Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Department of the Environment,
Transport, Energy and Communication DETEC

Swiss Federal Office of Energy SFOE
Energy Research

Final report

Energy efficiency, bounded rationality and energy-related financial literacy in the Swiss household sector

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Date: 03. July 2018

Place: Bern

Publisher:
Swiss Federal Office of Energy SFOE
Research Programme Energy - economics - society (EES)
CH-3003 Bern
www.bfe.admin.ch
energieforschung@bfe.admin.ch

Agent:
Centre for Energy Policy and Economics (CEPE)
ETH Zürich
Zürichbergstrasse 18
CH-8032 Zürich
www.eepe.ethz.ch

Author:
Prof. Dr. Massimo Filippini, CEPE, mfilippini@ethz.ch
Dr. Julia Blasch, VU Amsterdam, julia.blasch@vu.nl
Nina Boogen, CEPE, nboogen@ethz.ch
Nilkanth Kumar, CEPE, nkumar@ethz.ch

SFOE head of domain: Anne-Kathrin Faust, Anne-Kathrin.Faust@bfe.admin.ch
SFOE programme manager: Anne-Kathrin Faust, Anne-Kathrin.Faust@bfe.admin.ch
SFOE contract number: SI/501106-01

Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Centre for Energy Policy and Economics
Department of Management, Technology and Economics

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Bundesamt für Energie BFE
Office fédéral de l'énergie OFEN
Ufficio federale dell'energia UFE

Energy Efficiency, Bounded rationality and energy-related financial literacy in the Swiss Household Sector

Final Report for BFE

Prof. Massimo Filippini
Dr. Julia Blasch
Dr. Nina Boogen
Nilkanth Kumar

Centre for Energy Policy and Economics
ETH Zurich
Zürichbergstrasse 18
CH-8032 Zurich

June 2018

Zusammenfassung

Einleitung

Mehr als 60% des Endenergieverbrauchs der Schweiz wird durch Energie aus fossilen Brennstoffen gedeckt. Im Jahr 2014 entfielen beinahe 30% des gesamten Endenergieverbrauchs in der Schweiz auf den Haushaltssektor, wobei rund 58% des Haushaltsendenergieverbrauchs aus fossilen Brennstoffen (BFE, 2015) gewonnen wurden. Die Erhöhung der Energieeffizienz im Haushaltssektor ist essentiell, um den gesamten fossilen Energieverbrauch und die damit verbundenen CO_2-Emissionen in der Schweiz zu verringern, und um die energiepolitischen Ziele der Schweizer *Energiestrategie 2050* zu erreichen.

Auch wenn erhebliche Anstrengungen unternommen werden müssen, um den Verbrauch von Brennstoffen im Haushaltssektor zu verringern, so gibt es doch auch ein bedeutendes Potenzial für Effizienzsteigerungen im Stromverbrauch. In der Schweiz wird Elektrizität hauptsächlich aus Wasserkraft (60%) und Kernkraft (40%) erzeugt. Nach dem Atomunfall in Fukushima Daiichi im Jahr 2011 beschloss der Bundesrat den Ausstieg aus der Kernenergie. Die *Energiestrategie 2050* hat sich zum Ziel gesetzt, erstens den Stromverbrauch zu senken, indem das Effizienzniveau im Stromverbrauch erhöht wird, und zweitens den Anteil erneuerbarer Energien wie Wind- und Solarenergie an der Stromerzeugung zu erhöhen. In diesem Zusammenhang scheint der Haushaltssektor ein grosses Potenzial für Effizienzgewinne zu bieten und könnte einen wichtigen Beitrag zur Senkung des gesamten Endenergieverbrauchs leisten.

Ein wichtiges Element zur Senkung des Stromverbrauchs in Haushalten ist die Förderung von energieeffizienter Beleuchtung und Haushaltsgeräten. Eine tiefe Adoptionsquote von energieeffizienter Technologien hängt häufig mit der sogenannten ‘Energieeffizienzlücke’ (engl. energy-efficiency gap) zusammen. Das heisst mit der gängigen Beobachtung, dass Entscheidungsträger nicht das energieeffizienteste Haushaltsgerät wählen, selbst wenn dieses Haushaltsgerät aus individueller Sicht die kostengünstigste Wahlmöglichkeit (Minimierung der Betriebskosten über die Lebenszeit) darstellt. Die wissenschaftliche Literatur liefert mehrere Erklärungen für diese Lücke. Eine davon könnte mit der Tatsache zusammenhängen, dass Konsumenten *beschränkt rational* (engl. boundedly rational) sind. Tatsächlich ist die Auswahl des Gerätes mit den geringsten Lebenszeitkosten eine anspruchsvolle Aufgabe. Um finanziell rationale Entscheidungen treffen zu können, muss man die gesamten Kosten von Haushaltsgeräten über deren gesamte Lebensdauer vergleichen. Dies erfordert Wissen über den Kaufpreis, den Stromverbrauch, die erwartete Nutzungshäufigkeit, die aktuellen und zukünftigen Strompreise usw., sowie die Kompetenz, informierte energiebezogene Investitionen tätigen zu können (engl. energy-related investment literacy), welche die Verarbeitung und Verknüpfung der oben genannten Informationen umfasst.

Vor diesem Hintergrund ist es wichtig, dass die politischen Entscheidungsträger das tatsächliche Potenzial von Stromeinsparungen im Schweizer Haushaltssektor kennen. Das Energieeffizienzniveau von Haushalten kann einerseits mit einem Bottom-up-Ansatz ermittelt werden, indem eine Effizienzanalyse von Gebäuden vor Ort durchgeführt wird. Bei einem solchen ökonomisch-ingenieurtechnischen Ansatz werden Verhaltensaspekte bei der Energienutzung jedoch nicht berücksichtigt. In dieser Studie schätzen wir daher das Stromeffizienz-Niveau von Haushalten mit mathematischen und statistischen Methoden unter Berücksichtigung des gesamten Stromverbrauchs sowie Faktoren wie Grösse und Eigenschaften des Hauses/der Wohnung, Haushaltszusammensetzung, Anzahl und Art der genutzten Haushaltsgeräte, Anzahl der konsumierten Energiedienstleistungen, sozioökonomische und demografische Variablen sowie energiebezogenes Verhalten und Kompetenzen. Mit diesem Ansatz kann ein 'faires' Benchmarking der Schweizer Haushalte hinsichtlich ihres Stromverbrauchs durchgeführt werden. Zudem geht die vorliegende Studie auch der Frage nach, wie Informationen zum künftigen Energieverbrauch auf Produkten dargestellt werden sollten, damit Konsumenten das kosteneffizienteste Gerät leichter identifizieren können. Darüber hinaus untersuchen wir, ob und in welchem Ausmass kognitive Fähigkeiten sowie die Kompetenz, informierte energiebezogene Finanzentscheidungen treffen zu können (engl. energy-related financial literacy), die Konsumenten bei der Auswahl eines kosteneffizienten Geräts unterstützen.

Ziele und Inhalte der Kapitel

Die Hauptziele dieser Studie sind: *(1)* einen systematischen Überblick über die Beziehung zwischen Energienachfrage, der Produktion von Energiedienstleistungen, Inputpreisen und Energieeffizienz basierend auf der mikroökonomischen Produktionstheorie und der Haushaltsproduktionstheorie zu liefern; *(2)* das Niveau der der Stromnutzungseffizienz durch die Schätzung einer Stromnachfragegrenzfunktion (engl. electricity demand frontier function) unter Zuhilfenahme von ökonometrischer Methoden und Paneldaten basierend auf einer Stichprobe von Schweizer Haushalten zu ermitteln; *(3)* die energiebezogene Investitionskompetenz von Schweizer Haushalten zu messen und deren Rolle für die Energieeffizienz von Haushalten zu untersuchen; und *(4)* zu untersuchen, wie Informationen über den künftigen Energieverbrauch auf Produkten dargestellt werden sollten, damit Verbraucher dasjenige Haushaltsgerät, welches die Gesamtkosten über die Lebensdauer minimiert, leichter identifizieren können.

Der Bericht besteht aus zwei einleitenden Kapiteln, gefolgt von drei Kapiteln, die unterschiedliche empirische Analysen präsentieren. Das erste Kapitel bietet eine theoretische Einführung zur Effizienzmessung und zur Haushaltsproduktionstheorie. Das zweite Kapitel erläutert die dieser Studie zugrunde liegende grosse Haushaltsumfrage. Die beiden Kapitel 3 und 5 sind in sich geschlossene Artikel, die in internationalen wissenschaftlichen Zeitschriften veröffentlicht wurden. Kapitel 4 erweitert die in Kapitel 3 vorgestellte Analyse, durch den Einbezug der gesamten Daten aus der Haushaltsumfrage sowie durch eine Aufschlüsselung der Wachstumsrate der Stromnachfrage. Da einige dieser Kapitel in sich geschlossene Artikel sind und unabhängig voneinander gelesen werden können, kann es in den Kapiteln zu Wiederholungen einiger Konzepte kommen.

Im Kapitel 1 stellen wir eine systematische Analyse der Beziehung zwischen Energienachfrage, Energieeffizienz und technologischem Wandel vor. Die Konzepte der Produktionseffizienz, der Energieeffizienz, des technologischen Wandels und der Energieeffizienzlücke (engl. energy efficiency gap) werden im Rahmen der Haushaltsproduktionstheorie diskutiert. Wir präsentieren die mathematische Herleitung der Haushaltsproduktionstheorie. Zudem wird in diesem Kapitel auch die mathematische Aufschlüsselung der Wachstumsrate von Energieverbrauch und Energieproduktivität erläutert.

Kapitel 2 vermittelt einen Überblick über die Entwicklung und Umsetzung der grossen Online-Umfrage, die wir in Zusammenarbeit mit neun Schweizer Stromversorgungsunternehmen durchgeführt haben, um Daten für unsere empirische Analyse zu erheben. In diesem Kapitel beschreiben wir die Organisation der Stichprobenentnahme, den Prozess der Datenerhebung sowie die Struktur des Fragebogens. Die erhobene Stichprobe wird mit einigen öffentlich verfügbaren Bevölkerungsstatistiken aus den neun Regionen verglichen, um die Repräsentativität unseres Haushaltsdatensatzes abschätzen zu können. Zudem präsentieren wir in diesem Kapitel (aggregierte) deskriptive Statistiken für alle 8'378 Haushalte aus unserer Stichprobe.

In Kapitel 3 schätzen wir das Niveau der kurzfristigen (engl. transient) und strukturellen (engl. persistent) Stromnutzungseffizienz in Schweizer Haushalten mittels dem neu entwickelten 'generalized true random effects model' (GTREM). Aus einem unbalancierten Panel-Datensatz (2010–2014) von 1994 Schweizer Haushalten, der eine Teilmenge unseres in dieser Studie erhobenen Datensatzes bildet, schätzen wir eine Elektrizitätsnachfrage-Grenzfunktion (engl. electricity demand frontier function). Wir beschränken die Analyse in diesem Kapitel auf diese Untergruppe, da Informationen zur energiebezogenen Investitionskompetenz nicht für alle Haushalte verfügbar sind (bei den Kunden einiger Versorgungsunternehmen wurden diese Informationen nicht erhoben). Zudem analysieren wir, ob die Energie- und Investitionskompetenz einen Einfluss auf den Stromverbrauch von Haushalten haben. Die Ergebnisse zeigen signifikante Ineffizienzen in der Stromnutzung von Schweizer Haushalten: sowohl kurzfristige Ineffizienzen (11%) als auch strukturelle Ineffizienzen (22%). Wir stellen fest, dass die hohe strukturelle Ineffizienz auf strukturelle Probleme in den Haushalten und systematische Verhaltensdefizite im Haushaltsstromverbrauch hinweist. Diese empirisch beobachteten Unterschiede zwischen kurzfristiger und struktureller Effizienz weisen darauf hin, wie wichtig es ist, zwischen diesen beiden Komponenten zu unterscheiden.

Kapitel 4 erweitert die Analyse aus Kapitel 3 basierend auf Stromverbrauchsdaten aus den Versorgungsgebieten aller neun Stromunternehmen. Während Kapitel 3 sich auf die Rolle der Energie- und Investitionskompetenz konzentriert und daher nur Informationen von sechs der Stromversorgungsunternehmen aus unserer Umfrage verwendet werden, wird in diesem Kapitel eine Effizienzanalyse für die gesamte Stichprobe durchgeführt. Die durchschnittliche strukturelle Ineffizienz liegt bei etwa 22%, während die kurzfristige Ineffizienz bei etwa 14% liegt. Diese Ergebnisse sind vergleichbar mit den Ergebnissen aus Kapitel 3, die mit einer Teilmenge der Daten geschätzt wurden. Weiter analysieren wir in diesem Kapitel die Rolle von einigen nachfrageseitigen Effizienz-Massnahmen, die in den neun Versorgungsgebieten in den letzten 5 Jahren durchgeführt wurden, und schlüsseln zudem die Wachstumsrate der Stromnachfrage auf.

In Kapitel 5 untersuchen wir den Einfluss der Energie- und Investitionskompetenz auf die Wahrscheinlichkeit, dass Individuen sich beim Kauf für ein energieeffizientes Gerät entscheiden. Diese zusätzliche Analyse basiert auf zwei online durchgeführten randomisiert-kontrollierten Studien (engl. randomized controlled trials oder RCT), die in den Fragebogen der grossen Haushaltsbefragung dieser Studie integriert wurden. Anhand einer Serie von rekursiven bivariaten Probitmodellen und drei Stichproben von 583, 877 und 1'375 Schweizer Haushalten von drei Stromversorgern können wir aufzeigen, dass die Bereitstellung von Informationen über den Energieverbrauch von Haushaltsgeräten in monetären Einheiten (jährliche Stromkosten in CHF) anstatt in physikalischen Einheiten (jährlicher Stromverbrauch in kWh) die Wahrscheinlichkeit erhöht, dass ein Teilnehmer der Studie eine Investitionsanalyse durchführt, und somit das (kosten-) effizienteste Gerät auswählt. Darüber hinaus zeigen unsere ökonometrischen Ergebnisse, dass Personen mit einem höheren Niveau an Energie- und insbesondere Investitionskompetenz eher eine Optimierung durchführen als sich auf eine Entscheidungs-Heuristik zu verlassen.

Hauptergebnisse und energiepolitische Schlussfolgerungen

Die Ergebnisse dieser Studie bestätigen ein erhebliches Potenzial für Stromeinsparungen im Schweizer Haushaltssektor. Darüber hinaus zeigt die empirische Analyse, dass das Niveau der kurzfristigen und strukturellen Ineffizienz unterschiedlich hoch ist. Weiter können wir empirisch aufzeigen, dass sich die Kompetenz, informierte energiebezogener Investitionsentscheidungen treffen zu können, sowie energiesparendes Verhalten positiv auf die Energieeffizienz von Haushalten auswirken. Dieses Potential zu nutzen ist entscheidend, um das Reduktionsziel zu erreichen, das der Bundesrat im Rahmen der *Energiestrategie 2050* festgelegt hat.

Wir finden zudem bei Schweizer Haushalten ein tiefes Niveau der energiebezogenen Investitionskompetenz. Mehr als zwei Drittel der Schweizer Konsumenten scheinen sich eher auf einfache Entscheidungsfindungs-Heuristiken als auf einen Vergleich der Lebenszeitkosten verschiedener Geräte zu stützen, wenn sie eine

Kaufentscheidung treffen. Dies ist ein weiterer Hinweis dafür, dass Individuen nur begrenzt rational (engl. boundedly rational) sind und dass sie deshalb das finanzielle Einsparpotenzial von Energieeffizienzinvestitionen nicht ohne weitere Unterstützung ausschöpfen werden.

Aus energiepolitischer Sicht deuten die Ergebnisse dieser Studie darauf hin, dass eine Verbesserung der Energieeffizienz auf drei Wegen erreicht werden könnte: Erstens durch die Verpflichtung der Hersteller von Haushaltsgeräten, Informationen über den zukünftigen Energieverbrauch des Produkts in monetärer Form bereitzustellen. Dieser Ansatz könnte dem Beispiel des in den USA verwendeten EnergyGuide-Labels folgen, welches erfordert, dass auf den Energielabels bestimmter Geräten eine Schätzung der jährlichen Betriebskosten angezeigt wird (US-FTC, 2017). Eine zweite Strategie wäre, die Konsumenten über den Energieverbrauch verschiedener Geräte sowie Ansätze, um das kosteneffizienteste Gerät zu ermitteln, aufzuklären. Dies könnte zum Beispiel anhand von Broschüren und Kursen zur Energiekompetenz an Schulen stattfinden. Als dritter Ansatz scheinen politische Massnahmen, die das energiebezogene Wissen von Verbrauchern, und die Fähigkeit, komplexe (Investitions-)Berechnungen durchzuführen fördern, wichtig zu sein. Sie bilden eine Voraussetzung dafür, dass Verbraucher rationale und informierte energiebezogene Entscheidungen treffen können. Schliesslich könnten Entscheidungshilfen wie ein Online-Rechner, der die Kosten von Geräten über die gesamte Lebensdauer berechnet, im Einzelhandel, über mobile Anwendungen oder über eine vom Bund geförderte Webseite bereitgestellt werden.

Hierbei betonen wir nochmals die klare Unterscheidung zwischen der kurzfristigen und der strukturellen Energieeffizienz der Haushalte, da diese Unterscheidung dazu beitragen kann, die entsprechenden politischen Massnahmen auszuwählen. Zum Beispiel werden energiepolitische Massnahmen, die versuchen, Energiesparverhalten zu fördern (z.B. eine Informationskampagne) oder versuchen, das Niveau der Energiekompetenz zu erhöhen (z.B. Verteilen von Informationsmaterial an Haushalte), vor allem das kurzfristige Effizienzniveau beeinflussen. Hingegen könnten politische Massnahmen, die versuchen, die energiebezogene Investitionskompetenz der Haushalte zu verbessern (wie kurze Kurse zur Schulung von Verbrauchern bei der Bewertung von Investitionen oder Webseiten und Mobile-Apps, die bei der Berechnung der Gesamtkosten über die gesamte Lebensdauer der Geräte helfen) Auswirkungen auf die Kaufprozess von Geräten haben und somit auch auf das Niveau der strukturellen Effizienz.

Die Umsetzung dieser oben genannten politischen Massnahmen zusammen mit der einer Subvention von Energieberatungen in Haushalten sowie anderen politischen Instrumenten, etwa basierend auf Nudges und sozialen Normen, kann dazu beitragen, die Effizienz der Stromnutzung in Haushalten zu erhöhen. Aufgrund der inhärenten begrenzten Rationalität (engl. bounded rationality) der Verbraucher könnte die Wirkung einer ökologischen Steuer, die darauf abzielt, externe Kosten zu internalisieren, untergraben werden. Selbst wenn eine Energie- oder CO_2-Steuer den Strom teurer machen würde – und daher Investitionen in Energieeffizienz rentabler wären – würden begrenzt rationale Verbraucher diese Investitionen voraussichtlich nicht tätigen, da sie bei der Kaufentscheidung eines Haushaltsgerätes (kognitiv) nicht in der Lage wären, zukünftige Kosteneinsparungen zu berücksichtigen. Darüber hinaus kann die beschränkte Rationalität von Verbrauchern (engl. boundedly rational consumer) auch die Einführung effizienzbezogener Vorschriften und Normen rechtfertigen.

Résumé

Introduction

Plus de 60% de la consommation finale d'énergie de la Suisse est couverte par de l'énergie provenant de combustibles fossiles. En 2014, le secteur des ménages était à l'origine de près de 30% de l'ensemble de la consommation finale d'énergie en Suisse, dont environ 58% provenait de combustibles fossiles (BFE, 2015). Il est essentiel d'accroître l'efficacité énergétique des ménages pour réduire la consommation globale d'énergies fossiles et les émissions de CO_2 qu'elles génèrent en Suisse, et atteindre les objectifs de politique énergétique visés avec la *Stratégie énergétique 2050*.

Même si des efforts conséquents doivent être consentis pour réduire la consommation de combustibles dans le secteur des ménages, il existe toutefois aussi un important potentiel d'amélioration de l'efficacité en matière de consommation électrique. En Suisse, l'électricité provient principalement des centrales hydrauliques (60%) et nucléaires (40%). En 2011, après l'accident nucléaire à Fukushima Daiichi, le Conseil fédéral a décidé d'abandonner l'énergie nucléaire. La *Stratégie énergétique 2050* a fixé comme objectif, en premier lieu, de réduire la consommation d'électricité en optant pour une consommation électrique plus efficace, et, deuxièmement, d'accroître la proportion d'énergies renouvelables, comme l'éolien ou le solaire, dans la production d'électricité. Dans ce contexte, le secteur des ménages semble présenter un grand potentiel de gain en efficacité et pourrait contribuer significativement à faire reculer la consommation finale d'énergie dans son ensemble.

Pour faire baisser la consommation électrique des ménages, il est important de promouvoir des luminaires et des appareils ménagers efficients sur le plan énergétique. Souvent, un taux d'acceptation bas des technologies efficaces énergétiquement dépend de ce que l'on appelle l'écart d'efficacité énergétique (energy-efficiency gap en anglais). On observe couramment que les personnes qui prennent la décision d'acheter ne choisissent pas l'appareil ménager le plus efficace énergétiquement, même si de leur perspective individuelle celui-ci représente le choix le plus économique (minimisation des coûts de fonctionnement sur tout le cycle de vie). La littérature scientifique fournit plusieurs explications à cet écart. L'une d'entre elles pourrait être liée au fait que les consommateurs font preuve de rationalité limitée (boundedly rational en anglais). En effet, choisir l'appareil offrant les coûts les plus bas sur tout son cycle de vie est une tâche ardue. Pour pouvoir prendre une décision rationnelle sur un enjeu financier, il faut comparer l'ensemble des coûts des appareils ménagers sur tout leur cycle de vie. Cela nécessite une connaissance du prix d'achat, de la consommation d'électricité, de la fréquence d'utilisation prévue, des prix actuels et futurs de l'électricité, etc., ainsi que la capacité à faire des investissements éclairés en matière d'énergie (energy-related investment literacy), ce qui englobe le traitement et la corrélation de toutes ces informations.

Dans ce contexte, il est important que les décideurs politiques connaissent le véritable potentiel des économies d'électricité dans le secteur suisse des ménages. Le niveau d'efficacité énergétique des ménages peut être déterminé à l'aide d'une approche ascendante en effectuant une analyse d'efficacité sur site des bâtiments. Cependant, une telle approche d'ingénierie économique ne prend pas en compte les aspects comportementaux de l'utilisation de l'énergie. Dans la présente étude, nous estimons donc les niveaux d'efficacité énergétique des ménages en recourant à des méthodes mathématiques et statistiques tenant compte de la consommation totale d'électricité et de facteurs tels que la taille et les caractéristiques de la maison / de l'appartement, la composition du ménage, le nombre et le type d'appareils ménagers utilisés, le nombre de prestations énergétiques consommées, les variables démographiques et les comportements et compétences relatifs à l'énergie. Cette approche permet de réaliser un étalonnage «équitable» des ménages suisses en fonction de leur consommation d'électricité. En outre, la présente étude investigue la façon dont les informations concernant la consommation future d'énergie devraient être présentées sur les produits afin que les consommateurs puissent identifier aisément l'appareil le plus efficient en termes de coûts. De plus, nous étudions si et dans quelle mesure les capacités cognitives et la capacité à prendre des décisions financières éclairées dans le domaine de l'énergie (energy-related financial literacy) aident les consommateurs à choisir un appareil efficient en termes de coûts.

Objectifs et contenu du chapitre

Les objectifs principaux de la présente étude sont: *(1)* Fournir un aperçu systématique de la relation entre la demande d'énergie, la production de services énergétiques, les prix des intrants et l'efficacité énergétique sur la base de la théorie de la production microéconomique et de la théorie de la production des ménages; *(2)* Déterminer le niveau d'efficacité de l'utilisation de l'électricité en estimant une fonction frontière de la demande d'électricité avec des méthodes économétriques et des données de panel basées sur un échantillon de ménages suisses; *(3)* Dans les ménages suisses; mesurer l'expertise en matière d'investissements énergétiques et étudier son rôle dans l'efficacité énergétique; et *(4)* Examiner la façon dont les informations concernant la consommation future d'énergie devraient être présentées sur les produits afin que les consommateurs puissent identifier plus aisément l'appareil dont les coûts totaux sont les moindres sur tout son cycle de vie.

Le rapport se compose de deux chapitres introductifs, suivis de trois chapitres présentant différentes analyses empiriques. Le premier chapitre fournit une introduction théorique sur la mesure de l'efficacité et sur la théorie de la production domestique. Le deuxième chapitre décrit la vaste enquête auprès des ménages sur laquelle repose la présente étude. Les chapitres 3 et 5 sont des articles autonomes publiés dans des revues scientifiques internationales. Le chapitre 4 étend l'analyse présentée au chapitre 3 en incluant toutes les données de l'enquête auprès des ménages et en séquençant le taux de croissance de la demande en électricité. Puisque certains de ces chapitres sont des articles autonomes et peuvent être lus indépendamment les uns des autres, il est possible que certains concepts se répètent.

Au chapitre 1, nous présentons une analyse systématique de la relation entre la demande d'énergie, l'efficacité énergétique et le changement technologique. Les concepts d'efficacité de production, d'efficacité énergétique, de changement technologique et d'écart d'efficacité énergétique sont discutés dans le cadre de la théorie de la production domestique. Nous présentons l'origine mathématique de la théorie de la production domestique. En outre, ce chapitre explique également la ventilation mathématique du taux de croissance de la consommation d'énergie et de la productivité énergétique.

Le chapitre 2 donne un aperçu du développement et de la mise en œuvre de la vaste enquête en ligne que nous avons menée en collaboration avec neuf entreprises suisses d'approvisionnement en électricité afin de recueillir des données pour notre analyse empirique. Dans ce chapitre, nous décrivons l'organisation de l'échantillonnage, le processus de collecte des données et la structure du questionnaire. L'échantillon recueilli est comparé à certaines statistiques sur la population accessibles au public et provenant des neuf régions concernées, afin d'estimer la représentativité de notre corpus de données sur les ménages. En outre, nous présentons des statistiques descriptives (agrégées) pour l'ensemble des 8378 ménages de notre échantillon.

Dans le chapitre 3, nous estimons le niveau d'efficacité de l'utilisation de l'électricité à court terme (transitoire) et structurelle (persistante) dans les ménages suisses en utilisant le «modèle généralisé d'effets aléatoires réels» (generalized true random effects model ou GTREM) récemment développé. Nous estimons une fonction frontière de la demande d'électricité, à partir d'un jeu de données d'un panel non compensé (2010-2014) de 1994 ménages suisses, qui est un sous-ensemble de l'échantillon que nous avons recueilli pour la présente étude. Dans ce chapitre, nous limitons l'analyse à ce sous-groupe car les informations sur l'expertise en matière d'investissements liés à l'énergie ne sont pas disponibles pour tous les ménages (certaines entreprises d'approvisionnement n'ont pas collecté cette information auprès de leurs clients). En outre, nous analysons si l'expertise en matière d'énergie et d'investissements a un impact sur la consommation d'électricité des ménages. Les résultats montrent des inefficiences significatives dans l'utilisation de l'électricité par les ménages suisses: à la fois à court terme (11%) et au niveau structurel (22%). Nous notons que le niveau élevé d'inefficacité structurelle indique également des problèmes structurels dans les ménages et des déficits comportementaux systématiques dans la consommation d'électricité de ces derniers. Ces différences observées empiriquement entre l'efficacité à court terme et l'efficacité structurelle soulignent à quel point il est important de distinguer ces deux composantes.

Le chapitre 4 étend l'analyse menée au chapitre 3 sur la base des données relatives à la consommation électrique dans les zones de desserte de l'ensemble des neuf compagnies d'électricité. Tandis que le chapitre 3 se concentre sur le rôle de l'expertise en matière d'énergie et d'investissements, et n'utilise donc que des informations provenant de six des entreprises d'électricité de notre enquête, ce chapitre analyse l'efficacité de l'ensemble de l'échantillon. L'inefficacité structurelle moyenne est d'environ 22%, tandis que l'inefficacité à court terme est d'environ 14%. Ces résultats sont similaires aux résultats du chapitre 3, qui ont été estimés avec un sous-ensemble de données. En outre, dans ce chapitre, nous analysons le rôle de certaines mesures d'efficacité du côté de la demande qui ont été mises en œuvre dans les neuf zones de desserte au cours des cinq dernières années. Nous décomposons également le taux de croissance de la demande en électricité.

Au chapitre 5, nous examinons l'impact de l'expertise en matière d'énergie et d'investissements sur la probabilité que les individus choisissent un appareil écoénergétique lorsqu'ils achètent. Cette analyse supplémentaire est basée sur deux essais contrôlés aléatoires en ligne (ECA) (randomized controlled trials ou RCT) intégrés dans le questionnaire joint à la vaste enquête auprès des ménages de la présente étude. En utilisant une série de modèles probit bivariés récursifs et trois échantillons de 583, 877 et 1375 ménages suisses de trois entreprises d'approvisionnement en électricité, nous sommes en mesure de démontrer que fournir des informations sur la consommation d'énergie des appareils ménagers en unités monétaires (coût annuel de l'électricité en CHF) plutôt qu'en unités physiques (consommation annuelle d'électricité en kWh) augmente la probabilité qu'un participant à l'étude effectue une analyse d'investissement et sélectionne l'appareil le plus efficient en termes de coûts. De plus, nos résultats économétriques indiquent que les personnes ayant une expertise plus élevée en matière d'énergie et, en particulier, en matière d'investissements ont tendance à choisir l'optimisation plutôt qu'à compter sur une heuristique décisionnelle.

Résultats principaux et conclusions relatives à la politique énergétique

Les résultats de cette étude confirment un potentiel considérable d'économies d'électricité dans le secteur des ménages suisse. En outre, l'analyse empirique montre que les niveaux d'inefficacité à court terme et structurelle diffèrent. Nous sommes également en mesure de démontrer que la capacité à prendre des décisions éclairées en matière d'investissements liés à l'énergie et le comportement face à l'économie d'énergie ont un effet positif sur l'efficacité énergétique des ménages. L'exploitation de ce potentiel est décisive pour atteindre l'objectif de réduction fixé par le Conseil fédéral dans le cadre de la *stratégie énergétique 2050*.

Nous constatons également chez les ménages suisses un faible niveau d'expertise en matière d'investissement liés à l'énergie. Plus des deux tiers des consommateurs suisses semblent s'appuyer sur de simples heuristiques décisionnelles plutôt que de comparer le coût du cycle de vie de divers appareils lorsqu'ils décident d'un achat. C'est une indication supplémentaire que les individus ne font preuve que d'une rationalité limitée et qu'ils n'épuiseront pas le potentiel d'économies financières des investissements dans l'efficacité énergétique sans y être aidés.

Du point de vue de la politique énergétique, les résultats de cette étude suggèrent que l'efficacité énergétique pourrait être améliorée de trois manières: premièrement, en contraignant les fabricants d'appareils ménagers à fournir en termes monétaires des informations quant à la consommation d'énergie future du produit. Cette approche pourrait suivre l'exemple du label EnergyGuide utilisé aux États-Unis, qui exige une estimation des coûts de fonctionnement annuels à afficher sur les étiquettes énergétiques de certains appareils (US-FTC, 2017). Une deuxième stratégie consisterait à éduquer les consommateurs quant à la consommation d'énergie de divers appareils et aux démarches pour trouver l'appareil le plus rentable. Par exemple, cela pourrait se faire au travers de brochures et de cours de compétences énergétique dans les écoles. En troisième lieu, il semble que les mesures politiques favorisant les connaissances des consommateurs dans le domaine de l'énergie et leur capacité à effectuer des calculs (d'investissements) complexes revêtent une grande importance. Elles sont une condition préalable pour que les consommateurs prennent des décisions rationnelles et éclairées en matière d'énergie. Enfin, des outils d'aide à la décision, tels qu'un calculateur en ligne qui calcule le coût du cycle de vie des appareils, pourraient être fournis dans le commerce de détail, par le biais d'applications mobiles ou d'un site web parrainé par la Confédération.

Là encore, nous insistons sur la distinction claire entre l'efficacité énergétique à court terme et l'efficacité énergétique structurelle des ménages, car cette distinction peut aider à choisir les mesures politiques appropriées. Par exemple, les mesures de politique énergétique qui cherchent à promouvoir les comportements écoénergétiques (p. ex. une campagne d'information) ou à accroître le niveau d'expertise en matière d'énergie (p. ex. en distribuant des informations aux ménages) affecteront surtout l'efficacité à court terme. En revanche, celles qui entendent améliorer l'expertise des ménages dans les investissements liés à l'énergie (comme des cours pour former les consommateurs à l'évaluation des investissements ou des sites web et des applications mobiles permettant de calculer le coût total du cycle de vie d'un appareil) agiront sur le processus d'achat d'appareils et donc aussi sur le niveau d'efficacité structurelle.

La mise en œuvre de ces mesures, ainsi que la subvention de conseils énergétiques dans les ménages et d'autres instruments politiques reposant en partie sur des coups de pouce et des normes sociales, peuvent contribuer à accroître l'efficacité de l'utilisation de l'électricité par les ménages. Dans ce contexte, la rationalité intrinsèquement limitée des consommateurs pourrait compromettre l'impact d'une taxe environnementale visant à internaliser les coûts externes. Même si une taxe sur l'énergie ou le CO_2 rendait l'électricité plus chère – augmentant ainsi la rentabilité des investissements dans l'efficacité énergétique – les consommateurs faisant preuve d'une rationalité limitée n'investiraient probablement pas, car ils seraient (cognitivement) incapables de tenir compte des futures économies réalisables lors de l'achat d'un appareil ménager. En outre, la rationalité limitée des consommateurs peut également justifier l'introduction de prescriptions et de normes en matière d'efficacité.

Executive Summary

Introduction

More than 60% of the energy end-use consumption in Switzerland originates from fossil fuels. In 2014, the residential sector consumed nearly 30% of the total final energy consumption in Switzerland and about 58% of the energy end-use consumption of households was based on fossil fuels (BFE, 2015). Improving the energy efficiency in the residential sector is therefore one of the strategies to reduce total fossil energy consumption and related CO_2-emissions in Switzerland, in order to eventually meet the energy policy goals established in the Swiss *Energy Strategy 2050*.

While a major effort needs to be made for reducing the consumption of heating fuels, there is also a potential for enhanced efficiency in the electricity consumption of Swiss households. In Switzerland, electricity is primarily produced by hydro-power plants (60%) and nuclear power plants (40%). In 2011, after the Fukushima Daiichi nuclear accident, the Swiss federal council decided to abandon nuclear energy. One important goal of the *Energy Strategy 2050* is to reduce electricity consumption by improving the level of efficiency in the use of electricity and to increase the share of electricity produced with new renewable sources of energy, such as wind and solar. In this context, the residential sector seems to offer a great potential for efficiency gains and could make an important contribution to a reduction of total end-use electricity consumption.

One important avenue in reducing residential electricity consumption is to foster the adoption of energy-efficient lighting and household appliances. A low adoption of energy-efficient technologies is often related to the 'energy-efficiency gap', i.e. the frequent observation that individual decision-makers do not choose the most energy-efficient appliance, even if this appliance is also the most cost-efficient choice from the individual's point of view (minimizing lifetime operating costs). The literature offers several explanation for this gap. One of them could be related to the presence of *boundedly rational* consumers. In fact, the identification of the least lifetime cost and energy-efficient appliance is a challenging task. To make economically rational decisions, individuals need to compare the lifetime costs of electrical appliances. This necessitates knowledge of the purchase price of an appliance, its electricity consumption, expected frequency of use, current and future electricity prices etc., and also a certain level of energy-related investment literacy to process all this information.

Against this background, it is important for policy makers to have information on the potential for electricity savings in the Swiss residential sector. The level of energy efficiency of households can be measured with a bottom-up approach, by making an on-site efficiency analysis of buildings. However, with such an economic-engineering approach, the behavioral aspects in energy use are not accounted for. In this project, we therefore estimate a household's level of efficiency in the use of electricity with mathematical and statistical methods, accounting for total electricity consumption and factors such as size and characteristics of the residence, household composition, number and type of appliances, number of energy-services consumed, as well as socio-economic and demographic variables and energy-related behavior and literacy. With this approach a 'fair' benchmarking of Swiss households with respect to their electricity consumption can be performed. The research presented here also examines the question as to how information on future energy consumption should be displayed on products in order to enable consumers to identify the appliance that minimizes lifetime cost. Furthermore, we investigate whether and to what extent cognitive abilities as well as energy-related financial literacy support consumers in identifying a cost-efficient appliance.

Goals and contents of the chapters

The main objectives of this project are to: *(1)* provide a systematic overview based on the microeconomics of production and on the household production theory of the relation between energy demand, production of energy services, input prices and energy efficiency; *(2)* measure the level of efficiency in the use of electricity through the estimation using econometric methods of an electricity demand frontier function for a sample of Swiss households using panel data; *(3)* investigate the level of energy-related investment literacy among Swiss households and its role for energy efficiency; and *(4)* study how information on future energy consumption should be displayed on products in order to enable consumers to identify the appliance that minimizes lifetime cost.

The report consists of two introductory chapters followed by three chapters that present several empirical analyses. The first chapter provides a theoretical background to efficiency measurement and the household production theory. The second chapter introduces the underlying household survey. Chapters 3 and 5 are self-contained already published articles in international scientific journals. Chapter 4 extends the analysis presented in Chapter 3 in that it includes data from all utilities and provides a decomposition of the growth rate of electricity demand. As some of these chapters are self-contained and can be read independently of each other, a repetition of some concepts across the chapters could not be avoided.

In Chapter 1 we present a systematic analysis of the relation between energy demand, energy efficiency and technological change. The concepts of productive efficiency, energy efficiency, technological change and energy efficiency gap are discussed within the framework of the household production theory. We also present details on the basic mathematical framework of the household production theory. Finally, the mathematical decomposition of the growth rate of energy demand and energy productivity is also presented.

Chapter 2 provides an overview of the development and implementation of the online survey that we organized in cooperation with nine Swiss utilities to collect data for our empirical analysis. We inform about the organization of the sampling, the process of data collection as well as the general structure of the questionnaire. The collected sample is compared to some of the publicly available population statistics from the nine regions to give an idea of the representativeness of the collected data. We also provide (aggregate) descriptive statistics for all 8,378 households from our survey sample.

In Chapter 3 we estimate the level of transient and persistent efficiency in the use of electricity in Swiss households using the newly developed generalized true random effects model (GTREM). An unbalanced panel dataset of 1994 Swiss households from 2010 to 2014, which is a subset of our dataset collected via the household survey, is used to estimate an electricity demand frontier function. We restrict the analysis to this subset because information on energy-related investment literacy is not available for all utilities. We further investigate whether energy and investment literacy have an influence on the household electricity consumption. The results show significant inefficiencies in the use of electricity among Swiss households, both transient (11%) and persistent (22%). We note that the high persistent inefficiency is indicative of structural problems faced by households and systematic behavioral shortcomings in residential electricity consumption. This observed differences between the transient and persistent level of efficiency point out how important it is to distinguish between the two concepts.

Chapter 4 extends the analysis in Chapter 3 to include electricity consumption data from service regions of all utilities in our survey. While Chapter 3 focuses on the role of energy and investment literacy using data from six utilities, this chapter performs efficiency analysis on the full sample. The mean persistent inefficiency is found to be around 22% whereas the transient inefficiency is seen to be around 14%. These values are very similar to the one obtained with a subset of data and presented in Chapter 3. We also analyze the role of some of the demand-side measures that were in place in these regions over the last 5 years and provide a decomposition of the growth rate of electricity demand.

Chapter 5 provides an analysis of the influence of energy and investment literacy on the probability to purchase energy-efficient appliances. This additional analysis is based on two online randomized controlled trials (RCTs) that have been included in the questionnaire of the large household survey. Using a series of recursive bi-variate probit models and three samples of 583, 877 and 1,375 Swiss households from three participating utilities, we show that displaying information on energy consumption of electrical appliances in monetary terms (yearly energy cost in CHF), rather than in physical units (yearly energy consumption in kWh), increases the probability that an individual performs an investment analysis and hence chooses the most (cost-)efficient appliance. In addition, our econometric results suggest that individuals with a higher level of energy and, in particular, investment literacy are more likely to perform an optimization rather than relying on a decision-making heuristic.

Main results and policy implications

The results of the project thus confirm a considerable potential for electricity savings in the Swiss residential sector. Further, the empirical analysis show that the level of persistent and transient efficiencies is different. Moreover, a positive effect of energy-related investment literacy and energy-saving behaviour in reducing household electricity consumption could be identified. Tapping this potential will be crucial for reaching the reduction target defined by the Swiss federal council as part of the *Energy Strategy 2050*.

The level of energy-related investment literacy is found to be low among Swiss households. More than two thirds of Swiss consumers seem to rely on the use of simple decision-making heuristics rather than an assessment of the lifetime energy costs of various appliances before making a purchase decision. This provides further evidence that individuals tend to be boundedly rational and might not tap the financial savings potential of energy efficiency investments without further support.

From an energy policy point of view, the results suggest that an improvement in energy efficiency could be reached in three ways. First, with an obligation for the producers of electrical appliances to provide information on the future energy consumption of the product in the form of a monetary estimate. This could follow the example of the EnergyGuide label used in the United States that requires that on certain appliances an estimate of the annual operating energy cost is displayed (US-FTC, 2017). A second strategy would be to educate consumers about the energy consumption of different appliances and how to identify the most efficient appliances by means of brochures and energy literacy courses at schools. As a third strategy, policy measures that enhance an individual's energy-related knowledge and the ability to make complex (investment) calculations seems to be one important prerequisite to empower consumers to make rational and informed energy-related choices. Finally, decision support tools such as lifetime-cost-calculators could be provided in stores, mobile applications or through a web page promoted by the government.

The clear distinction between the persistent and transient inefficiencies faced by households are again emphasized, as it may help to channel the relevant policy measures. For instance, energy policy measures that try to promote energy saving behavior (such as an information campaign) or try to increase the level of energy literacy (such as distribution of information leaflets and booklets among households) will probably have an impact on the level of transient efficiency. On the other hand, policy measures that try to improve the level of financial literacy (such as short courses training individuals in assessing investments or web-pages and mobile-apps that help to calculate the lifetime cost of appliances) could have an impact on the buying process of appliances, and therefore, on the level of persistent efficiency.

Implementing these policy measures together with the promotion through subsidies of in-home energy audits and other measures, e.g., based on nudges and social norms may help in achieving improvements in the level of efficiency in the use of electricity. Nonetheless, the inherent bounded rationality within consumers could undermine the impact of an ecological tax aiming to internalize external costs, i.e. even if an energy or CO_2-tax made electricity more costly - and hence investments in energy efficiency more viable - boundedly rational consumers would probably not make these investments because they would still not be (cognitively) able to take future cost savings into account when choosing an appliance. Moreover, the presence of bounded rational consumers could also justify instruments such as efficiency-related regulations and standards for electrical appliances.

Contents

Introduction

More than 60% of the energy end-use consumption in Switzerland originates from fossil fuels. In 2014, the residential sector consumed nearly 30% of the total final energy consumption in Switzerland and about 58% of the energy end-use consumption of households was based on fossil fuels (BFE, 2015). Improving the energy efficiency in the residential sector is therefore one of the strategies to reduce total fossil energy consumption and hence the dependency on imported fossil fuels in Switzerland, in order to eventually meet the energy policy goals established in the Swiss *Energy Strategy 2050*.

