
Number of people in HH		-0.001	-0.001*	-0.001*	-0.003***
		(0.007)	(0.001)	(0.001)	(0.001)
Solar panels		-0.010	-0.011***	-0.011***	-0.009***
		(0.015)	(0.002)	(0.002)	(0.002)
Ecological bulbs > 50%		-0.001	-0.002	-0.002	-0.000
		(0.013)	(0.002)	(0.002)	(0.002)
Temp out of 11am-3pm	0.003***	0.003***	0.003***	0.003***	0.004***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Temp in 11am-3pm	-0.003***	-0.003***	-0.003***	-0.003***	-0.003***
	(0.001)	(0.001)	(0.001)	(0.001)	(0.001)
Holidays	-0.001	-0.001	-0.001	0.000	0.001
	(0.004)	(0.004)	(0.004)	(0.004)	(0.004)
Sunday	0.007	0.007	0.007***	0.006***	0.006***
	(0.010)	(0.010)	(0.002)	(0.002)	(0.002)
Saturday	-0.002	-0.002	-0.002	-0.002	-0.001
	(0.009)	(0.009)	(0.002)	(0.002)	(0.002)
Week FE	Yes	Yes	Yes	Yes	Yes
# Obs.	17,326	17,326	17,326	17,326	17,326
R-squared	0.006			0.044	0.134

Table 10 : Panel estimations for Control 2/Facture 2 (dependent variable: proportion 11am-3pm)

Note*: * p<0.1, ** p<0.05, *** p<0.01. Standard errors, robust and clustered at household level, in parentheses. Autocorrelation across the households is assumed in columns (3) and (4). Autocorrelation across and within the households is assumed in column (5).*

It is of interest not only to assess the impact of the treatments on the proportion of consumption, but also to evaluate how the consumption 11am-3pm and the total consumption are affected. This approach will unravel households' strategy to achieve the increases in the proportion of electricity consumption between 11am and 3pm.

We estimate eq. (1) by OLS, when the dependent variable is the (logarithm of) electricity consumption in 11am-3pm and the (logarithm of) total electricity consumption. The results are reported in Table 11. It will then be clearer which element of the proportion of the consumption 11am and 3pm is driving the results. In columns (1) and (4), we report the results of the full specification as described in eq. (1) and already accounted in column (7) of Table 7 and Table 8. Columns (2) and (3) explain the (logarithm of) electricity consumption in 11am-3pm and the (logarithm of) total electricity consumption using households not previously involved in other projects, while columns (5) and (6) are estimations with the same dependent variables but using households involved in *Solution* and *Smart Solution*.

	Control 1/Facture 1/Flexi			Control 2/Facture 2		
	(1)	(2)	(3)	(4)	(5)	(6)
	prop1115	logconso1115	logconsotot	prop1115	logconso1115	Logconso-tot
Constant	0.137***	-1.351***	1.107***	0.237***	-0.711**	1.196***
	(0.014)	(0.202)	(0.177)	(0.032)	(0.287)	(0.308)
After	0.001	0.010	0.028	0.001	-0.053	-0.072*
	(0.005)	(0.087)	(0.087)	(0.004)	(0.045)	(0.037)
Facture	-0.013	0.003	0.092	0.029**	0.305*	0.195
	(0.014)	(0.176)	(0.165)	(0.014)	(0.175)	(0.154)
Facture X After	0.001	-0.116	-0.161	0.000	0.018	0.029
	(0.006)	(0.105)	(0.110)	(0.006)	(0.049)	(0.043)
Flexi	-0.007	0.002	0.056			
	(0.013)	(0.159)	(0.155)			
Flexi X After	0.029	-0.002	-0.123			
	(0.019)	(0.098)	(0.101)			
Education level	0.015	-0.166	-0.247	0.005	0.057	0.056
	(0.019)	(0.142)	(0.176)	(0.017)	(0.156)	(0.142)
Age: 40-49	-0.001	0.163	0.196	-0.044*	-0.133	0.057
	(0.013)	(0.154)	(0.155)	(0.026)	(0.287)	(0.212)
Age: 50-64	0.021*	0.222	0.107	-0.028	0.317*	0.382**
	(0.011)	(0.213)	(0.184)	(0.024)	(0.175)	(0.171)
Age: 65+	0.088***	0.350*	-0.077	0.019	0.617***	0.451**
	(0.022)	(0.184)	(0.198)	(0.030)	(0.168)	(0.183)
Number of people in HH	0.013*	0.418***	0.338***	-0.001	0.203**	0.197***
	(0.007)	(0.063)	(0.067)	(0.007)	(0.077)	(0.063)
Solar panels	0.017	0.260*	0.172	-0.011	0.250	0.342**
	(0.014)	(0.150)	(0.133)	(0.015)	(0.170)	(0.131)
Ecological bulbs > 50%	0.011	-0.095	-0.128	-0.002	-0.082	-0.025
	(0.015)	(0.135)	(0.150)	(0.014)	(0.167)	(0.144)
Temp out of 11am-3pm	0.003***	0.027***	0.014***	0.003***	0.023***	0.009***
	(0.001)	(0.005)	(0.003)	(0.001)	(0.005)	(0.003)
Temp in 11am-3pm	-0.002***	-0.025***	-0.014***	-0.003***	-0.026***	-0.012***
	(0.001)	(0.004)	(0.002)	(0.001)	(0.004)	(0.002)
Holidays	0.001	-0.040	-0.062***	-0.001	0.002	0.002
	(0.003)	(0.028)	(0.018)	(0.004)	(0.028)	(0.023)
Sunday	0.014**	0.102**	0.028	0.007	0.102	0.051*
	(0.006)	(0.041)	(0.018)	(0.010)	(0.069)	(0.027)
Saturday	0.012**	0.055	0.001	-0.002	-0.005	-0.022
	(0.006)	(0.040)	(0.017)	(0.009)	(0.066)	(0.023)
Week FE	Yes	Yes	Yes	Yes	Yes	Yes
# Obs.	27,477	27,428	27,477	17,326	17,237	17,326
R-squared	0.130	0.331	0.360	0.058	0.172	0.259

Table 11 : OLS estimations (dependent variables: proportion 11am-3pm, log(consumption 11am-3pm), log(total consumption))

Note*: * p<0.1, ** p<0.05, *** p<0.01. Standard errors, robust and clustered at household level, in parentheses.*

Even if the results are not significant for the reasons already mentioned above, it is worth discussing the differences across groups. For households not yet included in ongoing projects, regardless of the experiment, the treatments decrease both the total as well as the consumption 11am-3pm. The impact of information feedback on these two variables is -11% and -16%, respectively. In the case of the monetary incentive experiment, the impact of the treatment is -0.2% and -12.3%, respectively.

It is possible that the information contained in the letters sent to households involved in the information feedback experiment was too much, or not clear. These households understood that something was going on, and they adopted an electricity saving behavior without really distinguishing between the periods of the day.[40] On the contrary, households participating to the monetary competition adopted the strategy of keeping their consumption between 11am and 3pm relatively constant while decreasing their total consumption, above all during the afternoons and the nights as documented also by Figure 27. The two effects combined led to an increase of the proportion of consumption during the solar energy production hour already discussed. We finally note that the treatment effect apparently induced households in group Facture 2 (columns (5) and (6)) to increase their consumption in every period of the day.

When estimating eq.(1) using a PCSE AR1 model for the two components of the proportion of the consumption 11am-3pm, the results are qualitatively unchanged, while the impact of the treatment become significant. More precisely, the results in Table 12 highlight a different strategy among households not already involved in other projects: those who were provided with monthly information feedback decreased their consumption without focusing on one specific period of the day. Instead, households who participated in the pecuniary competition kept consumption stable during the 11am-3pm (coefficient not significant) and they decreased total consumption, in particular during the evenings and nights as documented in Figure 27. PCSE AR1 estimations on the two types of consumption for households involved in ongoing projects confirm previous findings based on OLS estimations: the treatment does not display any significant effect.

Based on our results, we quantify the cost of moving 1 kWh towards the hours 11am-3pm using the following strategy. Flexi households have increased their electricity proportion between 11am and 3pm by about 2.9 percentage points. Moreover, their average consumption in the after period is 7.18 kWh per day (see Appendix 3), which corresponds to 215 kWh per month. This implies that 6.25 kWh (0.029*215) have been moved each month by each household. Because 22 households were included in this experiment and monthly rewards amounted to a total of CHF 450, the average cost corresponds to CHF 20.45 per household. Combining these two elements, we obtain a cost of around CHF 3.27 per kWh moved.

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[40] It is also worth mentioning that the decrease in total consumption by households of group Facture 1 (16%) appears substantial but not implausible and in line with the findings of recent studies. For instance, Bartusch et al. (2011) findings suggest a decline from 11 to 14% in total electricity consumption in the first two years following a switch to time-of-use pricing. Also, Ito et al. (2015) find that economic incentives have an impact on electricity consumption reduction between 14 and 17%, depending on the peak price. Given that we sent letters weekly (during the first month) and then monthly with information on actual electricity consumption, households were much more aware than in normal times that their actions could have an impact on their electricity bill. Moreover, note that the result does not depend from the choice of the before and after periods. In fact, when the two periods refer to the same months (from October to December) of two subsequent years (2013 and 2014) the results are even larger with a consumption decreasing by about 19% for households of Facture 1 group with respect to the corresponding control group.

	Control 1/Facture 1/Flexi			Control 2/Facture 2		
	(1)	(2)	(3)	(4)	(5)	(6)
	prop1115	logconso1115	logconsotot	prop1115	logconso1115	logconsotot
Constant	0.137***	-1.208***	1.046***	0.220***	-0.721***	1.137***
	(0.008)	(0.070)	(0.063)	(0.009)	(0.083)	(0.070)
After	0.002	0.011	0.046	0.001	-0.051	-0.086***
	(0.003)	(0.033)	(0.034)	(0.004)	(0.035)	(0.029)
Facture	-0.013***	-0.001	0.103***	0.029***	0.311***	0.199***
	(0.003)	(0.036)	(0.037)	(0.004)	(0.037)	(0.030)
Facture X After	0.001	-0.120***	-0.174***	0.000	0.018	0.044
	(0.004)	(0.039)	(0.040)	(0.004)	(0.041)	(0.033)
Flexi	-0.007**	0.002	0.066*			
	(0.003)	(0.041)	(0.039)			
Flexi X After	0.029***	-0.010	-0.132***			
	(0.004)	(0.046)	(0.044)			
Education level	0.015***	-0.181***	-0.251***	0.005**	0.048**	0.073***
	(0.002)	(0.019)	(0.019)	(0.002)	(0.022)	(0.017)
Age: 40-49	-0.001	0.163***	0.199***	-0.044***	-0.153***	0.055**
	(0.002)	(0.019)	(0.021)	(0.003)	(0.030)	(0.025)
Age: 50-64	0.021***	0.224***	0.107***	-0.028***	0.313***	0.371***
	(0.002)	(0.023)	(0.022)	(0.003)	(0.028)	(0.022)
Age: 65+	0.088***	0.340***	-0.070***	0.019***	0.622***	0.457***
	(0.003)	(0.025)	(0.024)	(0.004)	(0.033)	(0.026)
Number of people in HH	0.013***	0.422***	0.340***	-0.001*	0.204***	0.199***
	(0.001)	(0.009)	(0.009)	(0.001)	(0.008)	(0.007)
Solar panels	0.016***	0.258***	0.172***	-0.011***	0.227***	0.356***
	(0.002)	(0.025)	(0.025)	(0.002)	(0.025)	(0.018)
Ecological bulbs > 50%	0.011***	-0.103***	-0.128***	-0.002	-0.089***	-0.009
	(0.002)	(0.017)	(0.017)	(0.002)	(0.019)	(0.017)
Temp out of 11am-3pm	0.003***	0.023***	0.011***	0.003***	0.026***	0.010***
	(0.001)	(0.005)	(0.003)	(0.001)	(0.006)	(0.004)
Temp in 11am-3pm	-0.002***	-0.021***	-0.011***	-0.003***	-0.027***	-0.012***
	(0.001)	(0.004)	(0.002)	(0.001)	(0.005)	(0.003)
Holidays	0.003	0.001	-0.021*	0.000	0.015	0.031*
	(0.003)	(0.022)	(0.012)	(0.004)	(0.029)	(0.017)
Sunday	0.013***	0.081***	0.015***	0.006***	0.071***	0.024***
	(0.002)	(0.011)	(0.006)	(0.002)	(0.015)	(0.008)
Saturday	0.012***	0.048***	0.001	-0.002	-0.008	-0.016*
	(0.002)	(0.011)	(0.006)	(0.002)	(0.015)	(0.008)
Week FE	Yes	Yes	Yes	Yes	Yes	Yes
# Obs.	27,477	27,428	27,477	17,326	17,237	17,326
R-squared	0.089	0.158	0.126	0.044	0.096	0.123

Table 12 : PCSE-AR1 estimations (dependent variables: proportion 11am-3pm, log(consumption 11am-3pm), log(total consumption))

Note*: * p<0.1, ** p<0.05, *** p<0.01. Standard errors, robust and clustered at household level, in parentheses. Autocorrelation across the households is assumed.*

Additional covariates

Even if the primary goal of the study is to assess how information feedback and monetary incentives affect households' electricity consumption patterns, it is also of interest to shed light on the impact of individual features, flat characteristics as well as weather conditions. Figure 28 illustrates the coefficients obtained for these additional covariates in estimations explaining the proportion of consumption between 11am and 3pm for groups Control 1/Facture 1/Flexi. More precisely, the coefficients plotted are those from column (1) of Table 12. Note that very similar are obtained in all estimations conducted on these groups.