When thinking about reducing the energy consumption of households, three important questions arise: *(1)* How large are the potentials for energy savings in the Swiss residential sector for a given level of energy services? *(2)* How big are the differences in the levels of energy efficiency among Swiss households and to what extent are these differences driven by energy policy measures or behavioral factors? *(3)* What role does behavioral failures play on the level of energy efficiency and energy consumption in Swiss households?

To answer these questions, it is important to remember that a household's energy demand is not a demand for energy per se but a derived demand for energy services, such as cooling, heating, cooking or lighting. A reduction in energy consumption to produce a given level of energy services can be achieved either by improving the level of efficiency in the use of inputs (i.e. in the use of appliances), by adopting a new energy-saving technology (i.e. purchase of new appliances, investments in energy-saving renovations) or by both processes. Technological change can induce a reduction of energy consumption for a given level of energy services, provided that the inputs are used in an efficient way, i.e. given that the households are productively efficient. The total reduction in residential energy consumption is therefore a result of the interplay of adoption of energy efficiency technology and a household's behavior.

The level of energy efficiency of Swiss households can be measured with a bottom-up approach, by making an on-site efficiency analysis of buildings. However, with such an economic-engineering approach, the behavioral aspects in energy use are not accounted for. In addition, this approach is not based on the microeconomics of production. In this project, we therefore estimate a household's level of energy efficiency with mathematical and statistical methods, accounting for total energy consumption and factors such as size and characteristics of the residence, household composition, number and type of appliances, number of energy-services consumed, as well as socio-economic and demographic variables and energy-related behavior. With this approach, a 'fair' benchmarking of Swiss households with respect to their energy consumption can be performed.

The existing literature on the measurement of the level of energy efficiency in the residential sector using an economic approach is not very large. There are several studies using aggregate data, for example Filippini and Hunt (2012) measure the level of energy efficiency in the residential sector in the US using state level data. However, studies using dis-aggregated data are scarce. Weyman-Jones et al. (2015) estimated an energy input demand frontier function originally proposed by Filippini and Hunt (2011) using a cross-sectional household dataset from a survey in Portugal. Thus, they are one of the first to estimate energy efficiency using stochastic frontier analysis (SFA) with dis-aggregated household survey data. However, the model used by Weyman-Jones et al. (2015) is relatively simple and with few explanatory variables. In contrast, Boogen (2017) uses a much richer model using not only the information on appliance stock but also on the amount of energy services consumed to estimate the technical efficiency of a set of Swiss households using a sub-vector distance function. However, as Boogen (2017) uses a cross-sectional dataset, the unobserved heterogeneity cannot be accounted for. Moreover, only the level of technical efficiency is estimated. Very recently, Alberini and Filippini (2018) estimated the level of efficiency in the use of energy using dis-aggregated data for a large sample of US households. To our knowledge, this is the first report on the estimation of the level of efficiency in the use of electricity in Swiss households using a rich panel dataset.

While a major effort needs to be made for reducing the consumption of heating fuels, there is also a potential for enhanced efficiency in the electricity consumption of Swiss households. In Switzerland, electricity is primarily produced by hydro-power plants (60%) and nuclear power plants (40%). In 2011, after the Fukushima Daiichi nuclear accident, the Swiss federal council decided to abandon nuclear energy. One important goal of the *Energy Strategy 2050* is to reduce electricity consumption by improving the level of efficiency in the use of electricity and to increase the share of electricity produced with new renewable sources of energy, such as wind and solar. In this context, the residential sector seems to offer a great potential for efficiency gains and could make an important contribution to a reduction of total end-use electricity consumption.

One important avenue in reducing residential electricity consumption is to foster the adoption of energy-efficient lighting and household appliances. A low adoption of energy-efficient technologies is often related to the 'energy-efficiency gap', i.e. the frequent observation that individual decision-makers do not choose the most energy-efficient appliance, even if this appliance is also the most cost-efficient choice from the individual's point of view (minimizing lifetime operating costs). The literature offers several explanation for this gap. One of them could be related to the presence of *boundedly rational* consumers. In fact, the identification of the least lifetime cost and energy-efficient appliance is a challenging task. To make economically rational decisions, individuals need to compare the lifetime costs of electrical appliances. This necessitates knowledge of the purchase price of an appliance, its electricity consumption, expected frequency of use, current and future electricity prices etc., and also a certain level of energy-related investment literacy to process all this information.[1] If markets provide too little or inadequate information about these parameters, or if this information is not salient enough to the consumer, this constitutes a barrier to solving the optimization problem (Sanstad and Howarth, 1994a). In fact, in many purchase situations, the information about the energy-efficiency of an appliance and thus about the future energy costs is less salient than the purchase price.

The research presented here also examines the question as to how information on future energy consumption should be displayed on products in order to enable consumers to identify the appliance that minimizes lifetime cost. Furthermore, we investigate whether and to what extent cognitive abilities as well as energy-related financial literacy support consumers in identifying a cost-efficient appliance.

One of the initial goals of the project was to estimate a *total* energy demand frontier function and the underlying efficiency of Swiss households. However, the analysis presented here had to be restricted to estimating an electricity demand model (and hence the level of efficiency in the use of electricity) due to difficulty in obtaining reliable consumption data related to oil and gas consumption within the residential sector. Having said this, even though we have sometimes used the general term 'energy efficiency' in the discussions, the reader is informed that the analysis and conclusions in this research are in the context of 'electricity' consumption at the residential level.

[1] In a recent work, Blasch et al. (2018) discuss several concepts and definitions related to energy literacy and financial literacy in the existing literature. They also propose a new concept of 'energy-related financial literacy' which encompasses both energy-related knowledge and cognitive skills to process available information in order to take informed energy-related investment decisions.

The main objectives of the project "Energy Efficiency, Bounded rationality and energy-related financial literacy in the Swiss Household Sector" are:

a) to provide a systematic overview based on the microeconomics of production and on the household production theory of the relation between energy demand, production of energy services, input prices and energy efficiency;

b) to measure the level of efficiency in the use of electricity through the estimation of an electricity demand frontier function for a sample of Swiss households using panel data;

c) to investigate the level of energy-related investment literacy among Swiss households and its role for energy efficiency; and

d) to study how information on future energy consumption should be displayed on products in order to enable consumers to identify the appliance that minimizes lifetime cost.

Outline of this report

The report consists of two introductory chapters followed by three chapters that present several empirical analyses. The first chapter provides a theoretical background to efficiency measurement and the household production theory. The second chapter introduces the underlying household survey. Chapters 3 and 5 are self-contained already published articles in international scientific journals. Chapter 4 extends the analysis presented in Chapter 3 in that it includes data from all utilities and provides a decomposition of the growth rate of electricity demand. As some of these chapters are self-contained and can be read independently of each other, a repetition of some concepts across the chapters could not be avoided.

In **Chapter** 1 (Background in efficiency and household production theory) we presents a systematic analysis of the relation between energy demand, energy efficiency and technological change. The concepts of productive efficiency, energy efficiency, technological change and energy efficiency gap are discussed within the framework of the household production theory. We also present details on the basic mathematical framework of the household production theory. Finally, the mathematical decomposition of the growth rate of energy demand and energy productivity is also presented.

In **Chapter** 2 (The household survey) we provide an overview of the development and implementation of the online survey that we organized in cooperation with nine Swiss utilities to collect data for our empirical analysis. We inform about the organization of the sampling, the process of data collection as well as the general structure of the questionnaire. We compare the collected sample to some of the publicly available population statistics from the nine regions to give an idea of the representativeness of the collected data. We also provide extensive (aggregate) descriptive statistics for all 8,378 households from our survey sample. This includes information on the size and characteristics of the residences, household size and composition, energy services consumed by the households, number and age of appliances, energy sources used by the households as well as socio-demographics of the survey respondents. In addition, we report energy-related attitudes and behaviors, energy literacy and the adoption of demand-side measures offered by the utilities.

In **Chapter** 3 (Explaining electricity demand and the role of energy and investment literacy on end-use efficiency of Swiss households) we estimate the level of transient and persistent efficiency in the use of electricity in Swiss households. An unbalanced panel dataset of 1994 Swiss households from 2010 to 2014, which is a subset of our dataset collect via the household survey is used to estimate an electricity demand frontier function. We restrict the analysis to this subset because information on energy-related investment literacy is not available for all utilities. We further investigate whether energy and investment literacy have an influence on the household electricity consumption. This chapter is based on Blasch et al. (2017a).

In **Chapter** 4 (Efficiency analysis on full sample, policy analysis and decomposition) we extend the analysis in Chapter 3 to include electricity consumption data from service regions of all utilities in our survey. While Chapter 3 focuses on the role of energy and investment literacy using data from six utilities, this chapter performs efficiency analysis on the full sample. We also analyze the role of some of the demand-side measures that were in place in these regions over the last 5 years and provide a decomposition of the growth rate of electricity demand.

In **Chapter** 5 (Boundedly rational consumers, energy and investment literacy, and the display of information on household appliances) we investigate the influence of energy literacy on the probability to purchase energy-efficient appliances. This additional analysis is based on two online randomized controlled trials (RCTs) that have been included in the questionnaire of the large household survey. Using a series of recursive bi-variate probit models and three samples of 583, 877 and 1'375 Swiss households from three participating utilities, we analyze how displaying information on energy consumption of electrical appliances in monetary terms (yearly energy cost in CHF), rather than in physical units (yearly energy consumption in kWh), influences the probability that an individual performs an investment analysis and hence chooses the most (cost-)efficient appliance. This chapter is based on Blasch et al. (2017b).

Chapter 6 offers concluding remarks and provides some recommendations for the future of Swiss energy policy. It also gives an outlook on how we plan to continue the research in the field.

The final chapter, **Chapter** 7, lists the journal articles and working papers written within the project.

1 Background in efficiency and household production theory

In this chapter we present the basic theoretical concepts on which the empirical analysis presented in the following chapters are based upon.

1.1 An overview of efficiency concepts

Before we get into a discussion on how to measure the level of efficiency in the use of energy, we should first be able to clearly identify and understand different type of efficiency concepts used in microeconomic theory of production. This would not only help us in a better understanding of the available measurement techniques, but would also assist in making correct interpretations of the estimated efficiency values in empirical analysis.

We focus on three commonly used terminologies: **Productive efficiency**, **Input specific efficiency**, and the **Energy efficiency gap**. An excellent overview of these concepts is presented in a recent work by Filippini and Hunt (2015). We closely follow their work as the basis for this entire section.

1.1.1 Productive efficiency and energy efficiency

Any thought about efficiency of a system usually revolves around some sort of comparison involving the system's input and output. Most definitions of energy efficiency are primarily based on some sort of ratio of useful output of a process over the energy input into the process (Bhattacharyya, 2011). There could be several ways to quantify these outputs and inputs yielding different types of indicators of efficiency, e.g., thermodynamic efficiency, economic efficiency or hybrid efficiency (Patterson, 1996). An often used measure in energy analysis, efficiency rankings and reporting at the macro level is the energy-to-GDP ratio. However, when undertaking aggregate energy efficiency analysis, this approach is arguably too simplistic and a better way to proceed is to use the definition based on the microeconomic theory of production (see Huntington (1994)).

It is important to remember that people do not directly demand energy, rather they demand outputs that can be products or energy services such as lighting, cooked food and hot water. The demand for energy is simply a derived demand. Households and firms use inputs such as energy (electricity, gas), capital (appliances, heating and cooling systems) and labour to produce outputs (energy services). Therefore, there is an associated production function behind the production process of energy services. From an economic perspective, it is important to produce energy services in an efficient way; that is, by choosing the combination of inputs that minimizes the production cost.[1] In practice, we can observe households and firms producing outputs without minimizing the use of inputs or using an obsolete technology that

[1]The basic mathematical framework for the household production theory is presented in Section 1.2.

hinders in minimizing the quantity of energy, capital and labour, i.e. situations often characterized as 'waste' of energy.

Productive inefficiency in the production of energy services can be discussed using the microeconomic theory of production framework, particularly with isoquants and isocosts (Chambers (1988); Huntington (1994)).[2] In this context, the radial definition of technical, allocative and overall productive efficiency introduced by Farrell (1957) and the non-radial concept of input specific technical efficiency introduced by Kopp (1981) can be helpful to understand the concepts of energy efficiency.

Figure 1.1 presents the situation of an economic agent, e.g. a household, that is using capital (C) and energy (E) to produce an energy service (ES) such as heating. The situation is illustrated using a unit isoquant (IS_0) and an isocost line (IC_0). A technically efficient economic unit uses a combinations of E and C that lies on the isoquant IS_0.

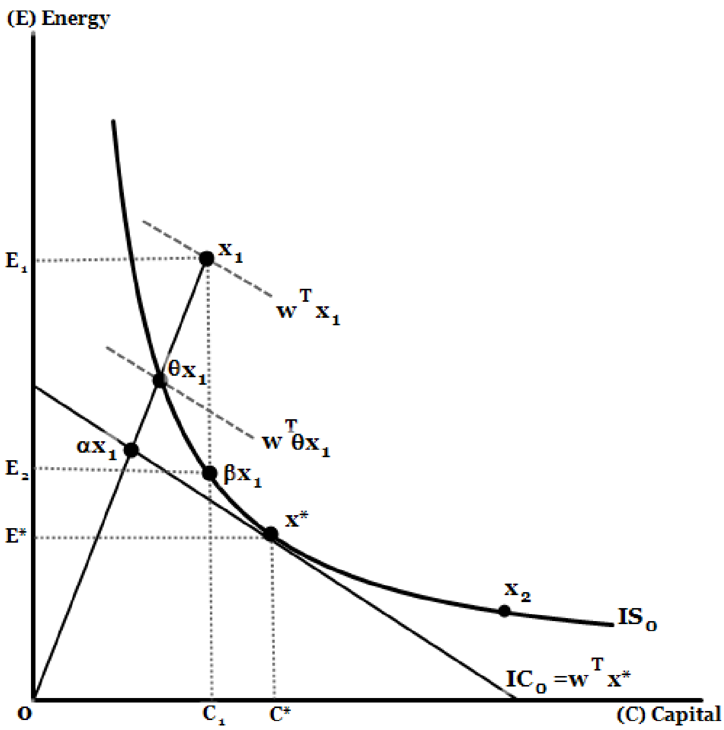


Figure 1.1: Technical, Allocative and Productive efficiencies explained using isoquant and isocost.

If the slope of the isocost line IC_0, the input price ratio, is known, a cost efficient input combination of capital and energy is identifiable. The point x^* where the isocost $w^T x^*$ is tangent to the isoquant IS_0 illustrates such a cost efficient household. This point on the isoquant reflects the production of a given level of energy service ES^*, the minimum cost for the production of which is $w^T x^*$.

Suppose another household uses a combination of inputs defined by point x_1 to produce a level of energy service that corresponds to the IS_0, it is said be technically inefficient as the point lies above IS_0. Using a classical input-oriented radial measure, the level of technical efficiency (TE) θ can be measured as the ratio between the distance from the origin to the technically efficient input combination θx_1 and the distance from the origin to x_1.[3]

[2]An isoquant is a contour line drawn through the set of points at which the same quantity of outputs is produced while changing the quantities of two or more inputs. An isocost line shows all combinations of inputs which cost the same total amount (Chiang, 1984; Varian, 1992).

[3]Since this measure is radial, it treats the contributions of each input towards the technical efficiency equally (equi-proportionate).

In Figure 1.1 the household operating at θx_1 is technically efficient but *allocatively inefficient* since it produces with higher costs (isocost $w^T\theta x_1$ lies above the line $w^T x^*$). The distance between αx_1 and θx_1 represents the allocative inefficiency of this household. The level of allocative efficiency is measured as the ratio between the distance from the origin to αx_1 and the distance from the origin to θx_1. The overall productive efficiency or cost efficiency α can be obtained as the ratio between the distance from the origin to αx_1 and the distance from the origin to x_1. To reach the optimal input combination, this household has to increase the use of input C and decreases the use of input E. For example, an increase of C could be reached by installing a device on a cooling system to improve the function of the system or by substituting the single glazing windows with double glazing windows.

Below we summarize the different efficiency terminologies just discussed in terms of the distances from the origin in Figure 1.1:

$$\text{Technical Efficiency } (TE = \theta) = \frac{O\theta x_1}{Ox_1} \tag{1.1}$$

$$\text{Allocative Efficiency } (AE) = \frac{O\alpha x_1}{O\theta x_1} \tag{1.2}$$

$$\text{Productive Efficiency } (PE = \alpha) = \frac{O\alpha x_1}{Ox_1} \tag{1.3}$$

Note that a household that uses quantities of inputs defined by point x_1 is technically as well as allocatively inefficient. The household could improve the level of overall productive efficiency by moving to the optimal input combination x^*. In this case, energy consumption will decrease, as energy is substituted with capital and used in a more parsimonious way allowing the household to consume less energy. This occurs for instance when a household or a firm improve the insulation of the building, change some electrical appliances, optimize the use of the heating or cooling system and the use of electrical appliances, in order to reach x^*.

So far, a radial notion of technical efficiency has been discussed wherein an improvement of the level of efficiency in the use of inputs requires a *proportional* reduction in energy and other inputs. For obtaining an input-specific technical efficiency measure, say an energy efficiency measure for the use of energy as an input, empirical analysis is based on a non-radial notion of efficiency introduced by Kopp (1981). This measure can be expressed as the ratio between the distance from the technically efficient input vector βx_1 and the input vector x_1 in Figure 1.1. Note that this is a special case of technical efficiency and, considering the input energy, is defined as the ratio of minimum feasible (E_2) to observed use of energy (E_1), conditional on the production technology and the observed levels of outputs and other inputs.

Filippini and Hunt (2011) motivated by the notion of non-radial input specific efficiency introduced by Kopp (1981), proposed that the way to econometrically estimate a measure of the efficient use of energy is to estimate a single conditional input demand frontier function, such as a demand function for energy. With this approach the difference between the optimal use of energy (E^*) that corresponds to the cost minimizing input combination x^* to produce a given level of energy services (ES^*) and the observed use of energy (E_1) should be measured.

In practice, frontier functions for production, cost or input demand are estimated empirically and the level of efficiency is then measured as deviations from these frontiers. The concluding part in the discussion above suggests that the non-radial measure of input specific efficiency is an interesting concept to use. Majority of the empirical studies dealing with the measurement of energy efficiency are indeed based on this non-radial measure of input specific efficiency.

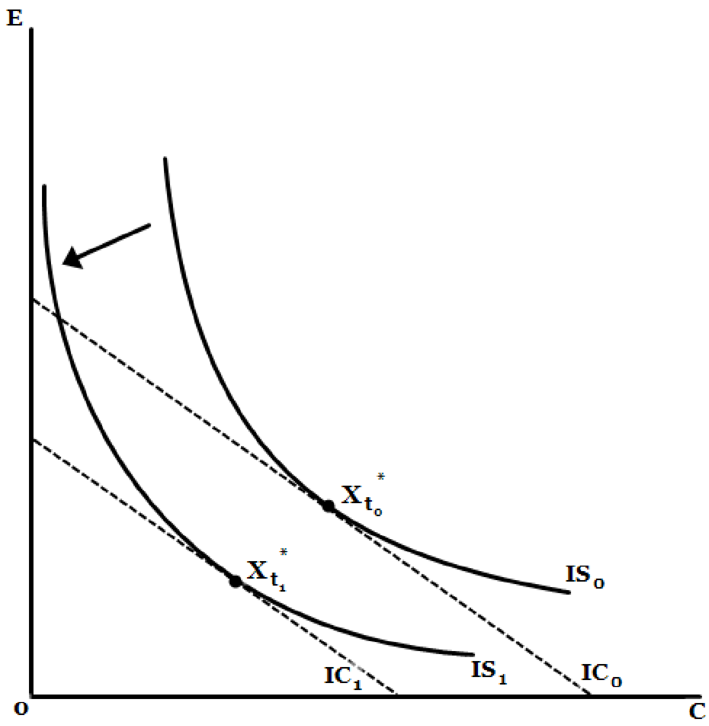


Figure 1.2: Technical progress shown by a shift in the isoquant.

This discussion is incomplete without considering an impact of a technological change on the efficient use of inputs. Consider an example where an introduction of a new insulation technology that keeps a house warm at the same room temperature, but with lesser energy and capital. When a technological progress allows the production of the same level of energy service ES^* with less energy and capital, the isoquant shifts! This is depicted in Figure 1.2 with the left shift of IS_0.[4] In this case the amount of energy and capital used to produce the energy service has decreased and the economic agent, e.g. a household, has reached the point $X^*_{t_1}$. If another household uses an obsolete technology and remain at $X^*_{t_0}$, a **technological gap** is observed. In energy economics terminology this gap is often referred to as the 'energy efficiency gap'.

Finally, it is worth recalling that the potential explanations for the presence of inefficiency in the use of energy or the existence of a technological gap tend to fall into one of the two categories below:

- *Market failures* such as information problems, misplaced incentives and principal agent problem.
- *Behavioural failures* such as heuristic decision making, status-quo, bounded rationality, risk aversion and inattentiveness.[5]

[4]See also Gillingham et al. (2009) for a discussion of this effect. In Figure 1.2, a homothetic production function is assumed implying a parallel shift of the isoquant.

[5]An interesting presentation of the different type of market and behavioural failures can also be found in Gillingham et al. (2009).

This section has focussed on the theoretical underpinnings of defining energy efficiency from an economics perspective. The following section therefore builds on this by considering the range of empirical parametric methods that could be considered for estimating energy efficiency based on this definition.

1.1.2 Empirical estimation of energy efficiency

The econometric methods used for estimation of energy efficiency are primarily categorized into two types of methods: parametric and non-parametric frontier analysis.[6] Non-parametric approaches like the Data Envelopment Analysis (DEA) assume the production or cost frontiers to be a *deterministic* function of some observed variables but no specific functional form is imposed. On the other hand, parametric approaches allow for unobserved heterogeneity among different economic agents but need to specify a functional form for the cost, production or input demand. The main advantage of parametric approaches over non-parametric ones is the separation of the inefficiency component from the statistical noise due to data errors and omitted variables, and accommodating formal statistical testing. The non-parametric methods' assumption of a unique deterministic frontier for all production units is strong even though this approach has its own advantages. We focus here on parametric methods which have come to be commonly known as *Stochastic Frontier Analysis (SFA)* since majority of these methods have a stochastic element in their frontier functions.[7] In order to estimate the input specific efficiency and the technological gap, we use the SFA approach.

Overview of estimation approaches

In the empirical part of this study, we are interested in measuring the input specific energy efficiency with help of an input requirement function and an energy demand function, and also the technical change. Reinhard et al. (1999) showed how to use a two-step procedure to obtain an indicator of input specific technical efficiency from the estimation of a production frontier. Kumbhakar and Hjalmarsson (1995), on the other hand, propose the measurement of input specific technical efficiency from the estimation of an input requirement function. This function indicates the minimum amount of an input that is necessary to produce a given level of output, given the technology and the quantity of other production factors. Zhou et al. (2012) propose the estimation of a Shephard energy input distance function which has been shown to be equivalent to the input requirement function (Boyd, 2008).

It is worth highlighting that all these three approaches are able to estimate only the technical efficiency in the use of an input. Filippini and Hunt (2015) advocates the use of another approach of an energy demand function suggested by Filippini and Hunt (2011) because it considers both allocative and technical efficiency. As per this approach, the estimation of a measure of the efficient use of energy could also be based on the estimation of a single conditional input demand frontier function, such as the demand function for energy. This function indicates the minimum amount of energy that is necessary to produce a given level of output (energy services), given the technology, input prices and other factors. In this context, actual energy demand differs from the energy frontier demand due to the presence of both allocative and technical inefficiency and not just technical inefficiency, as in Kopp (1981).

The actual empirical studies that estimate the level of efficiency in the use of energy are generally based on the estimation of three functions: i) an input requirement function (Boyd (2008)); ii) a Shephard energy distance function (Zhou et al. (2012)); and iii) an energy demand function (Filippini and Hunt (2011)).

[6] See for instance, Murillo-Zamorano (2004) for a general presentation of different methodologies.
[7] See Kumbhakar and Lovell (2003) and Greene (2008) for a discussion on the estimation of production, cost and input distance functions.

We can not use the approach by Reinhard et al. (1999) since we are in a multi-output framework and it is not possible to estimate a production function. Therefore, the following is related only to these three functions and not on the approach proposed by Reinhard et al. (1999).

From an econometric perspective, the estimation of these frontier functions is based on variants of the SFA frontier function approach proposed by Aigner et al. (1977). This approach is based on the assumption that the level of energy inefficiency can be approximated by a one-sided non-negative term. Table 1.1 provides an overview of the three approaches, their econometric specifications, and a couple of studies based on each of these.

Table 1.1: Approaches, specifications and examples of energy efficiency estimation.

Approach	**Econometric Specification**	**Examples in Practice**
Input Requirement Function	$\ln \mathrm{E}_{it} = \alpha + \beta' \mathbf{x}_{it} + \varepsilon_{it}$ $v_{it} \sim N[0, \sigma_v^2]$ $u_{it} = \lvert U_i \rvert, \ U_{it} \sim N[0, \sigma_u^2]$ $\varepsilon_{it} = v_{it} + u_{it}$	Boyd (2008); Lin and Wang (2014)
Shephard Input Distance Function	$\ln \left(\frac{1}{\mathrm{E}_{it}} \right) = \alpha + \beta' \mathbf{x}_{it} + \varepsilon_{it}$ $v_{it} \sim N[0, \sigma_v^2]$ $u_{it} = \lvert U_i \rvert, \ U_{it} \sim N[0, \sigma_u^2]$ $\varepsilon_{it} = v_{it} - u_{it}$	Zhou et al. (2012);Lin and Du (2013)
Input Demand Frontier Function	$\ln \mathrm{E}_{it} = \alpha + \beta' \mathbf{z}_{it} + \varepsilon_{it}$ $v_{it} \sim N[0, \sigma_v^2]$ $u_{it} = \lvert U_i \rvert, \ U_{it} \sim N[0, \sigma_u^2]$ $\varepsilon_{it} = v_{it} + u_{it}$	Evans et al. (2013); Filippini and Hunt (2011)

All the econometric specifications in Table 1.1 are specified for panel data but the estimation of such a stochastic frontier function can also be performed using cross-sectional data. However, panel data sets have the advantage that they allow the use of econometric models that can take into account the possible presence of unobserved heterogeneity in the model specification.

Econometric approach, SFA panel data: Transient and persistent efficiency

The econometric models available for estimating a stochastic frontier model using panel data are numerous.[8] Below we briefly *mention* some of the most commonly used models applicable to the task of estimating energy efficiency. These are: the pooled model (PM) that is basically the panel version of the model proposed by Aigner et al. (1977); the random effects model (REM); the true random effects model (TREM);[9] and the recently developed 'Generalized True Random Effects' model (GTREM hereafter).[10]

[8]For an overview of all the models for panel data, see Kumbhakar and Tsionas (2012) and Filippini and Greene (2016).
[9]See Greene (2008) and Farsi and Filippini (2009) for a discussion of these models.
[10]The reader is referred to Filippini and Hunt (2015) which provides a nice overview of the econometric specification (Table 1) and comparison between all these models.

As discussed in Filippini and Greene (2016), some of these models produce time invariant values of the level of efficiency (persistent efficiency), whereas others models estimate time variant values (transient efficiency). In the context of a household, the persistent inefficiency component might relate to the presence of structural problems in the production process of energy services like old electrical appliance stock or old buildings with very poor insulation. It might also relate to systematic behavioural shortcomings like frequently opening the windows and not switching off lights after use. Similarly, the transient inefficiency part might point towards the presence of non-systematic behavioural failures that could be solved in the short term, e.g., temporary use of an old and inefficient electrical appliance because the existing one is broken, or a visit by a guest who uses some appliances in an inefficient way.

It is worth noting that among the mentioned models, only GTREM allows for the possibility of simultaneously estimating the level of persistent and transient efficiency of an economic agent. The GTREM recognizes that the level of productive efficiency can be split into two components and the importance of estimating both components at the same time.[11] Although such a distinction between transient and persistent has traditionally been partially neglected in energy efficiency analysis, we think it is indeed very relevant and will gain importance in future research.

1.2 Household production theory

Below we provide the basic mathematical framework for the household production theory,[12] first using an intuitive two-stage optimization strategy by the households, and then again as a single-step mathematical approach.

1.2.1 Basic framework of the household production theory

When modeling the demand for energy in a very basic framework, it is important to remember that the demand for energy is somewhat special. Contrary to other goods such as food, clothes or houses, the consumption of energy does not directly yield utility but rather is used as an input to produce an energy service. More specifically, people derive utility from a heated house or from cooked food. People therefore combine energy, capital and their time to produce an energy service from which they derive utility. Using a basic household production model, we assume that households purchase inputs on the market such as energy and capital (in the form of appliances, electronics or heating systems) to produce energy services. From an economic perspective, the energy service should be produced efficiently – this means the households use the minimum amount of inputs in their production process to produce a certain amount of energy service while minimizing production costs of this service.

In a first simple but illustrative approach, the household produces an energy service S using the inputs capital K and energy E. A production function relates the use of inputs to the amount of output. As it is often the case in energy economics, and in order to keep calculations in a first step as simple as possible, we choose a cobb-douglas production function. Of course, there are advantages and drawbacks accompanying this choice. On one hand, calculations remain simple and model results are easily transferable to an econometric model where the model could be empirically evaluated. On the other hand, the cobb-douglas function may be too simple since even a vanishing amount of one input, say capital, still enables the output of an arbitrary amount of output given the amount used of the other input, say energy, is sufficiently

[11] Filippini and Greene (2016) also propose a novel approach using maximum simulated likelihood to simultaneously estimate both persistent and transient levels of efficiency of an economic agent.

[12] We refer primarily to Deaton and Muellbauer (1980a) and Todorova (2010) for this part.

high. Of course, this is an unrealistic assumption but we believe that for illustrative examples, this type of production function is useful.

In a first stage, the household minimizes the costs of production of an arbitrary amount of the energy service $S = \hat{S}$ by taking into account the production function and the input prices for energy, p_E, and capital, p_K.

$$\begin{aligned} &\text{minimize} \quad p_E E + p_K K \\ &\text{subject to} \quad \hat{S} = S(E, K) = E^{\alpha} K^{1-\alpha} \end{aligned} \tag{1.4}$$

Note that the production function is of cobb-douglas form. Since the exponents of its arguments sum up to one, it yields *constant returns to scale*. This means that a proportional increase in inputs capital K and energy E leads to the same increase in output of the energy service $\hat{S}$.

The lagrangian function to the optimization problem stated in equation (1.4) and the corresponding first-order conditions (FOC) with the solutions for the optimal input combination is derived below:

$$L = p_E E + p_K K + \lambda(\hat{S} - E^{\alpha} K^{1-\alpha})$$

FOC:

$$\left.\begin{aligned} &\text{I)} \quad \frac{\partial L}{\partial E} = p_E - \alpha\lambda\left(\frac{K}{E}\right)^{1-\alpha} \stackrel{!}{=} 0 \quad \Longrightarrow \lambda = \frac{p_E}{\alpha}\left(\frac{E}{K}\right)^{1-\alpha} \\ &\text{II)} \quad \frac{\partial L}{\partial K} = p_K - (1-\alpha)\lambda\left(\frac{E}{K}\right)^{\alpha} \stackrel{!}{=} 0 \quad \Longrightarrow \lambda = \frac{p_K}{1-\alpha}\left(\frac{K}{E}\right)^{\alpha} \end{aligned}\right\} E = \frac{\alpha}{1-\alpha}\frac{p_K}{p_E} K$$

$$\text{III)} \quad \frac{\partial L}{\partial \lambda} = \hat{S} - E^{\alpha} K^{1-\alpha} \stackrel{!}{=} 0 \Longrightarrow \hat{S} = E^{\alpha} K^{1-\alpha}$$

On solving these equations, we obtain:

$$\begin{aligned} \hat{K} &= \left(\frac{1-\alpha}{\alpha}\frac{p_E}{p_K}\right)^{\alpha} \cdot \hat{S} \\ \hat{E} &= \left(\frac{\alpha}{1-\alpha}\frac{p_K}{p_E}\right)^{1-\alpha} \cdot \hat{S}; \text{ and} \\ \hat{p}_S &= \frac{p_E \hat{E} + p_k \hat{K}}{\hat{S}} \\ &= \left[\left(\frac{1-\alpha}{\alpha}\right)^{\alpha} + \left(\frac{\alpha}{1-\alpha}\right)^{1-\alpha}\right] {p_E}^{\alpha} {p_K}^{1-\alpha} = \frac{{p_E}^{\alpha} {p_K}^{1-\alpha}}{\alpha^{\alpha}(1-\alpha)^{1-\alpha}} \end{aligned} \tag{1.5}$$

Given the choice to consume an arbitrary amount $\hat{S}$ of the energy service, equation (1.5) states how the inputs capital and energy should be allocated in the production process in order to produce the energy service in a cost-efficient way. Capital K and energy E can be substituted with each other. For instance, a decrease in the price of energy p_E would lead to an increase in the amount of energy used as input and in a decrease in the amount of capital used, provided that the amount of energy service produced is held constant. Equation (1.5) also calculates the unit price of the energy service $\hat{p}_S$ as a function of input prices p_E and p_K. It is important to note here that the cost-efficient unit-price of this energy service does not depend on the amount of the energy service consumed. The reason is that the production function is specified to yield constant returns to scale, which first is reflected by the fact that the optimal input allocation to the production process is proportionally increasing with $\hat{S}$ and second by calculating the unit price therefore cancels out after dividing production costs by the amount of service consumed. Of course, the assumption of constant returns to scale in the production process could be relaxed. First however, we think that the implication of this result, namely that the unit price of the energy service does not depend on the amount produced, makes sense. Second, the calculation of the optimal choice of how much of the energy service to produce would be strongly complicated.

In a second stage, the household is maximizing the utility that it derives from the consumption of the energy service S and 'other' goods X. We normalize the price of other goods to unity and assume for reasons of simplicity that the functional form of the utility function is also cobb-douglas. In addition, the household faces a budget constraint when choosing how much of each good to consume. Therefore, the optimization problem in the second stage is mathematically of the following form:

$$\begin{aligned} &\text{maximize} \quad U = S^{\beta} X^{1-\beta} \\ &\text{subject to} \quad I = X + \hat{p}_S S \end{aligned} \tag{1.6}$$

where U denotes utility and I the household's income. The lagrangian function to the optimization problem stated in equation (1.6) and the corresponding first-order conditions with the solutions for the optimal consumption quantities of S and X are derived below.

$$L = S^{\beta} X^{1-\beta} + \lambda (I - X - \hat{p}_S S)$$

FOC:

$$\left.\begin{aligned} &\text{I)} \quad \frac{\partial L}{\partial S} = \beta \left(\frac{X}{S}\right)^{1-\beta} - \lambda \hat{p}_S \overset{!}{=} 0 \quad \Longrightarrow \lambda = \frac{\beta}{\hat{p}_S} \left(\frac{X}{S}\right)^{1-\beta} \\ &\text{II)} \quad \frac{\partial L}{\partial X} = (1-\beta) \left(\frac{S}{X}\right)^{\beta} - \lambda \overset{!}{=} 0 \quad \Longrightarrow \lambda = (1-\beta) \left(\frac{S}{X}\right)^{\beta} \end{aligned}\right\} S = \frac{\beta}{1-\beta} \frac{1}{\hat{p}_S} X$$

$$\text{III)} \quad \frac{\partial L}{\partial \lambda} = I - X - \hat{p}_S S \overset{!}{=} 0 \Longrightarrow I = X + \hat{p}_S S$$

The previously mentioned advantage of constant returns to scale in the production function becomes obvious in the first first-order condition where the lagrangian is optimized with respect to S. If the cost-efficient price of the energy service $\hat{p}_S$ would be a function of S, then the equation would be different. The utility maximizing quantities $\hat{X}$ and $\hat{S}$ are given by equation (1.7), where the cost-efficient price of the energy service $\hat{p}_S$ is substituted from equation (1.5).

$$\begin{aligned} &\hat{X} = (1-\beta) I; \text{ and} \\ &\hat{S} = \frac{\beta I}{\hat{p}_S} = \frac{\beta I}{\left[\left(\frac{1-\alpha}{\alpha}\right)^{\alpha} + \left(\frac{\alpha}{1-\alpha}\right)^{1-\alpha}\right]} \cdot \frac{1}{p_E{}^{\alpha} p_K{}^{1-\alpha}} = \frac{\alpha^{\alpha}(1-\alpha)^{1-\alpha} \beta I}{p_E{}^{\alpha} p_K{}^{1-\alpha}} \end{aligned} \tag{1.7}$$

Since in the first stage the optimal input quantities are directly related to the amount of energy service $\hat{S}$ produced, the cost-efficient and utility-maximizing quantity of inputs are

$$\begin{aligned} \hat{K} &= \left(\frac{1-\alpha}{\alpha}\,\frac{p_E}{p_K}\right)^{\alpha} \cdot \frac{\alpha^{\alpha}(1-\alpha)^{1-\alpha}\beta I}{{p_E}^{\alpha}{p_K}^{1-\alpha}} &= \frac{(1-\alpha)\beta I}{p_K} \\ \hat{E} &= \left(\frac{\alpha}{1-\alpha}\,\frac{p_K}{p_E}\right)^{1-\alpha} \cdot \frac{\alpha^{\alpha}(1-\alpha)^{1-\alpha}\beta I}{{p_E}^{\alpha}{p_K}^{1-\alpha}} &= \frac{\alpha\beta I}{p_E} \end{aligned} \tag{1.8}$$

First, cost minimization in first-stage leads to cost-efficient input quantities for K and E given a fixed amount of energy service S, resulting in a cost-efficient unit price p_S for S. Then in a second stage, utility from consumption is maximized subject to the household's budget constraint and the utility-maximizing consumption of the energy service is derived.

Given the results stated in equation (1.8), a decrease in the price of energy leads to an increase in the amount of energy used as input in the production process of S. Also, according to equation (1.7), the amount of energy service consumed will increase *but less strongly* than the amount of energy since $\hat{S} \propto \frac{1}{{p_E}^{\alpha}}$ and $0 < \alpha < 1$.

1.2.2 Basic model in a single step optimization

The household production approach is useful to derive the cost-efficient input demand for energy when producing an energy service. In this section, we link the first stage where the household produces an arbitrary amount of energy service in a cost-efficient way with the second stage where the household maximizes utility that is derived from the consumption of the energy service and other goods. The reason is that comparative statics can more easily be calculated when linking both stages to one optimization stage.

We assume that the household maximizes utility from the consumption of the energy service and other goods while taking the individual budget constraint and the production function into account. The corresponding Lagrangian then is

$$L = U(S, X) + \lambda_1 (I - p_E E - p_K K - p_X X) + \lambda_2 (S - F(E, K)) \tag{1.9}$$

where $U(S, X)$ is a well-behaved[13] utility function with the consumption of the energy service S and other goods X as arguments. Income I is spent on input factors energy E and capital K with prices p_E and p_K but also on other goods X with a normalized price $p_X = 1$. The household faces a production technology $F(E, K)$ that is well-behaved in the same sense as the utility function which has inputs energy and capital and yields an output being the energy service S. λ_1 is the 'shadow value' of income and can be interpreted as the marginal utility that is derived from income and therefore is expected to be positive. λ_2 correspondingly is the marginal value of an additional unit of output S produced. An overproduction of energy service S would not be optimal since it would violate the cost-efficient input-use of energy and capital and therefore, λ_2 is expected to be negative.

[13] 'well-behaved' means that utility is strictly increasing with S and X. That is $\frac{\partial U}{\partial S} > 0$, $\frac{\partial U}{\partial X} > 0$ and is concave in a sense that $\frac{\partial^2 U}{\partial^2 S} > 0$, $\frac{\partial^2 U}{\partial^2 X} > 0$.

Equation (1.9) is optimized with respect to the amount of energy service S, the consumption of other goods X, the input use of energy E and capital K while taking both constraints into account. Therefore, the first-order conditions result into six equations describing the cost-efficient allocation of inputs given the characteristics of the production technology $F(E, K)$ and the utility-maximizing amount of energy service and other goods given the households budget constraint. The first-order conditions are:

$$\text{I)} \quad \frac{\partial L}{\partial E} = -\lambda_1 p_E - \lambda_2 \frac{\partial F}{\partial E} \stackrel{!}{=} 0 \implies \frac{\partial F}{\partial E} = -\frac{\lambda_1}{\lambda_2} p_E \tag{1.10}$$

$$\text{II)} \quad \frac{\partial L}{\partial K} = -\lambda_1 p_K - \lambda_2 \frac{\partial F}{\partial K} \stackrel{!}{=} 0 \implies \frac{\partial F}{\partial K} = -\frac{\lambda_1}{\lambda_2} p_K \tag{1.11}$$

$$\text{III)} \quad \frac{\partial L}{\partial S} = \frac{\partial U}{\partial S} + \lambda_2 \stackrel{!}{=} 0 \tag{1.12}$$

$$\text{IV)} \quad \frac{\partial L}{\partial X} = \frac{\partial U}{\partial X} - \lambda_1 \stackrel{!}{=} 0 \tag{1.13}$$

$$\text{V)} \quad \frac{\partial L}{\partial \lambda_1} = I - p_E E - p_K K - p_X X \stackrel{!}{=} 0 \tag{1.14}$$

$$\text{VI)} \quad \frac{\partial L}{\partial \lambda_2} = S - F(E, K) \stackrel{!}{=} 0 \tag{1.15}$$

Here, one could explain intuitively the meaning of the equations, e.g., equation (1.10) tells us that the marginal product of energy is proportional to the price of energy. Same for capital in equation (1.11). λ_1 and λ_2 according to equations (1.12) and (1.13) are linked to the marginal utilities derived from the consumption of S and X. However, the marginal utilities $\partial U/\partial S$ is linked to the production technology F itself and therefore also depends on E and K, whereas $\partial U/\partial X$ is linked to the income constraint.

In order to solve the set of equations in a comparable way as we have done before, we assume a cobb-douglas type production function and utility function, i.e.

$$F(E, K) = E^{\alpha} K^{1-\alpha} \quad \text{and} \quad U(S, X) = S^{\beta} X^{1-\beta}$$

From equations (1.10) and (1.11), we can derive the optimal ratio of input use E/K and the ratio of the shadow values λ_1/λ_2. We obtain:

$$\frac{\partial F}{\partial E} = \frac{p_E}{p_K} \cdot \frac{\partial F}{\partial K} \implies \alpha \left(\frac{K}{E}\right)^{1-\alpha} = \frac{p_E}{p_K} \cdot (1-\alpha) \left(\frac{E}{K}\right)^{\alpha}$$

$$\implies \frac{E}{K} = \frac{\alpha}{1-\alpha} \frac{p_K}{p_E} \tag{1.16}$$

which is the same input ratio as before given the ratio of input prices and therefore also ensures a cost-efficient input allocation given the production technology. The ratio of the shadow values is:

$$\frac{\lambda_1}{\lambda_2} = -\frac{\alpha^{\alpha}(1-\alpha)^{1-\alpha}}{{p_E}^{\alpha} {p_K}^{1-\alpha}} \tag{1.17}$$

Similarly, we proceed with equations (1.12) and (1.13) and then derive the optimal consumption ratio S/X by plugging in equation (1.17).

$$\begin{aligned}\frac{\lambda_1}{\lambda_2} &= -\frac{\partial U/\partial X}{\partial U/\partial S} = -\frac{1-\beta}{\beta}\frac{S}{X} \\ \Longrightarrow \frac{S}{X} &= \frac{\beta}{1-\beta} \cdot \frac{\alpha^\alpha(1-\alpha)^{1-\alpha}}{p_E{}^\alpha p_K{}^{1-\alpha}}\end{aligned} \tag{1.18}$$

Now using either of equation (1.12) or (1.13) with equation (1.18), we derive the following shadow values of income λ_1 and of production λ_2:

$$\begin{aligned}\lambda_1 &= (1-\beta)\left(\frac{\beta}{1-\beta} \cdot \frac{\alpha^\alpha(1-\alpha)^{1-\alpha}}{p_E{}^\alpha p_K{}^{1-\alpha}}\right)^\beta \quad > 0 \\ \lambda_2 &= -\beta\left(\frac{1-\beta}{\beta} \cdot \frac{p_E{}^\alpha p_K{}^{1-\alpha}}{\alpha^\alpha(1-\alpha)^{1-\alpha}}\right)^{1-\beta} \quad < 0\end{aligned} \tag{1.19}$$

Finally, with the help of equations (1.15), (1.16) and (1.18), we can compute the optimal consumption quantities of $\hat{E}$, $\hat{K}$ and $\hat{X}$ in terms of $\hat{S}$.

$$\begin{aligned}\hat{E} &= \left(\frac{\alpha}{1-\alpha}\frac{p_K}{p_E}\right)^{1-\alpha} \cdot \hat{S} \\ \hat{K} &= \left(\frac{1-\alpha}{\alpha}\frac{p_E}{p_K}\right)^{\alpha} \cdot \hat{S}\text{; and} \\ \hat{X} &= \frac{1-\beta}{\beta} \cdot \frac{p_E{}^\alpha p_K{}^{1-\alpha}}{\alpha^\alpha(1-\alpha)^{1-\alpha}} \cdot \hat{S}\end{aligned} \tag{1.20}$$

Note that the equations above are identical to the first stage of the two-stage household production theory framework. Finally, we substitute the above expressions in the income constraint in equation (1.14) to compute the final value of the energy service $\hat{S}$ and we obtain

$$\begin{aligned}\hat{S} &= \frac{\alpha^\alpha(1-\alpha)^{1-\alpha}\beta I}{p_E{}^\alpha p_K{}^{1-\alpha}} \\ \hat{E} &= \frac{\alpha\beta I}{p_E} \\ \hat{K} &= \frac{(1-\alpha)\beta I}{p_K}\text{; and} \\ \hat{X} &= (1-\beta)I\end{aligned} \tag{1.21}$$

The final optimal consumption quantities for the energy service S, other goods X, capital K and energy E are numerically identical to equations (1.7) and (1.8) derived in the household production theory in a two-stage optimization framework in section 1.2.1.

1.3 Decomposition of the growth rate of the energy demand and productivity in an empirical/econometric model

The estimation of energy demand becomes interesting in a panel setting when we have data over different time periods, e.g., yearly energy consumption of households, yearly household income and the change in energy and capital prices over the years. In such scenarios, we would like to analyse the effects of changes of different regressors over time on the change in input energy demanded. In other words, we would like to estimate and decompose the growth rate of household energy demand and the growth rate of energy productivity (measured with a simple indicator as the ratio of output to energy).

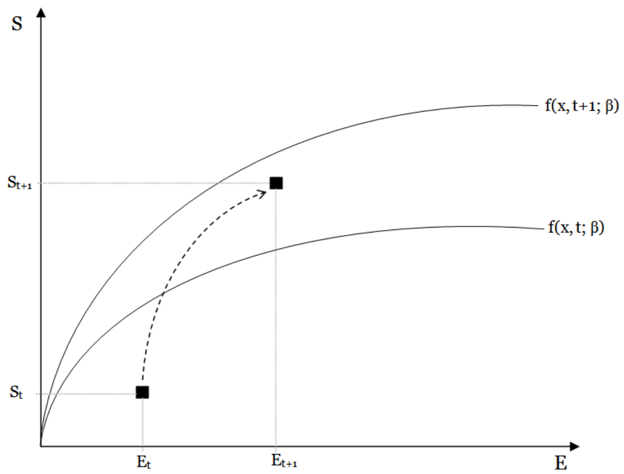


Figure 1.3: Estimation and decomposition of energy productivity change.

Following Kumbhakar and Lovell (2003, p. 282), the basic approach towards productivity change can be explained using the general structure illustrated in Figure 1.3, in which a single input energy E is used to produce a single output, the energy service S. The figure depicts that a household expands production from (E_t, S_t) to (E_{t+1}, S_{t+1}). Production technology is characterized by decreasing returns to scale, and technical progress has occurred between periods t and $t+1$, since $f(x, t+1; \beta) > f(x, t; \beta)$ where x represents the input E. Assuming there is no noise in the system, it is clear that the production of energy service is inefficient in both time periods as the household is below the respective production frontiers. We do notice however that the technical efficiency has improved from t to $t+1$, since the ratio $[S_t / f(E_t, t; \beta)] < [S_{t+1} / f(E_{t+1}, t+1; \beta)]$. It is also clear that energy productivity growth has occurred, since $(S_{t+1}/E_{t+1}) > (S_t/E_t)$. This implies an increase in the amount of energy service produced per unit of energy consumed. We are interested in decomposing the estimated rate of energy productivity into contributions associated with returns to scale, technical change, and change in technical efficiency.

Note that the amount of energy service produced is difficult to measure in empirical applications. If we think on the demand for automotive gasoline, the related energy service would be mileage. However in the context of residential electricity consumption, the amount of total energy service produced is difficult to measure – it would not be easy to assess a household's number of clothes washed per week in a questionnaire, or to obtain information on how many hot meals they prepare or on what level the average room temperature is set on a certain day.[14] Therefore, the energy service often is proxied in an empirical analysis, for instance an analysis on residential electricity consumption, with a variable that measures the number of rooms, area of the house, number of people living in the household or the household income itself.

[14]Note that in our survey questionnaire, we do ask the households to provide information on majority of the energy services they consume.

1.3.1 Decomposition of the growth rate of energy demand

As previously found in equation (1.20), the energy input required can be written as a function $f(\cdot)$ of the amount of service that is intended to be produced and the prices of the input factors. We could also include other household characteristics, for instance, the number of people living in the household and the household income. Climate related variables may also affect the demand for energy and can be included too. Often in empirical applications, the demand for energy is augmented with an exogenous technological change captured by a time trend or by time dummies. We then write the frontier energy demand function as [15]

$$E^F = f\,(S,\, p_E,\, p_K,\, inc,\, size,\, clim,\, t) \tag{1.22}$$

where in addition to S, p_E and p_K, *inc* represents the household income, *size* is the number of people living in the household, *clim* represents some climate related information like the number of heating and cooling degree days and t captures the time trend. The level of energy efficiency can be calculated as the ratio of energy at the frontier over the actual energy demanded.

$$EF_{it} = \frac{E^F_{it}}{E_{it}} \tag{1.23}$$

We now take into account that each of the variables in the above-equation evolves over time. By taking natural logarithms on both sides of the equation and by totally differentiating with respect to time, the growth rate of energy demand over time can directly be related to the growth rates of the explanatory variables, that is [16]

$$\begin{aligned} \hat{EF} = \eta(x;t)\,\hat{p_E} + \frac{\partial \ln E^F(x;t)}{\partial \ln S}\,\hat{S} + \frac{\partial \ln E^F(x;t)}{\partial \ln p_K}\,\hat{p_K} + \frac{\partial \ln E^F(x;t)}{\partial \ln inc}\,\hat{inc} \\ + \frac{\partial \ln E^F(x;t)}{\partial \ln size}\,\hat{size} + \frac{\partial \ln E^F(x;t)}{\partial \ln clim}\,\hat{clim} + \frac{\partial \ln E^F(x;t)}{\partial \ln t} - \hat{E} \end{aligned} \tag{1.24}$$

where the '*hat*' on a variable indicates its growth rate over time, e.g. $\hat{x} = \frac{d \ln x}{dt}$; x indicates a series of independent variables in the demand function; $\eta(x;t) = \frac{\partial \ln E^F(x;t)}{\partial \ln p_E}$ is the own-price elasticity of energy demand with respect to the price change. Rearranging the terms in equation (1.24), we obtain

$$\hat{E} = \alpha_{p_E}\,\hat{p_E} + \alpha_{p_K}\,\hat{p_K} + \alpha_S\,\hat{S} + \alpha_{inc}\,\hat{inc} + \alpha_{size}\,\hat{size} + \alpha_{clim}\,\hat{clim} + \alpha_{TC} - \hat{EF} \tag{1.25}$$

Equation (1.25) decomposes the growth rate of energy into terms related to: (i) changes of prices for energy and capital stock; (ii) economies of scale component for the production of energy services; (iii) changes in household income and household size; (iv) change of climate; (v) exogenous technological change; and (vi) change in the underlying energy efficiency.

1.3.2 Decomposition of the growth rate of energy productivity

In order to assess the efficiency in terms of energy use, it is more helpful to consider an equation that relates energy productivity to the inputs, that is energy service consumed divided by the amount of energy

[15] A cobb-douglas or a translog functional form is often used in such empirical studies.
[16] Subscripts i and t are omitted to avoid notational clutter.

used to produce this energy service

$$EP = \frac{S}{E}$$

where EP is energy productivity, S the energy service consumed and E the amount of energy required to produce the service.

By decomposing the energy productivity growth, we can identify the factors that contributes to the change of productivity, and explicitly capture the relationship between change of energy productivity and energy efficiency. The growth rate of energy productivity ($\hat{EP}$) can be expressed as the growth rate of energy service produced minus the growth rate of energy demanded, i.e.

$$\hat{EP} = \frac{d\ln(S/E)}{dt} = \frac{d\ln S}{dt} - \frac{d\ln E}{dt} = \hat{S} - \hat{E} \tag{1.26}$$

Substituting equation (1.25) into equation (1.26) and rearranging the terms we obtain

$$\begin{aligned} \hat{EP} &= \hat{S} - \hat{E} \\ &= \hat{S} - \Big(\alpha_{p_E}\,\hat{p_E} + \alpha_{p_K}\,\hat{p_K} + \alpha_S\,\hat{S} + \alpha_{inc}\,\hat{inc} + \alpha_{size}\,\hat{size} \\ &\qquad\qquad + \alpha_{clim}\,\hat{clim} + \alpha_{TC} - \hat{EF}\Big) \\ &= \hat{EF} - \alpha_{p_E}\,\hat{p_E} - \alpha_{p_K}\,\hat{p_K} + (1-\alpha_S)\,\hat{S} - \alpha_{inc}\,\hat{inc} - \alpha_{size}\,\hat{size} \\ &\quad - \alpha_{clim}\,\hat{clim} - \alpha_{TC} \end{aligned} \tag{1.27}$$

The above equation (1.27) decomposes the growth rate of energy productivity into four specific aspects. The first component of the right hand side of the equation shows the changes in energy technical efficiency. It is positive (negative) as the technical efficiency increases (decreases) over time. The technical efficiency EF_{it} can be interpreted as the rate at which an inefficient household moves toward the production frontier, everything else being constant. That is, a positive value of EF_{it} would indicate that a household is moving closer to the production frontier (technical efficiency increasing over time, *ceteris paribus*).

The second and the third term indicate the price effects on energy productivity caused due to changes in energy price and price of capital. The fourth term can be interpreted as the well-known measure of scale economies. Positive values stand for positive scale economies and negative numbers for scale dis-economies. The fifth and sixth term stand for the effects from growth of household income and household size. They reflect the life style and social structure of local residents. The seventh term shows the effect of change in climate. The last term indicates the effect due to exogenous technological change. This yields an indicator of the contribution of *technical progress* to energy productivity over each time period.[17]

Of course we should be aware in order to perform this type of decomposition analysis, we should use panel data which show variation of all variables over time. As we discuss later on in the report, our dataset has a panel format but some of the variables are not changing over time.

[17]The term $\partial \ln E^F(x;t)/\partial \ln t$ represents the rate of energy demand diminution. That is, $-\alpha_{TC}$ is the dual rate of technical change. However, $-\alpha_{TC}$ is a series of discrete formulation of the technological progress (TP_t) for each time period. We must assume that the discrete formulation $\Delta TP_t/\Delta t = -\alpha_{TC}$ is equivalent to the continuous formulation $\partial TP_t/\partial t$. According to Brown and Popkin (1962), we can interpret all differentials as discrete changes.

2 The household survey

In order to perform empirical research on the level of electricity efficiency, on the role of energy-related financial literacy in buying electrical appliances, and on the role of bounded rationality for the energy-efficiency gap, it is important for the researcher to be able to use a large dataset with information at the households level.

In general, data on Swiss residential energy consumption is rare. The Swiss Federal Statistical Office (SFSO) does not systematically collect data on domestic energy consumption that includes, for example, details on the number and type of appliances used and energy services consumed, together with information on household size and characteristics as well as socio-demographics. While governmental bodies in other countries collect data on residential energy consumption on a regular basis (examples are the Residential Energy Consumption Survey (RECS) in the US and the English Housing Survey in the UK), a comparable dataset for Switzerland is missing. Therefore, as part of the project "Underlying Energy Efficiency and Technological Change in the Swiss Household Sector", CEPE initiated a large household survey in cooperation with nine Swiss utilities with the aim of collecting the data needed to estimate the level of energy efficiency in Swiss households.

This chapter is laid out as follows: in Section 2.1 we provide an overview of the development and implementation of the online survey which was used to collect the data for the empirical analysis. The organization of the sampling, the process of data collection as well as the general structure of the questionnaire are presented here. In Section 2.2 we compare the collected sample to some of the publicly available population statistics from the 9 regions to give an idea of the representativeness of the collected data. Section 2.3 comprises the descriptive statistics of the data we collected based on the large household survey. This part provides information on the size and characteristics of the residences of the sampled households, energy sources used by the households, on household size, composition and characteristics, on the energy services consumed by the households, on number and age of appliances as well as socio-demographics of the survey respondents. In addition, we report energy-related attitudes and behaviors, energy literacy and the adoption of policy measures offered by the utilities (such as appliance rebates, investment support or online self-monitoring tools). Finally, we include a sample of the questionnaire underlying the household survey in the Appendix.

2.1 Organization of the survey

In the following, we describe the details of the organization and implementation of the survey.

2.1.1 Development and implementation of the survey

The survey questionnaire was developed by the Centre for Energy Policy and Economics (CEPE) based on insights from the survey methodology literature (Dillman et al., 2009; Groves et al., 2004) as well as from earlier household surveys on residential energy consumption (Alberini et al., 2013; VSE, 2011). It was peer-reviewed by researchers and professionals in the field of household energy consumption, and finally pre-tested on a student sample (ETH Master students). The questionnaire was examined and approved by the Ethics Commission of ETH Zurich under the reference EK 2015-N-06 and implemented online with the survey software SurveyMonkey.

2.1.2 Sampling

The sampling was organized in collaboration with nine Swiss utilities that operate in nine major cities in Switzerland – Aziende Industriali di Lugano (AIL), Aziende Municipalizzate Bellinzona (AMB), Energie Service Biel/Bienne (ESB), Energie Wasser Bern (EWB), Energie Wasser Luzern (EWL), IBAarau, IWB Basel, Services Industriels Lausanne (SiL) and Stadtwerk Winterthur (SW).

One of the criteria for the selection of these utilities was that they should operate mainly in urban and sub-urban areas in order to get a sample of households as homogeneous as possible in terms of environment. In addition, we predominantly approached multi-utilities that supply households not only with electricity but also with gas for heating, warm water and/or cooking, as this allows to expand the analysis to total energy consumption (at least for a sub-sample of the households). Furthermore, we wanted the utilities to represent all three major language areas of Switzerland.

Based on a list of all major Swiss utilities, a total of 23 utilities fulfilling the above mentioned criteria were contacted and asked for their interest in cooperating in the survey. As a next step, a meeting of the project team with the responsible person from the utility was arranged to give more details about the survey and to discuss the concrete steps for the implementation of the survey. The utilities were informed that survey participants will be asked for the permission to combine the survey data with actual electricity consumption (and gas consumption, if applicable) data from the utilities, based on their unique customer/service number (i.e. an unique identifier of the household). This would allow the joint analysis of the survey data and the actual consumption data of the participating households.

In exchange, CEPE promised all participating utilities to provide them with a brief report of the survey results, including descriptive statistics on the dwelling and household characteristics, number and types of appliances, energy services consumed, energy-related attitudes and behaviors as well as socio-demographic characteristics of the survey respondents. Nine utilities confirmed their interest in a participation after these meetings. Some others declined their participation for internal reasons.

In a next step, the above mentioned nine utilities invited either all or a sub-sample of their customers to take part in the online survey. If sub-samples of customers were drawn, all household customers had the same probability of being in the sample (random sampling). For a majority of the customers, the invitation was sent in the form of a letter that accompanied a bi-monthly, quarterly or yearly electricity or gas bill. If the utility had access to some of their customers' e-mail addresses (which is the case for AMB, ESB and IBAarau) the letter was attached in PDF to an e-bill. However, this applied only to relatively small share of the invited customers (Table 2.1).

While two utilities (AIL, SW) used personalized invitation letters (i.e. personal address at beginning of letter, personal customer/service number included in the letter) that were sent under separate cover, most utilities sent the invitation non-personalized and attached to a bill for cost and/or technical reasons. As we will show later, a personalized letter sent under separate cover expectedly led to a higher answer rate than the non-personalized letters attached to a bill.

Table 2.1: Overview of samples drawn by the participating utilities.

Utility	Approx. number of HH customers	Sample drawn	Thereof e-mail customers	Type of invitation letter
Aziende Industriali di Lugano (AIL)	91'000	26'532		Personalized
Aziende Municipalizzate Bellinzona (AMB)	30'000	30'000	5'000	Attached to bill
Energie Service Biel/Bienne (ESB)	38'000	38'000	5'000	Attached to bill
Energie Wasser Bern (EWB)	90'000	29'000		Attached to bill
Energie Wasser Luzern (EWL)	50'000	50'000		Attached to bill
IBAarau	28'000	28'000	3'000	Attached to bill
IWB Basel	130'000	23'000		Attached to bill
Services Industriels Lausanne (SiL)	120'000	100'000		Attached to bill
Stadtwerk Winterthur (SW)	55'000	15'000		Personalized
Total	632'000	339'532		

In all cases, the invitation letter briefly informed the customer about the purpose and content of the study as well as about data security and usage of the data. In addition, it included a clear description on how to access the online questionnaire by following a specified hyperlink to a survey web-page on CEPE's official university website. Furthermore, it was announced that all customers who complete the online questionnaire will automatically take part in a lottery. The announced prizes comprise 30 Smartboxes "Happy Day" per utility, worth 49.90 CHF each.[1]

The invitation letter also included a disclaimer with a short version of the conditions of participation, an information about the right of withdrawal from the study, as well as an e-mail address for further inquiries about the study and the questionnaire.

The response rates (number of total visits to the survey page divided by the total number of invited customers) varied between 1.8% and 7.6% (Table 2.2). The observed response rates were highest for the two utilities that sent personalized invitation letter. The highest response rate of 7.6% has been achieved by Aziende Industriali di Lugano (AIL) followed by Stadtwerk Winterthur (SW) with 6.7%, both of which can be attributed to the personalized invitation letters under separate cover.

Table 2.2: Response rates by participating utility.

Utility/Region	Sample drawn	Visits on survey page	Response rate (in %)	Usable samples
AIL / Lugano	26'532	2'022	7.6	1'406
AMB / Bellinzona	30'000	957	3.2	583
ESB / Biel/Bienne	38'000	1'308	3.4	877
EWB / Bern	29'000	1'163	4.0	916
EWL / Luzern	50'000	1'999	4.0	1'375
IBAarau / Aarau	28'000	1'074	3.8	826
IWB / Basel	23'000	422	1.8	300
SiL / Lausanne	100'000	1'915	1.9	1'356
SW / Winterthur	15'000	1'005	6.7	739
Total	339'532	11'865	3.5	8'378

The total number of visits on the survey page was 11'865 out of the possible 339'532 households reached (share = 3.5%). Accounting for the fact that not all respondents could provide their customer number at the beginning of the survey, or were filtered-out as not being part of the target sample (explained

[1] Smartbox homepage.

in Section 2.1.4), or did not complete the online questionnaire till the end; we have a total of 8'378 usable sample of households from this extensive survey.[2] Out of these, about 90% of the completed questionnaires can be expected to include the household's consent to the linking of the survey data to the actual consumption data of the household (see Section 2.1.5). The final sample is expected to provide a good representation of Swiss households residing in urban and suburban areas of Switzerland, i.e. to be representative not on the regional but on the national level.

2.1.3 Time period, duration and language

The online survey for 8 out of the 9 utilities was conducted over the year 2015. The survey for EWB (Bern) was conducted in the first quarter of 2016. The starting dates of each survey varied between utilities depending on internal processes related to the shipment of billing letters. Irrespective of the start-date, the duration for which a survey remained open for participation was kept fixed to a total period of 19 – 21 weeks.

The survey questionnaire had a length of about 15 to 20 minutes answering time. The length varied between utilities, as every utility had its own personalized questionnaire which, in most cases, also included utility-specific questions that were not part of the main questionnaire.

The questionnaire was offered in two languages: in the main (official) language of the respective municipality/canton and in English. In the bi-lingual city of Biel/Bienne, the questionnaire was offered in three languages: German, French and English.

2.1.4 Structure of the questionnaire

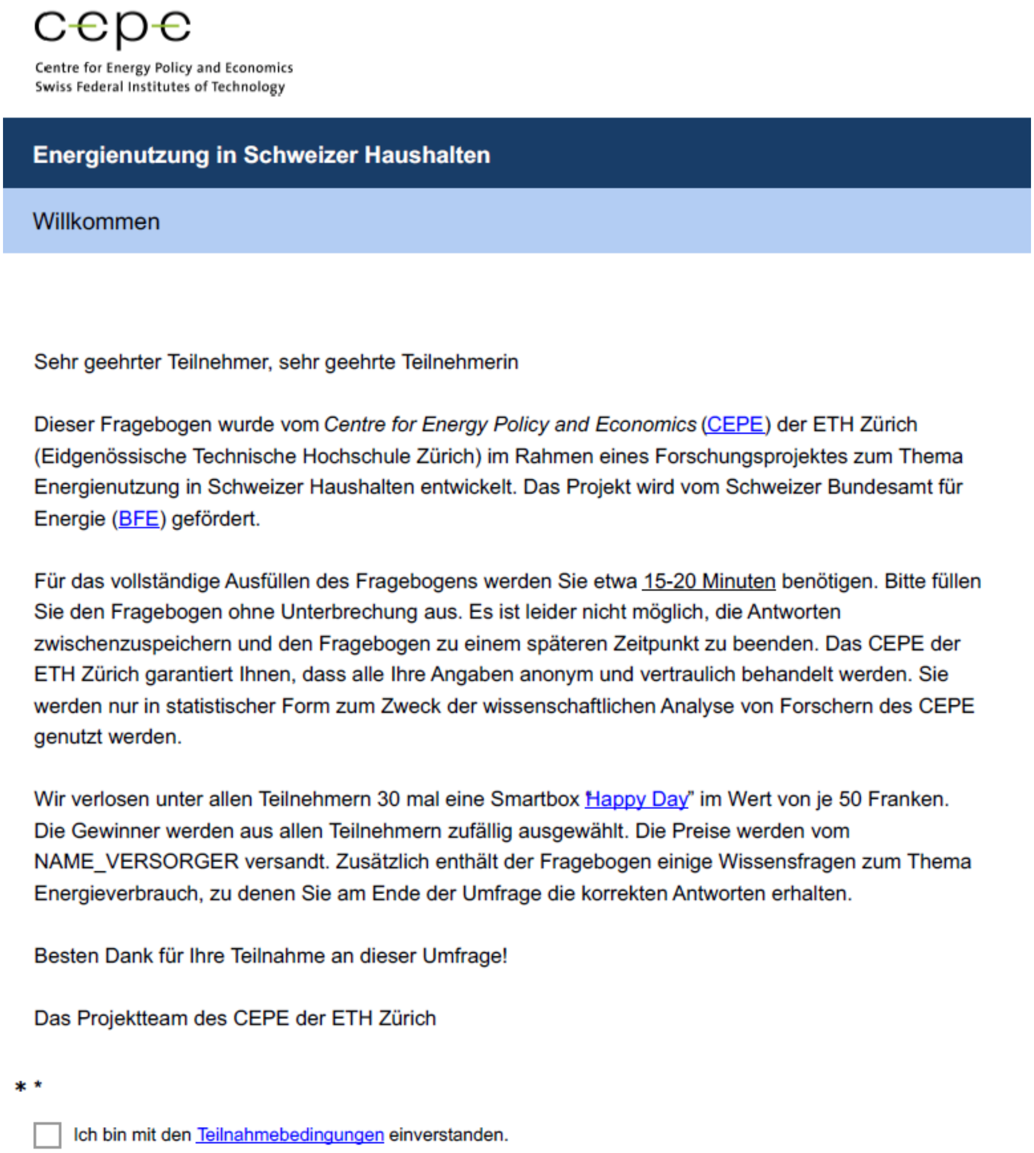
Every questionnaire started with an introductory page with information about the survey and a detailed information about the conditions of participation (see Figure 2.1). On this page, participants were once more informed that their responses remain anonymous and confidential at any time and will only be used in statistical form by the researchers of CEPE to carry out scientific analyses.

After the introductory page, participants were asked to enter their customer/service number to be found on one of their electricity or gas bills. The customer/service number was used to uniquely identify the participants for the lottery and (given the participant's approval) to link the survey data to the actual electricity/gas consumption of the respective household later on.

To prevent unnecessary loss of time and efforts on the part of the customers, three screening questions made sure that only respondents who fitted into our target group would complete the questionnaire (see Figure 2.2). The three screening questions comprised whether the entered customer or service number refers to the principal residence of the respondent, whether the respondent is one of the persons in the household responsible for paying the bills, and whether the respondent lived in his current residence already before January 1st 2015.

The main part of the questionnaire included sections about house/apartment characteristics and energy sources for heating and warm water, household composition, appliances present in the household and

[2] The usable survey response rates for all the nine survey regions are relatively low when compared to the number of invitation letters sent. One reason for this is the setting – the invitation to participate was sent on paper, including a link to the online survey. This invitation was sent with one of the regular utility bills, which unfortunately lowered the probability that it got the customers' attention.


cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Willkommen

Sehr geehrter Teilnehmer, sehr geehrte Teilnehmerin

Dieser Fragebogen wurde vom *Centre for Energy Policy and Economics* (CEPE) der ETH Zürich (Eidgenössische Technische Hochschule Zürich) im Rahmen eines Forschungsprojektes zum Thema Energienutzung in Schweizer Haushalten entwickelt. Das Projekt wird vom Schweizer Bundesamt für Energie (BFE) gefördert.

Für das vollständige Ausfüllen des Fragebogens werden Sie etwa 15-20 Minuten benötigen. Bitte füllen Sie den Fragebogen ohne Unterbrechung aus. Es ist leider nicht möglich, die Antworten zwischenzuspeichern und den Fragebogen zu einem späteren Zeitpunkt zu beenden. Das CEPE der ETH Zürich garantiert Ihnen, dass alle Ihre Angaben anonym und vertraulich behandelt werden. Sie werden nur in statistischer Form zum Zweck der wissenschaftlichen Analyse von Forschern des CEPE genutzt werden.

Wir verlosen unter allen Teilnehmern 30 mal eine Smartbox "Happy Day" im Wert von je 50 Franken. Die Gewinner werden aus allen Teilnehmern zufällig ausgewählt. Die Preise werden vom NAME_VERSORGER versandt. Zusätzlich enthält der Fragebogen einige Wissensfragen zum Thema Energieverbrauch, zu denen Sie am Ende der Umfrage die korrekten Antworten erhalten.

Besten Dank für Ihre Teilnahme an dieser Umfrage!

Das Projektteam des CEPE der ETH Zürich

* *

☐ Ich bin mit den Teilnahmebedingungen einverstanden.

Figure 2.1: Welcome page.

energy services used by the household. Furthermore, it comprised questions about environmental attitudes and energy-related behavior, about energy literacy and energy-related investment literacy. At the end of each questionnaire, socio-demographic characteristics were retrieved.

The section on house/apartment characteristics differed depending on whether the survey participant lived in a single-family house (i.e. semi-/detached or terraced house), or in an apartment in a multi-family house. All other sections were identical for all participants.

After completion of the questionnaire, respondents were asked whether they agree that CEPE links the survey data to the actual electricity/gas consumption data of the respective household (see Figure 2.3). The level of agreement to the linking of the data was high: on average, 93.4% of the respondents gave their consent that their utility provides CEPE with the consumption data based on their customer number.

Finally, respondents were redirected to a page that contained the answers to the quiz-style questions about energy consumption and energy-related investments that were used to evaluate the respondents' energy literacy. The answers to theses questions were followed by a brief information about electricity

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Qualifikation für die Umfrage

*

Bezieht sich die von Ihnen eingegebene Kundennummer auf Ihren Hauptwohnsitz?

- Ja
- Nein

*** Sind Sie eine der Personen in Ihrem Haushalt, die die Kaufentscheidungen trifft und/oder die Rechnungen bezahlt?**
(z.B. im Hinblick auf Ausgaben für Möbel, Haushaltsgeräte, Telefon- und Stromrechnung)

- Ja
- Nein

*** Wohnten Sie bereits vor dem 1. Januar 2015 in Ihrer derzeitigen Wohnung/in Ihrem derzeitigen Haus?**

- Ja
- Nein

Figure 2.2: Screening questions to filter out respondents fitting into our target group.

consumption of various household appliances, together with hyper-links to informative websites on household energy consumption.

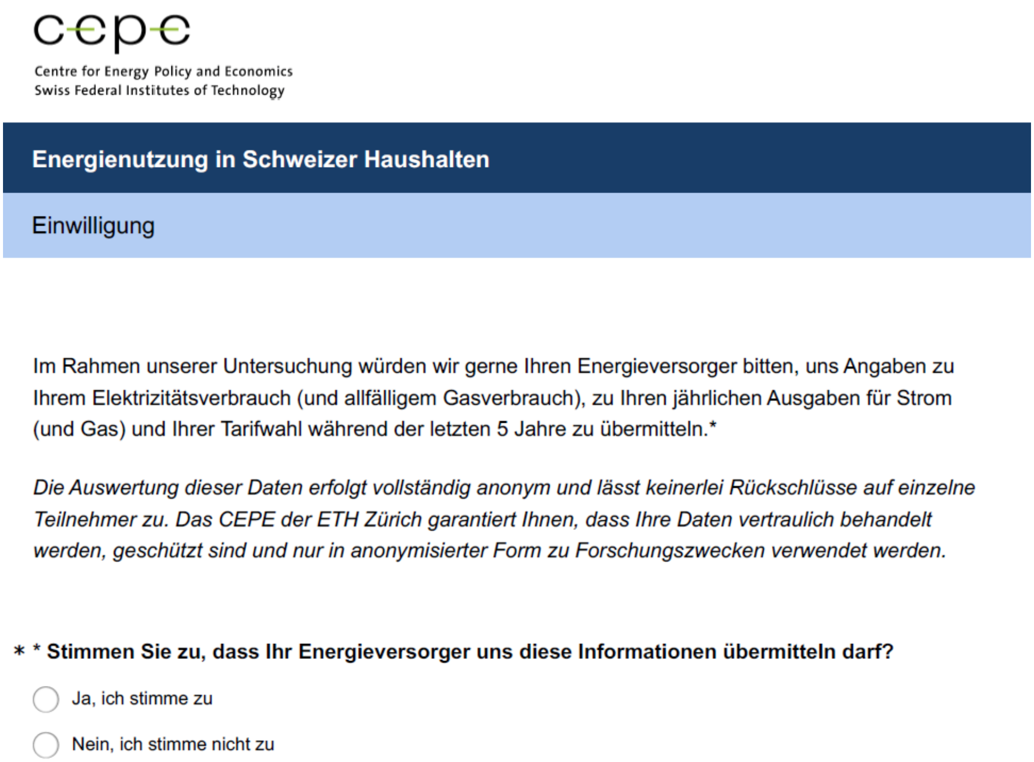
A complete example questionnaire can be found in Appendix D.

2.1.5 Linking of survey and consumption data

After the online surveys of each utility are closed, the customer/service numbers of those respondents who agreed to the linking of the survey data to their electricity/gas consumption data are transferred to the respective utilities. Data security agreements between CEPE and the utilities ensure that the utilities will have no access to the survey data, while CEPE will never receive any information on the identity of the customers. The customer/service number serves as the only and unique link between the survey data and the actual electricity/gas consumption data.

The respective utilities return data files comprising the customer/service numbers and total yearly electricity and gas consumption for the years 2010 to 2014 (5 years) to CEPE.[3]

[3] In some cases, information on the billing period, the chosen electricity/gas products and yearly billing amounts are also available.



Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Einwilligung

Im Rahmen unserer Untersuchung würden wir gerne Ihren Energieversorger bitten, uns Angaben zu Ihrem Elektrizitätsverbrauch (und allfälligem Gasverbrauch), zu Ihren jährlichen Ausgaben für Strom (und Gas) und Ihrer Tarifwahl während der letzten 5 Jahre zu übermitteln.*

Die Auswertung dieser Daten erfolgt vollständig anonym und lässt keinerlei Rückschlüsse auf einzelne Teilnehmer zu. Das CEPE der ETH Zürich garantiert Ihnen, dass Ihre Daten vertraulich behandelt werden, geschützt sind und nur in anonymisierter Form zu Forschungszwecken verwendet werden.

∗ * Stimmen Sie zu, dass Ihr Energieversorger uns diese Informationen übermitteln darf?

- Ja, ich stimme zu
- Nein, ich stimme nicht zu

Figure 2.3: Question asking respondent for consent to linking the survey data to the actual electricity/gas consumption of the respective household.

2.2 Comparison with population statistics

After accounting for the correct target group[4], incomplete responses, and duplicate entries, we have valid and complete data for 8,378 households. Of all respondents who started the online survey, filled in their customer number and were filtered-in as the target group, almost 90% completed the survey till the end. We do not find any significant selection among the sample of usable surveys relative to the target group. The observed samples are supposed to reflect the Swiss population living in urban (and sub-urban) areas, which accounts for about three quarters of the total population.[5]

In order to evaluate to what extent the full sample of customers of all participating utilities can be considered representative, we would need statistical data on the population living in the service areas of all participating utilities. However, since such data is not always available, we therefore, as a simple approximation, compare our descriptive statistics to the summary statistics at the city level and at the national level. It must be noted that either of the combinations of the two samples are not entirely identical. Hence, all comparisons have to be made with caution since the statistics at the city or federal level might not adequately reflect the characteristics of the population in some specific regions. Nevertheless, we think that the full-sample presented here may be more representative of the population living in **urban** and **sub-urban** regions of Switzerland.

[4]The target group consists of respondents (i) for whom the electricity/gas bill refers to their primary residence; (ii) who moved in their current residence before 01.01.2015; and (iii) who are one of the persons in their residence who decides about the purchase of goods and/or pays the bills. All nine samples combined, a total of 9,483 respondents were filtered-in as the target group, of which 8,484 completed the survey till the end.

[5]Data from the Swiss cities association (SSV) 2017.

2.2.1 Comparison to city level statistics

To evaluate how well our sub-samples reflect the basic demographic characteristics of the nine urban areas included in our analysis, we compare the sample characteristics to population statistics from the Swiss cities association (Table 2.3). It is to be noted that the statistics at the city level may not completely reflect the statistics of the surveyed areas, i.e. the service areas of the utilities, which usually also include neighboring municipalities.

In terms of gender composition, the households in our samples seem to represent the population in the six areas quite well. The same holds for age-groups, with some exceptions such as the samples from Bellinzona, Lugano and Aarau, in which a slight deviation can be observed (higher share of younger as compared to older household members in Bellinzona and Lugano, higher share of both younger and older household members as compared to the group of people aged 20 to 64 years in Aarau). Regarding the mean household size, we observe that households in our sample comprise slightly more people than the average household in the areas. Also the living space per person (m^2/person) is slightly above average in all six regions. This, however, does not hold for the number of people per room, which is mostly at the average level. The only exception is Biel/Bienne, where fewer people per room are observed than the population mean would suggest. In conclusion, the characteristics of the surveyed households are generally in line with the characteristics in the six areas (with some smaller exceptions). It is to be noted that the statistics at the city level may not completely reflect the statistics of the surveyed areas, i.e. the service areas of the utilities, which usually also include neighboring municipalities.

2.2.2 Comparison to national statistics

In the following, the datasets of all nine utilities is combined to get a broader representation of the Swiss population in major urban and suburban areas (i.e. at the national level). We compare these to available statistics at the national level. As mentioned, the surveyed customers of all utilities in our survey are not identical with the entire population of Switzerland, but the characteristics of the latter are used only as an approximation of the characteristics of the customer base of all utilities to get a rough idea about the representativeness of the data.

Considering the numbers presented in Table 2.4, we can observe that our sample represents the Swiss population fairly well in terms of household type, income as well as donations to environmental organizations. The slight under-representation of high income households might be due to a higher share of such households opting not to report their income. In terms of education level of the household members, the sample however does not appear to be representative. Highly educated households are over-represented in our sample when compared to the reference Swiss population.

2.3 Descriptives

In the following, we provide the descriptive statistics for several variables included in the questionnaire using the full sample gathered from all 9 participating utilities. A total of 8,378 households took part in the survey and completed the questionnaire until the final screen. This corresponds to a share of 2.47% of the households that received the letter of invitation, either together with one of their electricity or gas bills (most utilities), or separately (AIL and SW). The total number of households within our sample

Table 2.3: Comparison of basic demographic characteristics of the nine regions.

	AIL / Lugano		AMB / Bellinzona		ESB / Biel-Beinne		EWB / Bern		EWL / Lucerne		IBAarau / Aarau		IWB / Basel		SiL / Lausanne		SW / Winterthur	
	Sample (N=1,406)	*SSV*	*Sample (N=583)*	*SSV*	*Sample (N=877)*	*SSV*	*Sample (N=916)*	*SSV*	*Sample (N=1,375)*	*SSV*	*Sample (N=826)*	*SSV*	*Sample (N=300)*	*SSV*	*Sample (N=1,356)*	*SSV*	*Sample (N=739)*	*SSV*
Share of females (%)	51.69	51.85	51.06	52.87	52.61	51.14	51.10	52.02	51.39	52.12	50.35	51.13	52.76	51.67	52.78	51.95	50.35	50.91
Share of population by age (%)																		
young (0-19 years)	20.04	17.57	25.96	18.27	17.15	18.84	18.47	15.67	13.08	15.71	19.11	16.86	11.13	16.32	18.62	19.59	20.44	19.69
adult (20-64 years)	63.24	60.68	62.25	61.18	62.04	62.26	70.19	66.61	63.82	64.88	58.92	64.72	58.92	64.10	65.24	65.07	65.11	64.05
elderly (65+ years)	16.72	21.75	11.79	20.54	20.81	18.90	11.34	17.72	23.10	19.41	21.97	18.42	29.95	19.58	16.14	15.34	14.45	16.26
Mean household size	2.40	2.00	2.60	2.09	2.18	2.11	2.24	2.01	2.09	1.92	2.43	2.00	2.12	1.90	2.15	1.97	2.31	2.20
Dwelling (mean values)																		
living space per head (m^2)	54.19	46.00	52.62	45.00	51.63	39.00	44.55	39.00	52.44	45.00	62.36	48.00	53.91	41.00	40.96	37.00	49.10	43.00
people per room	0.63	0.62	0.65	0.60	0.57	0.66	0.66	0.67	0.57	0.58	0.53	0.55	0.59	0.60	0.67	0.69	0.61	0.61

Data at city level from 2015.
Data source: Swiss cities association (Schweizerischer Städteverband/SSV).

Table 2.4: Selected characteristics of sampled households compared to characteristics of population.

Characteristic	% of sample	% of population	Reference population
Type of residence			Switzerland
Single-family house	28.4	–	
Apartment in multi-family house	71.6	–	
Household type			Switzerland (2014)
Couple with/without children	60.8	72.0	
Single with/without children	33.6	24.0	
Non-family household	5.5	4.0	
Gross monthly household income (in 2014)			Switzerland (2009-2011 data)
up to 6'000 CHF	29.3	29.3	
6'001 to 12'000 CHF	41.9	45.0	
more than 12'000 CHF	15.1	25.7	
Don't know/No answer	13.6	n.a.	
Education of household members			Switzerland (2013)
Compulsory education	4.2	26.0	
Secondary education	37.5	47.0	
Tertiary education	55.8	27.0	
Other	2.5	n.a.	
Donations to environmental organizations (in 2014)	39.7	42.0	Switzerland (2014)

varies widely across the 9 utilities, ranging from 300 households for one utility to 1'406 households for another.

2.3.1 A typical household in our sample

To get a sense of the typical household in the full sample, Table 2.5 lists out the most frequently reported answer categories among all households living in single-family houses (SFH) or multi-family houses (MFH).

Table 2.5 shows that the typical household consists of two adults aged between 20 and 64 years. The most frequently reported household type is 'couple with children' in a single-family house and 'single-person-household' in a multi-family house, with a gross monthly household income in between 6'001 and 9'000 CHF. If the household resides in a single-family house it is most frequently reported to be owned by the household. Single-family homes most frequently comprise about 101 to 150 square meters of living space, distributed among 6 rooms, 1 kitchen and 2 bathrooms/WCs. Single-family homes are predominantly built in the period before 1940 and are heated by gas (space heating as well as water heating).[6] If the household resides in a multi-family house, then the apartment is most likely rented and comprises about 71 to 90 square meters of living space, with 3 rooms, 1 kitchen and 1 bathroom/WC. The multi-family houses are most frequently built in between 1940 to 1970.

[6] In the survey questionnaire the energy sources were not covered in detail for households living in multi-family houses.

Table 2.5: Overview of characteristics of the typical household in our sample, by type of residence.

Characteristic	Typical household living in SFH	Typical household living in MFH
Ownership status	Owned	Rented
Size of house/apartment in sqm (m^2)	100-150	71-90
Number of rooms (excl. kitchen/bathroom)	6	3
Number of kitchens	1	1
Number of bathrooms/WCs	2	1
Building period of house	before 1940	1940-1970
Energy source used for space heating	Gas	-
Energy source used for warm water	Gas	-
Energy source used for cooking	Electricity	Electricity
Number of household members	2	2
Number of females in household	1	1
Household type	Couple without children	Couple without children
Number of children/teenagers (<20y) in household	0	0
Number of elderly (>64y) in household	0	0
Gross monthly household income (in CHF)	6,001-9,000	6,001-9,000
Number of cooked lunches per week	7	7
Number of cooked dinners per week	7	7
Dishwasher use (cycles per week)	3	2–3
Washing machine use (cycles per week)	2–3	1–2
Tumbler dryer use (cycles per week)	0–1	0–1
Share of energy saving light bulbs	less than half of all bulbs	less than half of all bulbs
Average room temperature in living room	21 °C	21 °C

The typical household cooks with electricity. While most residents of both single-family houses and multi-family houses reported to prepare cooked lunches and dinners on a daily basis, households residing in multi-family houses also reported preparing 5 cooked dinners and 2 cooked lunches during a week as the second-largest answer category. The dishwasher is typically used three times a week within the single-family houses and 2–3 times a week within multi-family houses. The washing machine is normally used 2–3 times a week in SFH and 1–2 times a week in MFH. The share of energy-saving bulbs is less than half in both types of residences and the average heating temperature in the living room is most frequently reported to be 21°C.