Being more educated impacts positively the electricity consumption proportion between 11am and 3pm. More mature households perform better than the reference group (younger than 40): the proportion is 2.1 (8.8) percentage points higher if the respondent is between 50 to 64 years old (65 or older). This finding may be justified by the fact that older people do not work, so that they can potentially spend more time at home, having more flexibility to redirect their consumption in the period of interest. Furthermore, larger households seem to consume proportionally more in the period 11am-3pm. In such households, it is more likely that some family member is home during the day, which could make consumption redirection across periods of the day easier.

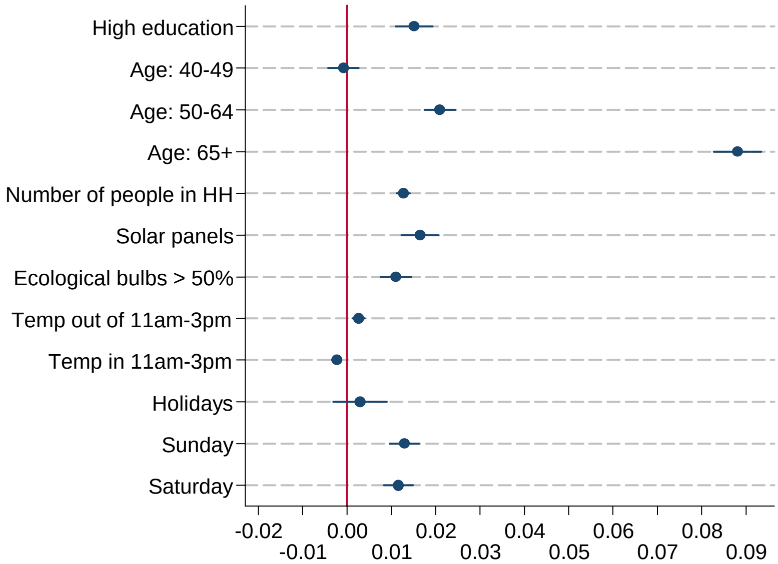


Figure 28 : Coefficients of additional covariates

Note: The coefficients refer to the specification in eq. (1) estimated using PCSE AR (1). The horizontal lines indicate 95% correlated panels corrected confidence intervals

Solar panels as well as the share of bulbs used in the flat may not only reflect savings oriented persons, but also stronger environmental feelings. We find that these two variables positively affect the share of electricity consumption during the period 11am-3pm.

Weather conditions in and out of the period of interest affect the dependent variable in opposite directions: on the one hand, higher temperature between 11am and 3pm negatively affects the proportion, while the opposite is true for higher temperature out of this time slot. It can be argued that during periods of good weather (higher temperature) people go out more so that their consumption decreases. If temperature is higher between 11am and 3pm, the proportion of consumption during this period decreases, while it increases if temperature is higher in the hours outside 11am-3pm.

Finally, the impact of holidays on the fraction of electricity consumption 11am-3pm is not significant. In these periods, households might leave or stay home more often so that the expected effect is ambiguous. Saturdays and Sundays positively affect the results. This result may be due to the fact that during the weekend people spend more time at home than during the week (in particularly for workers) so that they consume more during the day.

Timing of the effects

As already noted in Figure 24 to Figure 26, electricity consumption is characterized by seasonality: this feature may have driven the results of the experiments. In order to shed more light on this issue, we investigate how the treatment effect evolved over time by using alternative definitions of the treatment period. We here focus exclusively on the effect of the monetary incentives experiment. The coefficients are obtained from estimations similar to that reported in column (1) of Table 12.

Figure 29 shows the evolution of the treatment coefficient when the after period is expanded month-by-month. We observe that the effects of the treatment took some months to unfold. After a period of 8 months of steady increase, the estimated coefficients stabilize around the value of 0.029 that we obtain when using the entire period of observation.

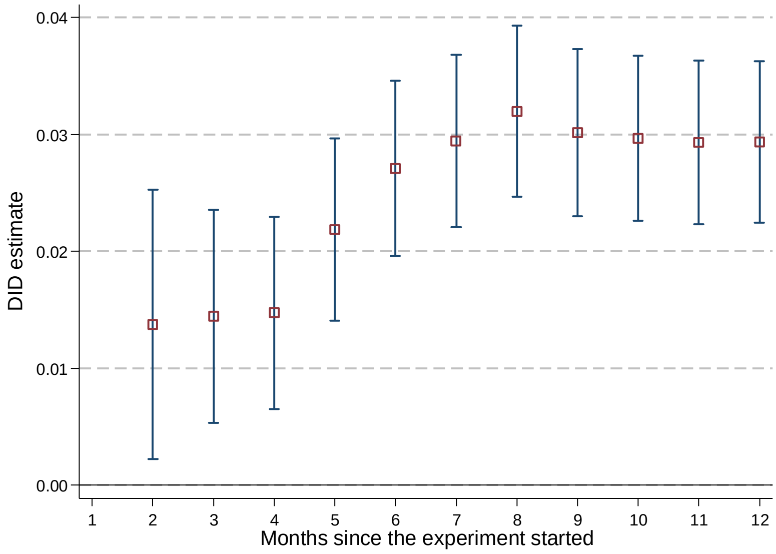


Figure 29 : Evolution of the treatment effect when the after period accumulates month after month, group Flexi
Note: The coefficients of the treatment effect refers to the specification in eq. (1) estimated using PCSE AR(1). The whiskers indicate 95% correlated panels corrected confidence intervals.

Figure 30 displays the treatment effect when the after period is a single month. For every month, the effect appears positive and significant. However, the coefficients estimated from May to August are significantly larger, all of them being between 0.04 and 0.05 while all others are below 0.03. Figure 30 supports the idea that the treatment effect is related to seasonal effects. Increasing the proportion of consumption between 11am and 3pm appears to be easier during the summer months thanks to the different factors mentioned earlier: summer activities take place outside, less cooking, lower needs for light. In contrary, Figure 30 does not reveal any weariness effects: between August and September, the treatment effect actually goes down sharply, but it increases again thereafter. If households were fed up with the experiment, we would instead expect a continuous decrease of the effect. Interestingly, we observe that the coefficient for December, the last treatment month, corresponds exactly to that found on the entire period from February to December.

Figure 31 reports the results of the treatment coefficient when the after period includes 3 months (i.e., the coefficient displayed in October is based on a treatment period from October to December). Again, we observe that the treatment increased at the beginning of the experiment, reached a maximum in the summer months, and then declined. As expected, variations are more gradual than in the month by month analysis. Once more, we highlight that the coefficient for the last period is very close to that obtained when the after period goes from February to December. This result is particularly important, because in this last analysis the control period is October to December 2013 while the treatment period refers to the same months one year later. Using the same months in consecutive years for both periods may allow controlling for unobserved variations that go beyond what is already accounted for by the covariates included in our estimations. In that sense, this final result provides convincing evidence that our findings are robust.

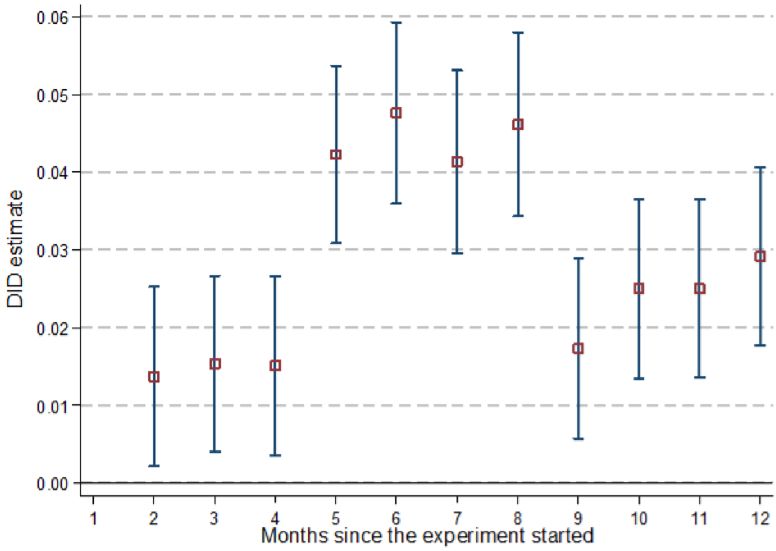


Figure 30 : Evolution of the treatment effect when the after period is a single month, group Flexi

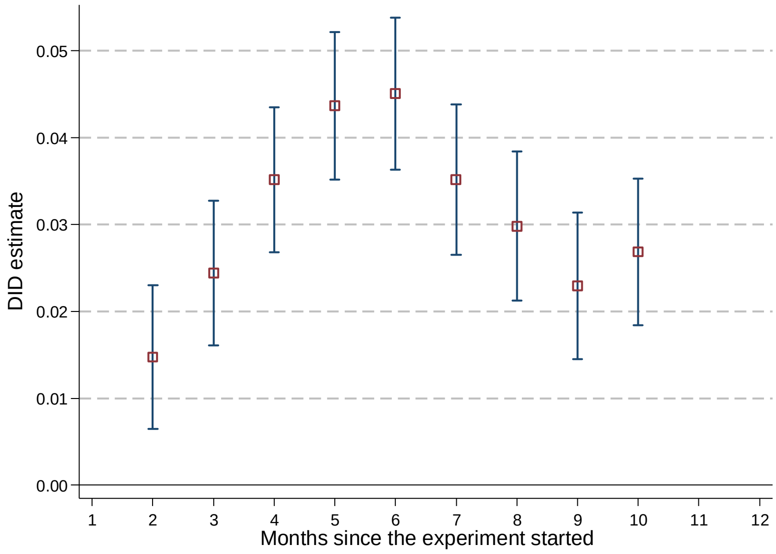


Figure 31 : Evolution of the treatment effect when the after period includes 3 months, group Flexi

Ranking, rewards, electricity costs and households' performance

We provide evidence that the monetary experiment leads to an increase in the proportion of electricity consumption during the solar electricity production hours peak (period from 11am to 3pm) of about 2.9 percentage points. In this section we put this result into perspective, by providing additional information about the behavior of the 22 households who participated in the competition.

Figure 32 displays the fraction (left axis) and number (right axis) of times a household was ranked in a specific position during the 12 months of the experiment. We first note that all households have won something. This is not really surprising, due to the fact that the number of winners each month (15 households) was relatively high compared to the number of participants (22 households). However, the number of times (and the amounts) won vary substantially across households: four of them never obtained the largest reward (CHF 50). Moreover, all households have been excluded from the ranking at least once. Finally, four households were ranked in the highest and second highest reward categories more than the 40% of the months.

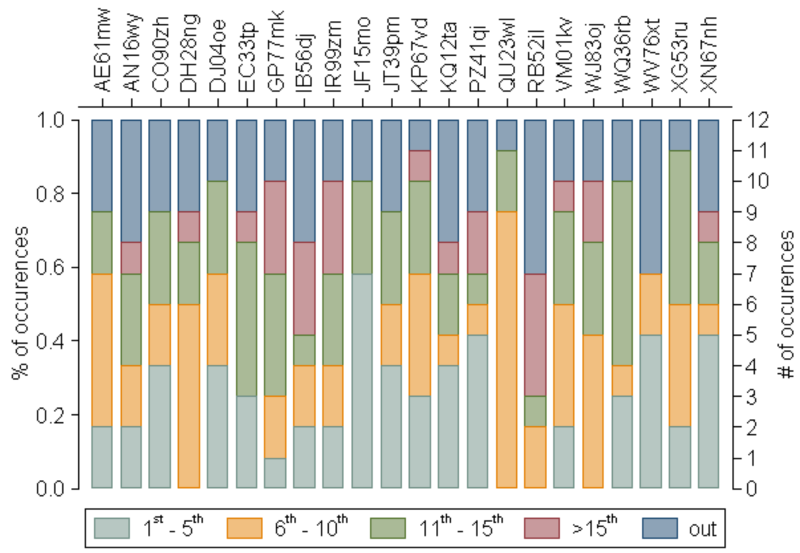
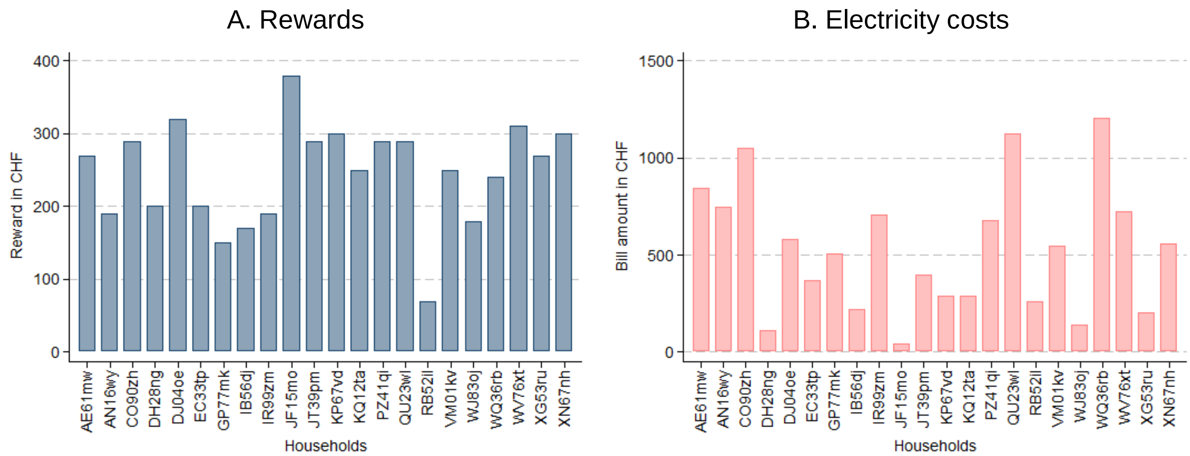


Figure 32 : Households' rankings

In Figure 33A we show the total amounts earned by each household. The average total gain per household is about CHF 245. The minimum reward is CHF 70, while the maximum is CHF 380. Parallel to the rewards, we document in Figure 33B the amounts corresponding to the yearly electricity bill of each household. The annual average cost is about CHF 527, the most parsimonious household only consumed the equivalent of CHF 44, 27 times less than the least parsimonious one.

We combine the information about the rewards and the costs in Figure 33C, which displays the ratio between these two variables. For one household, the relative reward amounts to more than 8 times the costs he sustained. Discarding this particular household, the average reward corresponds to approximately 60% of the electricity costs. Therefore, on average, the rewards distributed correspond to 60% of the annual electricity cost. Taken together, these 21 households have seen more than half of their electricity bills over the year of the experiment covered by the rewards earned. The graph also shows that 5 out of 22 households earned (in rewards) more than what they spent for electricity consumption.



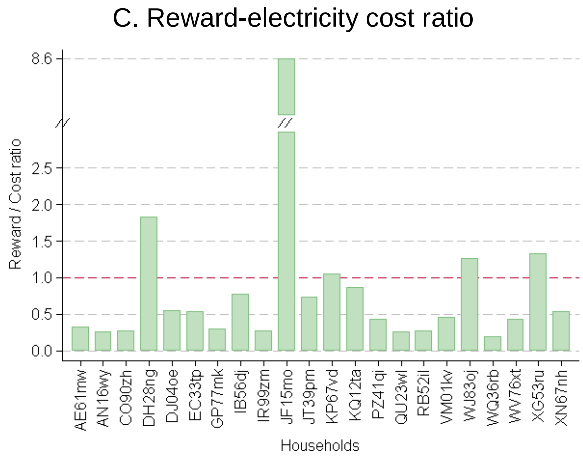


Figure 33 : Rewards and electricity costs

Finally, we assess the impact of the current ranking of a household on his next period rank, block of positions, and monthly consumption (total, during the solar electricity production hours, proportion). Such an analysis might reveal the presence of "boomerang effects", i.e., a situation in which households who are relatively better are unintentionally induced to modify their behavior so as to conform to the norm (see e.g., Allcott 2011 or Rasul and Holliwood 2012). More precisely, we estimate the following model:

$$y_{i,t} = \alpha + \beta_1 \times rank_{i,t-1} + \delta_t + \gamma_i + \varepsilon_{i,t} \qquad (2)$$

where *y* is (alternatively) the ranking, the block of positions, total monthly consumption, monthly consumption between 11am and 3pm, or the proportion of consumption between 11am and 3pm of household *i* in period *t*. Moreover, we include time fixed effects and household fixed effects.

	rank	block of positions	prop 11-15	conso tot	conso 11-15
	(1)	(2)	(3)	(4)	(5)
Rank (-1)	-.17*	-.018	-.044	1.04**	.26**
	(.083)	(.014)	(.058)	(.45)	(.09)
Const.	13.5***	2.16***	25.4***	245.4***	54.13***
	(1.42)	(.32)	(2.08)	(10.0)	(2.21)
N	242	187	242	242	242
Time fixed effects	Yes	Yes	Yes	Yes	Yes
HH fixed effects	Yes	Yes	Yes	Yes	Yes

Table 13 : The impact of rank in month t-1 on several variables of interest in month t

Notes: Significance level: * p<0.10, ** p<0.05, *** p<0.01. Robust standard errors clustered at household level in parentheses.

The results, reported in Table 13, show that an improvement of the ranking in the current month (i.e., a lower position) has a negative impact on next month ranking (i.e., position value increases). This effect is significant at 10%. Current ranking has no impact on block of positions, nor on the proportion of electricity consumption between 11am and 3pm. When taken separately, total consumption and consumption 11am and 3pm are affected by a household previous month position: when the ranking improves (rank value decreases) total consumption and consumption between 11am and 3pm decrease as well. Those results are hard to reconcile. In order to improve their position in the ranking, household had to increase their proportion of consumption between 11am and 3pm. Therefore, while an increase in consumption between 11am and 3pm could be expected for households ranked in bad positions, we would not have expected to see an increase in total consumption. The fact that the rank itself is influences by the rank in the previous month might indicate that the criteria we used to build the ranking creates a correlation of this sort by design.

Discussion / appraisal of the results / findings

In the electricity industry, demand side management is acquiring an important role. The shift of interest from the supply side to the demand aspects of the electricity market is the outcome of several factors. On the one hand, items such as solar panels and photovoltaic systems allowing households to produce electricity by themselves are becoming widespread. On the other hand, advanced technologies such as smart meters and in-home displays have improved and their cost has plummeted. As a consequent, an increasing number of households are equipped with this type of tools that can provide real-time information on electricity consumption. These novelties transformed households from mere electricity-consumers to electricity-producers (exploiting in particular solar energy) and at the same time, they helped in making households informed electricity consumers.

An issue with solar energy is that its production takes place at times when demand for electricity is not necessarily high. Households' electricity consumption indeed peaks in the evening, when solar production energy is at best low. This mismatch might be reduced in several ways: electricity might be transported and consumed elsewhere, it might be stored for later consumption, or households could be encouraged to align their consumption with solar energy production so that they consume it directly when it is produced. While the first two solutions imply high installation costs (in particular in remote villages), the latter intervention might prove relatively inexpensive and easy to implement.

In the economic part of the Flexi project, we assess the impact of two alternative experiments that seek to influence households' electricity consumption. While policies and research experiments generally push households to decrease electricity consumption, in this study we do something slightly different: we "nudge" households to shift their consumption towards the period of the day (11am-3pm) in which the production of solar energy is (supposed to be) the largest. If households do react to the type of incentives we provide, these could be used to narrow the gap between solar energy production and households' electricity consumption. The relevance of such a study is enhanced in the context of the energy transition, as renewable energies are bound to gain importance in the Swiss energy mix.

The first experiment consist in providing households with detailed information feedbacks about the evolution of their electricity consumption and about the fraction of electricity consumed between 11am and 3pm. In order to stimulate social competition, they have been also provided with information about the consumption of similar (in terms of number of people) households. The importance of aligning electricity consumption with solar energy production is highlighted and tips to achieve this result are offered. No other motivation is given to these households.

In the second experiment, households participate in a competition, in which they are ranked according to their proportion of electricity consumption during the solar energy production hours and its evolution. Every month, conditional on their position in the ranking, they could receive monetary prizes up to CHF 50. Participating households are aware of the rules of the competition, but minimal information about their electricity consumption is provided.

The results about the monetary incentives experiment are encouraging: we find that the treatment has a significant and quantitatively sizeable impact on the proportion of electricity consumed during the period 11am-3pm. Treated households increase this proportion by about 2.9 percentage points, which is considerable given that it is around 20% in average. Estimations explaining consumption in different periods of the day show that households achieved this outcome by reducing their consumption mostly in the evening. These findings are robust to the period of analysis considered and the econometric techniques employed.

The results about the information feedback experiment suggest that this type of "nudge" has no statistical impact on the proportion of electricity consumption between 11am and 3pm. When separating the two components of the ratio, however, we observe that households exposed to the information feedbacks decrease their consumption in all periods of the day. Those results seem to indicate that households involved in the information feedback experiment understand that something is going on, and undertake actions to decrease consumption, neglecting more complex information.

We draw two main policy implications from our results. First, monetary incentives matter: if policy makers are interested in affecting households' electricity consumption, a system of monetary rewards and penalties based on consumption during certain periods of the day could be implemented. Said otherwise, time-of-use tariffs can be expected to be an effective demand-side management tool. Second, even though our information feedbacks missed their target of shifting electricity consumption, results show that this type of tool may be used to achieve significant electricity conservation. More precisely, households provided with frequent (monthly) information feedback about their actual electricity consumption, according to our results, would become more careful. This finding suggests an inexpensive improvement of the current payment system, in which electricity bills are provided every two months and computed on expected consumption.

Finally, we highlight that our results need to be replicated and confirmed on a larger sample and longer period: in fact, an important caveat of our study is the sample of around 100 households. The fact that some of our results are weakly significant might be related to this point. A longer period of analysis would allow larger statistical reliability and a better analysis of middle to long term impacts.

Conclusions, outlook, next steps after closure of the project

Conclusion

In the Flexi project, households were encouraged to consume electricity in the theoretical period of peak solar energy production (11am-3pm) in order to consume directly when the solar plants produce. A first technical part evaluated the amount of electric consumption that could be shifted and potentially be synchronized with PV production. This study shows that indeed a part of the consumption can be shifted and this shift would help increase PV coverage without detrimental effects on the grid.
The first practical experiment tries to motivate a behaviour change by providing households with detailed information feedbacks about the evolution of their electricity consumption and about the fraction of electricity consumed between 11am and 3pm. The results from this experiment show that there is no statistical impact on the proportion of electricity consumption between 11am and 3pm. However, households exposed to the information feedbacks decrease their consumption in all periods of the day.
The second practical experiment ranked the households according to their proportion of electricity consumption during the solar energy production hours and its evolution. They could receive monetary prizes up to CHF 50.—. The results about the monetary incentives experiment show a significant and quantitatively sizeable impact on the proportion of electricity consumed during the period 11am-3pm.
In conclusion, change of habits to shift consumption is the least expensive measure but seems to be difficult to maintain in the long term. Although a part of 6-8% of the consumption (on average) could theoretically be easily shifted, households of the “Flexi group” managed to shift 2-3% on average. The only effective way to make households change their habits in terms of electricity consumption is to implement a system of monetary rewards and penalties. Even though the information feedbacks missed their target of shifting electricity consumption, results show that this type of tools may be used to achieve significant electricity conservation.
The results need to be replicated and confirmed on a larger sample and longer period. A longer period of analysis would allow better statistical reliability.

Outlook

The first part of the Flexi project shows a relative flexibility of the electrical household demand with a monetary incentive. However, the continuation of the project in the Cernier area encounters difficulties, in particular the accumulation of requests to the households (questionnaires, letters, contests, etc.) that generated a certain reluctance and explains the small number of potential participants.

Therefore it is undisputable that the continuation of the project can only be considered on a new area free from any other experiments. Moreover such an opportunity will offer the opportunity to validate the interesting results on a larger scale. We also suggest new experimentation, including studying the variability of the generation of solar power.