2.3.2 House and apartment characteristics

Type of residence

Out of the 8,378 observed households, 2,376 (28.4%) lived in single-family houses and 6,002 (71.6%) lived in apartments in multi-family houses (Figure 2.4). It turns out that 68.7% of all residential buildings in Switzerland are reported to be single-family houses and the rest 31.3% are multi-family houses.[7] But unfortunately, we do not have the equivalent statistics on the share of people living in these single and multi family houses.

[7]BFS: T 09.02.01.01 Gebäude nach Gebäudekategorie und Kantonen, Jahr 2014.

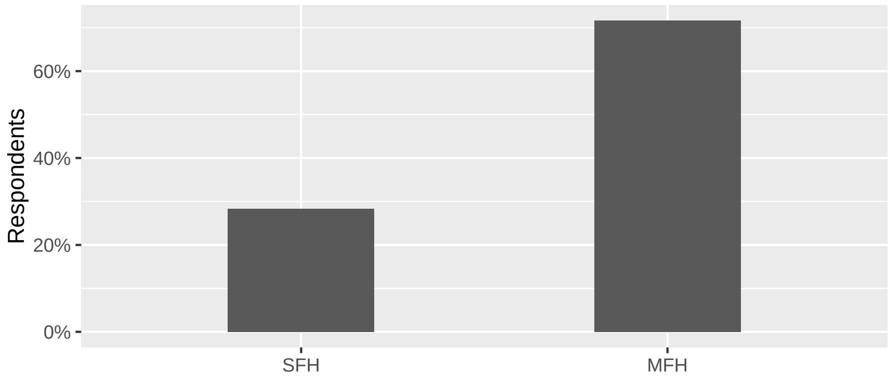


Figure 2.4: Type of residence.

Single-family houses were mostly reported to be detached houses (55.7%), and to a lesser extent, semi-detached houses (24.2%) or row houses (20.1%). Most of the multi-family houses (44.5%) were characterized as being of medium size (comprising 6 to 12 apartments), while 34.6% of the residents of multi-family houses characterized their building as a large MFH (more than 12 apartments), and 20.7% characterized their building as a small MFH (less than 6 apartments).

Ownership status

A total of 3,337 households (39.8%) reported to own their residence and 5,041 households (60.2%) reported to be tenants.

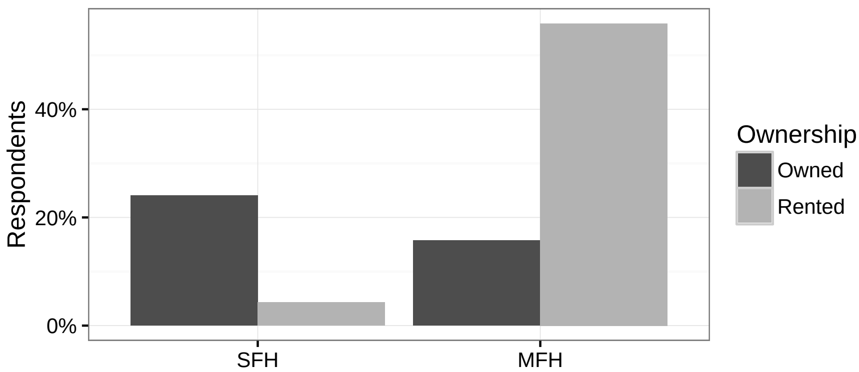


Figure 2.5: Ownership status by type of residence.

As expected, a great share of households living in single-family houses own their residence: 84.8%. This compares to only 22% of the residents of multi-family houses who own their apartments (Figure 2.5).

Size of residence

Out of the 2,376 households residing in **single-family houses**, 2,301 households reported more information about the size of their house in terms of square meters (sqm). Out of these, 34.5% live in houses with 101 to 150 sqm of living space, 29% live in houses with 151 to 200 sqm, and 17.6% in houses with 201 to 300 square meters. Only 12.5% live in houses smaller than 100 square meters and another 3.3% have more than 300 square meters of living space (Figure 2.6).

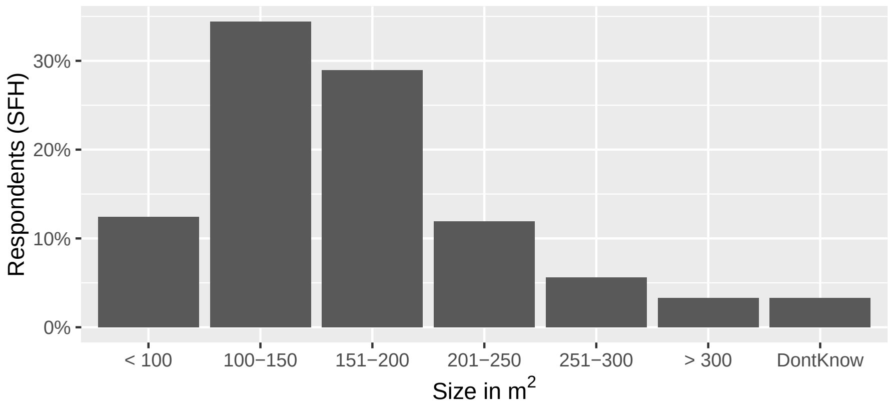


Figure 2.6: Single-family houses by size in square meters.

Most of the observed single-family houses (34.3%) have 6 or more rooms in addition to bathroom(s) and kitchen(s), followed by 31.8% with 5 rooms. 20.9% of the single-family houses have 4 rooms and only 13.1% have 3 rooms or less (Figure 2.7).

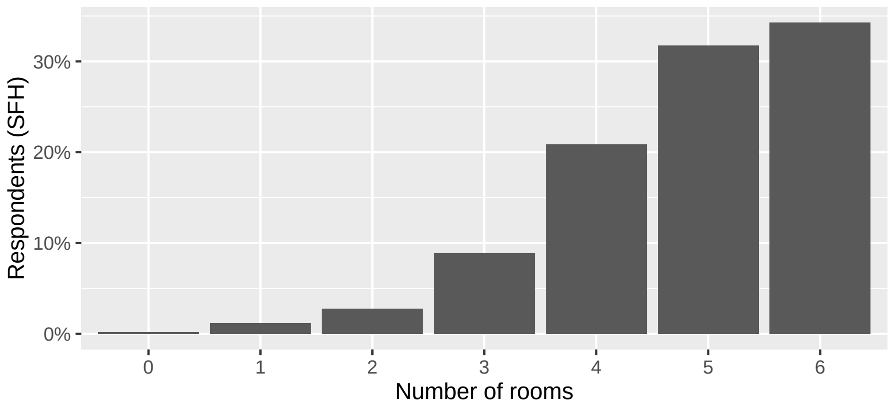


Figure 2.7: Number of rooms in SFHs (in addition to bathroom/kitchen).

Most single-family houses comprise one kitchen. Only 9.1% of single-family houses were reported to have more than one kitchen. 78.5% of the single-family houses comprise either 2 (54.3%) or 3 (24.2%) bathrooms/WCs.

Out of the 6,002 respondents who lived in apartments in **multi-family houses**, 5,923 reported the size of their apartment in square meters. The greatest share of households (24.9%) live in apartments with a size between 71 and 90 square meters, followed by those between 91 and 110 square meters (21.9%) and those with apartments of 70 square meters or less (21%). 22.5% of the respondents lived in apartments between 111 and 150 square meters and 8.3% lived in apartments of more than 150 square meters (Figure 2.8).

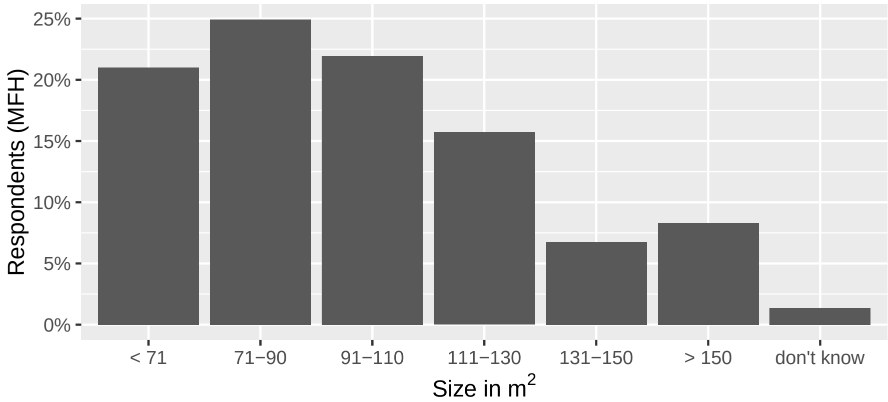


Figure 2.8: Multi-family houses by size in square meters.

In the multi-family houses, most apartments comprise of 3 or 4 rooms: out of the 6,002 observed apartments, 35.2% are apartments with 3 rooms, 28.6% have 4 rooms. 23.4% of the apartments have 2 rooms or less and 12.9% have 5 rooms or more (Figure 2.9).

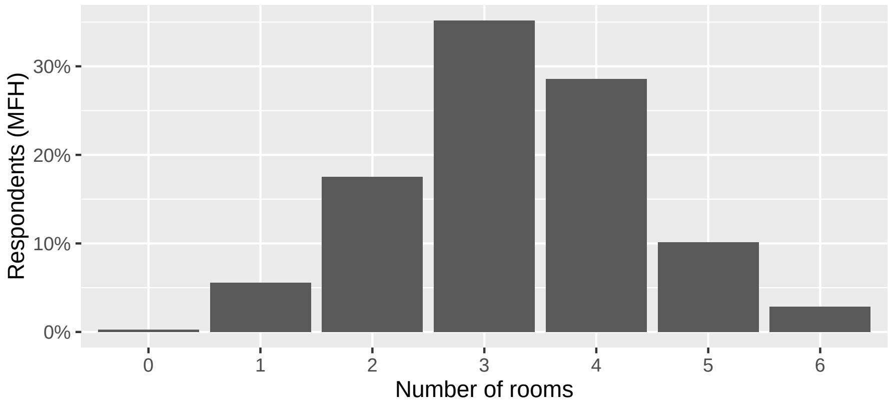


Figure 2.9: Number of rooms in MFHs (in addition to bathroom/kitchen).

The majority of these apartments contain one kitchen. Only 3.1% of the apartments have more than one kitchen. Most apartments have 1 bathroom/WC (52.7%), many of them have 2 bathrooms/WCs (38.4%) and only 5.6% have 3 or more bathrooms/WCs.

Building period, energy characteristics and renovations

As to the building period, 24.7% of all **single-family houses** were built before 1940, 23.4% were built between 1940 to 1970, 22.1% were built between 1970 and 1990 and 23% were built between 1990 and 2010. Only 2.7% of the single-family houses were built after 2010 (Figure 2.10).

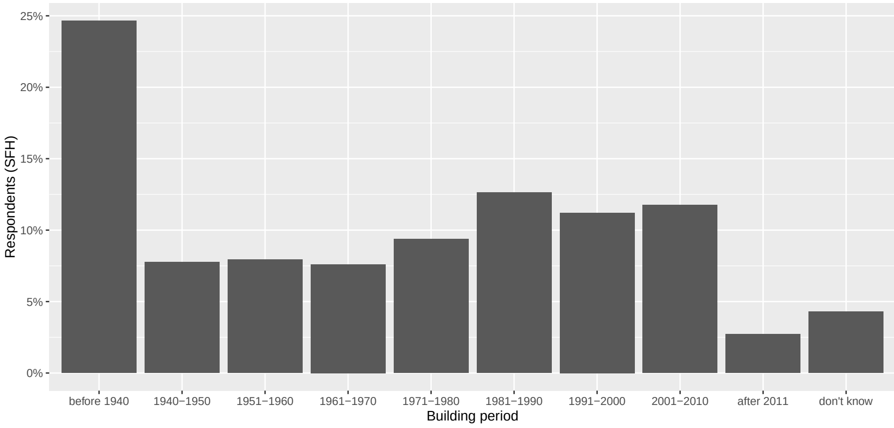


Figure 2.10: SFHs by building period.

5,238 of the 6,002 residents in **multi-family houses** gave information about the building period of their apartment. 21.1% said that their building was built before 1940, 26.1% were built between 1940 to 1970, 24.5% were built between 1970 and 2000 and 15.6% were built after 2001 (Figure 2.11).

Figure 2.11: MFHs by building period.

171 single-family houses and 522 multi-family houses were indicated to be Minergie houses, which corresponds to a share of 7.2%, respectively 8.7%, of the two sub-samples. More than half of the single-family houses complying with the Minergie standard were built after 1990 (59.1%). Also, most of the multi-family houses complying with the standard were built after 2001 (64.6%).[8] This suggests that, in tendency, the multi-family houses in this sample have more favorable energy characteristics than the single-family houses.

1,121 of the 2,376 single-family houses (47.2%) were reported to have undergone some kind of energy-efficient renovation since the year 2000. This includes all kinds of renovations such as replacement of windows or roof, renovation of the building envelope or change of heating system.

In most cases, an energy-saving renovation included a replacement of the windows, as this was reported by 886 out of the 1,121 respondents. Also a renovation of the space heating system was reported relatively frequently (725 households), followed by a renovation of the water heating system (654 households) and

[8]Note: The Minergie certificate can be acquired not only for new buildings but also for renovated buildings.

renovations of the the roof (576 households). The least frequently reported renovation measure was the renovation of the façade, which was reported by 321 households.

2.3.3 Household characteristics

Household composition

We have information about household composition for 8,180 households. The biggest share among all households were 2-people-households (42.6% of all households), followed by single-person households (27.2%), households with 3 people (13%) and households with 4 people (12.4%). Only 4.8% of households had 5 or more members (Figure 2.12). Our sample also shows that the average household size slightly decreased between 2010 (2.42 people) and 2014 (2.26 people).

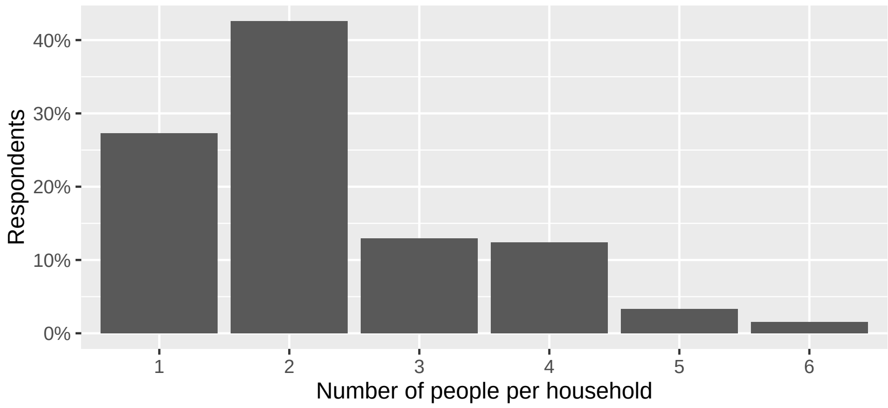


Figure 2.12: Number of people per household in 2014.

As a comparison, 35% of households in Switzerland are single-person households, 33% of the households are 2-people-households, 13% are 3-people-households and 13% consist of 4 people, and only 6% have 5 or more members.[9] This suggests that couple households are slightly overrepresented and single households underrepresented in the sample.

Household type

8,378 households informed about their household type (Figure 2.13). Out of these, 2,917 (34.8%) were couples without children in the household and 2,179 (26%) were couples with children. 2,367 (28.3%) were single households and 451 (5.4%) were single-person households with children. The remaining 464 households (5.5%) were non-family households.

According to the Swiss population statistics, the share of single households amounts to 18%. 29% are reported to be couples without children, 42% are couples with children and 6% of the households are single parent with children.[10] This again suggests that couples without children seem to be slightly over-represented in our sample.

[9] BFS (2014): STATPOP cc-d-01.05.01.11 Privathaushalte nach Kanton und Haushaltsgrösse am 31. Dezember 2013.

[10] BFS (2016): Strukturerhebung, su-d-40.02.01.02.08 Ständige Wohnbevölkerung ab 15 Jahren in Privathaushalten nach Haushaltstyp und Sprachgebiet, Jahr 2014.

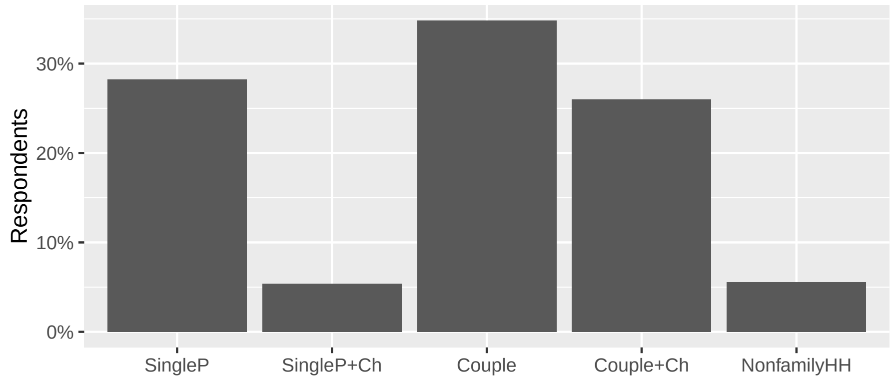


Figure 2.13: Households by type.

In 24.9% of the households at least one member was above 64 years old and in 23.5% of the households there was at least one child or teenager younger than 20 years. Only in 69 households (0.82%) at least one elderly person above 64 was present together with at least one child or teenager. In 52.41% of the households neither a child/teenager nor an elderly person was part of the household.

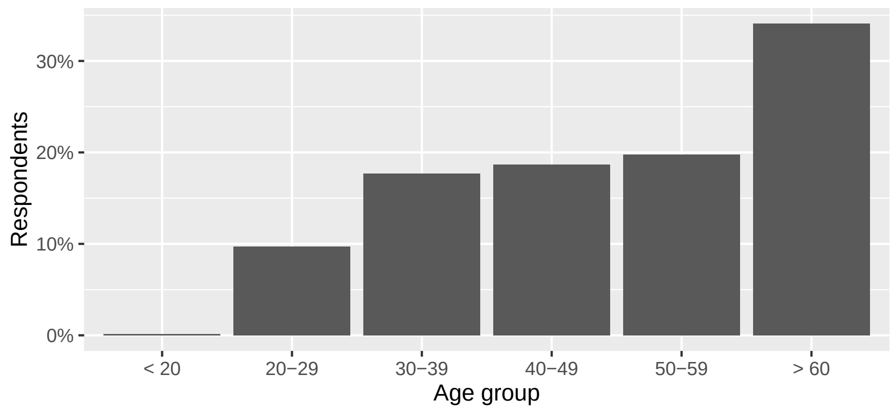


Figure 2.14: Survey respondents by age.

Of the 8,378 survey **respondents**, who were filtered-in to be one of the persons in their household who are in-charge of the households' purchase decisions and payment of bills, a greater share was male (58.6%) compared to female (41.4%). As can be seen in Figure 2.15, the share of male respondents increased with the age of the respondents, which could indicate a more traditional allocation of responsibilities among members of the household in the older generation.

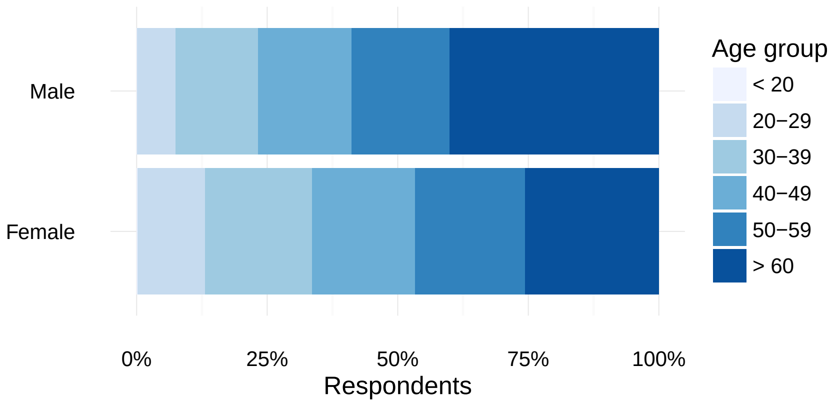


Figure 2.15: Survey respondents by gender and age.

Among all respondents and their partners living in the same household, 38.3% had some kind of academic degree (either from university, technical/pedagogical university or university of applied sciences). 28.2% had completed some kind of vocational training, and another 17.5% had some advanced professional training leading to some (advanced) Federal PET Diploma or PET college degree. 9.3% of the respondents and their partners had completed school with a baccalaureate or an intermediate vocational school certificate. 2.5% reported to have some other level of education and 4.2% reported to have completed obligatory school (Figure 2.16 and Figure 2.17).

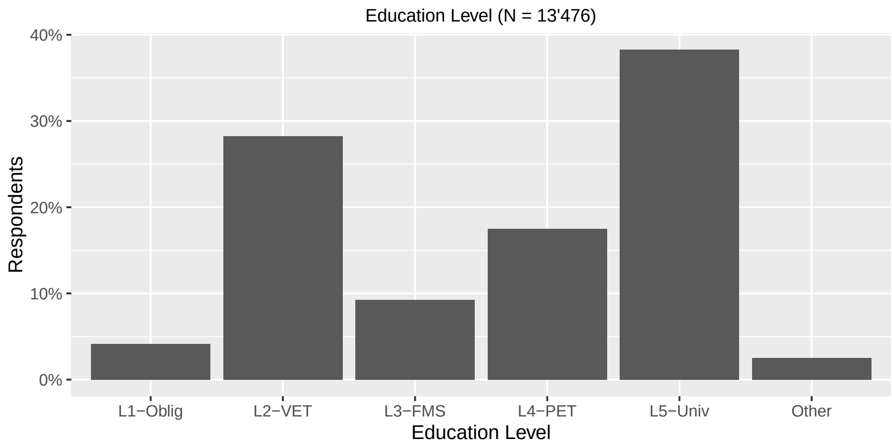


Figure 2.16: Survey respondents and their partners living in the same household by level of education (together).

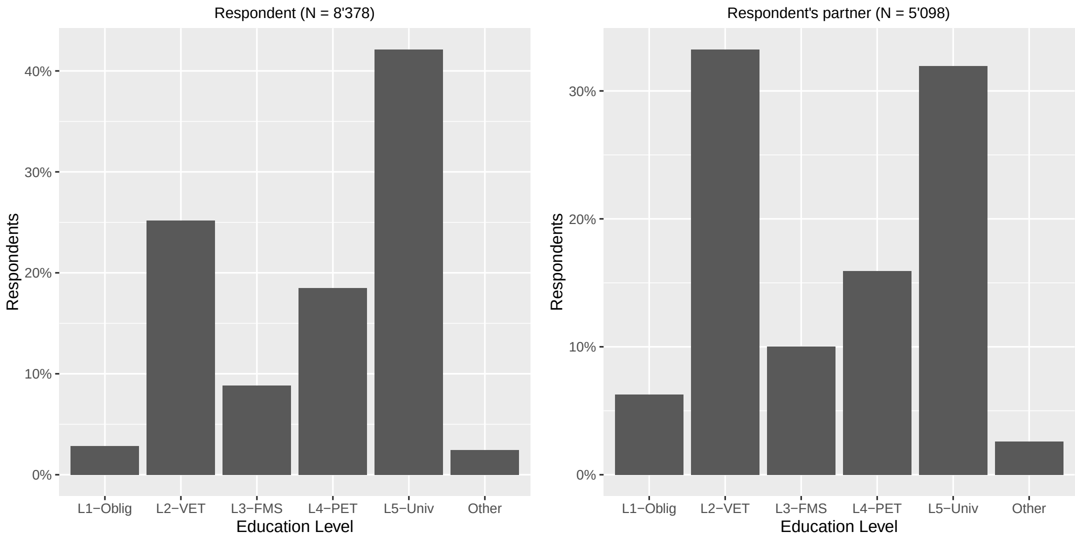


Figure 2.17: Survey respondents and their partners living in the same household by level of education (separate).

This compares to a share of 15% of the population in Switzerland who have an academic degree and 26% of the population who have completed obligatory school.[11] Another 36% had completed some kind of vocational training, and another 12% had some advanced professional training leading to some (advanced) Federal PET Diploma or PET college degree. Although our sample is not directly comparable to the entire population of the Switzerland, these numbers suggest that more educated respondents are over-represented in our sample.

Household income

The household's income in 2014 was reported by 7,080 households. 1,298 households didn't provide this information. A total of 29.3% of households earned a monthly income of 6'000 CHF or less (12.6% earned upto 4'000 CHF and 16.7% earned between 4'500 to 6'000 CHF). This is followed by another 26% having a household income between 6'001 and 9'000 CHF. 16% of the households had a gross monthly income of 9'001 to 12'000 CHF, and another 15.1% reported to have an income of more than 12'000 CHF per month (Figure 2.18).

[11] BFS (2014): Strukturerhebung su/d/15.08.02.07 Ständige Wohnbevölkerung ab 15 Jahren nach Kanton und höchster abgeschlossener Ausbildung, Jahr 2013.

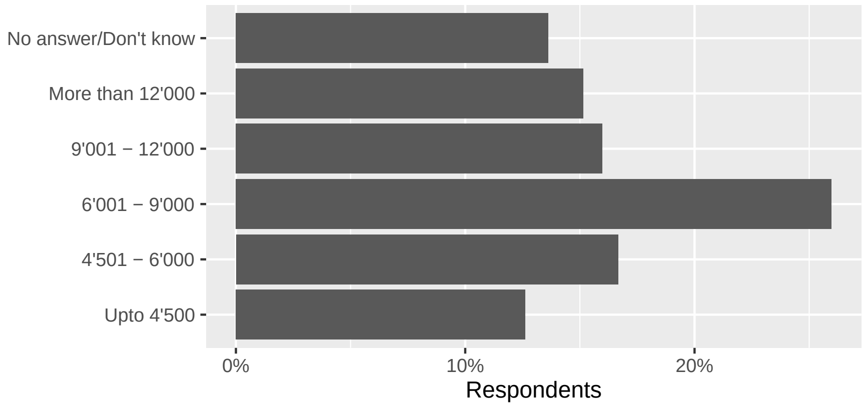


Figure 2.18: Household income in 2014 by income classes.

Overall, income does not vary too strongly between the years 2010 and 2014, although a slight increase in average household income can be noticed in Figure 2.19.

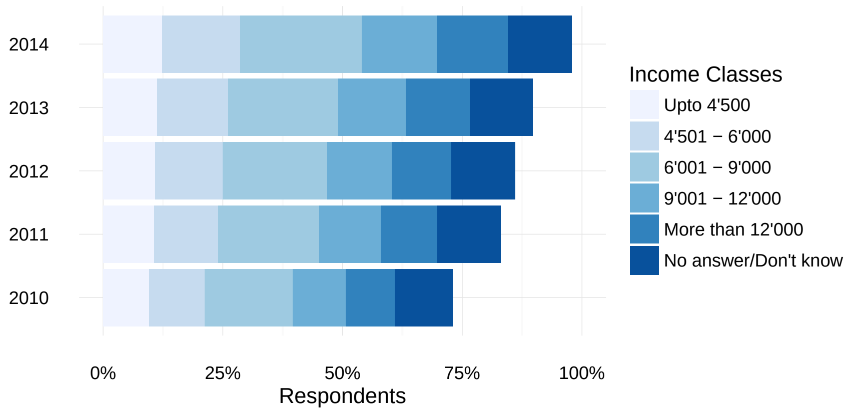


Figure 2.19: Change in household income between 2010 and 2014.

For Switzerland, the estimated average gross household income amounted to 10'052 CHF per month in 2013.[12] For the years 2009 - 2011, we know that the share of households with an income of more than 12'000 CHF amounted to 25.7% and the share of households with an income of 6'000 CHF or less was 29.3%, while 45% of the households are in the middle range of between 6'000 and 12'000 CHF.[13] This suggests that the sample more or less conforms to the income shares in the Swiss population, with only a slight underrepresentation of highest income households.

[12]BFS Haushaltsbudgeterhebung, 2009-2011 sowie 2012 und 2013, T20.02.01.01 Haushaltseinkommen und -ausgaben sämtlicher Haushalte nach Jahr.

[13]BFS Haushaltsbudgeterhebung (HABE) 2009-2011, 2014

2.3.4 Energy sources

Heating and warm water

The most frequently used energy source for space heating in the single-family houses in the sample is gas (46.2%), followed by heating oil (25.2%) and heat pumps (14.7%). Less frequently used heating energy sources are wood (5.2%), electricity (5.1%) and district heating (1.8%) as shown in Figure 2.20.

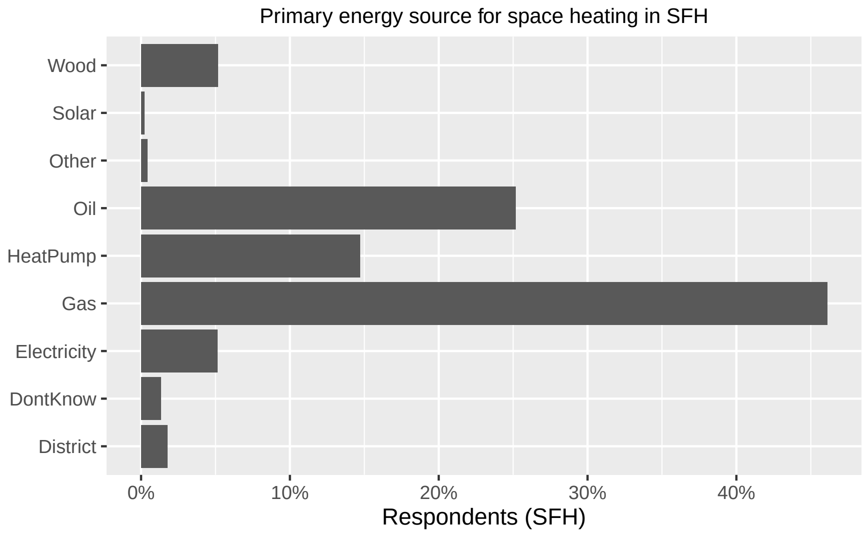


Figure 2.20: Energy sources used for space heating in SFHs.

The shares are different for water heating. The most frequently used energy source for water heating is still gas (36.2%), followed by electricity (26.7%), oil (15%), heat pumps (9.1%) and solar (8.5%). A small share of single-family houses heat water using district heating, wood or some other sources (Figure 2.21).

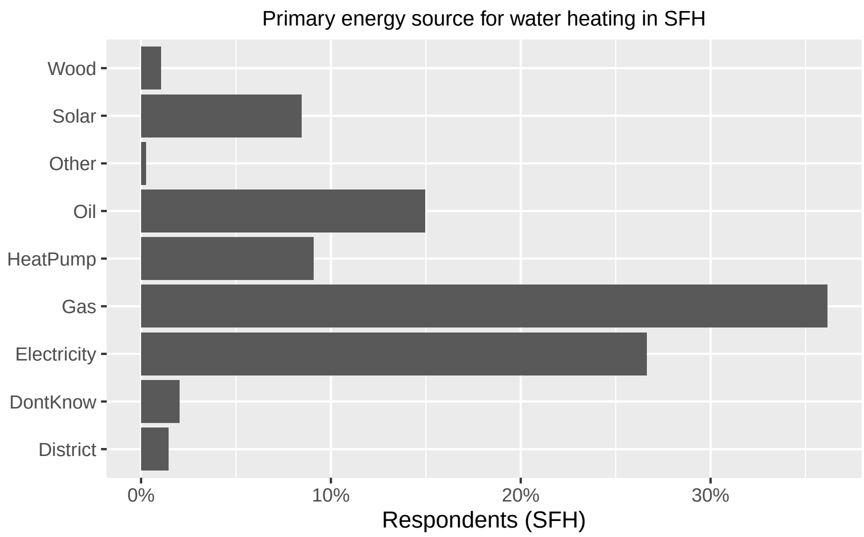


Figure 2.21: Energy sources used for water heating in SFHs.

Anticipating that residents of multi-family houses would be less informed about the heating energy sources used in their buildings, these respondents were not asked about the general energy sources for heating and warm water of the whole building, but only whether they have an independent heating system in their apartment (either electricity- or gas-based). While very few of the respondents reported to have separate heating systems for space heating (12.2%; where-in electric: 3.9%, gas-based: 4.7%, other: 3.6%), a slightly higher share of 16.9% stated to have a separate system for water heating. Most of the systems used for water heating were electric (69.3%) although some multi-family houses also reported to have gas based water heating system (19.9%).

Cooking

Both in single-family houses and in multi-family houses 92% (respectively 89.5%) of the households in the sample use electricity as energy source for cooking. 7.7% (9.7% in MFH) use gas for cooking and a negligibly small share uses other sources for cooking.

2.3.5 Appliances and energy services

A major determinant of a household's electricity (and gas) consumption is the presence of certain appliances in the household. In addition, the age of these appliances and the frequency of their use are decisive for the overall energy consumption of the household.

In the following, we provide an overview of the presence of different household appliances in the sample households, partitioned by their age. In the following subsections we will also report how often these appliances are used by members of the household.

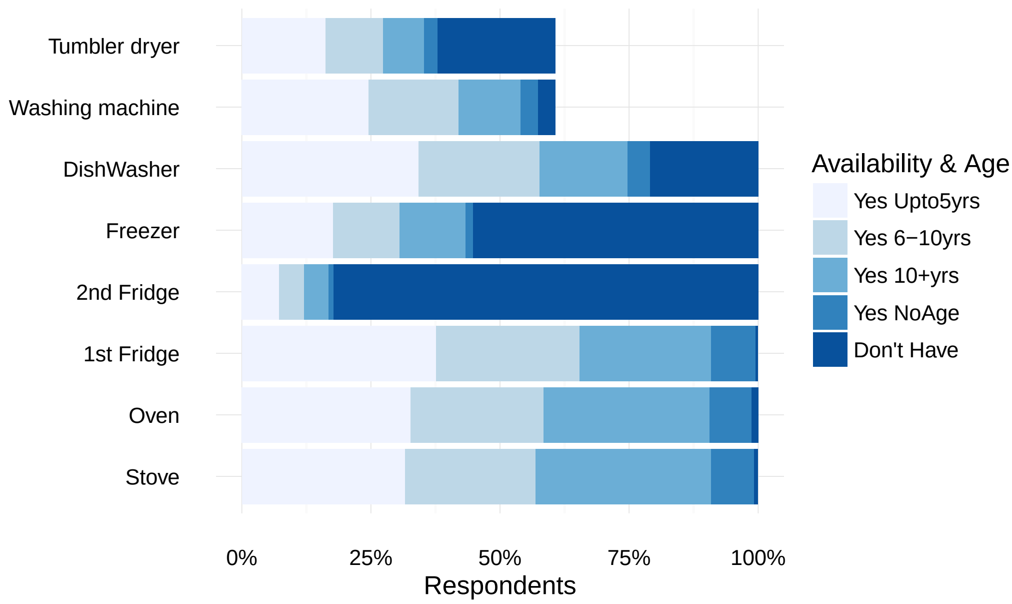


Figure 2.22: Overview of appliances (and their age) within the households.

While almost all 8,378 households owned at least a stove, oven and a fridge, 6,624 of the households (79.1% of the sample) also owned a dishwasher. 3,748 of the households (44.7%) had a separate freezer in their residence whereas 1,487 households (17.7%) had also a second fridge at home. 4,803 households (57.3% of the sample) owned their own washing machine and only 3,177 households (37.9%) owned their own clothes dryer.

The appliances that are most frequently reported to be more than 10 years old are stove and oven, followed by fridge, dishwasher, freezer and washing machine (Figure 2.22). We can therefore assume that, on average, replacing the primary appliances in the kitchen in the observed households would unlock a particularly high potential for energy-efficiency improvements.

On the other hand, primary fridges are most frequently reported to be less than or up to 5 years old, followed by dishwashers, oven, stove, washing machine and tumbler dryer.

Cooking and dish-washing

The number of cooked lunches and dinners is distributed relatively widely across households (Figure 2.23). Out of the 8,378 households we observed, 25.3% cook dinner every day and 21.8% cook lunch every day.

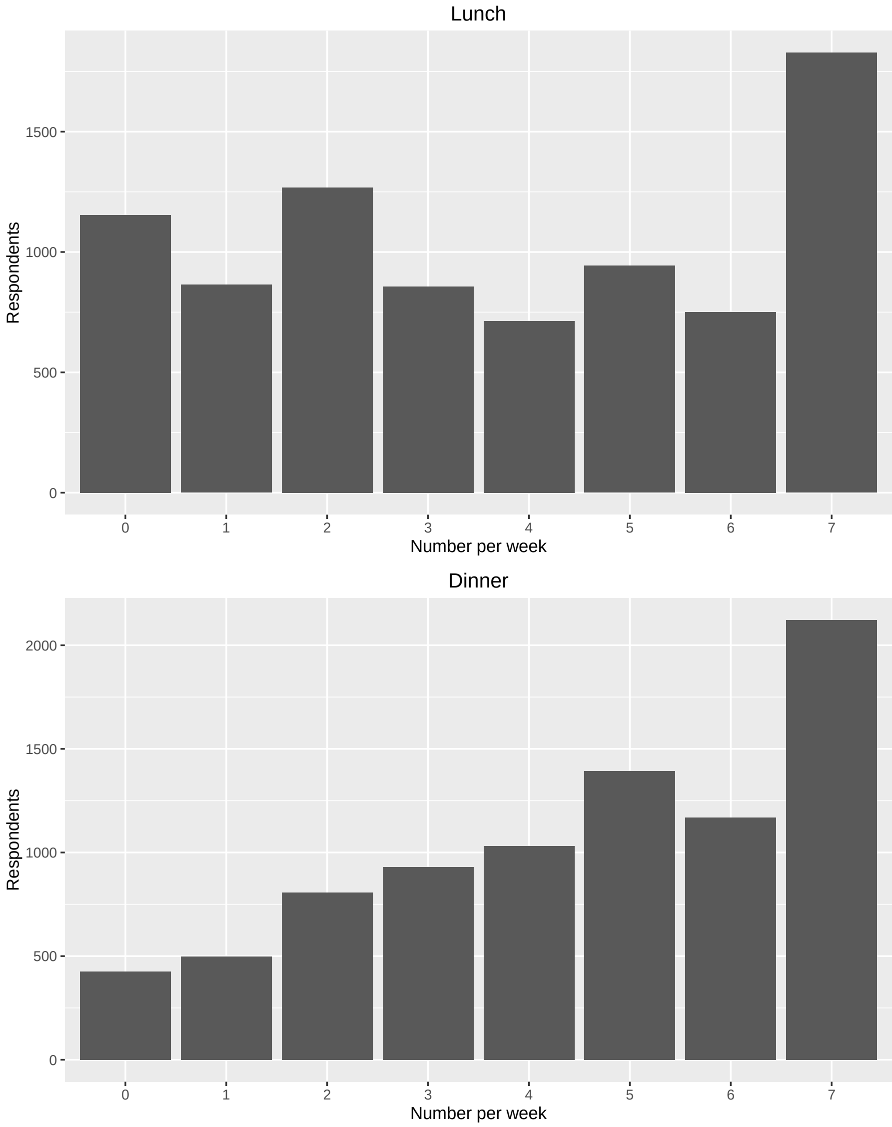


Figure 2.23: Number of cooked meals per week.

The usage of the dishwasher is seen to be relatively widely distributed across households. Among those households who have a dishwasher, the most frequent number of usages is 3 times per week (Figure 2.24).

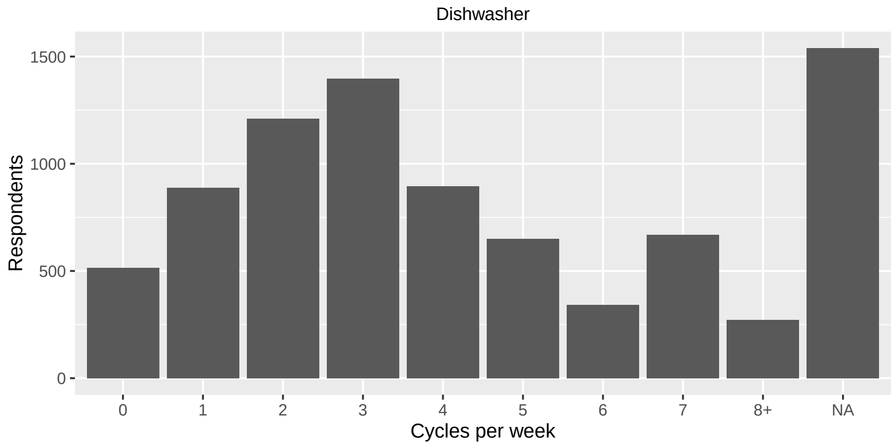


Figure 2.24: Number of dishwasher cycles per week.

Washing and drying

5,014 households reported on their washing machine usage with a valid response. Among most of these households (85%) the washing machine is running up to 5 times per week. The most frequent number of usages of the washing machine is 2 times per week (Figure 2.25).

Similarly, the clothes dryer is used upto 5 times a week in 63.7% of the 3,802 households who responded with a valid response. Most households report that they do not use their clothes dryer (31.1%) or use at most once per week (28.2%) or twice per week (16.3%).

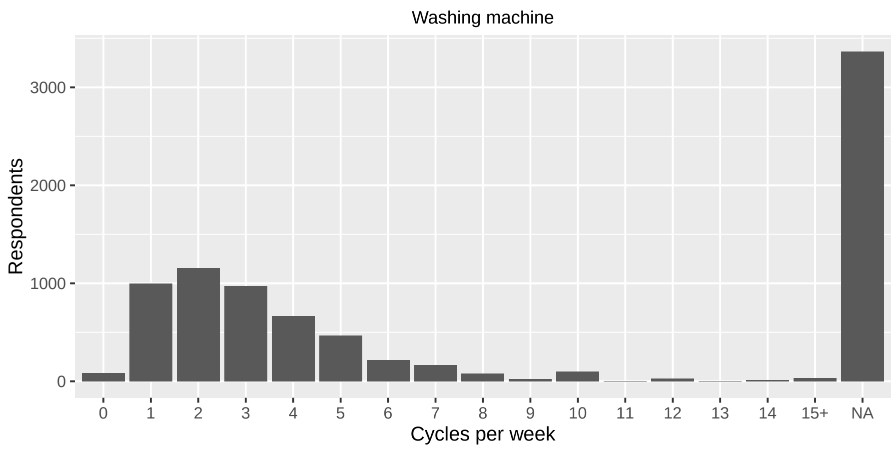


Figure 2.25: Number of washing machine cycles per week.

Electronics

As can be seen in Figure 2.26, most households appear to own 1 or 2 laptop/PCs and 1 TV set. Overall, it is more frequent that a household owns several computers than several TV sets.