Cooperation

National Cooperation

PV-LAB activities on demand side management were also supported by an EPFL project financed by EOS holding on PV with local storage (2011-2014).

PV-LAB is a partner of CTI project "SCCER-Furies" leaded by EPFL on electrical grids. Demand side management and storage are one topics addressed by this project.

The technical part of the project will be presented in the Bulletin of the VSE/ASE ElectroSuisse

IRENE is part of SCCER-CREST (Competence Center for Research in Energy, Society and Transition), http://www.sccer-crest.ch/.

International Cooperation

PV-Lab is collaborating with the Electrical Sustainable Energy Department of Delft University of Technology for seminars, discussions and joint project proposals.

The technical part of the project will also be presented at the European PV Solar Energy Conference 2015 in Hamburg.

The economic part of the project has been presented at the ENERDAY 2015 - 10th Conference on Energy Economics and Technology, Technische Universität Dresden, 17st April 2015.

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Appendix 1 : Appliance list, usage and power

Appliance	Appli-ance ID	Energy per year (kWh)	Active Power (W)	Standby Power (W)	devP(1)	devP(2)	devP(3)	devD (minutes)	Notes
Washing machine	WASHM		406	0	0.5	0.4		60	7)
Dishwasher	DISHW		1131	0	0.4	0.001		34	7)
Tumble dryer	TUMBL		2500	0	0.5	0		60	devP(1): if used directly after washing machine
Dryer cabinet	DRYC		0	0	0	0	0	0	not in surveys
Fridge (with freezer)	FRIDG	278	93.94	0	0.3378	0.3378		25	6)
Freezer (separated from fridge)	FREEZ	250	62.04	0	0.46	0.46		63	6)
Coffe / tea machine	COFFE		800	0.5	0.8	0.7	0.5	3	1)
TV set	TV		124	0.3	0.9	0.05	0.5	20	2), 3)
PC /fixed (incl. screen)	PC		110	1	0.5	0.1	0.2	30	4), 5)
Printer /scanner/fax	PRINT		23	1	0.1	0.05		5	5)
Modem / router Internet	MODEM		8	8	8				considered always on
Microwave oven	uWAVE		1250	0	0.3	0.5	0.4	5	1)
Electric kettle	KETTL		1800	0	0.3	0.5	0.8	2	1)
Humidifier	HUMID		236	0					
Mobile phone	MOBIL		4	0					
Wireless fixed phone	FIXNET		1	0					
Tablet computer	TABLET		7	0			0.4		4)
Photoframe	PHOTOF		6	6					considered always on
Sauna	SAUNA		2286	0					
HiFI set	HIFI		100	10	0.9	0.2	0.5	20	2), 3)
DVD reader	DVD		80	0	0.1	0	0	0	2)
Gaming station	GAMING		180	0	0.3	0	0.1	80	2) while doing “indoor activity” for t>devD
Aquarium	AQUARI		34.5	34.5					Considered always on
Solarium	SOLARI		1500	0					
Hair dryer	HAIRDR		600	0	0.2				
TV box	TVBOX		20	16	1	*)		*)	2) *)is bound to TV usage
Laptop computer	LAPTOP		55	1	0.5	0.2	0.4	20	4), 5)
Fridge (without freezer)	REFRIG	170	65.98	0	0.2941	0.2941		25	
Oven	OVEN		2400	0	0.05	0.3	0.4	50	1)
Vacuum cleaner	VACUUM		2000	0	0.5	0.2		10	7)
Lighting	LIGHT	300	136.98	68.49	0.25				[light]
Hot water heating (boiler)	BOILER		2000	0					
Hot water heating (heat pump)	HP		1000	0					
Stove / cooking group	STOVE		1200	0	0.5	1	1	30	1)

Notes

devP(x) : **Activity probability matrix, depends on the appliance (see notes)**

devD : **Estimated duration of the activity**

=not considered in simulation

1) devP divided into: breakfast, lunch and dinner time

2) devP(1): when actively consumed. devP(2): when passively consumed. devP(3): [for multi-person households] probability to turn on another device when one is already running. devD doesnt apply to the explicit activities “listen to radio” & “watching TV”

3) devP(1): not 100% because content could be consumed on Tablet/Computer

4) devP(3): when consumed in replacement for TV/HiFi

5) computers: devP(1): probability to use it during activity “use computer”; devP(2): for activity “work/study at home”; devD for sporadic use

6) Refrigerators: devD: active cooling duration. devP(1) duty cycle during the day. devP(2) duty cycle at night

7) devP(1): probability to use it once during the day. devP(2) probability to use it more than once per day

[light] consumption based on household with energy saving lamps as principal light source. devP(1) scaling Factor for one additional person at home

Appliance use is triggered by the following activity categories/activities

- Heating : space and water heating
- Cooking : cooking, eating
- Housekeeping : cleaning, set table/wash dishes, laundrying (including drying /ironing)
- Entertainment: during cooking, during eating, during showering, during work at home, use of computer , listening to radio, watching TV, gaming
- ICT : work at home, use of computer

Appendix 2 : Monthly total energy consumption

(In Wh, per household group and per type of appliances outside PV production hours and total with PV production hours (11:00-15:00))

Flexi group

	July 13	Aug. 13	Sept. 13	Oct. 13	Nov. 13	Dec. 13	Jan. 2014	Feb. 14	March 14	April 14	May 14	Juin 14	Jully 14	Aug. 14	Sept. 14	Oct. 14	Nov. 14	Dec. 14
'WASHM'	33184	46690	53565	47854	62362	49018	61929	39869	46446	33075	36946	30315	30125	30342	46338	36323	42359	35999
'DISHW'	56852	80603	75325	51498	92968	71328	77059	61602	50141	29708	39057	48331	43506	21414	31140	34533	41696	43280
'TUMBL'	62167	137833	136500	125000	196000	167333	228833	101833	69833	63167	81333	80333	46333	46500	130833	121167	141000	154167
'DRYC'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'FRIDG'	349292	350301	337288	347408	337050	350097	351037	314248	347937	336482	351648	338877	351003	350062	338299	350182	338620	350311
'FREEZ'	900251	901751	872871	900789	872947	902483	900848	810254	902640	874669	900232	871183	902270	902484	872287	903824	871361	903099
'COFFE'	26560	34773	35520	36640	35733	33120	36907	35200	37440	30933	40640	40480	40160	33120	36160	28960	33333	31840
'TV'	168938	226168	204823	252580	216810	225366	249199	196606	220439	186818	219298	200756	245818	207584	215371	206419	228681	223341
'PC'	56056	78100	82786	77924	69183	68882	60155	57464	56195	64489	68405	73913	77345	62495	70253	73143	62839	64482
'PRINT'	175	238	319	268	221	233	184	181	238	227	255	238	233	354	299	175	175	215
'MODEM'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'uWAVE'	47167	54500	52333	65417	62667	70667	66000	56750	52667	42833	43250	45083	48083	46083	46667	54083	48500	67500
'KETTL'	80280	83640	85440	90600	97680	89520	86040	81600	82800	78600	94080	79800	86520	87240	87360	87600	87000	93360
'HUMID'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'MOBIL'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'FIXNET'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'TABLET'	147	257	239	77	185	315	158	244	83	462	499	322	351	275	249	210	207	332
'PHOTOF'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'SAUNA'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HIFI'	9073	12607	14440	12907	11227	7940	9513	12907	11020	10267	16053	14527	14633	13120	7167	16073	11127	11907
'DVD'	10091	24416	16347	20912	17173	23531	17403	16293	13829	15227	15264	13717	18043	14267	17323	15691	19888	20267
'GAMING'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'AQUARI'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'SOLARI'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HAIRDR'	5560	7920	6800	5920	8160	6400	6160	5120	5440	4560	6880	6160	6560	5040	5760	5760	6200	8640
'TVBOX'	1261	2533	2903	3419	3173	3145	3895	3035	2884	2113	2805	2898	3187	2670	3205	2910	3404	3187
'LAPTOP'	18231	17703	16859	24270	22315	19184	24761	15477	21897	18000	16570	20684	20313	17237	16863	15279	16775	21710
'REFRIG'	480875	481945	592615	686467	664976	688386	692557	618762	690808	664096	679719	661839	689507	683097	663922	692613	664932	688162
'OVEN'	33760	56640	96960	123040	136800	133760	156480	134240	103680	44000	122720	85920	76800	116160	129120	149120	115040	143360
'VACUUM'	119200	142533	150400	208933	246000	210000	192000	147200	145867	113333	155600	105600	121733	116267	156533	190800	166133	172267
'LIGHT'	646429	918078	1199112	1686632	1926895	1905986	2051149	1527206	1417281	957080	913519	740262	875387	1023688	1229983	1550010	1807179	2151890
'BOILER'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HP'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'STOVE'	113920	166800	178960	233280	203280	209520	225600	182240	168000	98000	158720	115360	126240	121200	154880	188480	164640	214880
Standby'	812120	1106000	1153400	1257680	1425160	1450440	1453600	1260840	1289280	1036480	1011200	850040	884800	881640	875320	1188160	1437800	1466240
Group																		
Dischwasher,W	152202	265126	265390	224352	351330	287679	367821	203304	166421	125950	157337	158979	119964	98255	208312	192023	225056	233445
Housekeeping	124760	150453	157200	214853	254160	216400	198160	152320	151307	117893	162480	111760	128293	121307	162293	196560	172333	180907
Cooking	301687	396353	449213	548977	536160	536587	571027	490030	444587	294367	459410	366643	377803	403803	454187	508243	448513	550940
Fridge,Freezer	1730418	1733997	1802775	1934664	1874973	1940967	1944442	1743264	1941385	1875246	1931599	1871900	1942780	1935643	1874508	1946619	1874914	1941571
Computer,Hifi,	263972	362021	338716	392356	340286	348596	365268	302207	326586	297602	339149	327054	379924	318002	330730	329900	343096	345440
Light	646429	918078	1199112	1686632	1926895	1905986	2051149	1527206	1417281	957080	913519	740262	875387	1023688	1229983	1550010	1807179	2151890
Standby	812120	1106000	1153400	1257680	1425160	1450440	1453600	1260840	1289280	1036480	1011200	850040	884800	881640	875320	1188160	1437800	1466240
Midday Consu	1037967	1418901	1268858	1608042	1449447	1552958	1563160	1510837	1585073	1409968	1605995	1390725	1414259	1869784	1449624	1500396	1569529	1750212

Facture group #1

	July 13	Aug. 13	Sept. 13	Oct. 13	Nov. 13	Dec. 13	Jan. 2014	Feb. 14	March 14	April 14	May 14	Juin 14	Jully 14	Aug. 14	Sept. 14	Oct. 14	Nov. 14	Dec. 14
'WASHM'	149327	136876	163889	162183	167137	155498	145348	152683	135144	142046	149137	137580	125914	134765	127863	144942	154442	157961
'DISHW'	219037	196794	219339	236454	261110	223863	256737	180885	187067	192195	152157	162713	196115	179527	209235	192798	196719	199508
'TUMBL'	164667	202167	274333	309167	289833	341500	281000	247500	315333	189167	137167	185667	203833	162000	215500	144333	183833	239667
'DRYC'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'FRIDG'	711658	738207	704483	808916	805862	835825	833626	749347	827027	804931	830033	799012	833048	830279	802179	826247	807286	834073
'FREEZ'	754093	756634	733321	817709	807231	836276	836962	754672	836731	808366	836670	807779	840057	838824	808709	834734	806191	838175
'COFFE'	111520	106507	102240	110133	102880	106507	114293	103200	108747	112533	118880	112160	98667	103627	112053	103893	110933	106827
'TV'	516758	456155	486444	539342	523040	513773	480376	424460	489924	445317	477474	472556	441944	439332	430801	477772	492230	515914
'PC'	138497	132249	130636	126104	116292	130262	122291	96015	115236	119027	121513	121931	107470	110455	119335	119460	128407	127930
'PRINT'	527	595	704	669	457	451	524	541	653	619	701	451	520	469	647	520	570	540
'MODEM'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'uWAVE'	178000	178500	190000	202917	202583	202667	206750	195583	195917	187833	195250	185500	179750	177167	166083	187667	194083	188917
'KETTL'	119400	117720	127080	145200	132720	137280	140640	136440	149640	134040	143640	124680	107280	133800	123960	121800	143400	142920
'HUMID'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'MOBIL'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'FIXNET'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'TABLET'	519	1141	666	1212	669	346	852	490	576	896	498	641	703	810	550	299	503	599
'PHOTOF'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'SAUNA'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HIFI'	23907	24673	27980	34220	31707	25493	19567	24720	33427	27253	27433	32387	23733	26440	25093	32587	27587	34780
'DVD'	49573	33509	37920	41685	47851	44155	42133	27312	38197	43147	38160	37253	37792	40352	51200	46629	46203	58341
'GAMING'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'AQUARI'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'SOLARI'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HAIRDR'	11040	11760	10560	10280	11600	12880	12960	10040	10960	8640	11360	10640	10800	11040	8400	10640	11760	11840
'TVBOX'	8988	7621	8455	10229	9607	9610	8526	6990	8519	7504	8077	7629	7473	7432	6991	8707	9164	9336
'LAPTOP'	85023	82863	74378	76839	76663	64951	78540	73399	75321	82111	79515	84557	66458	67885	77018	68057	71687	84190
'REFRIG'	320993	319127	309629	320091	310166	320558	319539	287133	319781	309909	320134	309530	320353	320130	308727	320972	309773	319610
'OVEN'	77600	105440	126240	168000	165280	161600	194080	158240	147520	106400	132960	84800	86400	97440	112800	131200	142400	131200
'VACUUM'	221867	245067	297067	319467	367200	320800	317467	279333	302000	246533	276667	221733	262267	268800	229067	273600	305200	264933
'LIGHT'	1609730	1805665	2208610	2967781	3235491	3481578	3393484	2794296	2625765	2060128	1802414	1560047	1605086	1877634	2245080	2744006	3133572	3560604
'BOILER'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HP'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'STOVE'	265680	278320	318160	358800	412800	372320	394240	309520	348400	292240	281040	254960	270880	286080	268000	303200	316160	277280
Standby'	3621360	3327480	3472840	5093920	4907480	4341840	4430320	4651520	3599240	3286400	3877320	3292720	3627680	3602400	3393840	3507600	4152240	4449280
Group																		
Dischwasher,V	533030	535837	657561	707805	718080	720861	683085	581068	637545	523407	438461	485960	525863	476292	552598	482073	534994	597136
Housekeeping	232907	256827	307627	329747	378800	333680	330427	289373	312960	255173	288027	232373	273067	279840	237467	284240	316960	276773
Cooking	752200	786487	863720	985050	1016263	980373	1050003	902983	950223	833047	871770	762100	742977	798113	782897	847760	906977	847143
Fridge,Freezer	1786744	1813968	1747433	1946716	1923259	1992660	1990127	1791152	1983539	1923206	1986837	1916321	1993457	1989233	1919615	1981953	1923249	1991858
Computer,Hifi,	823792	738807	767183	830300	806285	789042	752809	653928	761853	725875	753372	757404	686094	693174	711637	754031	776350	831631
Light	1609730	1805665	2208610	2967781	3235491	3481578	3393484	2794296	2625765	2060128	1802414	1560047	1605086	1877634	2245080	2744006	3133572	3560604
Standby	3621360	3327480	3472840	5093920	4907480	4341840	4430320	4651520	3599240	3286400	3877320	3292720	3627680	3602400	3393840	3507600	4152240	4449280
Midday Consu	2086151	2085574	2294729	2849552	2733914	2716951	2719337	2755383	2558111	2390554	2570731	2145643	1959667	2257540	2214392	2219984	2524102	2500641

Facture group #2

	July 13	Aug. 13	Sept. 13	Oct. 13	Nov. 13	Dec. 13	Jan. 2014	Feb. 14	March 14	April 14	May 14	Juin 14	Jully 14	Aug. 14	Sept. 14	Oct. 14	Nov. 14	Dec. 14
'WASHM'	274700	272859	294729	278922	296136	322283	283956	280925	293132	275106	273536	276269	235101	265199	230743	253561	272209	280465
'DISHW'	455491	440788	456547	473964	522824	468611	479770	390949	430609	419827	402410	389592	406104	371496	440864	415303	425482	434907
'TUMBL'	375333	448500	575500	519333	548500	720500	505333	542500	540000	354333	425500	409167	439333	392500	434667	393000	429167	529833
'DRYC'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'FRIDG'	1692677	1718394	1650448	1785181	1752745	1816669	1812872	1631004	1805152	1750285	1807147	1747512	1810787	1810963	1748212	1803589	1754857	1812696
'FREEZ'	1410595	1411481	1366272	1474165	1442095	1492089	1491700	1345740	1494163	1441578	1492578	1441416	1495848	1494204	1442324	1490373	1357907	1395403
'COFFE'	236213	244533	230933	232800	224587	231947	243947	218240	236373	232907	239733	245813	232160	229493	230613	229120	223467	222347
'TV'	995646	966117	966266	1047345	1000159	1027290	957950	884103	990909	909937	962612	961488	922180	909490	862437	910234	916583	996753
'PC'	253455	264565	260179	247419	231359	238663	236016	218467	217023	223161	246363	250697	225647	230003	225573	244024	239844	237233
'PRINT'	1217	1392	1472	1276	1073	1006	1204	1181	1231	1201	1449	1222	1182	1136	1130	1178	1142	1247
'MODEM'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'uWAVE'	343667	374833	371833	387583	386333	388583	408167	369083	374417	366167	384917	358000	354583	349333	327667	359917	349917	367667
'KETTL'	358320	383400	373680	406560	374280	395400	392520	374640	406800	384720	400200	380760	353640	385560	355800	367800	373680	376320
'HUMID'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'MOBIL'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'FIXNET'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'TABLET'	1110	2017	1394	2050	1233	644	1507	1274	1563	1792	1091	1565	1370	1671	1260	916	1142	1103
'PHOTOF'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'SAUNA'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HIFI'	62767	62640	69747	72873	62573	60413	54987	53633	64840	56907	60127	68833	70100	59480	58613	64320	56113	63527
'DVD'	90709	79307	77152	87040	86176	97131	86885	74405	83301	78731	71691	72837	74992	92624	86069	79184	80203	104517
'GAMING'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'AQUARI'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'SOLARI'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HAIRDR'	22720	23200	24000	20720	22080	24640	24120	19640	22240	20880	22400	21600	21520	23760	18280	21520	21120	22960
'TVBOX'	18497	18313	18390	21185	19535	19790	18309	16736	19367	17701	19138	17961	17380	17822	15937	18318	18770	20015
'LAPTOP'	156460	172634	148218	147803	150718	148188	150627	153336	150476	161201	156878	164732	135150	150003	145171	153358	140261	155555
'REFRIG'	672218	669738	649688	671905	649458	671164	669262	602635	670867	649611	668462	647887	670934	670330	647898	672226	592652	602541
'OVEN'	193280	247360	299360	302880	346080	348800	416640	340160	336000	235360	300160	192480	202880	233280	258240	271200	298720	309920
'VACUUM'	510933	545733	623333	676800	712267	683467	679733	586000	631600	520800	623867	500000	527067	536400	512800	553067	600933	599733
'LIGHT'	3187049	3803457	4524916	5822547	6377547	6820206	6688553	5584237	5296438	4240870	3710388	3246444	3321904	3870935	4437133	5435078	6033979	6698756
'BOILER'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HP'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'STOVE'	605840	649440	705680	735360	788160	771840	824800	705120	704560	663840	652640	580560	618480	584480	591520	661520	660880	628080
Standby'	1412520	1447280	1469400	1949720	2347880	2651240	2695480	2303640	2366840	2142480	2072960	1576840	1649520	1674800	1823320	1997120	2167760	2565920
Group																		
Dischwasher,\	1105524	1162147	1326776	1272220	1367460	1511394	1269060	1214374	1263741	1049266	1101446	1075028	1080539	1029195	1106274	1061864	1126858	1245205
Housekeeping	533653	568933	647333	697520	734347	708107	703853	605640	653840	541680	646267	521600	548587	560160	531080	574587	622053	622693
Cooking	1737320	1899567	1981487	2065183	2119440	2136570	2286073	2007243	2058150	1882993	1977650	1757613	1761743	1782147	1763840	1889557	1906663	1904333
Fridge,Freezer	3775490	3799613	3666409	3931250	3844298	3979922	3973834	3579379	3970182	3841475	3968188	3836815	3977569	3975498	3838434	3966188	3705416	3810640
Computer,Hifi	1579860	1566984	1542818	1626992	1552828	1593125	1507484	1403137	1528710	1450629	1519349	1539336	1448000	1462230	1396190	1471533	1454059	1579950
Light	3187049	3803457	4524916	5822547	6377547	6820206	6688553	5584237	5296438	4240870	3710388	3246444	3321904	3870935	4437133	5435078	6033979	6698756
Standby	1412520	1447280	1469400	1949720	2347880	2651240	2695480	2303640	2366840	2142480	2072960	1576840	1649520	1674800	1823320	1997120	2167760	2565920
Midday Consu	3412700	3591640	3803781	4104175	4189618	4365068	4474674	4043819	4375205	4049635	4028930	3581521	3600111	3838682	3818245	3796151	3842987	3971437

Control group #1

	July 13	Aug. 13	Sept. 13	Oct. 13	Nov. 13	Dec. 13	Jan. 2014	Feb. 14	March 14	April 14	May 14	Juin 14	Jully 14	Aug. 14	Sept. 14	Oct. 14	Nov. 14	Dec. 14
'WASHM'	83880	46176	59114	64148	71943	93407	63282	61171	65420	57381	74596	63634	70265	70373	87209	62335	73459	65583
'DISHW'	93647	82940	110838	97945	108124	102619	133835	106389	141903	83015	130593	88821	58586	79472	111140	109330	105862	93647
'TUMBL'	91500	34000	39167	111833	167000	219500	132667	126333	120667	85000	62833	49167	60333	52500	102000	94000	114167	120500
'DRYC'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'FRIDG'	648593	648222	626289	649344	624325	647484	641153	583200	647923	627530	650284	625605	647072	648615	626462	649306	626913	647320
'FREEZ'	481525	480683	465278	481387	464876	481406	481246	432820	481300	464850	481034	465763	480890	481239	465448	481531	465341	481767
'COFFE'	72107	69547	69973	67840	72800	68320	70933	67467	77493	76960	74827	71200	72480	71467	66827	60373	67307	64053
'TV'	227581	220323	262235	232128	236369	239155	263550	276379	333486	321730	321044	291177	267063	261061	272800	262665	258160	227168
'PC'	78225	66440	92833	65230	74103	56826	58799	56379	79090	68992	78041	76927	74426	81129	75335	65743	69535	73231
'PRINT'	222	302	339	325	271	158	205	304	347	319	304	310	218	302	406	230	336	317
'MODEM'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'uWAVE'	107417	109917	108667	121833	115750	107083	123083	154083	169167	151833	172500	163583	147667	138833	138167	139667	146833	130167
'KETTL'	117120	114480	114480	128040	128640	120840	123240	112560	125040	120120	130800	117960	115080	105720	113760	111480	113640	102480
'HUMID'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'MOBIL'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'FIXNET'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'TABLET'	798	671	708	683	557	1107	531	681	952	610	904	658	760	1211	732	799	917	792
'PHOTOF'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'SAUNA'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HIFI'	24640	17420	17580	18107	16647	17873	17067	11420	22580	14660	17607	20340	15013	18520	15433	17953	16953	14007
'DVD'	17824	18736	16603	15099	15792	19168	20437	21920	25509	30763	25445	21408	21317	20981	18789	20725	26837	13952
'GAMING'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'AQUARI'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'SOLARI'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HAIRDR'	5840	6640	6400	7280	6160	8040	7360	7360	7960	7200	8240	7440	6560	7280	6000	5920	8040	7040
'TVBOX'	2069	2384	2708	2074	2078	2365	2833	2567	3347	2854	2373	1924	1587	1933	2151	1646	1812	1631
'LAPTOP'	56463	55334	56111	55598	42460	40682	51803	60889	58571	60518	60104	58377	65839	57464	55176	57735	52672	53665
'REFRIG'	174287	173426	168009	173881	167984	173468	172609	155283	173390	166454	173130	167202	172937	173261	168117	173472	167053	172942
'OVEN'	42880	33920	50080	48160	92480	67360	80640	54240	77920	44160	74880	55040	66720	68800	70560	28000	69120	61920
'VACUUM'	114000	91067	102133	126400	110533	157867	136133	110400	153467	108133	103200	98800	102667	83067	100933	105600	125200	113867
'LIGHT'	1272498	1537216	1970364	2352232	2622616	2838345	2856031	2527252	2442310	1919437	1627705	1451070	1603203	1862433	2146283	2502073	2868992	2971054
'BOILER'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HP'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'STOVE'	189040	155920	180880	195120	237520	243520	250720	226400	265280	220000	233280	193840	213680	203120	182640	212720	226480	183680
Standby'	1712720	1633720	1649520	2155120	2215160	2477440	2423720	2227800	2234120	2050840	2076120	1760120	1671640	1937080	1725360	1892840	2183560	2221480
Group																		
Dischwasher,	269026	163116	209118	273926	347067	415526	329784	293893	327990	225397	268022	201622	189184	202345	300348	265665	293487	279729
Housekeeping	119840	97707	108533	133680	116693	165907	143493	117760	161427	115333	111440	106240	109227	90347	106933	111520	133240	120907
Cooking	528563	483783	524080	560993	647190	607123	648617	614750	714900	613073	686287	601623	615627	587940	571953	552240	623380	542300
Fridge,Freezer	1304405	1302331	1259576	1304612	1257186	1302359	1295008	1171302	1302612	1258834	1304448	1258570	1300899	1303115	1260027	1304309	1259307	1302029
Computer,Hif	407822	381610	449116	389243	388277	377334	415224	430538	523883	500447	505823	471120	446223	442601	440824	427498	427221	384764
Light	1272498	1537216	1970364	2352232	2622616	2838345	2856031	2527252	2442310	1919437	1627705	1451070	1603203	1862433	2146283	2502073	2868992	2971054
Standby	1712720	1633720	1649520	2155120	2215160	2477440	2423720	2227800	2234120	2050840	2076120	1760120	1671640	1937080	1725360	1892840	2183560	2221480
Midday Consu	1192432	1154021	1264672	1436427	1459950	1623836	1645907	1469398	1583483	1386264	1480384	1334930	1244147	1440546	1309158	1349111	1520309	1548086