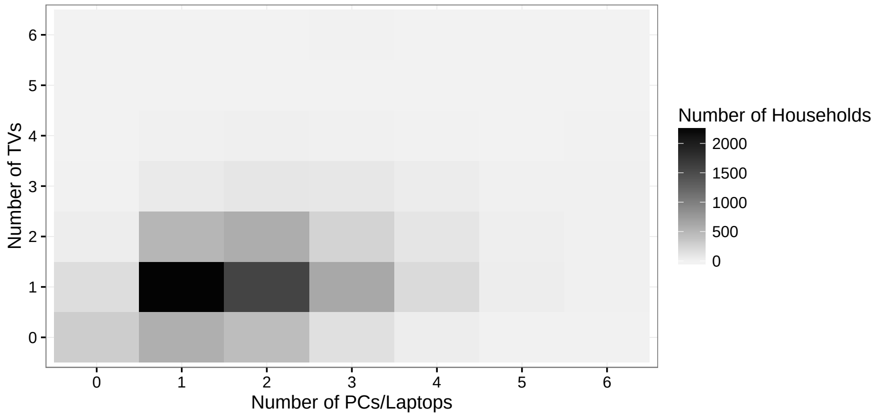


Figure 2.26: Number of TVs and PCs in the households in 2014.

Information on TV usage per day, i.e. combined use of all TVs at home, is provided by 7,070 households. 32.2% of the households watch TV for less than 2 hours per day, 38.9% for 2-4 hours per day and 18.7% for 4-6 hours per day. In 9.6% of the households, TV is running for more than 6 hours per day (Figure 2.27).

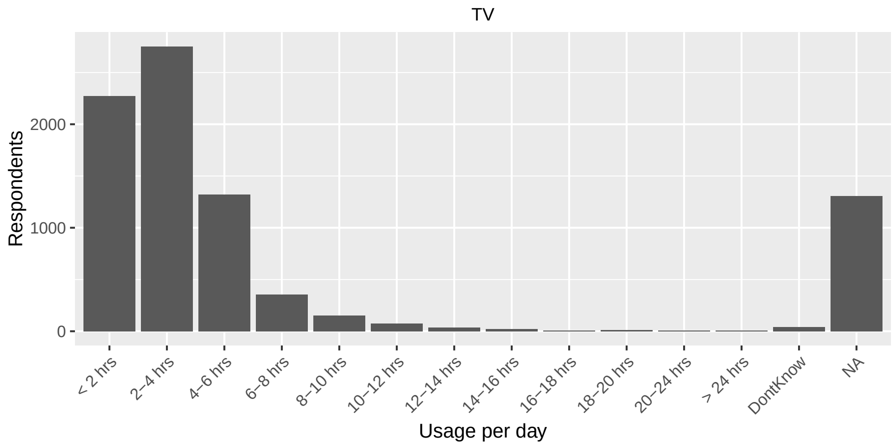


Figure 2.27: Usage of TVs per day.

Information on laptops and desktop computers usage is provided by 7,809 households. The total usage per day of these devices (i.e. combined usage of all available desktops and laptops at home) is reported to be less than 2 hours per day for about 40.3% of the households. This is followed by 26.6% households using computers for 2-4 hours per day, 14.2% for 4-6 hours per day and 6.7% for 6-8 hours per day. 11.5% of the households use computers for more than 8 hours per day (Figure 2.28).

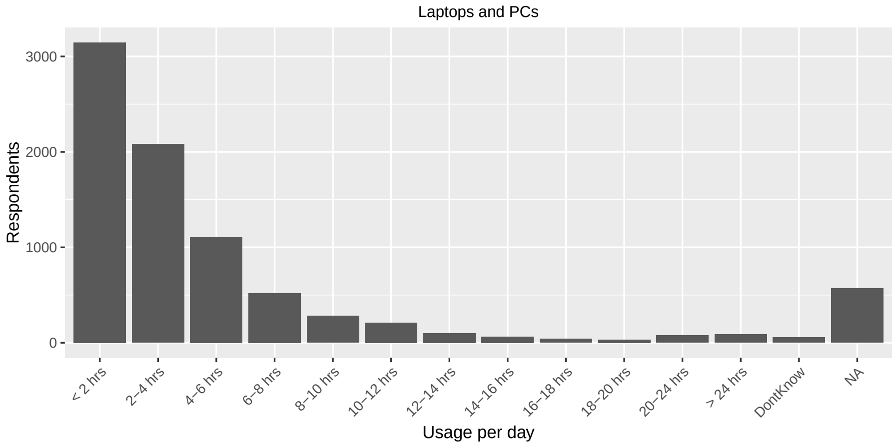


Figure 2.28: Usage of computers per day.

Lighting

Regarding the share of different light bulbs in the observed households, we notice that many households still rely to a large extent on conventional light bulbs (Figure 2.29). While only 4.7% of the households state that conventional light bulbs account for 100% of the lighting in their home, still, for 21.7% of the households conventional bulbs account for more than half of all light bulbs. 17% of households claim that more than half of their bulbs are energy-saving light bulbs and 9.2% state that the majority of their bulbs are LED bulbs. Tube-lights seem least common in the observed households.

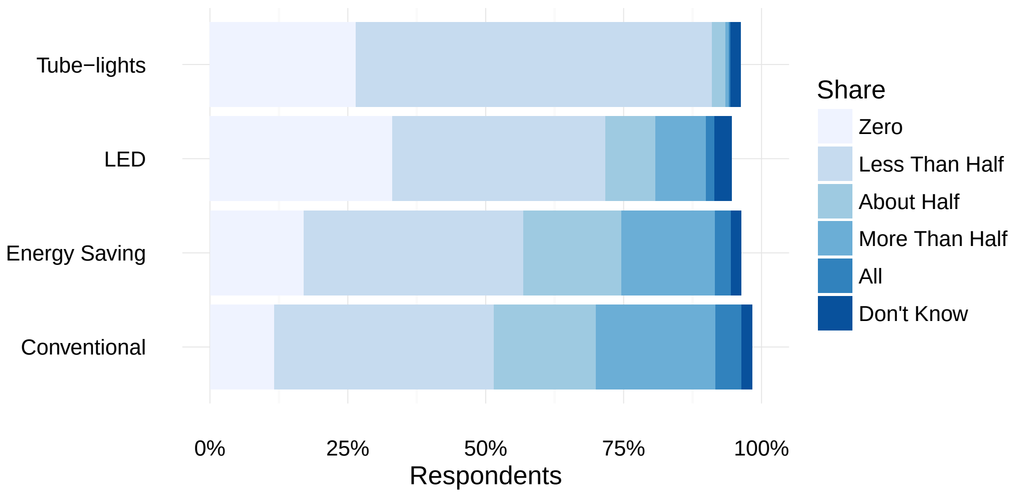


Figure 2.29: Share of different type of light-bulbs in the households.

Heating

8,248 households reported their average room-temperature in the living room during the heating period. The most frequently reported temperature is 21°C (reported by 25.6% of the households). Altogether, 70.7% of the households report an average room temperature of between 20°C and 22°C. 11.6% of the households report higher temperatures and 12.9% of the households report lower temperatures (Figure 2.30).

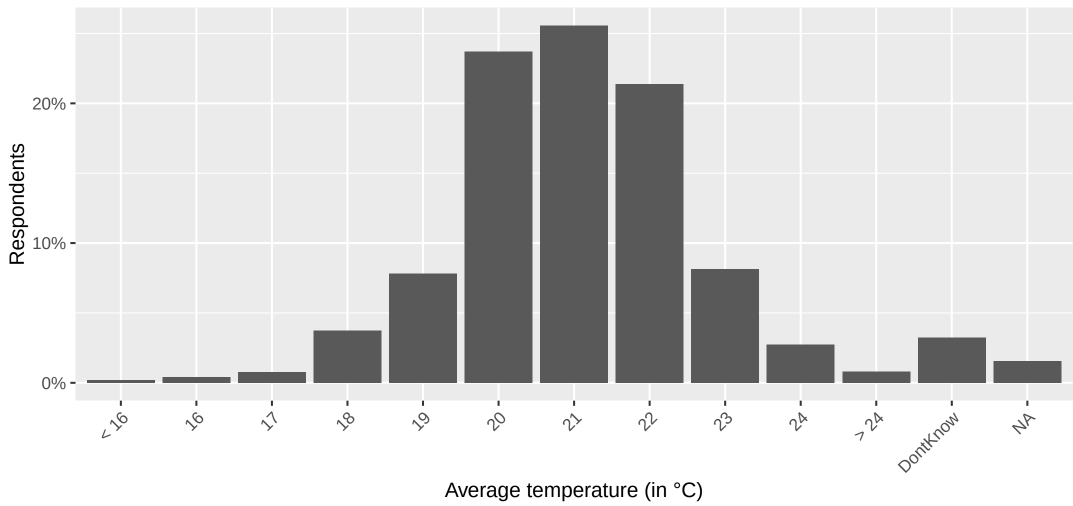


Figure 2.30: Average temperature in the living room during the heating period.

In addition, the frequency of use of the shower was also asked. 44.1% of the households report up to 7 shower operations per week. In turn, 36.9% of the households say they use the shower 8-14 times a week and the remaining 18.5% use the shower more than 14 times per week.

Miscellaneous

In addition to the usual household appliances, the presence of particular equipments or devices with significant electricity consumption was also asked in the survey questionnaire.

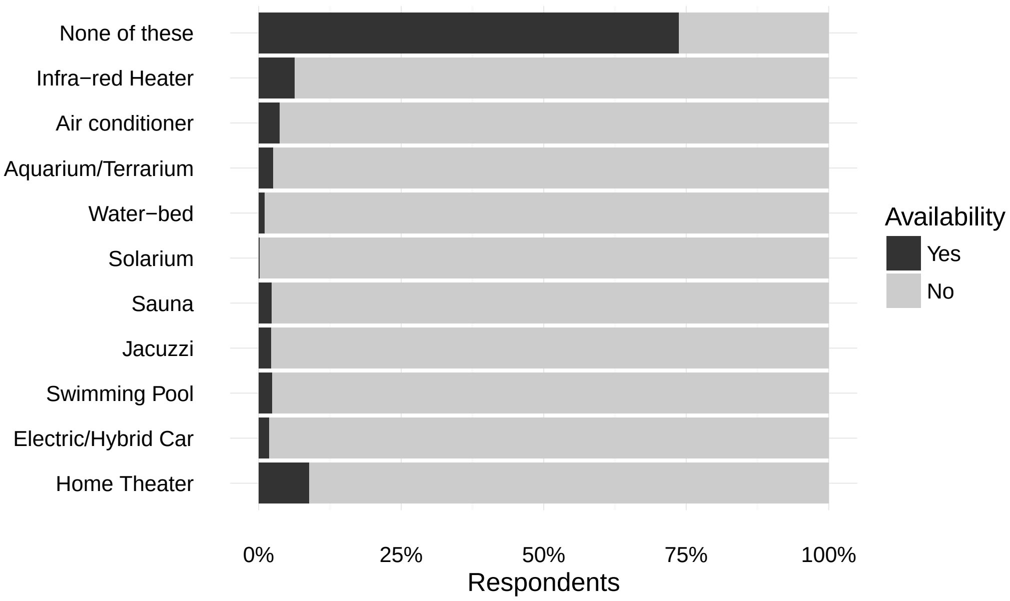


Figure 2.31: Presence of other equipments and installations.

741 households report they have a home theatre system. 531 have an infra-red heater and 306 households are equipped with air conditioning. In addition, 191 households have installed a sauna, 197 households a swimming pool, and 182 households have a whirlpool/jacuzzi. An aquarium exists in 216 households and 157 households report to also own an electric/hybrid car (Figure 2.31).

2.3.6 Adoption of policy measures

2,071 households (24.7% of the sample) profited from at least one of the five listed policy measures since the year 2010, i.e. every fourth household was reached by at least one of these policy measures.

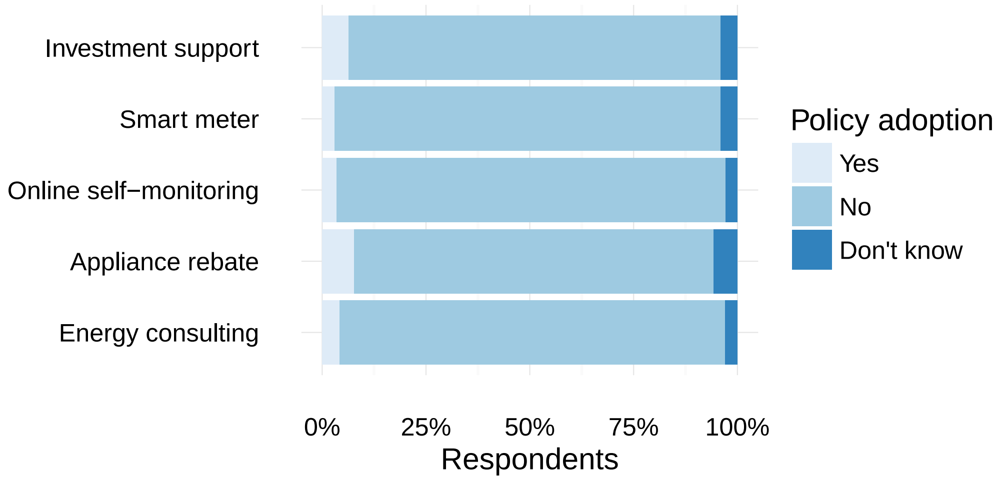


Figure 2.32: Adoption of several policy measures since 2010.

7.7% of the households profited from rebates on energy-efficient appliances and 6.3% of the households claim to have profited from some kind of financial support when having invested in energy-saving measures in their homes. Only 4.2% of the households had used a consulting service to get information about energy-efficiency measures in their homes. 3.4% of respondents had used some online (self-)monitoring tool and only 3% had used a smart meter to keep track of their electricity consumption.

2.3.7 Energy-related attitudes, behaviors and literacy

A few environment-related attitudes and energy consumption behaviour within the homes were also asked as part of the survey. We include below a summary of the results gathered across all respondents in our sample.

Attitudes

8,069 respondents reported their environment-related attitudes.[14] 73% of the respondents agreed with the statement “I feel morally obliged to reduce my energy consumption.” 68% of the respondents agreed

[14]Respondent from IWB (Basel) did not have the attitudinal questions in their questionnaire because the utility wanted the length of the survey to be short.

with the statement "I am willing to make compromises in my current lifestyle for the benefit of the environment." 80% of the respondents stated that they disagreed with the statement "I am not willing to reduce my energy consumption if others don't do the same" (Figure 2.33).

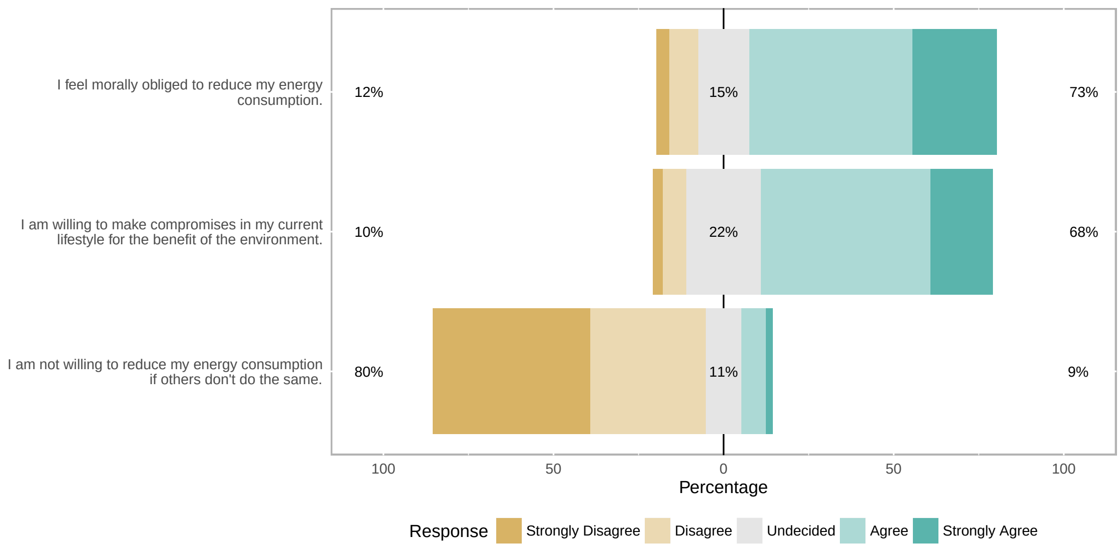


Figure 2.33: Energy-related attitudes of respondents.

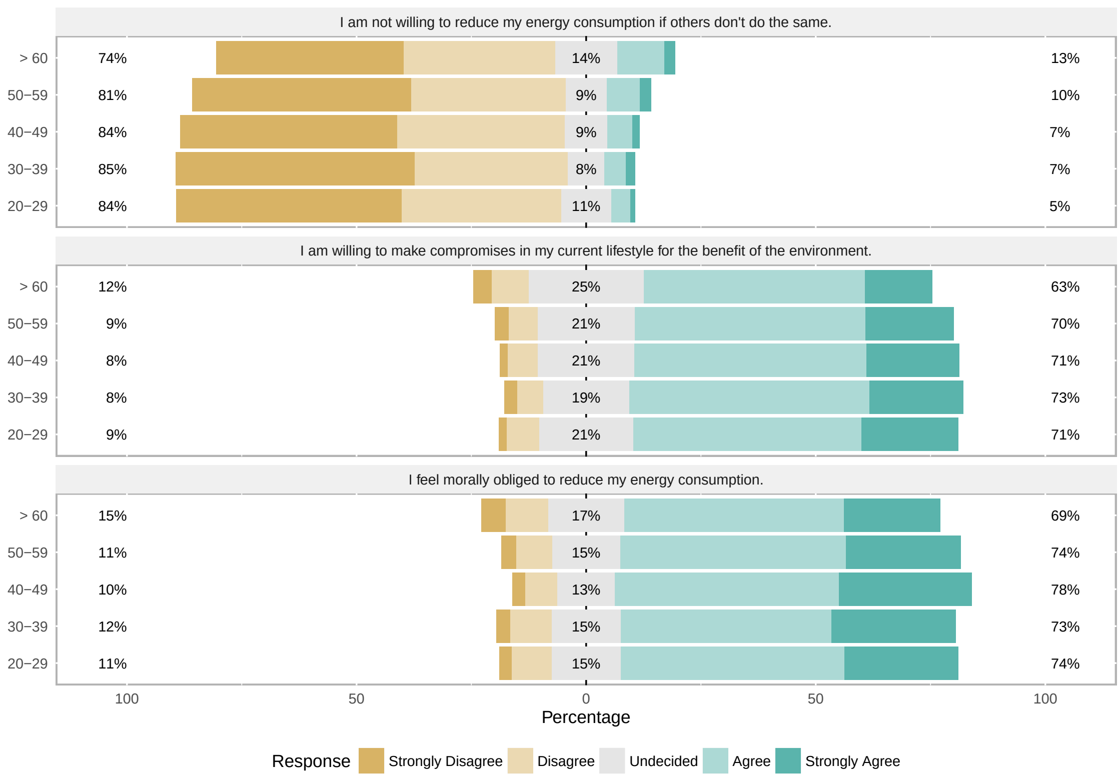


Figure 2.34: Energy-related attitudes by age group of respondents.

In tendency, the younger population seems to feel more responsible to reduce their energy consumption and to make compromises for the benefit of the environment (Figure 2.34). Respondents aged 60 or older showed the least agreement with the two positive statements and the least disagreement with the negative statement ("I am not willing to reduce my energy consumption if others don't do the same").

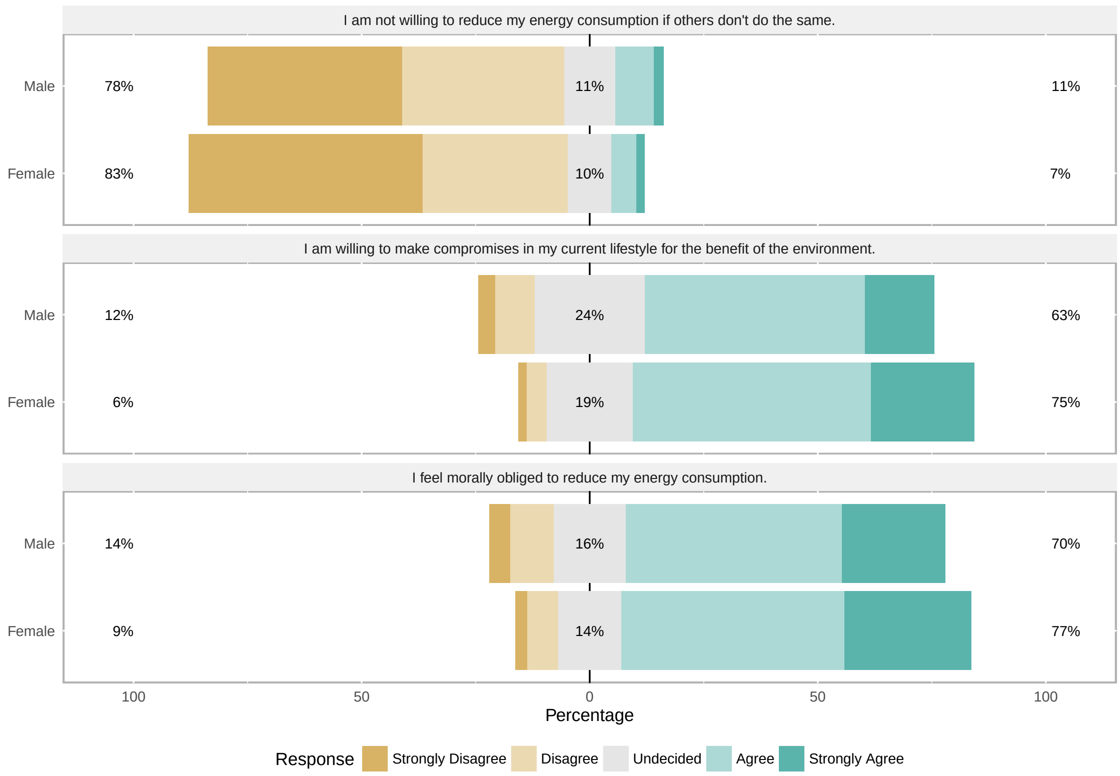


Figure 2.35: Energy-related attitudes by gender of respondents.

Regarding gender and attitudes, we observe a higher pro-environmental attitude among female respondents than male respondents across all three attitudinal parameters (Figure 2.35).

As another indicator of pro-environmental attitudes, 39.7% of the full sample claim to have donated to an environmental organization during the last 12 months prior to taking the survey. This compares to 42% of the respondents to the Swiss 'Spendenmonitor' who claimed to have donated money to an environmental organization in the year 2014.[15]

Behaviors

In terms of energy-conserving behaviors in everyday life (Figure 2.36), the most frequently reported behavior among those who responded is to run full loads when using the washing machine. 43.2% of 8,004 respondents claim to 'always' follow this behavioral rule. Also, 40.4% of 6,691 respondents 'always' choose the program of their dishwasher according to the level of dirtiness of the dishes, followed by 31.8% of 8,293 respondents who state that they 'always' completely switch off electronic devices after usage (no stand-by).

[15]GFS Zürich, Spendenmonitor 2014 des Forschungsinstituts gfs-zürich, 2015.

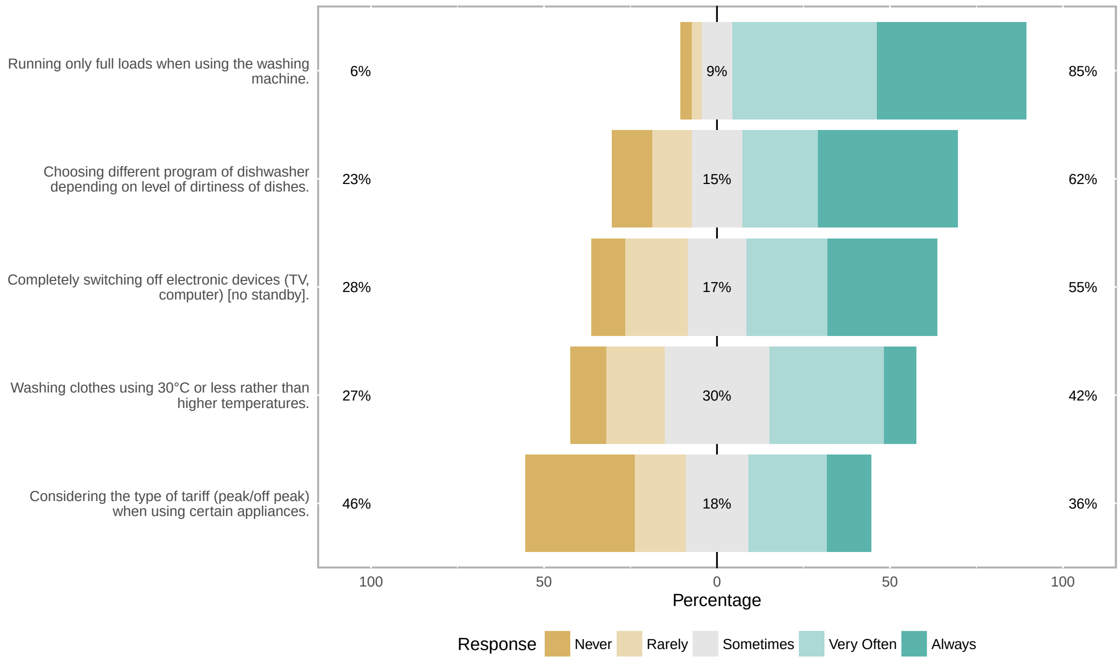


Figure 2.36: Frequency of practicing certain energy-related behaviors.

The least frequently reported energy-conserving behavior is noticed with respect to the consideration of peak/off-peak tariffs when consuming energy services at homes. Out of 7,247 respondents, 31.6% 'never' (and 14.7% 'rarely') consider the type of tariff when using appliances such as the washing machine. Also, only 9.4% of 8,034 respondents claim to 'always' run the washing machine on low temperatures (below 30°C), although 33% still do this 'very often' and another 30.4% do it 'sometimes'.

Awareness of electricity prices

Respondents from 7 out of 9 utilities also answered a few 'knowledge questions' related to the topic of energy and electricity consumption.[16]

Regarding awareness of the average electricity price in Switzerland, which we assume to be at 20 Rappen per kWh, we can observe that a substantial portion of respondents rather underestimates the average price of electricity (Figure 2.37).

Among the 6,679 people who responded to the question whether they knew the price of 1 kWh of electricity in Switzerland, 45.6% immediately claimed to not know the exact amount. The remaining 54.4% of the respondents gave an estimate of the average electricity price. The median across all estimated values was seen to be at 18 Rappen whereas the mean was at a much higher level at 29 Rappen per kWh.

[16] The utilities in Basel (IWB) and Lausanne (SiL) opted not to have the energy-literacy questions in their survey questionnaire because they wanted to keep the survey a bit shorter.

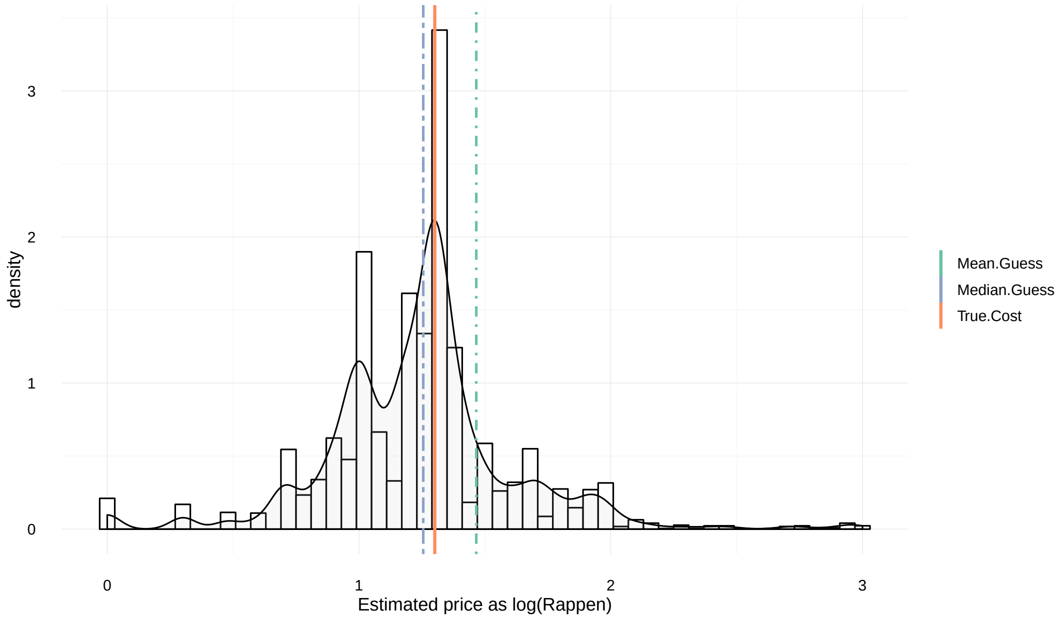


Figure 2.37: Distribution of respondents' estimated price of 1 kWh of electricity in Switzerland.

32.4% of those respondents who gave an estimate chose a value in the range of +/- 20% of the 'true' amount (i.e. a value in between 16 Rp. and 24 Rp.). Among these, 15.7% chose the 'correct' amount of 20 Rappen per kWh.

In tendency, a much greater share of respondents underestimates the electricity cost: 42.4% of the estimates were less than 15 Rp./kWh, compared to 25.3% of the estimates which were overestimated at 25 Rp. or more.

3 Explaining electricity demand and the role of energy and investment literacy on end-use efficiency of Swiss households†

3.1 Introduction

In Switzerland, electricity is primarily produced by hydropower plants (60%) and nuclear power plants (40%). In 2011, after the Fukushima Daiichi nuclear accident, the Swiss federal council decided to abandon nuclear energy. For this reason, the Swiss federal council developed a new energy policy concept, called *Energy Strategy 2050*. One important goal of this strategy is to reduce electricity consumption by improving the level of efficiency in the use of electricity and to increase the share of electricity produced with new renewable sources of energy such as wind and solar. The efficiency improvement and the development of new renewable sources should, therefore, allow substituting the amount of electricity produced by nuclear power plants. In this context, the residential sector is characterized by great potential for energy efficiency gains and could make an important contribution to a reduction of total end-use electricity consumption.[1]

Against this background, it is important for policy makers to have information on the potential for electricity savings in the residential sector. Moreover, it is important to know which are the determinants that influence the level of efficiency in the use of electricity. A low level of efficiency, as discussed in Filippini and Hunt (2015), may be due to the fact that households do not adopt and use energy efficient appliances or do not use their appliances in an optimal way. For instance, a household might postpone substituting an old and inefficient refrigerator that consumes a lot of electricity, or does not use a cooling system or washing machine in the most efficient way.

The determinants of residential energy efficiency have been widely covered in the economic literature (Allcott and Greenstone, 2012; Frederiks et al., 2015; Gillingham et al., 2009). The potential explanations for an inefficient use of appliances on the one hand and for an under-investment in energy-efficient household appliances on the other can be attributed to either market failures or behavioural failures (Broberg and Kazukauskas, 2015). Market failures that prevent investments in energy-efficient appliances can take the form of information problems (e.g., lack of information and information asymmetries), misplaced incentives and principal-agent problems such as the landlord-tenant problem. But even if these market failures could be overcome, several behavioral failures such as bounded rationality, loss aversion, status-quo bias, risk aversion or inattentiveness[2] potentially reduce the level of efficiency in a household's energy use. All these behavioral failures tend to prevent households from identifying the appliances that

†Published in the journal of Energy Economics: https://doi.org/10.1016/j.eneco.2017.12.004

[1]Although we have sometimes used the general term 'energy' in the discussions, the reader is informed that the analysis in this research refers to 'electricity' consumption at the residential level.

[2]Note that inattention to potential electricity savings may be justified on rational grounds (Sallee, 2014), especially if electricity prices are very low in relation to household income such that electricity costs are a marginal position in the household's budget. In such a case the consumer may anticipate that the information and search costs related to the purchase of a new appliance may outweigh the potential future energy savings.

minimize lifetime costs or from using the appliances in an efficient way. However, as shown by Blasch et al. (2017b), households that are scoring high with respect to investment and energy literacy seem to be less prone to boundedly rational behaviour.

To our knowledge, relatively few studies have looked into the relationship between energy and investment literacy and residential energy efficiency (for an example, see Brounen et al. (2013)). Investment literacy can be defined as the ability to perform an investment analysis and to calculate the lifetime cost of an appliance or energy-efficient renovation. Energy literacy can be defined as an individual's cognitive, affective and behavioral abilities with respect to energy-related choices. According to DeWaters and Powers (2011), energy literacy comprises an individual's or household's *(1)* knowledge about energy production and consumption and its impact on the environment and society; *(2)* attitudes and values towards energy conservation; and *(3)* corresponding behaviour. In this paper, we therefore put particular emphasis on examining the influence of energy literacy, investment literacy and energy-saving behavior on a household's level of efficiency in the use of electricity.[3]

Hence, in this paper, we provide an answer to the following questions: Which are the factors that influence the electricity demand at the household level? What is the level of efficiency in the use of electricity of Swiss households? How large are the potentials for energy savings in the residential sector for a given level of energy services? Does a household's level of energy and investment literacy influence its level of efficiency in the use of electricity?

To answer these questions, it is important to remember that a household's energy demand is not a direct demand for energy or electricity, but rather a derived demand for the production of energy services such as warm food, clean clothes and lit rooms. Therefore, behind electricity demand there is a production function. A reduction in energy consumption for the production of a given level of energy services can be achieved either by improving the level of efficiency in the use of inputs (i.e. in the use of appliances), or by adopting a new energy-saving technology (i.e. purchase of new appliances, investments in energy-saving renovations), or both. Technological change can induce a reduction of energy consumption for a given level of energy services, provided that the inputs are used in an efficient way, i.e. given that the households are productively efficient. The total reduction in residential energy consumption is therefore a result of the interplay of technological change and a household's behaviour.[4]

The level of energy efficiency of households can be measured with a bottom-up approach, by making an on-site efficiency analysis of buildings. However, with such an economic-engineering approach, the behavioural aspects in energy use are often not accounted for. In addition, this approach is not based on the microeconomics of production. In this paper, we therefore estimate a household's level of energy efficiency with econometric methods, accounting for total electricity consumption and factors such as the size and characteristics of the dwelling, household composition and other socioeconomic attributes, level of energy services consumed, energy literacy, investment literacy and energy-saving behaviour. With this approach a broader and more adequate bench-marking of Swiss households with respect to their electricity consumption can be performed.

The existing literature on the measurement of the level of energy efficiency in the residential sector using an economic approach is relatively sparse. While the Stochastic Frontier Analysis (SFA) has been used with aggregated energy data (e.g., Filippini and Hunt (2012); Filippini et al. (2014)), we use dis-aggregated data since residential consumers are typically very heterogeneous and household level data can add more detail to the knowledge of consumer response. Weyman-Jones et al. (2015) are one of the first to estimate energy efficiency using SFA with dis-aggregated household survey data. They estimate an energy input

[3]We consider a slightly narrower definition of energy literacy (described in Section 3.2) in this study.

[4]For a discussion on the concept of energy efficiency based on the production theory and on the measurement methods, see Filippini and Hunt (2015).

demand frontier function, originally proposed by Filippini and Hunt (2011), using a cross-sectional household dataset from a survey in Portugal. However, the model used by Weyman-Jones et al. (2015) is relatively simple with only a few explanatory variables. In contrast, Boogen (2017) uses a much richer model using not only the information on appliance stock but also on the amount of energy services consumed to estimate the technical efficiency of a set of Swiss households using a sub-vector distance function. However, as Boogen (2017) uses a cross-sectional dataset, the unobserved heterogeneity cannot be accounted for. Moreover, only the level of technical efficiency is estimated. Alberini and Filippini (2018) employ an energy demand frontier approach similar to Weyman-Jones et al. (2015) using a large panel dataset from US households to estimate the level of energy efficiency. By using panel data they are able to distinguish and estimate the level of persistent and transient energy efficiency.[5] The limitation of Alberini and Filippini (2018) is that the amount of energy services consumed by a household was not included as an explanatory variable.

In this paper, we follow the energy demand frontier approach using an unbalanced panel dataset of $1,994$ Swiss households from 2010 to 2014. Moreover, using an approach proposed by Coelli et al. (1999), we will also measure the level of efficiency by comparing the electricity consumption of all households to the optimal level obtained from an energy input demand frontier function associated with a high level of investment literacy.

The contribution of this paper is two-fold – firstly, we estimate the persistent and transient efficiency in electricity consumption of a large sample of Swiss households and demonstrate an application of the newly developed GTREM model (Colombi et al., 2014; Filippini and Greene, 2016) that estimates both types of efficiency conveniently by a simulated maximum likelihood approach. We benefit from a unique panel dataset covering a five-year period collected via a household survey conducted in 2015. The dataset includes information on the level of energy services, which is usually not measured as it can be difficult to collect this information.[6] Information on the level of energy services is a critical issue when using SFA (Filippini et al., 2014). Finally, to our knowledge, this paper is the first to provide a systematic analysis of the impact of both energy and investment literacy on the total electricity consumption of households while controlling for the effects of the general level of education of the household members. Our results can therefore provide new insights into the interrelations between the literacy and education variables and their role for transient and persistent efficiency in residential electricity consumption.

The rest of the chapter is organized as follows. Section 3.2 discusses the role of energy literacy and investment literacy for energy efficiency. Section 3.3 presents an econometric model of residential electricity demand using dis-aggregated household data and discusses the empirical specifications for estimating the level of efficiency in the use of electricity. Section 3.4 describes the household survey data and the variables used in the model. Section 3.5 presents the results and Section 3.6 concludes.

3.2 Energy and investment literacy

Residential energy efficiency is a function of the efficiency of the inputs used to produce a certain energy service (type of appliance) and of the efficiency in the use of these inputs (use of appliance). Both the choice of electric appliances and the efficiency of their use are necessarily influenced by the user's knowledge about the baseline energy consumption of an appliance and how it can be steered by a specific user behavior, such as switching it off after use rather than leaving it on stand-by. The choice of appliances

[5] The concept of persistent and transient efficiency was introduced by Colombi et al. (2014) and significantly developed by Filippini and Greene (2016).

[6] Generally, the energy services are approximated by household characteristics that influence the level of energy services in a household, e.g., in Alberini and Filippini (2018).

requires, in addition, some ability to evaluate different appliances with respect to their lifetime cost, accounting for the initial purchase price and the future spending for its electricity use. This evaluation requires complex calculations that are based on assumptions about the expected lifetime of the appliance, the electricity price now and in the future, as well as on the anticipated intensity of use of the appliance. The decision-maker thus does not only need to dispose of knowledge about the electricity price and the consumption of the appliance but also of the ability to calculate and to compare the net present values of several appliances to choose from (Gerarden et al., 2015; Sanstad and Howarth, 1994a,b; Scott, 1997).

Making these calculations can be burdensome for consumers, as suggested by the results presented in Allcott and Taubinsky (2015). Participants of an online randomized control trial in the US could choose between light bulbs with different levels of energy efficiency. If information about total lifetime cost of the light bulbs was provided, more consumers opted for the more efficient compact fluorescent light bulbs compared to the control condition. Also Blasch et al. (2017b) test whether providing consumers with information about the average yearly electricity cost for an appliance increases the probability that they opt for a more efficient appliance. They find a significantly positive relationship between the provision of monetary information on electricity consumption and the probability to perform an investment calculation rather than following a decision-making heuristic, and hence the probability to choose a more efficient appliance. In addition, they also find a positive impact of an individual's level of energy and investment literacy on the choice of the more efficient appliance.

A definition of what energy literacy comprises can be found in DeWaters and Powers (2011). According to them, energy literacy entails a cognitive (knowledge), affective (attitudes, values) and behavioral component. In our study, we focus on the cognitive aspect of energy literacy and add the dimension of investment literacy measured by a compound interest rate task. Compound interest rate tasks are frequently used to elicit an individual's level of financial literacy, such as in Lusardi and Mitchell (2009) or Brown and Graf (2013). Lusardi and Mitchell (2009) provide evidence that individuals who know about interest compounding are 15 percentage points more likely to be retirement planners (Lusardi and Mitchell, 2007). Brown and Graf (2013) find in a study on financial literacy in Switzerland that respondents scoring high on financial literacy are more likely to have an investment related custody account and to make voluntary retirement savings. That investment literacy may also be related to the choice of efficient appliances is suggested by results provided in Attari et al. (2010) who show that US citizens with a higher affinity to numerical concepts had more accurate perceptions of the energy consumption of different household appliances than their peers. Additionally, Brent and Ward (2017) show in a recent paper using a discrete choice experiment for the purchase of hot water systems that a higher financial literacy score also increases the willingness to pay for reduced operating cost.

Whether, and if yes, how strongly, an individual's energy-related knowledge and ability to make complex calculations eventually impacts on the final energy consumption of the individual's household is an interesting question to ask. If there is a significant influence, educating individuals about energy-related issues and instructing them how to perform an investment calculation would be a potential lever to enhance residential end-use energy efficiency. Nation-wide education campaigns, for example also in schools, could give a strong boost to energy efficiency of households.

So far, only a few studies have investigated the relationship between energy and investment literacy and actual energy consumption of households. As one of them, Brounen et al. (2013) study the influence of energy and investment literacy on conservation behavior of households in the Netherlands. Analysing data from a large national household survey, they find that energy literacy among households is very low. For example, only about half of the respondents are aware of the monthly amount they spend on energy consumption and about 40% were not able to correctly evaluate an investment into new and more energy-efficient equipment. Yet, they do not observe a significant effect of energy literacy on a household's self-reported energy consumption, and also not on a household's choice of the thermostat setting.

Mills and Schleich (2012) analyze how strongly the level of general education influences a household's energy use behavior and adoption of more efficient appliances based on survey data collected in 11 European countries. They observe a significantly positive influence of the level of education of the household head on the adoption of more efficient appliances (measured by an energy-efficient technology adoption index). In addition, they build an energy-use-knowledge index and find that the level of the index rises if the household head holds a university degree and is lowest if the household head holds a vocational degree. University education of the household head also impacts positively on the energy conservation index the authors built. Apart from these studies, Zografakis et al. (2008) report results from a small-scale energy-related information and education project in Greece that impacts positively on stated energy-saving behaviors of students and their parents. Overall, there is thus no conclusive evidence on the role of energy and investment literacy for the total energy consumption of a household, especially if the effect of the general level of education of the household members is accounted for.

3.3 An econometric model for electricity demand

Within the framework of household production theory, energy demand is derived from the demand for energy services. We assume that households purchase inputs such as energy and capital (household appliances) and combine them to produce outputs which are the desired energy services such as cooked food, washed clothes or hot water – which appear as arguments in the household's utility function (Flaig, 1990; Muth, 1966). Within this theoretical framework, it is possible to derive the optimal input demand functions for energy and capital (Alberini and Filippini, 2011; Flaig, 1990). Conventional theory assumes perfect knowledge of technical relationships and prices, and results in a situation characterized by overall productive efficiency[7] in the production of energy services. In practice, however, inefficiencies in the use of the inputs, i.e. combinations of inputs that do not minimize costs, are likely to occur.