Control group #2

	July 13	Aug. 13	Sept. 13	Oct. 13	Nov. 13	Dec. 13	Jan. 2014	Feb. 14	March 14	April 14	May 14	Juin 14	Jully 14	Aug. 14	Sept. 14	Oct. 14	Nov. 14	Dec. 14
'WASHM'	191930	209631	211174	240947	267743	212257	222732	224410	264983	218726	233504	224491	181780	236969	237023	250042	279057	234993
'DISHW'	291270	305144	334248	334173	344201	362749	357170	347971	375115	372099	397584	335756	304918	333796	365238	368329	360186	356567
'TUMBL'	223667	325667	356333	328500	368167	459000	482500	515500	422500	299833	425333	312833	270500	360667	447667	340333	383667	390500
'DRYC'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'FRIDG'	1154047	1151392	1117135	1240096	1194379	1237859	1235867	1106138	1235296	1190838	1232788	1197328	1235271	1233986	1193869	1236067	1199078	1239526
'FREEZ'	920796	925927	888962	995203	963697	996063	986833	897733	993997	965077	998794	962069	994145	996597	963736	994390	962394	996694
'COFFE'	129547	132853	128053	139733	130133	135307	124693	116160	132907	132480	141387	129013	126507	128000	134133	139200	124427	132053
'TV'	433463	487543	423650	439696	456378	498125	475449	431462	468174	453642	457403	425957	465496	493024	461602	445383	464785	490949
'PC'	144078	133349	138607	151265	123567	134530	141533	133547	152592	156105	167413	138028	139275	142428	145545	148691	150275	143557
'PRINT'	664	780	590	800	679	669	560	560	615	653	856	830	744	695	923	650	903	773
'MODEM'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'uWAVE'	168083	185250	169583	195750	186333	188750	172000	147250	179583	177917	189083	174083	164167	170917	183167	174917	185667	193667
'KETTL'	221040	243120	234960	260640	263520	259080	258360	227400	255360	248760	267120	247800	240000	258960	255480	254760	261960	256080
'HUMID'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'MOBIL'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'FIXNET'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'TABLET'	1183	1489	878	1207	1195	1140	1283	1040	1208	1397	1689	1038	958	1411	1013	1155	1204	944
'PHOTOF'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'SAUNA'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HIFI'	45853	42380	44787	43553	45853	43887	40027	46900	44227	50953	40867	41947	44113	49007	41133	48560	45500	45413
'DVD'	33232	38699	29717	33680	40213	36800	37829	32187	39008	40128	42411	35189	33824	31936	33499	33008	36619	39509
'GAMING'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'AQUARI'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'SOLARI'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HAIRDR'	12480	12400	11840	9760	12960	10800	10800	11640	12560	12400	10240	10640	12480	11920	11320	10160	15760	14400
'TVBOX'	12057	13607	11596	12185	12554	13639	12818	11527	12292	12165	11878	11596	12737	13321	12487	12139	13165	13650
'LAPTOP'	92114	102700	93925	101622	104273	94563	93159	88506	93207	102696	107122	91351	107166	103041	115757	101889	107217	104918
'REFRIG'	269215	269697	260574	269338	258926	269364	265335	239834	266046	260066	270056	258618	268403	270163	260504	268408	259512	269357
'OVEN'	73280	137760	146400	194400	232640	197120	216000	212800	202080	121760	179200	95520	90880	160960	152800	192160	181760	198080
'VACUUM'	285600	295600	369333	400133	451733	433867	446933	384667	443200	325067	363200	345600	310667	381333	384533	356667	428400	518933
'LIGHT'	1923964	2405615	2728194	3541542	3994561	4340423	3860544	3372337	3157243	2684416	2300172	1865838	2045770	2384402	2853012	3358740	3932089	4401739
'BOILER'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'HP'	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
'STOVE'	308480	359440	404640	454880	499840	510240	506960	443280	488560	410400	425280	348160	349600	405360	411920	386880	474960	427120
Standby'	2502720	2765000	3030440	3523400	3750920	3864680	3886800	3093640	3343280	3027280	2916680	2196200	2449000	2521680	2404760	3043080	3043080	3656120
Group																		
Dischwasher,\	706867	840442	901756	903620	980111	1034006	1062401	1087881	1062598	890658	1056422	873080	757197	931431	1049927	958704	1022910	982059
Housekeeping	298080	308000	381173	409893	464693	444667	457733	396307	455760	337467	373440	356240	323147	393253	395853	366827	444160	533333
Cooking	900430	1058423	1083637	1245403	1312467	1290497	1278013	1146890	1258490	1091317	1202070	994577	971153	1124197	1137500	1147917	1228773	1207000
Fridge,Freezer	2344059	2347016	2266671	2504637	2417002	2503286	2488036	2243706	2495339	2415980	2501638	2418016	2497819	2500746	2418109	2498864	2420984	2505577
Computer,Hif	762644	820548	743752	784008	784712	823353	802658	745728	811323	817739	829637	745935	804312	834861	811958	791475	819668	839714
Light	1923964	2405615	2728194	3541542	3994561	4340423	3860544	3372337	3157243	2684416	2300172	1865838	2045770	2384402	2853012	3358740	3932089	4401739
Standby	2502720	2765000	3030440	3523400	3750920	3864680	3886800	3093640	3343280	3027280	2916680	2196200	2449000	2521680	2404760	3043080	3043080	3656120
Midday Consu	2017926	2268592	2321583	2653582	2798954	2779549	2940819	2498141	2753095	2320436	2452173	2135825	2222598	2304464	2209907	2419772	2493676	2756009

Appendix 3 : Variables' definition and descriptive statistics

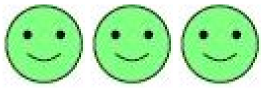
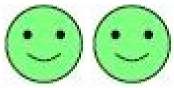
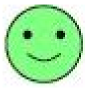
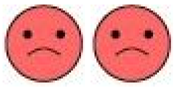
Variable	Definition
prop1115	Proportion of electricity consumption between 11am and 3pm
conso1115	Electricity consumption (kWh) between 11am and 3pm
consotot	Electricity consumption (kWh) per day
Education level	Dummy variable indicating whether the highest education level achieved by the members of the household is high (university or applied university)
Age	Age of the respondent: < 40 (base category), 40-49, 50-64, > 64
Number of people in HH	Number of people in the household: 1, 2, 3, 4, 5, > 5
Solar panels	Dummy variable indicating whether the household holds a solar panel at home
Ecological bulbs > 50%	Dummy variable indicating whether the percentage of ecological bulbs used by the household is larger than 50%
Temp out of 11am-3pm	Average temperature out of the period from from 0am to 11am and from 3pm to 24pm
Temp in 11am-3pm	Average temperature in the period from 11am to 3pm
Holidays	Dummy variable indicating whether there is a scholar holiday or a single-day holiday
Saturday	Dummy variable for Saturday
Sunday	Dummy variable for Sunday

	Control 1		Facture 1		Flexi		Control 2		Facture 2	
	Before	After	Before	After	Before	After	Before	After	Before	After
prop1115	0.20	0.21	0.18	0.19	0.20	0.24	0.19	0.20	0.22	0.23
	(0.10)	(0.10)	(0.09)	(0.09)	(0.10)	(0.15)	(0.10)	(0.11)	(0.11)	(0.11)
conso1115	1.70	1.69	1.90	1.69	1.73	1.72	1.90	1.73	2.18	2.02
	(1.48)	(1.55)	(2.11)	(1.82)	(1.71)	(1.74)	(1.63)	(1.49)	(1.60)	(1.58)
consotot	7.84	7.54	9.65	8.10	8.05	7.18	9.36	8.24	9.83	8.71
	(4.86)	(5.21)	(8.80)	(7.12)	(5.80)	(5.69)	(5.68)	(5.15)	(4.72)	(4.41)
Education level	0.33	0.35	0.25	0.22	0.36	0.36	0.55	0.56	0.43	0.43
	(0.47)	(0.48)	(0.43)	(0.41)	(0.48)	(0.48)	(0.50)	(0.50)	(0.49)	(0.50)
Age: < 40	0.33	0.35	0.45	0.42	0.27	0.27	0.15	0.15	0.19	0.19
	(0.47)	(0.48)	(0.50)	(0.49)	(0.45)	(0.45)	(0.36)	(0.36)	(0.39)	(0.39)
Age: 40-49	0.33	0.35	0.10	0.10	0.23	0.23	0.20	0.20	0.33	0.33
	(0.47)	(0.48)	(0.30)	(0.31)	(0.42)	(0.42)	(0.40)	(0.40)	(0.47)	(0.47)
Age: 50-64	0.12	0.09	0.35	0.37	0.23	0.23	0.45	0.44	0.38	0.38
	(0.33)	(0.28)	(0.48)	(0.48)	(0.42)	(0.42)	(0.50)	(0.50)	(0.49)	(0.49)
Age: 65+	0.21	0.22	0.10	0.10	0.27	0.27	0.20	0.20	0.10	0.10
	(0.41)	(0.41)	(0.30)	(0.31)	(0.45)	(0.45)	(0.40)	(0.40)	(0.29)	(0.29)
Number of people in HH	2.46	2.52	2.65	2.68	2.36	2.36	2.65	2.66	2.86	2.86
	(1.41)	(1.41)	(1.46)	(1.48)	(1.26)	(1.26)	(1.11)	(1.11)	(1.25)	(1.25)
Solar panels	0.29	0.30	0.10	0.10	0.23	0.23	0.25	0.25	0.14	0.14
	(0.45)	(0.46)	(0.30)	(0.31)	(0.42)	(0.42)	(0.43)	(0.43)	(0.35)	(0.35)
Ecological bulbs > 50%	0.25	0.26	0.30	0.27	0.36	0.36	0.60	0.61	0.38	0.38
	(0.43)	(0.44)	(0.46)	(0.44)	(0.48)	(0.48)	(0.49)	(0.49)	(0.49)	(0.48)
Temp out of 11am-3pm	3.64	7.96	3.61	7.91	3.63	7.96	3.63	8.01	3.63	8.00
	(5.00)	(5.64)	(4.99)	(5.65)	(5.00)	(5.63)	(5.00)	(5.63)	(5.00)	(5.63)
Temp in 11am-3pm	5.04	10.11	5.01	10.06	5.03	10.11	5.03	10.17	5.03	10.16
	(5.47)	(6.33)	(5.46)	(6.34)	(5.47)	(6.33)	(5.47)	(6.32)	(5.47)	(6.32)
Holidays	0.23	0.26	0.23	0.26	0.23	0.26	0.23	0.26	0.23	0.26
	(0.42)	(0.44)	(0.42)	(0.44)	(0.42)	(0.44)	(0.42)	(0.44)	(0.42)	(0.44)
Saturday	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)
Sunday	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14	0.14
	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)	(0.35)
# Obs.	2,204	7,681	1,834	6,388	2,024	7,346	1,840	6,602	1,932	6,952

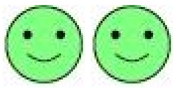
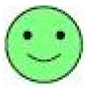
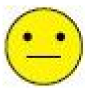
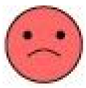
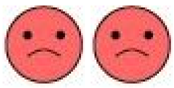
Before: 01OCT2013-31DEC2013. After: 01FEB2014-31DEC2014. Standard deviations in parentheses.

Appendix 4 : Thresholds used to define the number of smileys/frownies

Change (in percentage points) with respect to household's own proportion in previous period

Monthly letters	Weekly letters	Smileys/frownies shown
> +4	> +5	
> +2	> +2.5	
> +0.5	> +0.5	
[–0.5; +0.5]	[–0.5; +0.5]	
< –0.5	< –0.5	
< –2	< –2.5	
< –4	< –5	

Difference (in percentage points) between household proportion and average proportion

Monthly letters	Weekly letters	Smileys/frownies shown
> +6	> +10	
> +3	> +5	
> +1	> +1	
[–1; 1]	[–1; +1]	
< –1	< –1	
< –3	< –5	
< –6	< –10	

Appendix 5 : Questionnaire

Appendix 6 : Samples of the letters

Français

Intro

Bienvenue au questionnaire du projet Flexi.

Le projet Flexi a pour objectif d'étudier le potentiel de flexibilisation de la consommation d'électricité en vue de l'adapter à la production d'électricité à partir de sources renouvelables (en particulier, la production photovoltaïque). **Planair, Groupe e, l'EPFL et l'UniNE** sont les partenaires du projet Flexi, qui bénéficie également du soutien financier de l'Office Fédéral de l'Énergie (OFEN) et du soutien logistique de la commune de Cernier.

Dans le cadre de ce projet, le département d'économie de l'Université de Neuchâtel (IRENE) mène une étude afin de mesurer le potentiel de flexibilisation de la consommation d'électricité.

Pour répondre au questionnaire en totalité, il faut compter une quinzaine de minutes. Vous avez la possibilité d'interrompre le questionnaire et d'y revenir dans les 7 jours suivants. Vos réponses seront sauvegardées.

Les informations collectées seront bien évidemment traitées de façon anonyme et confidentielle.

Informations maison / appartement, appareils du ménage et habitudes

Vous habitez dans

un appartement	une maison (maison mitoyenne incluse)
○	○

Êtes-vous propriétaire ou locataire de votre logement?

propriétaire	locataire
○	○

Quelle est la surface habitable de votre logement en m^2?

moins de 80	entre 80 et 99	entre 100 et 149	entre 150 et 200	plus de 200
○	○	○	○	○

Combien de pièces votre logement possède-t-il?
(merci de bien vouloir inclure cuisine, séjour et chambres dans votre réponse)

1	1.5	2	2.5	3	3.5	4	4.5	5	plus de 5
○	○	○	○	○	○	○	○	○	○

Comment le chauffage de votre logement fonctionne-t-il?

Dans votre appartement, le chauffage est

Individuel	Collectif	Ne sait pas
○	○	○

Comment l'eau est-elle chauffée dans votre logement?

Disposez-vous d'un appoint solaire?

Oui	Non
○	○

Quels appareils ménagers possédez-vous?
(ne pas mentionner les équipements collectifs de l'immeuble)

- ☐ Machine à laver le linge
- ☐ Séchoir à linge
- ☐ Armoire à sécher le linge
- ☐ Lave-vaisselle
- ☐ Frigo (sans congélateur)
- ☐ Frigo (avec congélateur)
- ☐ Congélateur (séparé du frigo)
- ☐ Four traditionnel
- ☐ Four micro-ondes
- ☐ Machine à café
- ☐ Bouilloire électrique
- ☐ Humidificateur / évaporateur
- ☐ Télévision
- ☐ Lecteur DVD
- ☐ Box TV
- ☐ Ordinateur fixe
- ☐ Ordinateur portable
- ☐ Tablette
- ☐ Modem Internet
- ☐ Imprimante/scanner/fax
- ☐ Console de jeux vidéo
- ☐ Téléphone portable
- ☐ Téléphone fixe sans fil
- ☐ Chaîne Hifi / Radio/ Dock Station
- ☐ Aspirateur
- ☐ Cadre photo numérique
- ☐ Aquarium
- ☐ Sauna
- ☐ Solarium
- ☐ Séchoir à cheveux

Combien de fois par semaine utilisez-vous la machine à laver le linge?

Jamais	1-2 fois	3-5 fois	6-9 fois	10 ou plus
○	○	○	○	○

Après avoir utilisé la machine à laver le linge, à quelle fréquence utilisez-vous le séchoir?

Jamais	dans ~25% des cas	dans ~50% des cas	dans ~75% des cas	Toujours
○	○	○	○	○

Combien de fois par semaine utilisez-vous le lave-vaisselle?

0-1	2-3	4-5	6-7	plus de 7
○	○	○	○	○

Combien des appareils suivants possédez-vous?

	1	2	3	plus de 4
Télévision(s)	○	○	○	○
Ordinateur(s)	○	○	○	○
Chaîne Hifi / Radio/ Dock Station	○	○	○	○
Console(s) de jeux vidéo	○	○	○	○

Combien d'heures par jour utilisez-vous les appareils suivants (à votre domicile)?

(si plusieurs appareils semblables, cumuler les heures)

	0-3 heures	4-6 heures	7-9 heures	plus de 9 heures
Télévision	○	○	○	○
Ordinateur	○	○	○	○
Chaîne Hifi / Radio / Dock Station	○	○	○	○
Console(s) de jeux vidéo	○	○	○	○

Lorsqu'ils ne sont pas en fonction, les appareils suivants sont généralement

	complètement éteints	en mode stand-by
Télévision(s)	○	○
Ordinateur(s)	○	○
Chaîne Hifi / Radio / Dock Station	○	○
Box TV	○	○

Mode d’éclairage (principal) :

Quel pourcentage d'ampoules basse consommation utilisez vous?

0	~25%	~50%	~75%	100%
○	○	○	○	○

Comment votre cuisinière fonctionne-t-elle?

Électricité	Gaz	Autre
○	○	○

Cuisinez-vous en utilisant les couvercles?

Jamais	Dans la plupart des cas	Ça dépend
○	○	○

Combien de repas par semaine sont préparés à la maison?

	Aucun	1-2	3-4	5-6	7
à midi	○	○	○	○	○
le soir	○	○	○	○	○

Chaque jour, combien de douches sont-elles prises à la maison?

0-2	3-5	plus de 5
○	○	○

Informations sur les personnes du ménage

Nombre de personnes dans le ménage (enfants inclus)

1	2	3	4	5	plus de 5
○	○	○	○	○	○

De quel type est votre ménage?

Famille / Couple	Famille monoparentale	Personne seule	Co-location	Autre
○	○	○	○	○

Nombre d'enfants

0	1	2	3	plus de 3
○	○	○	○	○

Nombre d’enfants jusqu'à 10 ans

0	1	2	3	plus de 3
○	○	○	○	○

Avez-vous une personne qui s'occupe des enfants à domicile pendant la journée?

Oui	Non
○	○

Avez-vous recours à une femme de ménage?

Oui	Non
○	○

Quand la femme de ménage travaille-t-elle chez-vous?

	Lundi	Mardi	Mercredi	Jeudi	Vendredi	Samedi	Dimanche
Matin	☐	☐	☐	☐	☐	☐	☐
Après-midi	☐	☐	☐	☐	☐	☐	☐

Activité des personnes du ménage

	Emploi à temps plein	Emploi à temps partiel	Étudiant ou écolier	Sans emploi	Retraité	Autre
Personne 1	○	○	○	○	○	○
Personne 2	○	○	○	○	○	○
Personne 3	○	○	○	○	○	○
Personne 4	○	○	○	○	○	○
Personne 5	○	○	○	○	○	○
Personne 6	○	○	○	○	○	○

Quel est le niveau d'éducation le plus élevé dans le ménage?

- ○ Autres formations complètes
- ○ Sans formation prof. complète
- ○ Formation acquise en entreprise
- ○ Apprentissage complet (CFC)
- ○ Maturité
- ○ Formation prof. supérieure, écoles sup.
- ○ Haute école spécialisée (HES), HEP
- ○ Haute école universitaire (UNI, EPF)
- ○ Master
- ○ Doctorat

Pour chaque personne active du ménage, quelle est la catégorie qui représente le mieux son activité

	Directeurs, cadres de direction, gérants	Prof. intellectuelles et scientifiques	Professions intermédiaires	Employés de type administratif	Pers. des services, commerçants, vendeurs	Agriculteurs, sylviculteurs	Métiers de l'industrie et de l'artisanat	Conduc et assemb
Personne 1								
Personne 2								
Personne 3								
Personne 4								
Personne 5								
Personne 6								

Horaire de travail

	Régulier	Irrégulier
Personne 1		
Personne 2		
Personne 3		
Personne 4		
Personne 5		
Personne 6		

Nombre de personnes du ménage qui travaillent le samedi ou le dimanche

0	1	2	3	plus de 3

Lieu de travail

	Extérieur	Domicile	Extérieur et domicile (suivant les jours)
Personne 1			
Personne 2			
Personne 3			
Personne 4			
Personne 5			
Personne 6			

Y a-t-il des personnes du ménage qui passent la semaine (ou une partie) hors du domicile principal pour des raisons professionnelles ou d'études?

0	1	2	3	plus de 3

Entre lundi et vendredi, de 8 à 18 heures, combien de jours les personnes sont-elles *présentes* au domicile principal?

	0	0.5	1	1.5	2	2.5	3	3.5	4	4.5	5
Personne 1											
Personne 2											
Personne 3											
Personne 4											
Personne 5											
Personne 6											

Information sur le répondant

Quelle est votre position dans le ménage?

Conjoint / Père	Conjointe / Mère	Fils / Fille	Co-locataire	Autre

Quel est votre âge?

moins de 18	18-29	30-39	40-49	50-64	plus de 65

Combien d'heures par mois l'ensemble des personnes du ménages investissent-elles dans des activités bénévoles?
(associations sportives, religieuses, caritatives, politiques, ...)

0	1-5	6-10	plus de 10

Quelle est la méthode que vous privilégiez pour payer vos factures?

Office postal	E-banking (online)	Débit automatique (LSV)	Autre

Indiquez le revenu mensuel de votre ménage
(brut et en Francs Suisses)

Combien de voitures votre ménage possède-t-il?

0	1	2	3	plus de 3

Combien de kilomètres par an les personnes du ménage effectuent-elles en voiture?

Lorsque vous êtes à la maison, quelles activités de loisir pratiquez-vous?

- jardinage
- ordinateur
- bricolage
- cuisine
- lecture
- TV
- musique
- autre

Dans la deuxième partie du questionnaire, nous allons vous poser des questions concernant votre sensibilité à l'égard des problématiques environnementales. Il n'y a pas de réponses correctes ou incorrectes. Il faut répondre selon vos sentiments et points de vue.

Vous sentez-vous concerné par le thème de l'effet de la consommation d'énergie sur le "changement climatique"?
(1 = pas du tout, ..., 5 = très concerné)

1 2 3 4 5

Pensez-vous que votre comportement et vos habitudes peuvent avoir une influence positive pour lutter contre le réchauffement climatique?
(1 = aucune influence, ..., 5 = une grande influence)

1 2 3 4 5

Êtes-vous attentif à votre consommation d'énergie?
(1 = pas du tout, ..., 5 = très attentif)

1 2 3 4 5

Pour vous, quelle est la raison la plus importante de faire des économies d'énergie?

Économiser de l'argent | Préserver l'environnement | Les deux sont également importantes

En termes d'électricité, quelles mesures concrètes avez-vous déjà adoptées (plusieurs réponses possibles)?

- Ampoules économiques
- Appareils classe A, A+, A++
- Arrêt des appareils en stand-by à l'aide d'interrupteurs
- Autres mesures
- Aucune mesure

Diriez-vous que vous avez changé votre manière d'utiliser l'énergie (comportements, habitudes) au cours des deux dernières années?

Oui	Non
○	○

Comment estimez-vous votre potentiel d'économie énergétique?

Petit	Moyen	Grand	Ne sait pas
○	○	○	○

Comment jugez-vous les énergies renouvelables (provenant du soleil, du vent, de l'eau, du bois)?
(1 = pas nécessaires, ..., 5 = nécessaires)

1	2	3	4	5
○	○	○	○	○

Attachez-vous de l'importance à la manière dont votre électricité est produite (à partir de sources renouvelable plutôt que non renouvelables)?
(1 = pas du tout, ..., 5 = beaucoup)

1	2	3	4	5
○	○	○	○	○

Accepteriez-vous de payer plus pour pouvoir bénéficier d'une énergie renouvelable à la place d'une énergie conventionnelle?