Filippini and Hunt (2011, 2015) propose a non-radial input specific measure of efficiency in the use of energy based on the difference between the optimal use of energy (one which minimizes input costs) and the observed use of energy. In this paper, we follow this approach and estimate a measure of efficiency in the use of electricity based on the estimation of a single conditional input demand frontier function, i.e. the demand function for electricity. The function represents the minimum or baseline electricity demand of a model household that has a highly efficient appliance stock and uses the most efficient production process to produce a given level of energy services, given electricity price, price of capital stock and other factors. If a household is not on the frontier, the distance from the frontier measures the level of inefficiency in the use of electricity. In our empirical work, which uses dis-aggregated data from Swiss households, we posit the following household electricity demand function:

$$\begin{aligned}\ln E_{it} &= \alpha_0 + \alpha_p \ln p_{it}^E + \alpha_M M_{it} + \alpha_H H_{it} + \alpha_{ES} ES_{it} + \alpha_L LOC_{it} \\ &\quad + \alpha_w W_{it} + \alpha_{LT} LIT_{it} + \alpha_{BE} BEH_{it} + \alpha_T T_t + \alpha_{TT} T_t^2 + \varepsilon_{it}\end{aligned} \tag{3.1}$$

where E_{it} is the electricity demand (in kWh), p_{it}^E is the electricity price, M_{it} is a vector of household characteristics, H_{it} is a vector of dwelling characteristics, ES_{it} is the amount of energy services consumed, LOC_{it} is the utility service area and W_{it} is the number of heating degree days (HDD) and cooling degree days (CDD) that the household experiences. LIT_{it} represents the level of energy and investment literacy of the respondent, BEH_{it} captures the energy saving behaviour of the household, T_t and T_t^2 capture the time trend, and ε_{it} is the overall error term. This equation represents the minimum electricity consumption

[7] As defined by Farrell (1957).

as a function of electricity price, weather influences, household and dwelling characteristics, stock of special appliances[8], level of energy services, energy and investment literacy, and energy saving behaviour. We use a log-log model specification in the empirical analysis presented in this paper.

Note that it would be possible to include many non-linearities (beyond those implied by the log-log setting) and higher order dependencies in the model specified in Eq. (3.1). A quadratic time trend is an example. It is also plausible that an additional household member does not necessarily increase the energy demand linearly. Other variables like weather or electricity prices may as well have different effects in different regions. However, if too many non-linear terms are included, convergence problems within the estimation procedure may arise. In our log-log model specification we decided to include a quadratic time trend.[9]

In order to obtain the level of efficiency in the use of energy, we estimate Eq. (3.1) using the stochastic frontier function approach introduced by Aigner et al. (1977). Traditionally, the SFA approach has been used in production theory to empirically assess the economic performance of production processes. The basic idea is that the frontier function estimates the maximum (or minimum) level of an economic indicator reachable by a decision making unit, e.g., a firm or an economic agent like a household. In the case of residential electricity consumption, the frontier gives the minimum level of electricity input used by a household for any given level of energy services. The difference between the observed input and the optimal input demand on the frontier represents inefficiency. Furthermore, the difference between the observed input and the cost-minimizing input demand on the frontier depicts both technical as well as allocative inefficiency (Kumbhakar and Lovell, 2003).

In the SFA approach the so called error term ε_{it} is composed of several components. One of these is a symmetric disturbance capturing the effect of noise assumed to be normally distributed as usual. The other components, discussed in details in Section 3.3.1, are interpreted as an indicator of the inefficient use of electricity at the household level.

3.3.1 Estimation methodology

There are several econometric models available for estimating a stochastic frontier using panel data. Below we briefly mention some of the most commonly used models in empirical analysis.

The first is the basic random effects model by Pitt and Lee (1981) (REM hereafter). Next is the true random effects model (TREM hereafter) proposed by Greene (2005a,b) and the third is the generalized true random effects model (GTREM hereafter) by Colombi et al. (2014) and Filippini and Greene (2016).[10] As discussed in Filippini and Greene (2016), some of these models estimate time invariant values of the level of efficiency (persistent efficiency) whereas others produce time variant values (transient efficiency).

The REM by Pitt and Lee (1981) overestimates the level of inefficiency since it regards any time-invariant and group-specific unobserved heterogeneity as inefficiency. The REM does not provide an estimation of the time-varying transient inefficiency indicator. On the other hand, the TREM by Greene

[8]Equation (3.1) should be interpreted as a long-run electricity demand function, because the capital stock can vary. We just include a few variables to take into account the presence of a second fridge, a separate freezer, and whether or not the household owns a special appliance, such as a sauna. Further, the price for appliances is assumed to be the same for all households.

[9]We tried other higher order terms and found that the obtained value of the two types of efficiencies are extremely similar (correlations in the range 0.994 – 0.999) when compared to the results from the specification presented here. Furthermore, the coefficients on our parameters of interest (i.e. the two literacy variables) were also comparable.

[10]See Kumbhakar and Tsionas (2012) and Filippini and Greene (2016) for an overview of all these models. The reader is also referred to Filippini and Hunt (2015) who provide a summary of different econometric specification and comparison between these models.

Table 3.1: The GTREM specification for the stochastic cost frontier.

Model:	$y_{it} = \alpha + \boldsymbol{\beta}'\mathbf{x}_{it} + \varepsilon_{it}$
Full random error (ε_{it}):	$\begin{cases} \varepsilon_{it} = w_i + h_i + u_{it} + v_{it} \\ u_{it} \sim N^{+}[0, \sigma_u^2] \\ h_i \sim N^{+}[0, \sigma_h^2] \\ v_{it} \sim N[0, \sigma_v^2] \\ w_i \sim N[0, \sigma_w^2] \end{cases}$

Note: A log-log model specification is used in the empirical analysis. $\mathrm{E}(h_i|\mathbf{y}_i)$ captures the persistent inefficiency and $\mathrm{E}(u_{it}|\mathbf{y}_i)$ captures the transient inefficiency.

(2005a,b) controls for time-invariant unobserved heterogeneity, but any time-invariant component of inefficiency is then completely absorbed in the household-specific constant terms. Hence this model tends to underestimate the level of inefficiency and as such gives only a measure of the transient inefficiency and not of any time-invariant persistent inefficiency.

In the context of a household, the persistent inefficiency component might relate to the presence of structural problems in the production process of energy services like an old electrical appliance stock or old buildings with very poor insulation. It might also relate to systematic behavioural shortcomings like frequently opening the windows in the heating period and not switching off the lights after use. Similarly, the transient inefficiency part might point towards the presence of non-systematic behavioural failures that could be solved in the short term, e.g., the use of an additional cooling appliance for a few weeks during a hot summer, or the temporary presence of guests visiting the household, hence increasing the demand for energy services temporarily.[11]

This paper focuses on the third and the most recent model, the GTREM, which offers the possibility to simultaneously estimate the persistent and transient parts of inefficiency. Colombi et al. (2014) provided a theoretical construct that distinguishes between persistent and transient inefficiency and Filippini and Greene (2016) have developed a straightforward empirical estimation method for the GTREM by exploiting the Butler and Moffitt (1982) formulation in the simulation. The GTREM is obtained by adding to the TREM a time persistent inefficiency component in the time varying stochastic frontier.

As shown in Table 3.1, this model has a four-part disturbance term with two time-variant and two time-invariant components. One of these components (h_i) captures the persistent inefficiency in the use of energy that may be due to regulations, investments in inefficient appliances or buildings, or habits and consumption behaviours that tend to waste energy. Another component (u_{it}) captures the transient inefficiency that may be, e.g., due to non-optimal use of electrical appliances or heating systems. In the short run, even in the presence of some inflexibility, a household may be able to adjust the use of appliances and heating systems. The remaining two components are assumed to be normally distributed and they respectively represent a symmetric disturbance capturing the effect of noise (v_{it}) and time-invariant household specific effects (w_i).

To understand how the four different components of the error term could be separately identified, we emphasize the crucial insight noted in Filippini and Greene (2016) that the four part disturbance should be instead visualized as only a two part disturbance. One of the parts is time varying ($u_{it} + v_{it}$) and the

[11] Although such a distinction between transient and persistent inefficiency has been partially neglected in empirical studies, we believe it will gain much more importance in future research. This distinction is crucial with respect to the choice of policy instruments to improve end-use energy efficiency.

other is time invariant ($w_i + h_i$), and both parts follow their own skewed normal distribution (rather than normal distribution). Within the simulated likelihood approach, it then follows that the TREM could be easily extended for the purpose of identifying the inefficiencies in a GTREM model. It is a trivial step to simulate draws from a skewed normal distribution as the sum of a normal plus the absolute value of a normal draw (see Filippini and Greene (2016, p. 191–192) for a complete discussion).

The approach used here therefore relies on the approximation of the level of the energy efficiency of Swiss households by two one-sided non-negative terms, u_{it} and h_i.[12] Following Filippini and Greene (2016), the level of efficiency in the use of electricity can be expressed in the following way:

$$EF_{it} = \frac{E^F_{it}}{E_{it}} \tag{3.2}$$

where E_{it} is the observed electricity consumption and E^F_{it} is the frontier or minimum demand of household i in year t. An electricity efficiency level of one indicates a household on the frontier, thereby implying an efficiency level of 100%. Households that are not located on the frontier receive efficiency scores below one, thereby implying the presence of inefficiency in household electricity consumption.

3.4 Data

The data for this research was gathered by means of a large household survey in cooperation with six Swiss utilities.[13] Utilities operating in urban and suburban areas were selected in order to get a sample of households as homogeneous as possible in terms of environment. The participating utilities invited either all or a sub-sample of their customers to take part in an online survey. If sub-samples of customers were drawn, all household customers had the same probability of being in the sample. The invitation letter was sent either separately or accompanying a bi-monthly, quarterly or yearly electricity or gas bill.[14]

The survey questionnaire was developed based on insights from the survey methodology literature (Dillman et al., 2009; Groves et al., 2004), reviewed by several experts in the field of residential energy-efficiency and pre-tested on a student sample. It included questions on dwelling characteristics, socioeconomic attributes, appliance stock and the level of energy services consumed by the household. In addition, the survey comprised questions about the respondents' environmental attitudes, energy saving behaviour at home, energy-related literacy and investment literacy.

At the end of the survey questionnaire, sociodemographic characteristics such as age, gender, employment status and level of education of the respondent were recorded. On completion, respondents were asked whether they agreed that the survey data be linked to the actual energy consumption data of their household. In case of the consumer's accordance, the actual electricity consumption data from 2010 to 2014 was linked to the survey data of the respective household to allow a joint analysis.

[12]The estimation procedures are readily available in `NLOGIT` (Greene, 2012). In this paper, the models were estimated using `NLOGIT 5`.

[13]The six utilities are Aziende Industriali di Lugano (AIL), IBAarau (IBA), Stadtwerk Winterthur (SW), Energie Service Biel/Bienne (ESB), Energie Wasser Luzern (EWL), Aziende Municipalizzate Bellinzona (AMB) that operate respectively in (and the surrounding areas of) Lugano, Aarau, Winterthur, Biel/Bienne, Lucerne and Bellinzona. Among these regions, Aarau, Winterthur and Lucerne are German speaking; Lugano and Bellinzona are Italian speaking; and Biel/Bienne is bilingual (German/French speaking).

[14]The response rates (defined as share of survey page visits over total number of invited customers) varied between 3.2% and 7.4%.

After accounting for the correct target group[15], incomplete responses, and duplicate entries, we have valid and complete data for 1,375 (Lucerne), 583 (Bellinzona), 877 (Biel), 1,406 (Lugano), 739 (Winterthur) and 826 (Aarau) survey respondents.[16] The observed samples are supposed to reflect the Swiss population living in urban (and sub-urban) areas, which accounts for about three quarters of the total population.[17] Of all respondents who started the online survey, filled in their customer number and were filtered-in as the target group, almost 88% completed the survey. We do not find any significant selection among the sample of usable surveys relative to the target group.

To evaluate how well our sub-samples reflect the basic demographic characteristics of the six urban areas included in our analysis, we compare the sample characteristics to population statistics from the Swiss cities association (see Table 5 in the Appendix). In terms of gender composition, the households in our samples seem to represent the population in the six areas quite well. The same holds for age-groups, with some exceptions such as the samples from Bellinzona, Lugano and Aarau, in which a slight deviation can be observed (higher share of younger as compared to older household members in Bellinzona and Lugano, higher share of both younger and older household members as compared to the group of people aged 20 to 64 years in Aarau). Regarding the mean household size, we observe that households in our sample comprise slightly more people than the average household in the areas. Also the living space per person (m^2/person) is slightly above average in all six regions. This, however, does not hold for the number of people per room, which is mostly at the average level. The only exception is Biel/Bienne, where fewer people per room are observed than the population mean would suggest. In conclusion, the characteristics of the surveyed households are generally in line with the characteristics in the six areas (with some smaller exceptions). It is to be noted that the statistics at the city level may not completely reflect the statistics of the surveyed areas, i.e. the service areas of the utilities, which usually also include neighboring municipalities.

The variables used for the household electricity demand estimation are explained below and an overview of the summary statistics can be found in Tables 3.2 and 3.3.

Dwelling characteristics The residence-related attributes comprise non-varying features of the dwelling like the area size in square meters (`SQM`), the time-period when the building was built[18], a dummy indicating whether the dwelling is built according to the Minergie standard, a standard for efficient buildings in Switzerland, (`MINERGIE`)[19] and another binary variable captures whether the household uses electricity for cooking (`COOKEL`). It is also known in which of the six utility service areas the dwelling is located.

Household composition and socioeconomic attributes With respect to household composition, our data set includes information on the presence of children/teens younger than 20 years (`HAS_YOUN`), or elderly person above 64 years (`HAS_ELDE`) in the household at the end of the year 2014. The total number of people who have regularly lived in the residence between 2010 and 2014 (i.e. yearly household size

[15] The target group consists of respondents (i) for whom the electricity/gas bill refers to their primary residence; (ii) who moved in their current residence before 01.01.2015; and (iii) who are one of the persons in their residence who decides about the purchase of goods and/or pays the bills. All three samples combined, a total of 6,688 respondents were filtered-in as the target group, of which 5,917 completed the survey.

[16] The response rates (defined as share of survey page visits over total number of invited customers) varied between 3.2% and 7.4%. The usable survey response rates for all the six survey regions are relatively low when compared to the number of invitation letters sent. One reason for this is the setting – the invitation to participate was sent on paper, including a link to the online survey. This invitation was sent with one of the regular utility bills, which unfortunately lowered the probability that it got the customers' attention.

[17] Data from the Swiss cities association (SSV) 2017.

[18] In four categories: before 1940 (`BLT1940`) as reference; 1940–1970 (`BLT1970`); 1970–2000 (`BLT2000`); and after 2000 (`BLT2015`).

[19] The Minergie certificate can be acquired not only for new buildings but also for renovated buildings.

HHSIZE) is accounted for. Furthermore, the households reported the average number of weeks per year during which their residence remains unoccupied, e.g., due to longer work-related assignments, vacations or stays at a second home (WABS5TO8 is 1 if the residence remains unoccupied 5–8 weeks per year). Finally, with respect to the level of education, we also capture whether the survey respondents (UNIV), as well as their partners (UNIV_PAR), hold a university degree.[20]

Monthly gross household income is captured by dummies representing three income classes: less than CHF 6,000 (INC6K as reference); between CHF 6,000 to 12,000 (INC6_12K); and more than CHF 12,000 (INC12K).

Energy services Information on the consumption level of several energy services is available – number of warm meals prepared per week (NMEALS) which is the sum of total number of prepared lunches and dinners in a typical week; number of dishwasher cycles in a typical week (NDISHWCY); number of washing-related cycles per week (NWASHING), which is the sum of total number of washing machine and clothes dryer cycles in a typical week; number of entertainment services consumed per day (NENTT) which is the sum of total hours of typical daily usage of all the TVs (CRTs and flat-screens) and computers (desktops and laptops) within the residence.

Two dichotomous variables represent if the household own a second fridge (HAS_FR2) or a separate freezer (HAS_FREEZER). Another binary variable captures whether the household owns a special energy intensive appliance or equipment like an air-conditioner.[21] These three variables are used as simple proxies for the corresponding energy services.

Weather The yearly weather related information comprises the total number of heating degree days (HDD) and cooling degree days (CDD) which is measured at a weather station that is located in, or nearby, each of the six different service regions.[22] As the service regions of the utilities in our dataset are mostly city utilities, the service areas are geographically relatively small, therefore, all households in one service area are matched to the same weather station.

Electricity consumption The yearly electricity consumption (response variable Q_E) ranges from 501 kWh to 38,124 kWh, with a mean value of about 3,123 kWh.[23] The residential sector can be highly heterogeneous in terms of electricity consumption. For example, dwellings with an electricity based space or water heating system would be expected to consume much larger amounts of electricity compared to the dwellings using oil or gas based heating. Since we are interested in measuring the *inefficiency in the use in electricity*, households having an electricity-based space or water heating system (including heat pumps) were excluded from the sample as these would exhibit significantly higher electricity consumption than households with non-electricity-based heating systems.

Within the context of estimating a demand function, concerns relating to price of electricity being endogenous (in short and/or long run) is typical. To overcome this, we use marginal prices that do not directly depend upon the individual electricity consumption but are defined using the default electricity tariff for each utility over the 5 years. The electricity price during the period 2010–2014 is measured as an

[20] UNIV and UNIV_PAR is 1 if a person holds a degree from a university, university of applied sciences or university of teacher education.

[21] The variable NONE_APPL takes the value 1 if a household reports that it does not own any of these appliances: Home theater system, Electric/Hybrid Car, Swimming pool, Jacuzzi, Sauna, Solarium, Water-bed, Aquarium/Terrarium, Air Conditioner(AC) or Infra-red heater.

[22] HDD and CDD data is gathered from *MeteoSchweiz* and is based on SIA (1982) and ASHRAE (2001) respectively.

[23] Given the context of household electricity consumption, we impose a minimum yearly consumption of 500 kWh.

Table 3.2: Summary statistics (unbalanced panel of 1,994 households).

Variable	Mean	Std. Dev.	Min.	Max.	N
Panel variables...					
Q_E	3122.77	2326.19	501	38124	8295
MP_AVG	18.68	2.47	13.06	24.32	8295
HHSIZE	2.36	1.19	1	6	8295
INC6K	0.3	0.46	0	1	8295
INC6_12K	0.52	0.5	0	1	8295
INC12K	0.18	0.39	0	1	8295
HDD	2949.75	386.83	1925.6	3602.2	8295
CDD	177.31	86.79	73	458.6	8295
IS_SFH	0.29	0.46	0	1	8295
SQM	122.69	54.41	20	400	8295
BLT1940	0.19	0.39	0	1	8295
BLT1970	0.26	0.44	0	1	8295
BLT2000	0.37	0.48	0	1	8295
BLT2015	0.17	0.38	0	1	8295
MINERGIE	0.07	0.26	0	1	8295
WABS5TO8	0.08	0.27	0	1	8295
HAS_FR2	0.19	0.39	0	1	8295
HAS_FREEZER	0.53	0.5	0	1	8295
NONE_APPL	0.68	0.46	0	1	8295
COOKEL	0.89	0.31	0	1	8295
LUG	0.26	0.44	0	1	8295
AAR	0.11	0.31	0	1	8295
WINT	0.13	0.34	0	1	8295
BIEL	0.18	0.39	0	1	8295
LUZ	0.24	0.42	0	1	8295
BELL	0.08	0.27	0	1	8295
UNIV	0.36	0.48	0	1	8295
UNIV_PAR	0.17	0.38	0	1	8295
Cross-sectional variables (2014) ...					
HAS_YOUN	0.23	0.42	0	1	1994
HAS_ELDE	0.31	0.46	0	1	1994
NMEALS	8.52	3.41	0	14	1994
NDISHWCY	2.99	2.32	0	8	1994
NWASHING	3.04	3.82	0	30	1994
NENTT	6.57	4.99	0	44	1994

average of the peak and off-peak marginal prices using a representative average time-of-use share of peak consumption as weight.[24] Endogenous prices would have been a serious issue if we were using electricity prices based on individual electricity consumption. Moreover, it is worth pointing out that we are not interested in estimating the price elasticity in this study.

From the sample, we also exclude the households who reported that, on average, their residence in completely unoccupied either for more than 8 weeks a year, or for more than 4 days a week (e.g., due to regular travel for work). Lastly, we have an unbalanced panel data comprising of households for which electricity consumption in the same residence for at least 2 out of the 5 time periods from 2010 to 2014

[24]The yearly marginal electricity prices were obtained from the tariff-sheets of each of the six utilities in our sample. In order to avoid any endogeneity problems, instead of individual share of peak consumption (i.e. $[E_{peak}/E_{total}]_{it}$), we use a representative mean value of the share of peak consumption over 8 broad household categories (defined by ElCom) across the 6 regions and from 2010 to 2014 ($\overline{TOU}_{peak}$) so that there is some variation in prices over the 5 years. For customers on a time-of-use tariff system (peak = p; off-peak = op), we used $p^E_{it} = \overline{\text{TOU}}_p \cdot \text{MP}_p + (1 - \overline{\text{TOU}}_p) \cdot \text{MP}_{op}$. For single tariff consumers (without time-of-use prices), the marginal price based on the standard single tariff was directly used.

is available.[25] Due to this, all the 1994 households are not represented in every period, but at least in any two or more of the five periods. The descriptive statistics of most of the main variables appear to be similar across all periods (Table 6 in the Appendix).

Energy and investment literacy Energy literacy was measured by an index that accounts for several dimensions of energy literacy: knowledge of the average price of 1 kWh of electricity in Switzerland, knowledge of the usage cost of different household appliances (running a PC for one hour, running a washing machine cycle with full load) as well as knowledge of the electricity consumption of various household appliances. For example, respondents were given two energy services and were asked which of the two consumed more electricity or whether they consumed about the same, e.g., boiling 1 litre of water on a stove compared to boiling 1 litre of water using an electric kettle. Responses to all these questions were combined into a simple measure of energy literacy by assigning a certain amount of points for each correct answer. Depending on the number of correctly answered questions, respondents could achieve a value between 0 and 11 on the energy literacy score (`ENLIT`).

Investment literacy (`INVLIT`) was measured by a binary variable that takes the value one if the respondent correctly solved a compound interest rate calculation. Compound interest rate calculations are usually used to assess an individual's investment literacy (Brown and Graf, 2013; Lusardi and Mitchell, 2007, 2009).

Similar to findings reported in the study of Brounen et al. (2013), we observe a rather low level of energy literacy in our sample. For example, only about 27% of the respondents knew about the average price of electricity in Switzerland. Regarding the level of investment literacy among Swiss consumers, we find that 71% of the participants in our survey were able to correctly solve the compound interest calculation.

Energy-saving behaviour One section of the survey asked respondents whether they exercised certain energy-saving behaviours when consuming energy services at home. The respondents had to indicate their agreement on a 5-point likert scale ranging from 'strongly disagree' to 'strongly agree' with respect to these behaviours – completely switching off electronic appliances after use (no standby); running the washing machine only on full load; washing clothes on a lower water temperature of less than 30°C; and selecting a dishwasher program cycle based on the level of dirtiness. From these four types of energy-saving behaviour we calculated an index score. The household received one index point for each of these behaviours if they stated that they exercised this behaviour 'always' or 'very often'. Therefore, the values of the score lie within the range from 0 to 4 points (`BEHAV`).

An overview of the energy-saving behaviour score, the energy literacy score and investment literacy can be found in Table 3.3. The survey questions are presented in Figures 1–5 in the Appendix.

Table 3.3: Overview of energy literacy, investment literacy and energy saving behaviour.

Variable	Mean	Std. Dev.	Min.	Max.	N
ENLIT	4.39	2.84	0	11	1994
INVLIT	0.71	0.45	0	1	1994
BEHAV	2.35	1.05	0	4	1994

[25]The panel is unbalanced primarily because (i) the availability of electricity consumption data (response variable) is conditional on when the households moved into their current residence; (ii) consumption data for households in the utility in Lucerne is unavailable for the year 2010; and (iii) it is required that each household has at least two years of consumption data (i.e. is a panel).

Next we estimate the ad-hoc electricity demand in Eq. (3.1) wherein we use a log-log specification. The transformation to logs further helps to interpret estimated coefficients as a measure of *relative* change in electricity demand per unit change of a continuous explanatory variable, e.g., level of an energy service or the energy literacy score.[26]

3.5 Empirical results

Results for two model specifications are presented in Table 3.4. GTREM-1 presents estimation results for the electricity input demand frontier function defined in Eq. (3.1), whereas GTREM-2 presents a more traditional model without any energy services. Both specifications include energy literacy, investment literacy and the energy saving behaviour of the households. The traditional specification that does not include information on energy services should lead to a lower level of energy efficiency. In fact, within this model, the households that consume a relatively high amount of energy services would be classified as less efficient than the households that consume a lower amount of energy services. This is of course not an appropriate assessment, as the fact that a household consumes more energy services could be due to special preferences and needs. In this paper, we are mainly interested in estimating the level of efficiency in the use of energy among households that consume a similar amount of energy services.

Most estimated coefficients have the expected signs and are seen to be statistically significant at the 1% level. The parameter λ, which represents the relative contribution of the transient inefficiency term over the complete disturbance term, is significant in both specifications. Further, σ_h, the standard deviation of the one-sided time-invariant component h_i is also significant. This result shows the presence of persistent inefficiency. Since we use a log-log functional form for the total electricity demand and other continuous variables in the model, the estimated coefficients on such variables can be interpreted as demand elasticities, e.g., the price elasticity is found to be statistically significant and negative.

Electricity consumption increases with dwelling size and single family houses have higher electricity consumption than households living in apartments. Compared to the buildings built before 1940 (reference category), newly built houses generally consume lower electricity, with the exception of those built between the years 1970 and 2000.

Electricity consumption also increases with household size. Households, in which elderly people of 60 years or older are present, tend to consume more electricity, whereas households with children consume less. Income levels are found to be less significant when accounting for all other variables included in the model.[27]

The coefficients for the presence of a second fridge or a separate freezer are positive and significant. Electricity consumption is higher for higher levels of energy services with stronger effects for entertainment services (televisions and computers), followed by dishwashers, and washing services. The preparation of

[26]Many of the continuous variables have a skewed distribution and transforming to logs is one way to help stabilize the variances. The energy services (`NMEALS`, `NDISHWCY`, `NWASHING`, `NENTT`), the energy literacy index (`ENLIT`) and the energy consumption behaviour (`BEHAV`) can take a minimum value of zero (Table 3.2 and Table 3.3). These variables were first transformed by adding 1 to all sample points, i.e. $\{0, 1, 2, \ldots, 11\} \longmapsto \{1, 2, 3, \ldots, 12\}$, and then log is taken. This should not be of too much of a concern here as we are interested in the relative measure and not on the absolute values. As a robustness check we also estimated the model without taking logs on these count variables and also taking a square root transformation instead of logs. The obtained efficiency estimates were found to be very similar.

[27]The weak (or non-) significance of income may be due to the income effect being captured by some residential and household characteristics like the number of rooms and household size. We estimated a simple model with only the price of electricity, income, regional dummies and a time trend. The results show that in this simple model income is positive and significant.

Table 3.4: Estimation results.

	GTREM-1		GTREM-2	
	Coefficient	*Std. error*	*Coefficient*	*Std. error*
(Log) price of electricity	-0.3032***	(0.037)	-0.2882***	(0.037)
Single family household	0.1674***	(0.007)	0.2305***	(0.007)
(Log) household size	0.3472***	(0.011)	0.4338***	(0.011)
(Log) dwelling size in m2	0.3921***	(0.009)	0.4778***	(0.009)
Has young people	-0.0449***	(0.008)	0.0011	(0.008)
Has elderly people	0.0346***	(0.006)	0.0215***	(0.006)
Income in 6k - 12k	-0.0119**	(0.006)	-0.0090	(0.006)
Income above 12k	-0.0180**	(0.009)	-0.0134	(0.009)
Built in 1940 - 1970	-0.0773***	(0.008)	-0.0736***	(0.008)
Built in 1970 - 2000	0.0440***	(0.007)	0.1076***	(0.007)
Built in 2000 - 2015	-0.0558***	(0.009)	0.0408***	(0.009)
Minergie house	0.0185*	(0.010)	0.0633***	(0.010)
Absent 5 to 8 weeks/year	-0.1506***	(0.009)	-0.1526***	(0.009)
Has 2nd fridge	0.1042***	(0.007)	0.1494***	(0.007)
Has separate freezer	0.1126***	(0.005)	0.1481***	(0.005)
No special appliances	-0.0767***	(0.006)	-0.0858***	(0.006)
(Log) number of cooked meals	0.0021	(0.006)	—	—
(Log) dishwashing cycles	0.1151***	(0.004)	—	—
(Log) cloth washing/drying cycles	0.1009***	(0.004)	—	—
(Log) hours of tv/pc	0.1708***	(0.004)	—	—
Cooks using electricity	0.0957***	(0.008)	0.1598***	(0.008)
(Log) heating degree days	-0.1051	(0.111)	-0.0777	(0.110)
(Log) cooling degree days	0.1923***	(0.046)	0.1717***	(0.046)
Region = Aarau	0.0559***	(0.020)	0.0314	(0.020)
Region = Winterthur	-0.1312***	(0.040)	-0.0879**	(0.040)
Region = Biel/Bienne	0.0768***	(0.024)	0.0396	(0.024)
Region = Lucerne	-0.0514***	(0.017)	-0.0846***	(0.017)
Region = Bellinzona	-0.2524***	(0.066)	-0.2864***	(0.065)
University degree	-0.0144***	(0.006)	-0.0434***	(0.006)
University degree (partner)	-0.0185***	(0.007)	-0.0088	(0.007)
(Log) energy saving behaviour	-0.0227***	(0.007)	-0.0412***	(0.007)
(Log) energy literacy index	-0.0126***	(0.004)	-0.0157***	(0.004)
Investment literacy	-0.1137***	(0.006)	-0.1109***	(0.006)
Time trend (linear)	-0.1190***	(0.022)	-0.1072***	(0.022)
Time trend (quadratic)	0.0230***	(0.004)	0.0213***	(0.004)
α	5.6722***	(0.719)	5.5717***	(0.713)
σ_w	0.3960***	(0.002)	0.4228***	(0.002)
$\sigma_{(v+u)}$	0.2542***	(0.003)	0.2894***	(0.003)
λ	0.7553***	(0.041)	1.2193***	(0.041)
σ_h	0.5411***	(0.017)	0.2696***	(0.014)
Observations:	8295		8295	
Log-likelihood:	-1735.7		-1867.4	

***, **, * ⇒ Significance at 1%, 5%, 10% level.

warm meals does not appear to be significant, although using electricity as the energy source for cooking is expectedly associated with a higher demand for electricity.

Using the region of Lugano as the reference, it appears that households in the region of Bellinzona (followed by Winterthur and Lucerne) consume significantly less electricity, whereas households in the region of Biel/Bienne and Aarau consume more. In terms of weather, HDD is seen to be insignificant whereas CDD is significant and positive. One would normally expect both weather variables to be significant and positive, as both these variables should contribute to increasing electricity demand. The result shown here is likely due to identification problems since regional dummies and time trends may also capture the same effects.[28] The coefficient that captures the quadratic time trend is positive and that

[28]We perform some robustness checks by estimating several models: (i) including HDD but no CDD; (ii) including CDD but no HDD; (iii) using total Degree Days (DD) that is the sum of HDD and CDD; and (iv) including both HDD and CDD but no regional

of the linear trend is negative. The coefficient on the dummy for a university degree of the respondent is significant and negative in both models, and that of the partner is significant and negative only in GTREM-1. This indicates that electricity consumption decreases with education. It is important to control for education when analyzing the effect of energy and investment literacy in order to disentangle the effects of education and the effect we want to measure with the literacy score.

In both GTREM specifications, the estimates of the energy literacy score, investment literacy and the behavioural index are negative and significant. This means that for households exhibiting energy-saving behaviour, electricity consumption is seen to be lower. Similarly, households possessing a higher level of energy-related literacy and investment literacy are also associated with lower electricity consumption, although investment literacy seems to play a more vital role.[29] As discussed later in this section in more detail, the fact that households with a high level of investment literacy consume (ceteris paribus) less electricity, implies that it is possible to identify different demand frontier functions *conditional* on the level of investment literacy.

Level of efficiency

Using the estimations above and Eq. (3.2), we can estimate the level of efficiency. Table 3.5 provides summary statistics of the estimated efficiency levels for the two GTREM specifications.[30]

In GTREM-1, the short-run or the transient part of the efficiency in residential electricity consumption is found to be between 63.4% and 97.4%, with a mean value of about 89.2%. The long-run component representing the persistent part of the efficiency ranges from 39.4% to 84.1% and has a mean value of 78.4%.

In GTREM-2, which is a more traditional SFA model without any energy services, the mean level of transient efficiency is observed to be at 84.8%, and the level of persistent efficiency at 84.0%. Persistent efficiency is observed to be lower both in terms of the mean value and the variance in both specifications, implying higher long-run inefficiencies. This high value of inefficiency is indicative of structural problems faced by Swiss households, who probably rely on an old appliance stock within their homes. Moreover, this also possibly points to systematic behavioural shortcomings in terms of consumption of energy services.

The efficiency levels presented above indicate that there is a significant potential for the Swiss residential sector in the urban and sub-urban areas to save energy. In fact, households could save as much as 22% of

dummies. In all these cases, we find the coefficient (respectively) on `HDD`, `CDD`, `DD`, and both `HDD` and `CDD` to be positive and significant. We also found the estimates and efficiency values to be very similar.

[29] It needs to be stated that, in the literature on stochastic frontier analysis, it is possible to find econometric models that assume that the energy and investment literacy variables explain the level of efficiency in the use of electricity instead of directly the demand for electricity as in Eq. (3.1). This would mean that the one-sided error terms h_i and u_{it} are functions of `ENLIT` and `INVLIT`. Unfortunately, such an estimation strategy within the econometric approach proposed by Filippini and Greene (2016) is relatively complicated and currently it is not implemented for GTREM. As a robustness check, we decided to estimate Eq. (3.1) using some econometric models that do not distinguish between the two components of inefficiency (transient and persistent) but allow the level of inefficiency to be a function of `ENLIT` and `INVLIT`. For this purpose, we decided to use the REM, Battese and Coelli (Battese and Coelli, 1995), and TREM; both energy and investment literacy were found to be significant in explaining the level of efficiency.

[30] For comparison, we also estimated the model using older approaches (REM and TREM) discussed in Section 3.3.1. The results are included in Table 7 and Table 8 in the Appendix. As expected the efficiency levels from TREM are highly correlated with those from the transient efficiency from GTREM (correlation = 0.931). The persistent efficiency levels from GTREM exhibit a lower correlation with REM estimates (correlation = 0.397). Furthermore, REM estimates of efficiency levels are much lower than those of TREM and GTREM since REM regards any time-invariant and group specific unobserved heterogeneity as inefficiency.

Table 3.5: Efficiency scores (transient and persistent).

Efficiency type	*Median*	*Mean*	*Std. Dev.*	*Minimum*	*Maximum*
			GTREM-1 (with energy services)		
Transient	0.894	0.892	0.026	0.634	0.974
Persistent	0.785	0.784	0.013	0.394	0.841
			GTREM-2 (without energy services)		
Transient	0.856	0.848	0.051	0.395	0.966
Persistent	0.841	0.840	0.006	0.675	0.951

their electricity usage in the long-run if they could improve on systematic and structural inefficiencies. With the reduction of transient inefficiencies in the short-run, the potential to save electricity is up to 11%.

Level of efficiency conditional on investment literacy

In the context of residential electricity demand and given the discussion on stochastic frontier models, it is interesting to note that one could identify several frontiers. For example, structural frontiers may exist based on building-age wherein dwellings built in two different time-periods represent different reference frontiers.

Similarly, considering the level of investment literacy in our specification which is represented by a dummy, one could identify two distinct best practice frontiers – with, and without high investment literacy. The efficiency values given by the estimation is conditional on their respective best practice frontiers (*net efficiency* or *conditional efficiency*). Moreover, the inefficiency resulting as a consequence of the distance between the two frontiers can be measured by the coefficient on the dummy variable capturing investment literacy which indicates the difference in the level of efficiency in the use of electricity given the level of investment literacy.[31] Given the *net efficiencies* and the coefficient on the dummy variable, one can obtain a measure of *gross efficiencies* or *unconditional efficiencies* by comparing every household to the most favorable frontier (Coelli et al., 1999).

Table 3.6: Mean efficiency conditional on investment literacy.

	GTREM-1		**GTREM-2**	
	Net-eff	*Gross-eff*	*Net-eff*	*Gross-eff*
Transient	0.892	0.796	0.848	0.759
Persistent	0.784	0.700	0.840	0.752

Table 3.6 shows the mean unconditional and conditional efficiency levels for both GTREM specifications. The two efficiency levels can give policymakers a hint as to if they can try to reduce a part of the unconditional inefficiency by targeting policies on a particular aspect, which in this context is investment literacy as we focus on conditional efficiencies subject to investment literacy. We notice that the unconditional

[31] Of course, we are aware that it could be interesting to estimate the level of efficiency in the use of electricity conditional on the level of energy literacy. However, due to the fact that the level of energy literacy is not measured with a dummy variable, the definition of the reference frontier is not straightforward.

efficiency levels are seen to be significantly lower which emphasizes the role played by investment literacy in defining the level of efficiency in the use of electricity.

3.6 Conclusion

A household's energy demand is not a demand for energy per se but a derived demand for energy services, such as cooling, heating, cooking and lighting. A reduction in energy consumption for the production of a given level of energy services can be achieved by either improving the level of efficiency in the use of inputs (i.e. in the use of appliances), by adopting a new energy-saving technology (i.e. purchase of new appliances, investments in energy-saving renovations) or by both processes. Technological change can induce a reduction of energy consumption for a given level of energy services, provided that the inputs are used in an efficient way, i.e. given that the households are productively efficient. The total reduction in residential energy consumption is therefore a result of the interplay of technological change and a household's behaviour.

To measure this inefficiency in the use of electricity in Swiss households, we estimate a stochastic frontier model for residential electricity demand. We use data from a Swiss household survey conducted in 2015 that collected panel data over five years. The dataset includes information on the level of energy services, which is crucial, but often difficult to measure. The newly developed generalized true random effects model (GTREM) is used to estimate the transient and persistent levels of efficiency in the use of electricity. This study contributes to the literature on efficiency measurement by highlighting the importance of the distinction between the two types of efficiencies. Our unique panel dataset includes information on the level of energy services, which is usually not measured but critical for the application of SFA. In addition, we analyze the impact of energy and investment literacy on the total electricity consumption of households while controlling for the effects of education of the household members. Our results therefore provide new insights into the interrelations between the literacy and education variables and their role for transient and persistent efficiency in residential electricity consumption. The median persistent inefficiency is found to be around 22% whereas the transient inefficiency is seen around 11%. These results suggest that there is a considerable potential for saving electricity and thus reaching the reduction target defined by the Swiss federal council as part of the *Energy Strategy 2050*.

We further investigate if energy literacy, investment literacy and energy-saving behaviour have an influence on the household electricity consumption. We construct a score on energy literacy, a binary variable for investment literacy, and an index that aggregates several energy saving behaviours and include these in our GTREM specification. The results show that for households exhibiting energy saving behaviour, electricity consumption is seen to be lower. Similarly, households possessing a higher energy literacy and, in particular, investment literacy are also associated with lower electricity consumption.

From the point of view of policy makers, we note that the high persistent inefficiency is indicative of structural problems faced by households and systematic behavioral shortcomings in residential electricity consumption. The results presented here indicate a positive role of energy literacy, investment literacy and energy-saving behaviour in reducing household electricity consumption and perhaps addresses part of the systematic behavioural failure exhibited by households. Policies that target an improvement of energy literacy, investment literacy and promote energy-saving behaviour among the Swiss population could help in improving efficiency in the use of energy within households, which could prove much more beneficial in the long run. Finally, we emphasize again that clear distinction has to be made between the persistent and transient inefficiencies faced by households in order to appropriately channel the relevant policy measures. For instance, energy policy measures that try to promote energy saving (such as an information campaign) or try to increase the level of energy literacy (such as distribution of information leaflets and booklets among households) will probably have an impact on the level of transient efficiency. On the other hand, policy measures that try to improve the level of investment literacy, such as short courses training individuals in assessing investments or web-pages and mobile-apps that help to calculate the life-cycle cost of appliances, could have an impact on the buying process of appliances, and therefore, on the level of persistent efficiency.

Acknowledgements

We are grateful to the Bundesamt für Energie (BFE) for financial support. BFE was not responsible for the study design, the collection, analysis and interpretation of data or in the writing of this paper. The content does not necessarily represent the official views of BFE. This research is also part of the activities of SCCER CREST, which is financially supported by the Swiss Commission for Technology and Innovation (CTI). All omissions and remaining errors are our responsibility. Furthermore, we would like to thank all the cooperating utilities who sent out invitations to participate in the household survey. Comments from two anonymous referees as well as from participants of the 2016 Atlantic Workshop on Energy and Environmental Economics (AWEEE) are gratefully acknowledged.

4 Efficiency analysis, role of policy measures, and decomposition

4.1 Introduction

In this chapter, we extend the analysis in Chapter 3 to include electricity consumption data from service regions of all utilities in our survey. Our focus here is to provide an estimate of the level of transient and persistent inefficiency in the use of electricity among Swiss households living in urban and suburban areas.[1] We collected information on $8,378$ Swiss households served by nine different utility companies out of which a panel data of electricity consumption of about $3,936$ households is available for analysis. We also analyze the role of some of the demand-side measures that were in place in these regions over the last 5 years and provide a decomposition of the growth rate of electricity demand.

The rest of the chapter is organized as follows. Section 4.2 comprises an overview of some of the DSM measures across the participating utilities. Section 4.3 presents a simple econometric model of residential electricity demand using dis-aggregated household data. Section 4.4 provides and overview of the dataset used in the model. Section 4.5 presents the results and Section 4.6 concludes.

4.2 Overview of policy measures

Measures to promote energy efficiency can be implemented by central and local governments, and also by electricity distribution utilities. Measures undertaken by the government are termed 'energy policy'. In the case of utilities, these measures are generally referred to as demand-side management (DSM) measures. If the utility is public, DSM measures could be expected to overlap with energy policy goals of a government.

4.2.1 Demand-side management (DSM)

Demand-side management (DSM) refers to the *"planning, implementing, and monitoring activities of electric utilities that are designed to encourage consumers to modify patterns of electricity usage, including the timing and level of electricity demand"* (Energy Information Administration, 1999). Early examples of DSM programmes, initiated primarily by utilities in the west coast, can be traced back to late 1970s in response to the energy crises in the USA. Implementation of DSM soon reached to the east coast and other regions of the USA and to British Columbia, Ontario and other provinces in Canada. DSM

[1] Basel (IWB) and Lausanne (SiL) opted not to have the energy-literacy questions in their survey questionnaire because they wanted to keep the survey a bit shorter. Since the literacy data is not available, in the efficiency estimation we will not focus on the role of energy and investment literacy in order to be able to estimate the level of energy efficiency for the full sample.

efforts have been limited outside of North America till the 1990s (Nadel and Geller, 1996), but have since been adopted also in Australia and several countries in Europe, Latin America and Asia.

DSM programmes were originally introduced with the intention of modifying the load faced by an utility by altering the pattern of electricity demand by consumers. Over the years, it has been adapted to also take into account programmes and initiatives that are undertaken by utilities and governments to promote energy efficiency. Hence, DSM incorporates energy efficiency, energy conservation, and load management (Carley, 2012). Utilities and government bodies have tried to meet these objectives in various ways in the past. These include, among other things, policies like appliance standards, financial incentive programmes, information campaigns and voluntary programmes (Gillingham et al., 2006). Table 4.1 provides a brief overview of some typical market and non-market based instruments for demand-side management, both for load management and for reducing energy demand.

For Switzerland, Boogen et al. (2015) provide a qualitative analysis of DSM programmes of a sample of 30 utilities as well as an econometric analysis of the effectiveness of such programmes on Swiss residential electricity demand. Moreover, for a detailed description of the DSM literature and DSM in Switzerland, please also refer to Boogen et al. (2015).

Table 4.1: Demand-side management instruments. Source: Boogen et al. (2015)

	Load management	**Energy efficiency**
Market instruments	1. Time-of-use tariff 2. Critical peak pricing 3. Critical peak rebates 4. Real-time pricing 5. Interruptible load tariff	1. Efficiency bonus 2. Rebate systems 3. Energy tax
Non-market instruments	1. Ripple control 2. Smart metering	1. Information campaign 2. Voluntary agreements on efficiency goals 3. Appliance standards 4. Labelling

4.2.2 DSM across our sample

Following the completion of the survey phase, the utilities were asked to provide information on which of the policy measures were implemented in their region over a period of five year from 2010 to 2014.[2] The utilities specified, by a ‘yes’ or ‘no’, which of the policy measures were active in their service regions over the last five years. In some cases, utilities also furnished additional remarks with respect to implementation, coverage, time-period etc. of these measures.[3]

[2] The five year period for EWB (Bern) was from 2011 to 2015.

[3] We are primarily concerned with DSM measures that existed and applied to all private households. So, based on remarks from the utilities and additional online information, availability of some measures were updated, e.g., a DSM measure that applied only to very-large industrial consumers, or was only a pilot project with a handful of households was marked as non-existing in that region as it does not affect all private consumers.

We collected information on several market and non-market instruments. These policy instruments (listed below) can be noticed to fall under five broad categories – information distribution (p1 – p3); feedback on consumption (p4 – p7); consulting and audit (p8, p9); investment aid or subsidy (p10 – p12); and efficiency-linked measure (p13).

p1 - Information distribution to consumers via printed means.
p2 - Information distribution to consumers via online means.
p3 - Information campaigns, e.g., public campaigns, news coverage and promotional events.
p4 - Rental of electricity measuring instruments to households.
p5 - Smart-Meter pilot project with real-time feedback on electricity consumption.
p6 - Comparison with the previous year's electricity consumption on household's current electricity bill.
p7 - Specialized consumption monitoring tools, portals and apps, e.g., from BEN Energy.
p8 - Personalized energy consulting at home regarding identifying energy intensive activities, efficiency improvement possibilities and questions related to renovations.
p9 - Energy consulting at a central office or a customer care centre (instead of home).
p10 - Investment aid/subsidy in making efficiency investments in household appliances.
p11 - Investment aid/subsidy in making efficiency investments in heaters and boilers.
p12 - Investment aid/subsidy in making efficiency investments in building envelope.
p13 - Specialized tariff related measures, e.g., an efficiency bonus.

Table 4.2 presents the collected data on all DSM measures by service regions. It can be noticed that service regions across all utilities have had some sort of information related non-market instrument in place over the last five years. Most of the regions, except AIL and AMB, also had measures related to providing feedback on household electricity consumption.[4] With respect to audit and consulting services being offered, either at home or at a central audit-centre, it is seen that six out of the nine utilities provide this service. In terms of providing assistance in the form of an aid or subsidy when making efficiency investments, AIL, ESB and IWB do not have any measures. EWB has all the three types of investment support in place whereas other utilities only have some of these measures. The same applies for policies providing an efficiency bonus directly linked with individual reduction in electricity consumption - this measure existed in three utilities over some years.

4.3 An econometric model for electricity demand

Filippini and Hunt (2011, 2015) proposed a non-radial input specific measure of efficiency in the use of energy based on the difference between the optimal use of energy (one which minimizes input costs) and the observed use of energy. We follow this approach and estimate a measure of efficiency in the use of electricity based on the estimation of a single conditional input demand frontier function, i.e. the demand function for electricity. The function represents the minimum or baseline electricity demand of a model household that has a highly efficient appliance stock and uses the most efficient production process to produce a given level of energy services, given electricity price, price of capital stock, weather and other factors. If a household is not on the frontier, the distance from the frontier measures the level of inefficiency in the use of electricity. We can write:

$$E = f(P_E, HH, DW, ES, WE, T) \quad (4.1)$$

where E is the electricity demanded (in kWh), P_E is the electricity price, HH represents a vector of household characteristics, DW is a vector of dwelling characteristics, ES is the amount of energy services

[4]Note that pilot projects like smart-meter and other specialized consumption monitoring devices are usually confined to a handful of households.

Table 4.2: DSM measures over 5 years across the service regions of the 9 utilities.

utility	**year**	p1	p2	p3	p4	p5	p6	p7	p8	p9	p10	p11	p12	p13
AIL	2010	0	0	1	0	0	0	0	0	0	0	0	0	0
	2011	0	0	1	0	0	0	0	0	0	0	0	0	0
	2012	0	0	1	0	0	0	0	0	0	0	0	0	0
	2013	0	0	1	0	0	0	1	0	0	0	0	0	0
	2014	0	0	1	0	0	0	1	0	0	0	0	0	0
AMB	2010	1	1	1	0	0	0	0	0	0	0	1	0	0
	2011	1	1	1	0	0	0	0	0	0	0	1	0	0
	2012	1	1	1	0	0	0	0	0	0	0	1	0	0
	2013	1	1	1	0	0	0	0	0	0	0	1	0	0
	2014	1	1	1	0	0	0	0	0	0	0	1	0	0
ESB	2010	1	1	1	1	0	1	0	0	0	0	0	0	0
	2011	1	1	1	1	0	1	0	0	0	0	0	0	1
	2012	1	1	1	1	1	1	0	0	0	0	0	0	1
	2013	1	1	1	0	0	1	0	0	0	0	0	0	0
	2014	1	1	1	0	0	1	1	0	0	0	0	0	0
EWB	2011	1	1	0	0	0	1	0	1	0	1	1	1	1
	2012	1	1	1	0	0	1	0	1	0	1	1	1	1
	2013	1	1	0	0	1	1	0	1	0	1	1	1	1
	2014	1	1	0	0	1	1	0	1	0	1	1	1	0
	2015	1	1	0	0	1	1	0	1	0	1	1	1	0
EWL	2010	1	1	1	1	0	0	0	1	1	1	0	0	0
	2011	1	1	1	1	0	0	0	1	1	1	0	0	0
	2012	1	1	1	1	1	0	0	1	1	1	0	0	0
	2013	1	1	1	1	1	0	0	1	1	1	0	0	0
	2014	1	1	1	1	1	0	0	1	0	1	0	0	0
IBA	2010	1	1	0	0	0	1	0	0	0	0	1	0	0
	2011	1	1	1	1	0	1	0	1	0	0	1	0	0
	2012	1	1	1	1	1	1	1	1	0	0	1	0	0
	2013	1	1	1	1	1	1	1	1	0	0	1	0	0
	2014	1	1	1	1	1	1	1	1	0	0	1	0	0
IWB	2010	1	1	1	0	0	1	0	0	1	0	0	0	1
	2011	1	1	1	0	0	1	0	0	1	0	0	0	1
	2012	1	1	1	0	0	1	0	0	1	0	0	0	1
	2013	1	1	1	0	0	1	0	0	1	0	0	0	1
	2014	1	1	1	0	0	1	0	0	1	0	0	0	1
SIL	2010	1	1	1	1	0	0	0	1	1	0	0	1	0
	2011	1	1	1	1	0	0	0	1	1	0	0	1	0
	2012	1	1	1	1	1	0	0	1	1	0	0	1	0
	2013	1	1	1	1	0	0	0	1	1	0	0	1	0
	2014	1	1	1	1	0	0	0	1	1	0	0	1	0
SW	2010	1	1	1	1	0	1	0	1	0	0	0	0	0
	2011	1	1	1	1	0	1	0	1	0	0	0	0	0
	2012	1	1	1	1	0	1	1	1	0	0	1	1	0
	2013	1	1	1	1	1	1	1	1	0	0	1	1	0
	2014	1	1	1	1	1	1	1	1	0	0	1	1	0

consumed, and WE represents the weather influence which is usually captured by the number of heating degree days (HDD) and cooling degree days (CDD) that the household experiences. T is the time trend that is assumed to capture the common underlying energy demand trend (UEDT). The UEDT, according to Filippini and Hunt (2011), captures both ‘exogenous’ technical progress and other exogenous factors that influence all households simultaneously, e.g., general changes in awareness of climate change. Hence, it allows for the impact of ‘endogenous’ technical progress through the price effect and ‘exogenous’ technical progress through the UEDT.[5]

[5]Other than technological and socioeconomic factors, there could be other exogenous behavioral factors that are important in explaining the level of energy consumption at the household level. These exogenous changes are unlikely to impact the demand in a consistent manner over time. Hunt et al. (2003) suggest to specify the UEDT in a way that it is non-linear and can

In our empirical setting, we posit the following household electricity demand function:

$$\begin{aligned}\ln E_{it} = \alpha_0 + \alpha_P \ln P_{E_{it}} + \alpha_{HH} HH_{it} + \alpha_{DW} DW_{it} + \alpha_{ES} ES_{it} \\ + \alpha_{wE} WE_{it} + \alpha_T T_t + \alpha_{TT} T_t^2 + \varepsilon_{it}\end{aligned} \tag{4.2}$$

where ε_{it} is the overall error term. This equation represents the minimum electricity consumption as a function of electricity price, household and dwelling characteristics, weather influences, stock of special appliances and the level of energy services.[6]

Note that it would be possible to include many non-linearities (beyond those implied by the log-log setting) and higher order dependencies in the model specified in Eq. (4.2). A quadratic time trend, T_t^2, is one example. It is also plausible that an additional household member does not necessarily increase the energy demand linearly. Other variables like weather or electricity prices may as well have different effects across different regions. However, if too many non-linear terms are included, convergence problems within the estimation procedure may arise.[7]

As already discussed in Chapter 3, there are several econometric models available for estimating a stochastic frontier using panel data. We focus on the most recent model – the generalized true random effect (GTRE) model, which offers the possibility to simultaneously estimate both the persistent and transient parts of inefficiency in the use of electricity.

The GTRE model specification for the stochastic cost frontier is given as:

$$\begin{aligned}&\text{Model}: \quad y_{it} = \alpha_0 + f(\mathbf{x}_{it}; \boldsymbol{\beta}) + \varepsilon_{it} \\ &\text{Full random error } (\varepsilon_{it}): \begin{cases}\varepsilon_{it} = w_i + h_i + u_{it} + v_{it} \\ u_{it} \sim N^+\left(0, \sigma_u^2\right) \\ h_i \sim N^+\left(0, \sigma_h^2\right) \\ v_{it} \sim N\left(0, \sigma_v^2\right) \\ w_i \sim N\left(0, \sigma_w^2\right)\end{cases}\end{aligned} \tag{4.3}$$

This model has a four-part disturbance term with two time-variant and two time-invariant components. One of these components (h_i) captures the persistent inefficiency in the use of energy that may be due to regulations, investments in inefficient appliances or buildings, or habits and consumption behaviours that tend to waste energy. Another component (u_{it}) captures the transient inefficiency that may be, e.g., due to non-optimal use of electrical appliances or heating systems. In the short run, even in the presence of some inflexibility, a household may be able to adjust the use of appliances and heating systems. The remaining two components are assumed to be normally distributed and they respectively represent a symmetric disturbance capturing the effect of noise (v_{it}) and time-invariant household specific effects (w_i).

The approach used here therefore relies on the approximation of the level of the energy efficiency of Swiss households by two one-sided non-negative inefficiency components, u_{it} and h_i, which are assumed to follow half-normal distributions (denoted as N^+). Following Filippini and Greene (2016), the level of

increase and/or decrease over the time period considered. This can be achieved by using time dummies. We estimated the model presented here also with time dummies and the results obtained were similar.

[6] Equation (4.2) should be interpreted as a long-run electricity demand function, because the capital stock can vary. We just include a few variables to take into account the presence of a second fridge, a separate freezer, and whether or not the household owns a special appliance, such as an air-conditioner or a sauna. Further, the price for appliances is assumed to be the same for all households.

[7] In our log-log model specification we decided to include a quadratic time trend. We tried other higher order terms and found that the obtained value of the two types of efficiencies are extremely similar.

efficiency in the use of electricity can be expressed in the following way:

$$EF_{it} = \frac{E^F_{it}}{E_{it}} \tag{4.4}$$

where E_{it} is the observed electricity consumption and E^F_{it} is the frontier or minimum demand of household i in year t. An electricity efficiency level of one indicates a household on the frontier, thereby implying an efficiency level of 100%. Households that are not located on the frontier receive efficiency scores below one, thereby implying the presence of inefficiency in household electricity consumption.

Once the transient efficiency (TE) and persistent efficiency (PE) values have been estimated, it is possible to obtain a measure of the overall technical efficiency. Kumbhakar et al. (2014) define the overall technical efficiency (OTE) as the product of the time-invariant persistent efficiency and the time-varying transient efficiency, i.e., $OTE = PE * TE$.

4.4 Data

The complete data-set collected as part of the household survey has been already discussed in much detail in Chapters 2 and 3. Below we simply present an overview of the variables that we include in our estimation model (Table 4.3).

The yearly electricity consumption (response variable `Q_E`) ranges from 500 kWh to 29, 885 kWh, with a mean value of about 2, 848 kWh.[8] The residential sector can be highly heterogeneous in terms of electricity consumption. For example, dwellings with an electricity based space or water heating system would be expected to consume much larger amounts of electricity compared to the dwellings using oil or gas based heating. Since we are interested in measuring the *inefficiency in the use in electricity*, households having an electricity-based space or water heating system (including heat pumps) were excluded from the sample as these would exhibit significantly higher electricity consumption than households with non-electricity-based heating systems.

To account for the cost of electricity, we use the individual specific average electricity price (`AVP_E` in Rappen) which is calculated as the total yearly expense on the electricity bill divided by the total yearly kWh consumed. Note that the use of such an average price would clearly be endogenous in a demand model. In order to correct for this, we use a two-stage residual inclusion approach for non-linear models suggested by Terza et al. (2008). According to this two-stage approach, first the endogenous average price is regressed against exogenous as well as instrumental variables.[9] In the second stage, the original equation is estimated by including also the residual obtained from the first stage. The use of average price is motivated by the fact that we do not have enough variation in tariffs over the period of 5 years across the 8 different utilities in our sample. The average price adds variation to the price data. Moreover, it is also worth pointing out that we are not interested in the price elasticity. Our focus is more in finding the socioeconomic determinants of household electricity demand and efficiency in the use of electricity.

From the sample, we also exclude the households who reported that, on average, their residence in completely unoccupied either for more than 8 weeks a year, or for more than 4 days a week (e.g., due to regular travel for work). Lastly, we have an unbalanced panel data comprising of households for which

[8]Given the context of household electricity consumption, we impose a limit on yearly consumption to be between 500 kWh and 30, 000 kWh. IWB households were excluded due to a very small sample size and unreliable consumption data.

[9]As instrument, we use an average of peak and off-peak marginal prices weighted by considering a representative share of peak and off-peak consumption over 8 broad household categories (as defined by ElCom). For consumers without a time-of-use tariff, the marginal price based on the standard single-tariff was used.

Table 4.3: Summary Statistics for N = 15, 632 (unbalanced panel of 3, 936 households).

Variable	Description	Mean	Std. Dev.	Min.	Max.
Q_E	Electricity consumed (kWh)	2848.22	2139.23	500	29 885.0
AVP_E	Avg. price of electricity (Rp.)	20.46	7.14	0	225.4
HHSIZE	Household size	2.35	1.21	1	6
HAS_YOUN	HH has young member(s)	0.25	0.43	0	1
HAS_ELDE	HH has elderly member(s)	0.30	0.46	0	1
INC6K	HH income below 6k	0.33	0.47	0	1
INC6_12K	HH income in 6k - 12k	0.50	0.50	0	1
INC12K	HH income above 12k	0.18	0.38	0	1
HDD	Heating degree days	2828.08	450.11	1925.6	3670.3
CDD	Cooling degree days	203.86	106.29	51.4	458.6
IS_SFH	Single family hh	0.24	0.43	0	1
SQM	Dwelling size (m^2)	115.42	54.52	20	400
BLT1940	Built before 1940	0.23	0.42	0	1
BLT1970	Built in 1940 - 1970	0.30	0.46	0	1
BLT2000	Built in 1970 - 1999	0.33	0.47	0	1
BLT2015	Built in 2000 - 2015	0.14	0.35	0	1
MINERGIE	Minergie house	0.07	0.25	0	1
WABS5TO8	Absent 5 to 8 weeks/year	0.08	0.27	0	1
HAS_FR2	Has a 2nd fridge	0.19	0.39	0	1
HAS_FREEZER	Has a separate freezer	0.48	0.50	0	1
NONE_APP	Has no special appliances	0.72	0.45	0	1
COOKEL	Cooks using electricity	0.90	0.31	0	1
NMEALS	Number of cooked meals	8.58	3.41	0	14
NDISHWCY	Dishwashing cycles	2.87	2.39	0	8
NWASHING	Cloth washing/drying cycles	2.71	3.57	0	28
NENTT	Hours of media/entertainment	6.78	5.37	0	52
UNIV	University degree	0.38	0.49	0	1
UNIV_PAR	University degree (partner)	0.18	0.39	0	1

electricity consumption in the same residence for at least 2 out of the 5 time periods is available.[10] Due to this, all the 3, 936 households are not represented in every period, but at least in any two or more of the five periods.

Next we estimate the ad-hoc electricity demand in Eq. (4.2) wherein we use a log-log specification. The transformation to logs further helps to interpret estimated coefficients as a measure of *relative* change in electricity demand per unit change of a continuous explanatory variable, e.g., level of an energy service.[11]

4.5 Results

The estimation results for the GTRE model specification of the household electricity demand is presented in Table 4.4.

[10]The panel is unbalanced primarily because (i) the availability of electricity consumption data (response variable) is conditional on when the households moved into their current residence; (ii) consumption data for households in the utility in Lucerne is unavailable for the year 2010; and (iii) it is required that each household has at least two years of consumption data (i.e. is a panel).

[11]Many of the continuous variables have a skewed distribution and transforming to logs is one way to help stabilize the variances. The energy services (`NMEALS`, `NDISHWCY`, `NWASHING`, `NENTT`) can take a minimum value of zero. These variables were first transformed by adding 1 to all sample points, i.e. $\{0, 1, 2, \ldots\} \longmapsto \{1, 2, 3, \ldots\}$, and then log is taken. This should not be of too much of a concern here as we are interested in the relative measure and not on the absolute values.

Table 4.4: GTRE Estimation results.

Variables	*Coefficient*	*Std. error*
LN_AVP_E	-0.0442 **	0.0225
RES2SRI[a]	-0.4178 ***	0.0226
IS_SFH	0.1258 ***	0.0050
LN_HS	0.2112 ***	0.0049
LN_SQM	0.3413 ***	0.0058
HAS_YOUN	-0.0364 ***	0.0051
HAS_ELDE	0.0271 ***	0.0040
INC6_12K	0.0073 *	0.0040
INC12K	0.0195 ***	0.0059
BLT1970	-0.0020	0.0048
BLT2000	0.1237 ***	0.0052
BLT2015	0.0299 ***	0.0072
MINERGIE	0.0271 ***	0.0072
WABS5TO8	-0.0497 ***	0.0062
HAS_FR2	0.0645 ***	0.0045
HAS_FREEZER	0.1423 ***	0.0037
NONE_APP	-0.0566 ***	0.0039
LNMEALS	0.0463 ***	0.0041
LNDISH	0.1246 ***	0.0028
LNWASHIN	0.0975 ***	0.0024
LNENTT	0.1681 ***	0.0030
COOKEL	0.0741 ***	0.0055
LNHDD	0.3026 ***	0.0150
LNCDD	0.0236 ***	0.0048
UNIV	-0.1087 ***	0.0038
UNIV_PAR	-0.0219 ***	0.0047
T	-0.0370 ***	0.0076
T*T	0.0092 ***	0.0012
α_i	2.7488 ***	0.1649
σ_w	0.4338 ***	0.0015
$\sigma_{(v+u)}$	0.2711 ***	0.0017
λ	1.2808 ***	0.0247
σ_h	0.5105 ***	0.0106
Observations:	15632	
Log-likelihood:	-1827.82	

***, **, * ⇒ Significance at 1%, 5%, 10% level.
[a] Residual inclusion parameter for the average price.
Variables starting with LN are after taking logs.

Most estimated coefficients have the expected signs and are seen to be statistically significant at the 1% level. The parameter λ, which represents the relative contribution of the transient inefficiency term over the complete disturbance term, is found to be significant. Further, σ_h, the standard deviation of the one-sided time-invariant component h_i is also significant. This result shows the presence of persistent inefficiency. Since we use a log-log functional form for the total electricity demand and other continuous variables in the model, the estimated coefficients on such variables can be interpreted as demand elasticities, e.g., the (average) price elasticity of electricity demand is found to be rather inelastic (-0.0442).

Electricity consumption increases with dwelling size and single family houses have higher electricity consumption than households living in apartments. Electricity consumption also increases with household size. Households, in which elderly people of 60 years or older are present, tend to consume slightly more electricity, whereas households with children consume less. The highest income level households

(INC12K) are found to consume more electricity than the reference income category (INC6K) when accounting for all other variables included in the model. [12]

The coefficients for the presence of a second fridge (HAS_FR2) or a separate freezer (HAS_FREEZER) are positive and significant. Electricity consumption is found to be higher for higher levels of energy services with stronger effects for use of entertainment services (televisions and computers), followed by dishwashers and washing services. The preparation of warm meals appears to be significant as well and the use of electricity as the energy source for cooking is unsurprisingly associated with a higher demand.

The high coefficient on heating degree days (HDD) is seen to be positive and significant which is expected as higher HDDs (cold weather) could mean people staying indoors and hence consuming more electricity. The number of cooling degree days (CDD) is also significant and positive but the effect is much less than that of HDD. The coefficient that captures the linear time trend is negative and significant hinting towards technological progress. The coefficient on the quadratic time trend is weak but significant and is indicative of the non-linear nature of the UEDT. The coefficient on the dummy for a university degree of the respondent and that of the partner is significant and negative indicating that education plays a crucial role in the demand for electricity at the household level.

4.5.1 Level of efficiency

Following the estimation results above and using Eq. (4.4), one can estimate the level of efficiency in the use of electricity by Swiss households. Table 4.5 provides summary statistics of the estimated transient, persistent and overall efficiency levels.

Table 4.5: Efficiency scores.

Efficiency type	*Mean*	*Std. Dev.*	*Minimum*	*Maximum*
Transient	0.857	0.046	0.281	0.971
Persistent	0.779	0.009	0.359	0.872
Overall	0.668	0.014	0.239	0.789

The short-run or the transient part of the efficiency in residential electricity consumption is found to be between 28% and 97%, with a mean value of about 85.7%. The long-run component representing the persistent part of the efficiency ranges from 36% to 87% and has a mean value of 77.9%. Persistent efficiency is observed to be lower both in terms of the mean value and the variance implying higher long-run inefficiencies. Note that the high persistent inefficiency of about 22% is indicative of structural problems faced by Swiss households, who probably rely on an old appliance stock within their homes. Moreover, this also possibly points to systematic behavioural shortcomings in terms of production and consumption of energy services.

The mean overall inefficiency in the use of electricity by Swiss households is found to be at 33%. These estimates indicate that there is a significant potential for the Swiss residential sector in the urban and sub-urban areas to save energy. In fact, households could save as much as 22% of their electricity usage in the long-run if they could improve on systematic and structural inefficiencies. With the reduction of transient inefficiencies in the short-run, the potential to save electricity is up to 14%.

[12] Note that part of the income effect may be captured by some dwelling characteristics like the size of the residence and whether the household lives in a newly built building.

4.5.2 Role of DSM measures

In Chapter 4.2.2, we summarized the different DSM policy measures that were in place for the regions covered by the utilities in our sample (Table 4.2). It would be interesting to investigate whether or not the efficiency scores are different based on the existence of some of these policy instruments. Notice that such a comparison should be performed only across households that, during a period, differ in treatment of only one type of policy. If the comparison of efficiency levels is done across households that were treated with different policies over different time periods, it would not be possible to comment on the role of a particular policy. Furthermore, note that the analysis presented below do not comment on causality but correlations.

Our primary interest lies in those DSM measures that existed for all private households. Hence, we consider the following dichotomous policy variables for which we have comparable households across the different regions in our sample.

dsm_Information: This DSM measure is 1 if consumers were distributed information offers via both printed and online means.

dsm_Feedback: This DSM measure is 1 if consumers are provided a feedback on previous year's electricity consumption on their current electricity bill.

dsm_Audit: This DSM measure is 1 if consumers have access to a personalized energy consulting service at their residence.

dsm_Subsidy: This DSM measure is 1 if consumers have access to an investment aid or subsidy for investing in a new household appliance.

Suppose we want to determine if the level of efficiency in the use of electricity is different for two groups of households that either: (a) have a policy implemented; or (b) does not have the same policy implemented. We can check this by using a Kruskal-Wallis test which is a rank-based non-parametric test. The null hypothesis is that the efficiency scores across the two groups are identical population. When the p-value of the Kruskal-Wallis test is close to zero, the null hypothesis is rejected implying that there are statistically significant differences between the two groups, i.e. the density of efficiency estimates which differ by that policy measure are non-identical populations.[13]

Table 4.6 reports the results of Kruskal-Wallis tests to determine if the overall efficiency score is different across groups defined by each of the four DSM measure.[14] For each DSM measure, the table shows the regions for which the households are comparable, i.e. they differ in treatment of only the concerned instrument. Information on the Kruskal-Wallis tests include number of observations in each group, observed $\chi^2(1)$-value, significance level (p-value), and whether the null hypothesis was rejected at the 5% significance level.

The Kruskal-Wallis test can not reject the null hypothesis for two DSM instruments, **dsm_Information** and **dsm_Feedback**. For both these instruments, the overall efficiency scores across the group of respondents with policy and without policy are identical population. However, the tests shows that there is a statistically significant difference in the overall efficiency levels between the groups based on **dsm_-Audit**. The result is confirmed across two different sets of comparable samples. Similarly, a significant difference in overall efficiency is also found between the two groups based on **dsm_Subsidy**.

[13] The Kruskal-Wallis test does not need any normality assumption over the underlying distributions.

[14] We also ran t-tests to check if the difference between means of the total efficiency measure across each of the two groups is significant or not and we obtained similar results.

Table 4.6: Overall efficiency and DSM measures.

		Kruskal-Wallis test			
DSM Measure	*Regions*	*No. of Observations*	χ^2 (1)	*p-value*	H_0 *rejected?*
dsm_Information	AIL, AMB	0 → 786 1 → 232	1.390	0.2383	No
dsm_Feedback	AMB, ESB	0 → 232 1 → 431	0.019	0.8892	No
dsm_Audit	IBA, SW, ESB	0 → 467 1 → 559	40.183	0.0001	Yes
	AMB, SIL	0 → 232 1 → 740	10.768	0.0010	Yes
dsm_Subsidy	SIL, EWL	0 → 740 1 → 709	251.495	0.0001	Yes

These results suggest that policy instruments related to energy audit at home, and that for investment support for new household appliances, are associated with a higher overall efficiency. Note that we are talking about correlation and not causality. One also has to be cautious of the fact that a DSM measure can be implemented differently across regions, e.g., an investment subsidy for new appliances may apply for refrigerators in one region but on light-bulbs in another region. It is also worth mentioning that these results are conditional on the assumption that the households are indeed comparable and that there are no systematic differences between them other than the policy-related instrument under consideration. In our empirical model for residential electricity demand in urban and sub-urban areas, we account for the influence of price, weather, household, dwelling and other characteristics and assume that there are no other significant regional differences remaining.

4.5.3 Decomposition of the growth rate of energy demand

We now take into account that the variables in our equation for electricity demand change over time. One might be interested in calculating and decomposing the growth rate of electricity demand. By totally differentiating Eq. (4.2) with respect to time, the growth rate of energy demand over time can directly be related to the growth rates of the explanatory (panel) variables, that is [15]

$$\hat{E} = \alpha_{P_E}\,\hat{P_E} + \alpha_{P_K}\,\hat{P_K} + \alpha_{ES}\,\hat{ES} + \alpha_{HH}\,\hat{HH} + \alpha_{WE}\,\hat{WE} + \alpha_{TC} - \hat{EF} \tag{4.5}$$

where the '*hat*' on a variable indicates its growth rate over time.

Eq. (4.5) decomposes the growth rate of energy into terms related to: (i) changes of prices for energy and capital stock; (ii) economies of scale component for the production of energy services; (iii) changes in household attributes like income and household size; (iv) change of weather; (v) exogenous technological change; and (vi) change in the underlying energy efficiency. As we have limited panel variables in our empirical setting, we use a simpler version of the decomposition of the growth rate of electricity demand:

[15] Subscripts i and t are omitted to avoid notational clutter.

$$\hat{E} = \alpha_{P_E} \hat{P_E} + \alpha_{HS} \hat{HS} + \alpha_{HDD} \hat{HDD} + \alpha_{CDD} \hat{CDD} + \alpha_{TC} - \hat{EF} \tag{4.6}$$

Table 4.7 reports the decomposition of the growth rate of electricity demand (ED) over 2010 – 2015. The average annual growth rate of weather conditions, namely HDD and CDD, from one year to another is prominent. The growth rate of transient inefficiency also seems to vary from one year to the next. Electricity prices and household size have relatively remained stable over the considered period. Lastly, the growth rate of residual component in the model also appears to be quite significant.

Table 4.7: Electricity demand (ED) growth rate decomposition of Swiss households - average values (in %).

Nr.	*ED Growth component*	2011	2012	2013	2014	2015	*Full sample*
1	Average Price	-0.136	-0.957	0.352	-0.277	-0.095	-0.243
2	HDD	-5.626	2.987	1.724	-6.127	3.100	-1.579
3	CDD	-0.186	0.368	0.193	-1.203	8.112	-0.043
4	Household size	-0.059	0.020	-0.014	0.075	-0.109	0.011
5	Technical change (UEDT)	0.018	0.018	0.018	0.018	0.018	0.018
6	Short-run inefficiency	1.858	-0.996	0.078	0.487	-1.023	0.221
7	Residual	7.010	0.447	13.434	4.185	-6.100	5.943
	ED growth (1 + 2 + 3 + 4 + 5 + 6 + 7)	2.880	1.888	15.785	-2.840	3.903	4.328

Number of households in each year: 1957(2011), 2732(2012), 3058(2013), 3544(2014), 312(2015).

Overall, when considering the effects of all the underlying components together, an increase of 4.3% in the growth rate of electricity demand is observed for the full sample. The average growth rate of transient inefficiency is found to have increased by about 0.22% which contributes to this overall increase in the ED growth rate. Notice that the strong residual effect is indicative of the highly heterogeneous nature of residential electricity demand, and also of the attitudes and behaviours of household members - one that is complex to measure and to quantify. Furthermore, part of the residual effect is possibly due to the limitations of the model in capturing changes of important attributes, e.g., household income and capital stock, and other factors over the years.

4.6 Conclusion

To measure the inefficiency in the use of electricity in Swiss households, we estimate a stochastic frontier model for residential electricity demand. We use data from our Swiss household survey conducted in 2015–2016 that collected panel data over five years. The dataset includes information on the level of energy services, which is crucial, but often difficult to measure. The newly developed generalized true random effects (GTRE) model is used to estimate the transient and persistent levels of efficiency in the use of electricity.

The mean persistent inefficiency is found to be around 22% whereas the transient inefficiency is seen to be around 14%. The high persistent inefficiency of about 22% is indicative of structural problems faced by Swiss households, who probably rely on an old appliance stock within their homes. Moreover, this also possibly points to systematic behavioural shortcomings in terms of production and consumption of energy services. These results suggest that there is a considerable potential for saving electricity and thus reaching the reduction target defined by the Swiss federal council as part of the *Energy Strategy 2050*.

We further investigate the role of demand-side management measures on the level of efficiency in residential electricity consumption. We perform Kruskal-Wallis tests on the estimated efficiency levels to investigate if the distributions of efficiency scores are non-identical across two sub-populations that differ on the existence of a DSM measure. Instruments related to energy audit at home, and that for investment support for new household appliances, are found to be positively associated with a higher level of overall efficiency. On the other hand, no such effect is observed for the policy instruments related to information distribution and for feedback provision on the level of consumption. Note that these results are only indicative and should be used with precaution.

Decomposition of the growth rate of demand for electricity shows an overall increase and highlights the role of changes in weather, increase in transient inefficiency and technical progress. Furthermore, the results are also indicative of the highly heterogeneous nature of residential electricity demand, and of the attitudes and behaviours of members of the household.

From the point of view of policy makers, we note that the high level of overall inefficiency indicates that there is a significant potential for the Swiss residential sector in the urban and sub-urban areas to save energy. Finally, we emphasize again that clear distinction has to be made between the persistent and transient inefficiencies faced by households in order to appropriately channel the relevant policy measures.

5 Boundedly rational consumers, energy and investment literacy, and the display of information on household appliances†

5.1 Introduction

The residential sector consumes nearly 30% of the total final energy consumption in Switzerland and about 58% of the energy end-use consumption of households is based on fossil fuels (BFE, 2015). Improving the energy efficiency in the residential sector is therefore one of the strategies to reduce total fossil energy consumption and related CO_2-emissions in Switzerland. While a major effort needs to be made to reduce the consumption of heating fuels, there is also a potential for enhanced energy efficiency in the electricity consumption of Swiss households. One important pillar of reducing residential electricity consumption is to foster the adoption of energy-efficient lighting and household appliances. A low adoption of energy-efficient technologies is often related to the 'energy-efficiency gap' (Allcott and Greenstone, 2012; Howarth and Sanstad, 1995; Sanstad and Howarth, 1994a), i.e. the frequent observation that individual decision-makers do not choose the most energy-efficient appliance, even if this appliance is also the most cost-efficient choice from the individual's point of view (minimizing lifetime operating costs).[1] The list of potential underlying causes for the 'energy-efficiency gap' is long and includes a myriad of market and behavioral failures (Broberg and Kazukauskas, 2015; Sanstad and Howarth, 1994b). A large body of literature studies, for example, (implicit) subjective discount rates and their role for the persistence of the energy efficiency gap (Bruderer Enzler et al., 2014; Coller and Williams, 1999; Epper et al., 2011; Harrison et al., 2002; Hausman, 1979; Min et al., 2014; Train, 1985). In this paper, we abstract from subjective discounting and other market and behavioral failures to focus on those market and behavioral failures that are related to the provision and processing of energy-related information.

In order to choose between two similar electrical appliances, a rational, utility-maximizing consumer should solve an optimization problem in order to choose the appliance that minimizes the sum of the purchase price and the present value of future energy costs (Gerarden et al., 2015; Sanstad and Howarth, 1994a,b). This optimization requires knowledge on the purchase prices of the appliances to choose from, the electricity consumption of the respective products, the expected intensity and/or frequency of use, the expected lifetime of the appliance as well as current and future electricity prices. If markets provide too little or inadequate information about these parameters, or if this information is not salient enough to the consumer, this constitutes a barrier to solving the optimization problem (Sanstad and Howarth, 1994a). In fact, in many purchase situations, the information about the energy-efficiency of an appliance and thus about the future energy costs is less salient than the purchase price. However, even if information on the energy consumption of the appliance is provided, the optimization regarding the lifetime cost of an appliance depends on additional information as mentioned above.

†Published in the journal of Resource and Energy Economics: https://doi.org/10.1016/j.reseneeco.2017.06.001

[1] It is important to note that throughout this paper, we define cost-efficiency from the (private) point of view of the individual and not from a societal point of view in which we would also have to account for the avoidance of external cost in the production of electricity.

To carry out the optimization, the consumer needs to gather the required information and then process this information correctly. This creates both 'information cost' and 'optimization cost' (Conlisk, 1988), given that the consumer needs to deliberate upon the options to choose from. Acknowledging the presence of 'deliberation cost' (Pingle, 2015) is equivalent to acknowledging that individuals are 'boundedly rational' (Sanstad and Howarth, 1994a; Simon, 1959), which means that they are not always able to acquire and process all the necessary information to trade-off all the alternatives in real decision making situations. This is because information acquisition is costly and the processing of information is cognitively burdensome. As a consequence of being boundedly rational individuals tend to have problems solving the optimization problem when making an investment decision. Instead, they often rely on simple rules of thumb or decision heuristics (Frederiks et al., 2015; Wilson and Dowlatabadi, 2007), which potentially widens the energy efficiency gap.[2]

Against the background of the described information-related market and behavioral failures, the research presented in this paper deals with the question how information on future energy consumption should be displayed on products in order to enable consumers to identify the appliance that minimizes lifetime cost. Furthermore, we investigate whether and to what extent cognitive abilities as well as energy and financial literacy support consumers in identifying a cost-efficient appliance. We hereby assume that consumers may follow two different types of decision-making strategies: One is to optimize over the lifetime cost of the appliance. This is in line with the neoclassical concept of a fully rational and informed consumer. The other type of decision-making strategy, which is in line with the concept of bounded rationality, is heuristic decision-making, i.e. choosing an appliance according to a specific and salient characteristic of the appliance, e.g., a low purchase price, a high energy-efficiency rating or a lower physical energy consumption. The choice of the decision-making strategy is determined, on the one hand, by the information that is readily available in the purchase situation, e.g., in the form of information display on the products. On the other hand, it is determined by an individual's ability to process the available information, which is influenced by socioeconomic factors as well as the individual's level of energy and financial literacy. The latter determine the individual-specific deliberation cost. We thus assume, that the deliberation cost are a function of energy and investment literacy, with energy literacy being defined as the individual's prior energy-related knowledge, such as knowledge about energy prices and energy consumption of different appliances, and investment literacy being defined as the individual's cognitive ability to perform an investment analysis.

To examine the role of information display, energy and investment literacy on the choice of electrical appliances of boundedly rational consumers, we organized a household survey and conducted two online randomized controlled trials with simple decision tasks. In two experiments, respondents were presented two similar appliances and had to determine which of the two minimizes lifetime cost. With these experiments we thus did not elicit consumers preferences but their ability to calculate the lifetime cost of the appliances.[3] Individuals were randomly assigned to a treatment in which yearly energy consumption of the appliances was displayed in either monetary terms or physical units. In the empirical part of the paper, we analyze the individual decisions in the experiments while accounting for the respondents' energy and investment literacy, their attitudes towards energy conservation, as well as their sociodemographics. Drawing on three samples of 583, 877 and 1,375 households from three major Swiss urban areas the data is analyzed in a series of (recursive) bivariate probit models.

We find that displaying information on energy consumption in monetary terms rather than in physical units positively influences the probability to perform an investment analysis which in turn increases the

[2]Alternatively, individuals may be inattentive to energy information on rational grounds, assuming that taking future energy cost into account would be a minor factor in their calculation anyway (Sallee, 2014). This aspect, however, is not in the focus of our discussion in this paper.

[3]The two experiments are not hypothetical stated choice experiments in which people are asked to state their preferences for either the one or the other appliance. Instead, our framework encompasses the impact of an actual decision based on real calculations of lifetime costs.

probability to choose the most (cost-)efficient appliance. Also a higher level of energy and investment literacy clearly enhances the individuals' probability to do an investment calculation and to choose the most efficient appliance. This supports the view that both displaying monetary information on future energy consumption as well as consumers' prior knowledge and cognitive abilities are decisive factors when attempting to reduce the energy-efficiency gap. Investing in consumer education to increase their energy and investment literacy could thus be an important element in a set of policy measures to enhance residential energy efficiency.

The remainder of this chapter is organized as follows. Section 5.2 presents a literature review and discusses the theoretical considerations and hypotheses. The dataset and the experimental design is presented in Section 5.3 and the econometric specifications are presented in Section 5.4. Section 5.5 presents the results and Section 5.6 concludes.

5.2 Literature review and hypotheses

5.2.1 Information, rationality and the choice of efficient appliances

Are individuals able to make fully rational decisions by minimizing total lifetime cost when choosing electric appliances? Or are they 'boundedly rational' (Simon, 1959) and therefore lack the cognitive abilities to perform the optimization task? The discussion about rational decision-making in the domain of energy efficiency and the role of information in the choice of efficient appliances is going on for a while (Sanstad and Howarth, 1994a,b). McNeill and Wilkie (1979) and Anderson and Claxton (1982) investigate how the provision of information about energy consumption in either monetary or physical units impacts on the choice of household appliances. While both studies do not find significant effects of information display, more recent studies do so. For example, Heinzle (2012) examines the impact that different ways of disclosing energy-related information have on the choice of TVs in online experiments in Germany. The effects of three different disclosure formats of energy labels on appliance choice are compared: annual energy consumption in terms of physical units (kWh), annual energy operating cost in monetary terms and lifetime energy operating cost in monetary terms. Heinzle (2012) shows that individuals tend to overestimate potential cost savings between two TV sets if provided with information on energy consumption in physical units. When disclosing energy consumption in monetary terms, respondents' willingness to pay (WTP) for energy efficient TV sets only increased when lifetime energy cost but not when annual operating cost were displayed. The display of annual operating cost in monetary terms even reduced WTP compared to the display in physical units. Similar results are reported in Deutsch (2010): based on a randomized field experiment on a commercially operating price comparison website it is shown that disclosing the life-cycle cost of an appliance instead of the purchase price induces consumers to purchase cooling appliances that are on average 2.5% more efficient than in the absence of life-cycle cost disclosure.

Also Newell and Siikamäki (2013) test the effects of different forms of energy efficiency labeling. Among other features, they evaluate the impact of a label including the estimated yearly operating cost versus the impact of a label including physical information on energy use. Based on a choice experiment among 1,214 US home owners, they find that providing information on estimated yearly operating cost is more effective in enhancing willingness to pay for more efficient water heaters than providing information about energy use in physical units. These findings are partly in line with the findings in Heinzle (2012), except that in the study of Newell and Siikamäki (2013) the display of annual operating cost (as opposed to lifetime operating cost) had a positive influence on the choice of more efficient appliances. For light bulbs, Min et al. (2014) test the influence of energy labeling on implicit discount rates in an incentivized choice experiment among 168 US residents and also conclude that the provision of information on annual operating costs of the bulbs increases consumers' WTP for more efficient bulbs.

Allcott and Taubinsky (2015) tested the effect of simultaneous information about yearly and lifetime energy cost on consumers' choices of either compact fluorescent (CFL) or incandescent light bulbs. In both an online and an in-store experiment, they provide information about yearly and lifetime costs of the bulbs to a treatment group. While the treatment increases the market share of CFLs by about 12% in the online experiment, a similar treatment in the in-store experiment seemed less effective. Although the effects of displaying yearly and lifetime energy cost cannot be separated in their experiments, their results further support the view that providing monetary information supports consumers in accounting for operating cost.