Non	Jusqu'à 5% en plus	Jusqu'à 10% en plus	Jusqu'à 20% en plus	Plus de 20% en plus
○	○	○	○	○

Seriez-vous d'accord de contribuer solidairement à un fond pour le développement des énergies renouvelables (par exemple au travers d'une taxe sur l'électricité)

Oui	Non	Ça dépend
○	○	○

Une limitation des possibilités de recours contre les projets de production d’énergies renouvelables est

Efficace	Inefficace	Ça dépend
○	○	○

Si vous deviez acheter une voiture, quelle importance dans la décision du choix donneriez-vous aux critères suivants?
(1 = aucune, ..., 5 = beaucoup d'importance)

	1	2	3	4	5
Prix	○	○	○	○	○
Consommation énergétique	○	○	○	○	○
Marque	○	○	○	○	○
Confort	○	○	○	○	○
Sécurité	○	○	○	○	○

Au supermarché, quelle importance accordez-vous aux caractéristiques suivantes pour acheter vos produits?
(1 = aucune, ..., 5 = beaucoup d'importance)

	1	2	3	4	5
Prix	○	○	○	○	○
Qualité	○	○	○	○	○
Quantité	○	○	○	○	○
Production biologique	○	○	○	○	○
Production locale	○	○	○	○	○
Actions / promotions	○	○	○	○	○
Publicité	○	○	○	○	○

Au moment de choisir un appareil électroménager, quelle importance accordez-vous aux caractéristiques suivantes?
(1 = aucune, ..., 5 = beaucoup d'importance)

	1	2	3	4	5
Prix	○	○	○	○	○
Consommation énergétique	○	○	○	○	○
Marque	○	○	○	○	○
Actions / promotions	○	○	○	○	○
Publicité	○	○	○	○	○

Vous venez de répondre à la dernière question.
Avant de valider définitivement, vous pouvez revenir en arrière afin de vérifier et/ou modifier vos réponses. Après avoir validé le questionnaire, vous n'aurez plus la possibilité d'y apporter des modifications.

Si vous désirez participer au tirage au sort permettant de gagner la somme de **200 CHF en espèces**, et/ou si vous désirez recevoir des informations concernant les résultats qui seront obtenus au terme du projet, veuillez s'il vous plaît inscrire votre adresse électronique dans les champs ci-dessous. Nous utiliserons cette adresse électronique pour vous transmettre les informations.

Nous vous remercions de votre participation.

Tirage au sort

Résultats du projet

Pour toute question ou clarification, veuillez s'il vous plaît contacter projet.flexi@unine.ch

Projet Flexi

Neuchâtel, le 3 février 2014

Madame, Monsieur,

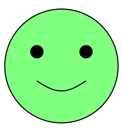
Dans le cadre du projet Flexi, votre ménage a été sélectionné pour prendre part à une expérience qui va se dérouler entre janvier et décembre 2014. Votre participation n'implique aucun coût ni engagement, mais pourrait vous permettre de gagner des récompenses en espèces.

Chaque mois, les 22 ménages participant à l'expérience seront classés en fonction de la proportion d'électricité consommée entre 11 et 15 heures. Votre objectif est de maximiser la *part* d'électricité que vous consommez dans cette tranche horaire. Autrement dit, votre objectif est de *déplacer* votre consommation vers cette tranche horaire, sans toutefois augmenter votre consommation totale. Un moyen d'atteindre ce but serait par exemple de programmer votre machine à laver le linge afin qu'elle démarre à 11 heures. Les ménages dont la consommation augmente artificiellement seront exclus du classement.

Chaque mois, les récompenses suivantes seront distribuées (en espèces) :

1$^{\text{er}}$-5$^{\text{ème}}$: 50 CHF   6$^{\text{ème}}$-10$^{\text{ème}}$: 30 CHF   11$^{\text{ème}}$-15$^{\text{ème}}$: 10 CHF

Le mois passé, votre ménage s'est classé **12$^{\text{ème}}$** et vous recevez donc **10 CHF** :



Des informations détaillées concernant la façon d'établir le classement sont disponibles sur le site web du projet. Le classement anonymisé est disponible sur `http://www.unine.ch/flexirank`. Votre ménage y est identifié à l'aide du code `EC33tp`.

Merci de l'attention portée à ce courrier. Cordiales salutations,

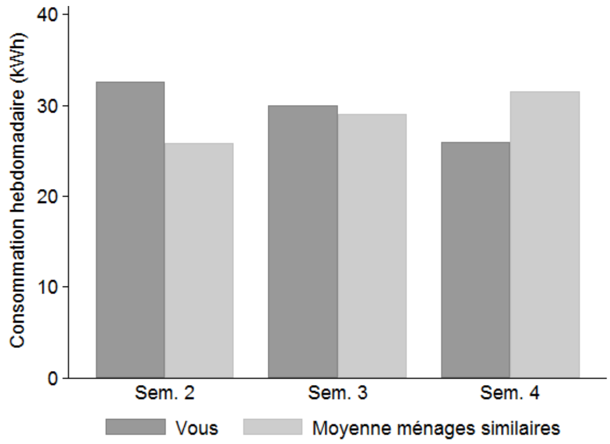
L'équipe du projet Flexi

Projet Flexi

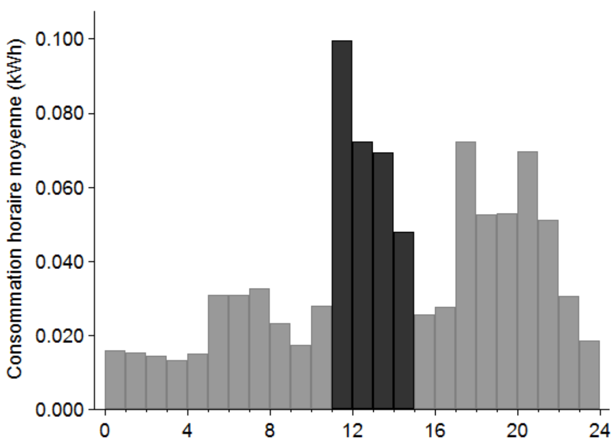
Neuchâtel, le 27 janvier 2014

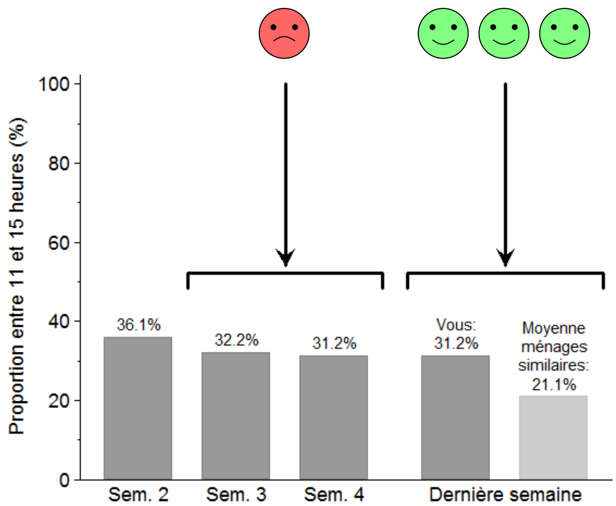
Madame, Monsieur,

Cette semaine, vous avez consommé 26 kWh. Le coût hebdomadaire de l'électricité se monte ainsi à CHF 5.14 (TVA et redevances communales non-comprises). Ces valeurs sont indicatives. Légalement, seule la facture que vous recevrez de Groupe E fait foi.
Par rapport à la semaine dernière, votre consommation a diminué. Votre consommation est actuellement inférieure à la consommation moyenne des ménages similaires.



Votre profil de consommation horaire pour la semaine écoulée est représenté ci-dessous (graphique de gauche). Votre consommation entre 11 et 15 heures représente 31% de votre consommation totale (graphique de droite). Par rapport à la semaine précédente, vous avez **diminué** cette proportion. Pour la semaine écoulée, votre comportement est **meilleur** que celui de la moyenne des ménages similaires. *Déplacer* votre consommation vers cette plage horaire, sans toutefois augmenter votre consommation totale, permet de limiter l'écart entre production solaire et consommation d'électricité. Un moyen d'atteindre ce but serait par exemple de repasser en fin de matinée ou en début d'après-midi.



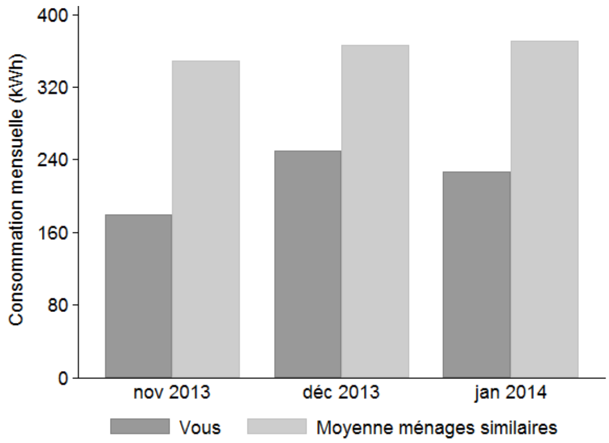


Merci de l'attention portée à ce courrier. Cordiales salutations,
L'équipe du projet Flexi

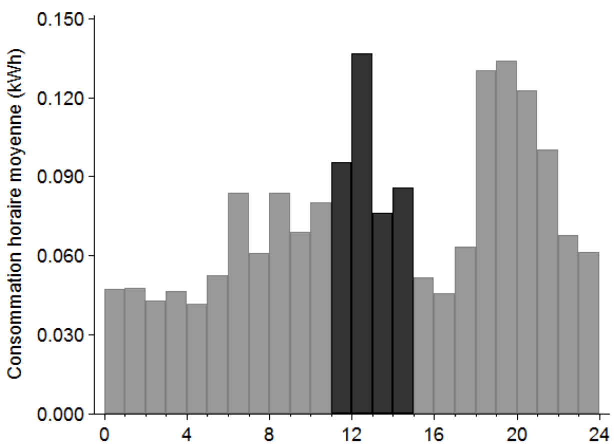
Neuchâtel, le 3 février 2014

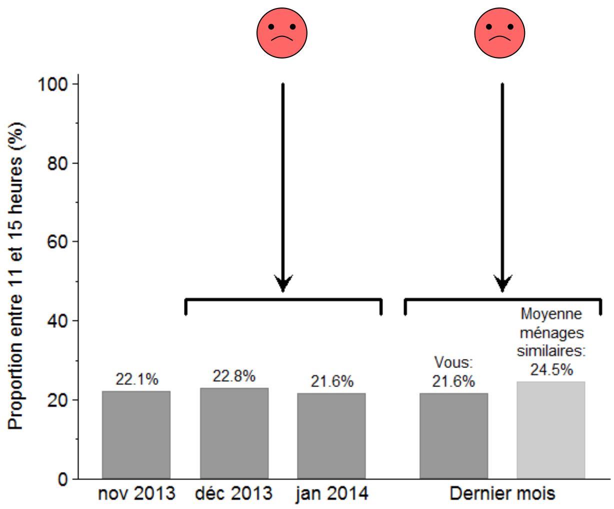
Madame, Monsieur,

Ce mois, vous avez consommé 226 kWh. Le coût mensuel de l'électricité se monte ainsi à CHF 44.93 (TVA et redevances communales non-comprises). Ces valeurs sont indicatives. Légalement, seule la facture que vous recevrez de Groupe E fait foi.
Par rapport au mois passé, votre consommation a diminué. Votre consommation est actuellement inférieure à la consommation moyenne des ménages similaires.



Votre profil de consommation horaire pour le mois écoulé est représenté ci-dessous (graphique de gauche). Votre consommation entre 11 et 15 heures représente 22% de votre consommation totale (graphique de droite). Par rapport au mois précédent, vous avez **diminué** cette proportion. Pour le mois écoulé, votre comportement est **moins bon** que celui de la moyenne des ménages similaires. *Déplacer* votre consommation vers cette plage horaire, sans toutefois augmenter votre consommation totale, permet de limiter l'écart entre production solaire et consommation d'électricité. Un moyen d'atteindre ce but serait par exemple d'enclencher le lave-linge en fin de matinée ou en début d'après-midi.





Merci de l'attention portée à ce courrier. Cordiales salutations,
L'équipe du projet Flexi