Other studies consider the role of energy-efficiency rating scales on the choice of appliances. The results of these studies suggest that the information on energy use provided on energy labels tends to be disregarded in the presence of a rating scale. Both the results presented in Waechter et al. (2015) and Hille et al. (2015) indicate that the display of an energy-efficiency rating scale on electric appliances may divert attention from the information on actual energy consumption of the products, suggesting that the EU energy label in its current form is used as a decision-making heuristic by many consumers, rather than supporting a rational and informed decision making.[4] Houde (2014) reaches a similar conclusion. He finds evidence that an energy label can act as a substitute for more precise information on energy consumption of an appliance and that consumers that rely on the energy label often overestimate the energy savings associated with the certified product.

5.2.2 The role of energy literacy and education for appliance choice

Another potentially important prerequisite for rational decision-making in the domain of electric appliances is energy literacy, which can be defined as an individual's ability to make informed and deliberate choices in the domain of household energy consumption. In the literature, energy literacy is defined as a comprehensive concept that has a cognitive, an affective and a behavioral dimension (DeWaters and Powers, 2011). According to DeWaters and Powers (2011), energy literacy thus comprises of *(1)* knowledge about energy production and consumption as well as its impact on the environment and society, *(2)* attitudes and values towards energy conservation as well as *(3)* corresponding behavior. In this paper, we use a narrower definition of energy literacy that mainly reflects the individual's knowledge about energy prices and the energy consumption of different household appliances. This is because our main goal is to examine what knowledge and cognitive abilities consumers need to have in order to identify cost-efficient appliances.

With respect to investments in energy-efficient appliances, an additional component gets relevant: investment literacy, i.e the individuals' ability to perform an investment analysis and hence to correctly evaluate different investment alternatives, for example when choosing appliances or when deciding about energy-saving renovations. Regarding this ability, the literature on financial literacy is informative. Lusardi and Mitchell (2009) show, for example, that more educated people are more likely to correctly answer a question on compound interest and that this indicator of financial literacy has a relevant influence on economic decisions in several domains: inter alia, individuals who know about interest compounding are 15 percentage points more likely to be retirement planners (Lusardi and Mitchell, 2007). In a study on financial literacy in Switzerland, Brown and Graf (2013) find that respondents scoring high on financial

[4] Of course, if the energy rating score is negatively correlated with the lifetime cost of the appliance, there may still be a chance that consumers who consider the rating scale on the label make, consciously or unconsciously, a rational decision from the societal point of view, i.e. when also the avoided negative externalities from electricity production are taken into account.

literacy are more likely to have an investment related custody account and to make voluntary retirement savings.

One of the first studies that investigates the effect of energy and investment literacy on electricity consumption in a large sample is the study of Brounen et al. (2013). They examine the effect of energy and investment literacy on household conservation behavior and energy consumption in an online survey in the Netherlands. Their indicators for energy and investment literacy are three items capturing the households' awareness of the amount of their monthly gas/electricity bill, the respondents' choice in a decision between two alternative heating systems with different levels of energy efficiency, and the answer to the question whether the household uses green electricity. They find that older and male respondents are more likely to know about their gas bill and that more educated respondents are more likely to make a rational investment decision in the heating system example. However, Brounen et al. (2013) do not find that energy literacy has an impact on energy conservation behavior among the sampled households in terms of thermostat settings, and also not on the overall electricity and gas consumption of the household.

In addition, there seems to be a role for education more generally when it comes to energy-related decision-making. Some studies find a positive correlation between an individual's level of education and energy literacy or energy-related investment literacy. For example, Mills and Schleich (2010) find that education, among other socio-economic characteristics, is positively correlated with knowledge about energy efficiency labels on appliances. In another study, Mills and Schleich (2012) build an energy-related knowledge index and find that the knowledge index increases when the most educated member of the household has an university degree, whereas a high-school degree does not have any effect and vocational training has a negative effect on the knowledge index. Also Nair et al. (2010) report from a Swedish sample that a higher level of education as well as a better knowledge about energy efficiency measures in buildings increases the likelihood that a household invests in building envelope measures.

Apart from the study of Brounen et al. (2013), there is only little research about the role of energy literacy and energy-related investment literacy on investment decisions in the domain of residential electricity consumption. In particular, we are not aware of any study that investigates the impact of energy and investment literacy on the choice of household appliances. This paper therefore contributes to the existing literature along three dimensions: first, further empirical evidence is provided on the role of displaying monetary information about the energy consumption of an appliance for the choice of electrical appliances. Second, according to our best knowledge, this is one of the first studies which analyzes the impact of the level of energy literacy on the choice of electrical appliances and the impact of energy literacy, investment literacy and monetary information on the choice of the decision making strategy (optimization vs. heuristic decision making). Lastly, we also analyze the impact of the decision making strategy on the choice of the appliance in a recursive model.

5.2.3 Theoretical considerations and hypotheses

In the following, we provide some theoretical reasoning that can explain the role of energy information display, energy literacy and financial literacy on the choice of appliances.

According to household production theory (Deaton and Muellbauer, 1980b) households purchase inputs such as energy and capital (i.e. household appliances) and combine them to produce outputs which are the desired energy services such as cooked food, washed clothes or hot water. These energy services appear as arguments in the household's utility function (Flaig, 1990; Muth, 1966). The utility function of a household is based on the consumption of both energy services and all other goods and is maximized under the budget constraint. A high level of expenditure for energy services will reduce the options to consume all other goods.

Therefore, when facing the choice of light bulbs or household appliances, consumers are confronted with the optimization problem of choosing the appliance that provides the desired energy service at the minimum lifetime cost. Consumers wish to reduce their overall expenditure for energy services and to maximize their opportunities to consume all other goods, otherwise they experience a loss in utility.[5] For the minimization of lifetime cost consumers have to consider the purchase price and future operating costs of the appliance, which depend on the energy consumption of the appliance (in Watts), the lifetime of the appliance, the frequency and intensity of use of the appliance as well as on current and future electricity prices.[6]

Lifetime cost and intensity of use cannot be predicted with certainty in the moment an appliance is purchased, so the individual needs to form expectations regarding lifetime cost and intensity of use for each appliance within the set of appliances to choose from. The process of forming expectations and comparing the expected lifetime cost of several appliances requires time and other resources that can be considered as 'decision cost' (Pingle, 2015). To study the role of 'decision cost' for the choice of the decision-making strategy and for the choice of an appliance, we provide a simple 2-period-model of expectation formation that explicitly takes decision costs into account. This model is based on the model in Conlisk (1988) and assumes that an individual assesses the expected lifetime cost of an appliance before purchase.[7] Similar as in Conlisk (1988), we assume that the individual faces two potential sources of a loss that he or she wants to minimize: *i)* experiencing a loss in inter-temporal utility by either underestimating the lifetime cost of an appliance in period 1 and thus not allocating enough of the budget in period 2 on the consumption of the energy service, or, by overestimating the lifetime cost of an appliance in period 1 and thereby restricting consumption of other goods in period 1 itself due to the individual's budget constraint, and *ii)* spending too much time and resources on decision making itself.

Suppose that the individual thus faces a loss function which takes the following simple form:

$$(E(L(T)) - L)^2 + \beta CT \tag{5.1}$$

with $E(L(T))$ representing the estimated lifetime cost of the appliance after having spent T units of time and other resources on deliberation, and L representing the true lifetime cost of the appliance. The decision cost βCT are composed of C denoting the unit cost of performing the calculation task and T denoting the amount of time and other resources devoted to deliberation. The parameter $\beta \in [0, 1]$ captures the individual's capacity for performing the calculation task. The lower β, the lower the individual's effort needed to perform the task, and hence the lower the decision cost.

As both $E(L(T))$ and L contain random elements that cannot be perfectly predicted (e.g., the future electricity price, frequency and intensity of use of the appliance) and because the individual does not know in advance to which result $E(L(T))$ his or her costly reasoning will lead, the individual will form expectations over both $E(L(T))$ and L and minimize the following objective function to determine the

[5] In the following, we abstract from the fact that a reduction in lifetime cost per unit of energy service consumed might lead to an increase in the consumption of energy services (rebound effect). However, accounting for such a reallocation of resources would not have direct implications for our analysis.

[6] Also the individuals' subjective discount rates will influence the outcome of the optimization. Yet, in the following model, the discount rate is assumed to be a constant factor that is not modeled explicitly. Including discounting in our analysis would not change any of the results.

[7] Note that the theoretical model in Conlisk (1988) concerns a completely different macroeconomic setting wherein a model for a worker's expectation formation of future price level was considered. Here, we have implemented the theoretical model in the framework where we examine an individual's expectation of the lifetime cost of a household appliance which eventually determines whether or not the individual chooses this appliance.

optimal investment in terms of time and other resources, $T^\star$:

$$Min! \quad E[(E(L(T)) - L)^2] + \beta CT \tag{5.2}$$

The lifetime cost of the appliance that was estimated after having invested the optimal amount of units $T^\star$ for decision making can thus be expressed as $L(T^\star)$ and can be considered as a realization of the random expectation variable $E(L(T))$.

Next, we assume that we can define R as the rational expectation of L and that individual j's estimate $E(L(T))$ of R is a weighted combination of two elements: a free estimator f, that is based on a simple rule of thumb and is thus generated without any decision cost, and a costly improvement of f denoted as $r(T)$, that depends on the time spent on deliberation. We further assume that the individual makes his or her decision as if the costly improvement $r(T)$ was as accurate as a sample mean of T independent observations taken from a distribution with mean R and variance σ^2 and as if f was as accurate as a sample mean of S independent observations which represents a lower number of draws taken from the same distribution with mean R and variance σ^2.

The intuition here is that for an individual who performs a detailed analysis, it would imply drawing a large number of T thoughts from the distribution with mean R and variance σ^2 thereby increasing the probability that he or she arrives close to R which is the rational expectation of L. However, in a heuristic approach (rule of thumb), the judgment can be considered to be based upon only a small number of S thoughts, which can a priori be assumed to be objectively biased (note that from the point of view of the individual, the guess itself may be considered unbiased; otherwise he or she would make a different guess altogether).

Based on these assumptions and following the reasoning of Conlisk (1988), we can write the estimate of the lifetime cost to be:

$$E(L(T)) = \frac{S\, f + T\, r(T)}{(S + T)} \tag{5.3}$$

The expected value of this estimate would be R and its variance would be $E[(E(L(T)) - R)^2]$, which corresponds to $\sigma^2/(S + T)$. We can therefore rewrite the objective function defined in equation (5.2) as follows:

$$Min! \quad \frac{\sigma^2}{(S + T)} + \beta CT \tag{5.4}$$

Minimizing this objective function, we can derive the optimal investment of time and other resources for decision making:

$$T^\star = \frac{1}{\sqrt{\beta C/\sigma^2}} - S \tag{5.5}$$

It is obvious that the lower bound for the optimal time spent on deliberation $T^\star$ is at least 0. This equation gives us some insight into the optimality of different decision-making strategies. Consider the case when an individual has a lower capacity to perform a calculation task (i.e. higher β) and the analysis is costly relative to the size of the problem (large C/σ^2) to the extent that the initial guess is reliable (large S). If these conditions hold with enough force, the corner solution $T^\star = 0$ applies and the individual spends no resources on deliberation but only follows the rule of thumb f which in this case is good enough.

Substituting T by $T^\star$ in equation (5.3), we can rewrite the individual's expected lifetime cost of the appliance as:

$$E(L(T^\star)) = \alpha f + (1 - \alpha) r(T^\star) \quad (5.6)$$

with

$$\alpha = \frac{S}{(S + T^\star)} = S\sqrt{\beta C/\sigma^2} \quad (5.7)$$

By definition, α has an upper bound of 1 when the corner solution $T^\star = 0$ applies, i.e. when individual's rule of thumb choice is good enough. Equation (5.6) can be seen to cover both the extremes; when $T^\star$ goes to infinity, the expected lifetime cost converges to the rational expectation R. On the other hand, when $T^\star = 0$, i.e. when $\alpha = 1$, the expected lifetime cost is the free estimator f. Depending upon the different parameters, an individual could be lying anywhere between the range of unboundedly rationality and a rule of thumb approximation (Conlisk, 1988).

The estimation of the lifetime cost of the appliance will thus be more closer to the rational expectation R as α gets smaller. From equation (5.7), α is the lower

- the lower β, i.e. the lower the individual's effort needed to perform the estimation of lifetime cost of the appliance
- the lower C relative to σ^2, i.e. the lower the decision making cost related to the complexity of the problem
- the lower S, i.e. the lower the amount of (costless) best guesses spent on estimating R, i.e. the less reliable the rule of thumb

Any individual having to decide between several appliances on offer, will first assess the lifetime cost of all the appliances separately and then, in a second step, compare them to identify the one with the minimum lifetime cost. From the above described model, we derive two hypotheses with respect to whether the individual deliberates or follows a rule of thumb when comparing the appliances (choice of decision-making strategy). As a natural consequence, but not directly related to the above theoretical model, we can identify two more hypotheses in relation to what determines whether the individual successfully identifies the most cost-efficient appliance (choice of cost-efficient appliance).

First, we expect that individuals with a higher level of energy and investment literacy are more likely to choose an investment analysis as the decision-making strategy as the process of deliberation is less costly to them, i.e. a lower β in the theoretical model (*H1a*). We further assume that disclosing yearly energy consumption in monetary terms (CHF) rather than in physical units (kWh) decreases the value of C and hence increases the probability that the individual carries out an investment analysis rather than following a heuristic decision-making strategy as this lowers the per unit cost of deliberation (*H1b*).

In a second step when an individual compares the lifetime costs of two appliances, we expect that an individual that carries out an investment analysis is more likely to identify the more cost-efficient appliance (*H2a*). In addition, we expect that disclosing yearly energy consumption in monetary terms increases the probability that the individual identifies the more cost-efficient appliance, again, as the display of monetary information lowers the per unit cost of deliberation (*H2b*).

Our hypotheses can be summarized as follows:

- *H1a:* The level of energy and investment literacy has a positive impact on the individuals' ability to follow an optimization strategy rather than a heuristic strategy.

- *H1b:* Displaying information on the yearly energy consumption of an appliance in monetary terms rather than in physical units has a positive impact on the individuals' ability to follow an optimization strategy rather than a heuristic strategy.

- *H2a:* Opting for optimization as the decision-making strategy has a positive impact on the probability to identify the most cost-efficient appliance.

- *H2b:* Displaying information on the yearly energy consumption of an appliance in monetary terms rather than in physical units has a positive impact on the probability to identify the most cost-efficient appliance.

5.3 Experimental design

We use an explanatory research approach in order to examine the role of information, energy literacy, and investment literacy on the choice of the decision-making strategy for choosing an electrical appliance as well as on the ability to identify the appliance with the lowest lifetime cost. For this purpose, we have organized a web-based survey in which two online randomized controlled trials were embedded. The survey was organized in cooperation with three Swiss electricity providers operating in three major urban areas in Switzerland (Lucerne, Bellinzona, Biel/Bienne). The two online experiments were part of the online survey, which was conducted among electricity and gas customers during the year 2015. For this survey, customers of the electricity providers were invited with a letter accompanying one of their electricity (or gas) bills to access an online questionnaire.[8] The invitation letter was sent to a total of 50,000 (Lucerne), 30,000 (Bellinzona) and 38,000 (Biel/Bienne) customers of which 1,999 (Lucerne), 958 (Bellinzona) and 1,308 (Biel) accessed the survey page (corresponding to response rates of 4% (Lucerne), 3.2% (Bellinzona) and 3.4% (Biel/Bienne)). After accounting for the correct target group[9], incomplete responses, and duplicate entries, we have valid and complete data for 1,375 (Lucerne), 583 (Bellinzona) and 877 (Biel) survey respondents.[10] The three observed samples should relate to the Swiss population living in urban (and sub-urban) areas.

Among people who accessed the survey page, dropouts primarily happened either because they did not provide their customer number with the electrical utility (which they had to fill in at the beginning of the survey), or if they were disqualified as not being part of the target group of the survey. Of all respondents who started the online survey, filled in their customer number and were filtered-in as the target group, almost 85% completed the survey and we do not find any significant selection among the sample of usable surveys relative to the target group.

[8]The survey questionnaire was pre-tested in two steps: First, it was reviewed by experts and colleagues working on residential energy efficiency. As a second step, we ran two pretests among university students and employees of the participating utility companies. Based on feedback from the expert review and the pre-tests, the survey questionnaire was further refined and adapted.

[9]The target group consists of respondents (i) for whom the electricity/gas bill refers to their primary residence; (ii) who moved in their current residence before 01.01.2015; and (iii) who are one of the persons in their residence who decides about the purchase of goods and/or pays the bills. All three samples combined, a total of 3,318 respondents were filtered-in as the target group, of which 2,835 completed the survey.

[10]The usable survey response rates for all the three survey regions are undoubtedly low when compared to the number of invitation letters sent. One obvious reason is because of the setting – the invitation to participate was sent on paper, including a link to the online survey. This invitation was sent with one of the regular utility bills, which unfortunately lowered the probability that it got the customers' attention.

Next we compare the available basic demographic characteristics of the three urban areas with the sample population relating to households reached via the survey (Table 5.1). In terms of gender and age-groups, the population represented by the surveyed households seems comparable to the overall population in the three cities, except in Bellinzona where the share of young population is higher and that of the elderly is lower. The average number of people living in a household seems to be higher in our sample, especially in Bellinzona. Other deviations include the Biel/Bienne sample having a larger living space per person. Bellinzona seems to have more people per room on average whereas Biel/Bienne has less people per room on average than represented by the respective population statistics. Finally, we find that two-person households as compared to one-person households are slightly over-represented across all three samples (data not shown in the table). It is to be noted that the statistics at the city level may not completely reflect the statistics of the surveyed areas, i.e. the service areas of the utilities, which usually also include neighboring municipalities.

As the availability of information about socioeconomic variables at the city level is limited, we also compare other crucial attributes with the information available at the national level. The share of respondents who donated money to an environmental organization within the 12 months preceding the survey is largely in line with the share reported for the Swiss population (42%)[11]. The average Swiss household income in 2013 was CHF 10'052. The household income across our samples is recorded as income categories and about 50% of the households fall in the category representing an household income between CHF 6'000 and CHF 12'000.

Considering this discussion and the low response rates, we acknowledge that our sample may not be completely representative of the population living in these regions on all socio-economic dimensions. However, note that a selection issue in this context could be considered less of a concern since we are working in a multivariate framework and are focused primarily on the treatment effects. Nevertheless, generalizations of the results to the entire Swiss population should be considered carefully.

Table 5.1: Comparison of basic demographic characteristics of the three urban areas.

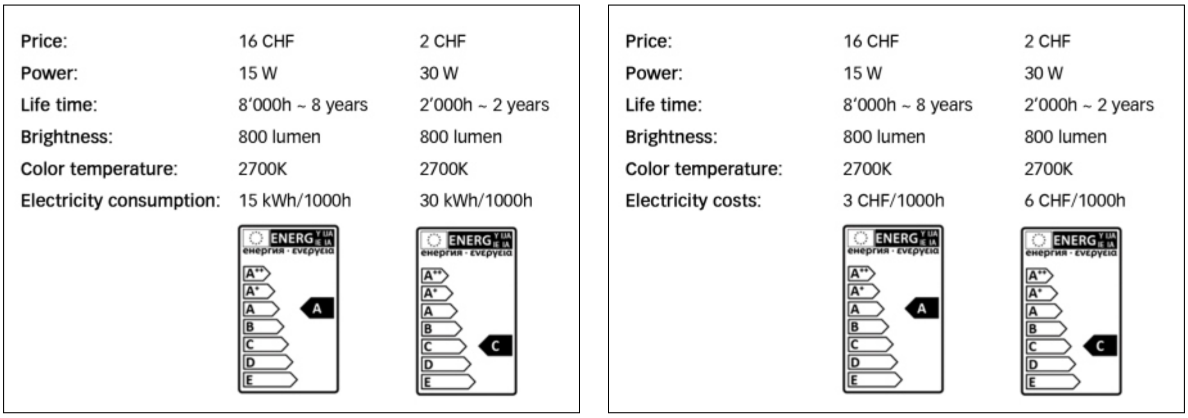
	Biel/Bienne		**Lucerne**		**Bellinzona**	
	Sample (N=877)	*BFS*	*Sample (N=1,375)*	*BFS*	*Sample (N=583)*	*BFS*
Share of females (%)	52.61	51.14	51.39	52.12	51.06	52.87
Share of population by age (%)						
young (0-19 years)	17.15	18.84	13.08	15.71	25.96	18.27
adult (20-64 years)	62.04	62.26	63.82	64.88	62.25	61.18
elderly (65+ years)	20.81	18.90	23.10	19.41	11.79	20.54
Mean household size	2.18	2.11	2.09	1.92	2.60	2.09
Dwelling (mean values)						
living space per head (m^2)	51.63	39.00	52.44	45.00	52.62	45.00
people per room	0.57	0.66	0.57	0.58	0.65	0.60

Population (gender and age) and household size data at city level from 2014.
Dwelling related data at city level from 2013.
Data source: Swiss Federal Statistical Office (BFS) and the Swiss cities association (Schweizerischer Städteverband).

[11]GFS Spendenmonitor 2014: share of population donating to environmental organizations (data from 2014).

One of the two experiments was embedded towards the end of the online surveys. Customers of the utilities in Bellinzona and Lucerne saw *Experiment 1*, customers of the utility in Biel/Bienne saw *Experiment 2*. Survey respondents who saw *Experiment 1* were asked to imagine a situation in which they had to replace a light bulb in their living room. As a replacement, they were shown two bulbs that differed in their purchase price, power, lifetime, electricity cost as well as energy efficiency rating (A versus C rating). The information display corresponded to the current version of the EU energy label for light bulbs (see Figure 5.1). It is important to note that the two described bulbs only differed in price and energy-related characteristics but not in their color temperature and brightness.[12]

Respondents were randomly assigned to two different treatments. In *Treatment 1*, the information on energy consumption of the two bulbs was displayed in terms of physical consumption (kWh) per 1000 hours, as it is displayed in the current version of the EU energy label. In *Treatment 2*, energy consumption was again displayed in monetary terms, i.e. in the form of an estimate of the energy cost per 1000 hours (in CHF, see Figure 5.1). Additionally, we controlled for order effects by randomly changing the order of presentation of the two light bulbs in both treatments.



(a) Consumption displayed in kWh **(b)** Consumption displayed in CHF

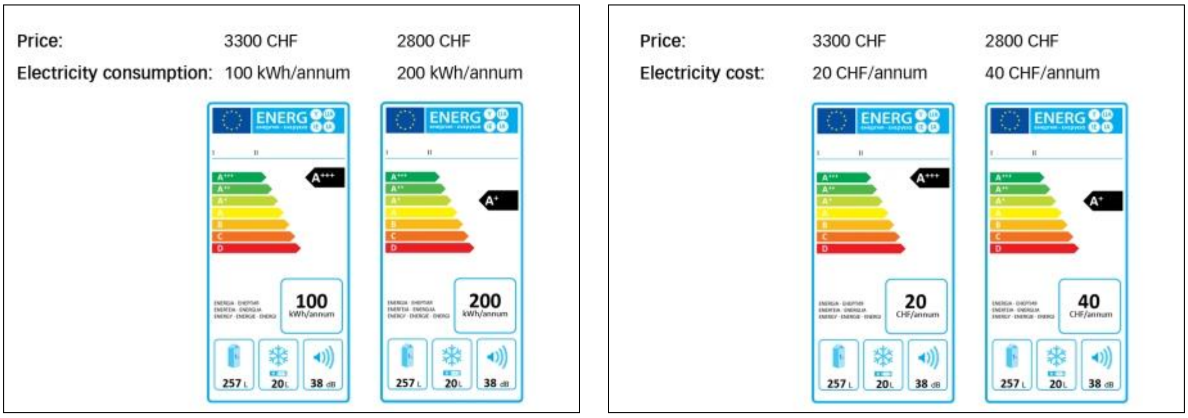
Figure 5.1: Light bulb options in Experiment 1.

Respondents were asked which of the two light bulbs would minimize their expenditure for lighting during 8 years of planned usage. Thus, as already discussed in the Introduction, our online experiment is not a hypothetical stated choice experiment but an online randomized controlled trial with the goal of real calculations of lifetime costs of the appliances from an objective point of view under different conditions. In principle, the result of the comparison of lifetime cost will also be driven by the individual's subjective discount rate. Assuming that the average participant of our study is not familiar with the concept of discounting and would need a calculator to incorporate discounting in the analysis, we refrained from providing respondents with a 'reference discount rate' that they should use. Instead we assumed that consumers, in case they opted for an investment analysis, would consider the undiscounted future operating cost to evaluate the lifetime cost of the two bulbs. Also Allcott and Taubinsky (2015) present undiscounted operating cost in an online experiment on consumers' choices of light bulbs, presumably for the same reasons.

The respondents who saw *Experiment 2* were asked to imagine a situation in which they need to replace their refrigerator. Among two refrigerators, they were asked to identify the refrigerator with the lowest lifetime cost. The two appliances differed only in terms of their purchase price, their energy consumption, and the energy efficiency rating (A^{+++} versus A^{+}). The remaining characteristics of the two refrigerators

[12] Figure 6 in the appendix shows the actual question as presented in *Experiment 1*.

were identical. The information was presented in the same way as it is presented in the current version of the EU energy label for refrigerators (see Figure 5.2).[13]



(a) Consumption displayed in kWh **(b)** Consumption displayed in CHF

Figure 5.2: Refrigerator options in Experiment 2.

The participants were randomly assigned to one of two different treatments. In *Treatment 1*, the information on yearly energy consumption of the two appliances was displayed in terms of physical consumption (kWh), as it is displayed in the current version of the EU energy label (see Figure 5.2). In *Treatment 2*, the information on electricity consumption was displayed in monetary terms, i.e. in the form of an estimate of the yearly energy cost. As mentioned, we controlled for order effects by randomly changing the order of the two refrigerators in both treatments. In both experiments, also the order of the answer options was randomized in order to control for order effects in the presentation of the answer options.[14]

Respondents were asked which of the two refrigerators would minimize their expenditure on the cooling of food and beverages during 10 years of planned usage. Again, the question was not about the respondent's subjective preference for either the one or the other refrigerator, but about which of the two appliances creates less lifetime costs.

In *Experiment 2*, at the Swiss average electricity price of 20 Rp./kWh, the 100 kWh more energy-efficient refrigerator has an annual energy cost of CHF 20 compared to that of CHF 40 for the 200 kWh refrigerator (Figure 5.2). Over 10 years of planned usage, the total energy costs (in the absence of discounting) are CHF 200 and CHF 400 respectively, which from the private perspective does not justify the difference of CHF 500 in the upfront purchase prices. The less energy-efficient refrigerator is hence minimizing the total lifetime costs.[15]

While the general setup was very similar in both experiments, it has to be highlighted that they also differed in a decisive way: While in *Experiment 1* the more energy-efficient bulb was also the one that minimizes lifetime cost, *Experiment 2* was designed in a way that the refrigerator with the lower energy consumption, i.e. the more energy-efficient appliance, was not the appliance that minimized lifetime cost. This seems

[13] Figure 7 in the appendix shows the actual question as presented in *Experiment 2*.

[14] As a general rule, answer options to a question in the survey questionnaire were presented in a random order to control for order effects.

[15] One could still deduce the CHF 3'300 fridge to be more cost-efficient over 10 years if he or she assumes an unusually high electricity price of 50 Rp./kWh in absence of discounting. Electricity prices for private households in Switzerland are on average around 20 Rp./kWh and have not changed much in the last 15 years (Data source: *VSE* and *Elcom*). In the three regions from which our samples are drawn, electricity prices in 2015 ranged from 17 Rp./kWh to 25 Rp./kWh across the most common types of residential customers (Electricity Commission of the Swiss Government, 2017). Moreover, in a separate question of the survey, the respondents were also asked to guess the average electricity price in Switzerland and we found that the respondents rather underestimate the cost of electricity.

counter-intuitive, as in such a case an ‘energy-efficiency gap’ does not exist. It is perfectly rational for the consumer to choose the less efficient appliance, at least from a private perspective. The reason why this specific setting was chosen was to identify those individuals who performed an investment analysis and to distinguish them from the respondents who followed a heuristic decision-making strategy. If the more expensive (and more energy-efficient) appliance would have had the lowest lifetime cost, individuals following a decision heuristic (such as choosing based on the energy-efficiency rating provided on the energy label) would have ended up making the same choice as the ones who performed an investment analysis. This would not allow to discriminate between the two groups of decision-makers.

In a debriefing question after the choice task, respondents were asked about the decision-making strategy they had adopted when making their choice. Several decision making strategies were offered: one being performing an investment analysis (comparison of lifetime cost) and the other being heuristic decision-making strategies such as comparing the purchasing prices of the two products, comparing the yearly electricity consumption, comparing the energy-efficiency ratings on the labels or making a random choice. The light bulb experiment also had another strategy choice to compare based on the lifetime of the two bulbs. An open answer option “Other reason” was also provided (Figure 8 in the appendix). Answer options were again randomized to control for order effects. The introduction of this debriefing question gives us the possibility to econometrically analyze the factors that influence the choice to perform an investment analysis, and, therefore, to adopt a rational decision strategy. However, it has to be noticed that in *Experiment 2*, among all respondents who claimed to have performed an investment analysis as their decision strategy, almost 37% incorrectly selected the more costly fridge as the most (cost-)efficient appliance (in *Experiment 1*, the number of such cases was about 5.1%). There are two possible explanations for this: either the calculation was not performed correctly or the self-reported decision-making strategy does not necessarily coincide with the actual strategy applied.

In *Experiment 1*, about 28.0% of the respondents claimed to have compared the electricity consumption of the two light bulbs. About 22.9% mentioned that they made an investment calculation before making the choice. Another 24.4% of the respondents reported to have compared the energy-efficiency ratings on the label and 13.0% said they made their choice based on the lifetime of the two bulbs. 2.9% answered that they had compared the purchase prices of the two bulbs and another 7.6% of the respondents either mention other reasons for their choice or report that they made a rather random choice. In *Experiment 2*, most of the respondents self-reported that they compared the energy-efficiency ratings on the energy labels (45.2% of respondents). 27.7% of the respondents claimed to have compared the electricity consumption of the two refrigerators, and 17.6% claimed that they made an investment calculation to evaluate the two appliances. Only 1.9% of respondents reported to have compared the purchasing prices, 3.0% indicated that they made a rather random choice and 3.5% stated that they had other reasons for their decision.[16]

Table 5.2 gives a summary on how the respondents were distributed as the two treatment groups, and also their responses for the two outcomes of focus in this study: the choice of investment analysis as their decision strategy, and the correct identification of the cost-efficient household appliance.

In addition to the randomized controlled experiment, the questionnaire included several other questions related to the household’s energy consumption as well as questions on sociodemographics of the respondent

[16] We expect that displaying monetary information should enable more people to perform investment calculation, which is one of our hypotheses *(H1b)*. However, it could be possible to imagine that respondents provided with monetary information declared to do the investment analysis (just because of the nature of the information), although they did not perform such an analysis. To elucidate this issue, we compared how many respondents in the two conditions (with/without monetary information) declared that they performed an investment analysis and how many correctly identified the cost-efficient appliance. We do not find any evidence that respondents may be declaring that they are performing an investment calculation while in fact they do not (assuming that those who perform an investment calculation should generally be able to identify the correct appliance).

Table 5.2: Overview of the responses from the randomized controlled experiments.

	Light bulb (N=1,958)			**Refrigerator** (N=877)		
	N	*INVCALC=1*	*CHOICE=1*	*N*	*INVCALC=1*	*CHOICE=1*
TREATKWH	969	175	911	446	48	52
TREATCHF	989	274	955	431	106	124
Total =	**1,958**	**449**	**1866**	**877**	**154**	**176**

INVCALC=1: investment analysis selected as the decision strategy.
CHOICE=1: correct identification of the more cost-efficient appliance.

and other household members. We included information on respondents' age, gender and level of education, their attitudes towards energy conservation as well as their energy and investment literacy, which is used in the econometric analysis.

The gender is represented by a binary variable (FEMALE) which takes value one if the respondent is female. Age of the respondent is captured through three binary variables representing age groups –less than 40 years (AGE40M as reference category), between 40–60 years (AGE40_69) and 60 years or above (AGE60P). The ownership status of the residence (owned or rented) is captured via a binary variable (OWNER) that takes value one if the residence is owned by either the respondent or another member of the household. Monthly gross household income is captured through three binary variables representing income groups –less than CHF 6'000 (HHI6K as reference category), between CHF 6'000 – CHF 12'000 (HHI6_12K) and more than CHF 12'000 (HHI12K).[17]. The binary variable UNIEDU takes value one if the respondent holds a university degree. The survey language in which the respondent has taken the survey is also accounted for. The dummy variable ITALSP is 1 for survey taken in Italian (applies to the light bulb experiment) and the dummy variable FRENCHSP is 1 for survey taken in French (applies to fridge experiment).

All econometric specifications also control for the respondents' level of energy literacy and investment literacy. Energy literacy is measured by an index (ENLIT_IN) that accounts for several dimensions of energy-related knowledge. This index ranges from 0 to 11 and is based on correct responses to several questions that examine (i) knowledge of the average price of a kilowatt hour of electricity in Switzerland; (ii) knowledge of the usage cost of different household appliances; and (iii) knowledge of the electricity consumption of various household appliances. Investment literacy is measured by a binary variable (INVLIT) that takes the value one if the respondent correctly solved a compound interest rate calculation.[18] Compound interest rate calculations are usually used to assess an individual's financial literacy (Brown and Graf, 2013; Lusardi and Mitchell, 2007, 2009).

Furthermore, we account for the individual's pro-environmental moral attitude (ATTMORAL) and their concern for free-riding (ATTCONCE) by asking for agreement or disagreement to two statements on a 5-point likert scale. The two statements are "I feel morally obliged to reduce my energy consumption" and "I am not willing to reduce my energy consumption if others don't do the same". Each of the two binary variables takes the value one if the respondent chooses 'agree' or 'strongly agree'.

[17]Missing values on the household income variable either due to non-response or selecting "Don't know/No Answer" as a response were imputed using the standard multiple imputation approach. We make use of available socioeconomic information, e.g., employment status of respondent and his/her partner, their level of education, number of people within the house, age and sex of the respondent, and available residence characteristics, e.g., living in an owned or rented residence, if it is a single family house or an apartment, size of the residence and postcode.

[18]We asked respondents to imagine that they have CHF 200 in a savings account which earns 10% interest per year. We asked them how much they would have in the account at the end of 2 years.

Lastly, all specifications control for the treatment effects of displaying the yearly electricity consumption in monetary terms (binary variable `TREATCHF`), as well as for any effect of the order in which the two appliances are presented (binary variable `ORDEFF`).

Table 5.3: Summary statistics for the two experiments.

	Light bulb (N=1,958)		**Refrigerator** (N=877)			
	Mean	*Std.Dev.*	*Mean*	*Std.Dev.*	*Min.*	*Max.*
FEMALE	0.396	0.489	0.447	0.497	0	1
AGE40M	0.27	0.444	0.193	0.395	0	1
AGE40_59	0.373	0.484	0.388	0.488	0	1
AGE60P	0.358	0.479	0.42	0.494	0	1
OWNER	0.42	0.494	0.414	0.493	0	1
HHI6K	0.321	0.467	0.403	0.491	0	1
HHI6_12K	0.527	0.499	0.446	0.497	0	1
HHI12K	0.152	0.359	0.152	0.359	0	1
UNIEDU	0.377	0.485	0.363	0.481	0	1
ITALSP	0.297	0.457	—	—	0	1
FRENCHSP	—	—	0.351	0.478	0	1
ENLIT_IN	4.455	2.853	3.987	2.748	0	11
INVLIT	0.668	0.471	0.637	0.481	0	1
ATTMORAL	0.782	0.413	0.706	0.456	0	1
ATTCONCE	0.075	0.264	0.07	0.255	0	1
TREATCHF	0.505	0.5	0.491	0.5	0	1
ORDEFF	0.511	0.5	0.481	0.5	0	1
INVCALC	0.229	0.421	0.176	0.381	0	1
CHOICE	0.953	0.212	0.201	0.401	0	1

An overview of the summary statistics for the variables used in our econometric models for *Experiment 1* and *Experiment 2* is presented in Table 5.3. The two samples are found to be similar in terms of ownership, share of higher income households, share of respondents with university education and their attitudes towards environment. The sample in the refrigerator experiment has a larger share of old population than in the light bulb experiment. It also has a higher share of female respondents and low income households. The sample in *Experiment 1* appears to have a higher energy-related literacy as well as investment literacy. We also notice that about 23% of respondents in the *Experiment 1* employ investment calculation as their decision strategy compared to 18% in the *Experiment 2*. Unsurprisingly, due to the experimental design, most of the respondents in the light bulb experiment are able to correctly identify the most cost-efficient light bulb. In the refrigerator experiment though, only 1 in 5 respondents correctly identifies the most cost-efficient refrigerator.

5.4 Empirical model

The data collected from the survey and from the two experiments allows us to analyze the impact of the display of monetary information about future energy consumption as well as the level of energy and investment literacy on the ability to identify the light bulb and refrigerator with lowest lifetime cost. Further, the debriefing question about the decision making strategy gives us the possibility to analyze the factors that influence the choice to perform an investment analysis. Therefore, from the econometric point of view, we are interested in explaining the impact of information, energy and investment literacy and other socioeconomic factors on two binary outcome variables. In one case, the dependent variable takes the value 1 if someone chose the most cost-efficient appliance and 0 otherwise. In the second case when analyzing the decision strategy, the outcome variable takes the value 1 if someone chose to perform an investment calculation and 0 otherwise. From a methodological point of view, such binary outcome variables are the simplest case of a discrete choice situation and can for example be analyzed using a probit model (Greene, 2018).

In a probit framework, the expression for the probability of choosing the most (cost-)efficient appliance can be written as:

$$Pr(y = 1|\mathbf{x}) = \Phi(\boldsymbol{\beta}'\mathbf{x}) \tag{5.8}$$

Pr is the probability that the respondent chose the most (cost-)efficient appliance, $\boldsymbol{\beta}$ is a vector of coefficients, and $\mathbf{x}$ represents a set of regressors such as socioeconomic characteristics, a dummy variable indicating whether or not future energy consumption was displayed in monetary terms to the consumer as well as the level of energy and investment literacy and the chosen decision strategy. This model estimates the probability that a (cost-)efficient appliance instead of a less (cost-)efficient appliance is chosen, given a set of explanatory variables. Further, this simple probit model can also be used to estimate the probability that an optimization strategy is chosen instead of a more heuristic approach, conditional on a set of explanatory variables. The probit models are usually estimated using maximum likelihood based approach.[19]

The separate estimation of two single equation probit models described above is based on the assumption that the two outcome variables can be independently determined. This may or may not hold true in reality. We believe in our context it can be safely assumed that the two outcome variables should be determined jointly rather than individually. In this case, from an econometric point of view, a bivariate probit model could be applied for a simultaneous estimation of the two binary outcome variables. Furthermore, even more precisely, the ability to identify the most cost-efficient appliances could be modeled as a **two stage decision process**, explaining first the choice to adopt a decision strategy based on an investment calculation, and then the identification of the cost efficient appliance. In this case, an appropriate econometric model for this sequential decision-making process is the recursive bivariate probit as it accounts for the likely endogeneity of the investment calculation variable in the equation related to the identification of the cost efficient appliance.[20] Most of the following discussions and results refer to the recursive bivariate probit model, which is our preferred model. Nevertheless, in this paper we still decided to estimate two separate probit models and a bivariate probit model for each of the two experiments for comparison purposes.

The outcome variables in the recursive model (correct identification of cost-efficient appliance, choice of decision-making strategy) are both dichotomous and are jointly modeled allowing for a correlation between the error terms of the two equations. The decision strategy outcome variable is endogenous and also appears as an explanatory variable in the equation for the identification of the appliance (hence the

[19] The focus in this paper is on the effect of performing an investment calculation versus following a heuristic approach. If one is also interested in the different types of heuristic based approaches, then the choice of decision strategy could be modeled in a multinomial logit framework. Note that this may be simple to estimate in a single equation setting, but otherwise, a simultaneous determination of a multinomial outcome variable and a binary outcome variable would be much more complex.

[20] The recursive bivariate probit approach, also denoted as *a recursive model of simultaneous equations* by Greene (2018), was proposed by Burnett (1997) who analyzed the presence of a gender economics course in the curriculum of a liberal arts college. In a follow-up work, Greene (1998) provided an alternative theoretical specification and a maximum likelihood based estimation approach for an appropriate treatment of a model where two binary variables are simultaneously determined. The computation of marginal effects in such a setting were also discussed in details in Greene (1998). In the literature it is possible to find several studies that use a recursive bivariate probit model. See for instance, Jones (2007) who analyzes individual's self-assessed health and smoking and Kassouf and Hoffmann (2006) who analyze the probability of suffering work-related injuries and use of personal protective equipment. Some of the recent studies in energy related application areas are: Martínez-Espiñeira and Lyssenko (2011); Pérez-Urdiales and García-Valiñas (2016); Shi (2014).

term ‘recursive’). Hence, our recursive bivariate setting looks like:

$$y_1^* = \boldsymbol{\beta}_1'\mathbf{x}_1 + \varepsilon_1, \qquad y_1 = 1 \text{ if } y_1^* > 0, y_1 = 0 \text{ otherwise,} \tag{5.9}$$

$$y_2^* = \boldsymbol{\beta}_2'\mathbf{x}_2 + \delta y_1 + \varepsilon_2, \quad y_2 = 1 \text{ if } y_2^* > 0, y_2 = 0 \text{ otherwise} \tag{5.10}$$

where it holds that

$$[\varepsilon_1, \varepsilon_2] \sim \Phi_2[0, 0, 1, 1, \rho], \rho \in [-1, 1]$$

Φ_2 indicates the distribution function for the bi-variate standard normal distribution with ρ as the dependency parameter. δ is the coefficient on the binary investment analysis outcome variable from the first step appearing in the appliance choice equation in the second step.

The variables in our model are:

y_1 = Decision to perform an investment analysis (= `INVCALC`)
y_2 = Correct identification of appliance (= `CHOICE`)
$\mathbf{x}_1$ = Independent variables in the investment analysis equation
$\mathbf{x}_2$ = Independent variables in the appliance choice equation

The exogenous variables in the model comprise socioeconomic characteristics of the respondent (age, sex and university education) and that of the household (household income and if the residence is owned or rented); environment related attitudes; the level of energy and financial literacy of the respondent; the treatment variable (i.e. yearly electricity consumption shown in physical or monetary units) and some other variables like language in which the survey was taken and the order in which the two appliance choices were presented.

It is important to note that the model is identified irrespective of whether the exogenous variables $\mathbf{x}_1$ and $\mathbf{x}_2$ in the two equations are different or not.[21] Moreover, such a recursive model of simultaneous equation can be estimated using the full information maximum likelihood (FIML) approach ignoring the simultaneity.[22]

For the model specified in equations (5.9) and (5.10), following Greene (1998), probability of the two outcomes may be written as:

$$\begin{aligned}
Pr[y_2 = 1, y_1 = 1|\mathbf{x}_1, \mathbf{x}_2] &= \Phi_2(\boldsymbol{\beta}_1'\mathbf{x}_1, \boldsymbol{\beta}_2'\mathbf{x}_2 + \delta, \rho)\\
Pr[y_2 = 1, y_1 = 0|\mathbf{x}_1, \mathbf{x}_2] &= \Phi_2(-\boldsymbol{\beta}_1'\mathbf{x}_1, \boldsymbol{\beta}_2'\mathbf{x}_2, -\rho)\\
Pr[y_2 = 0, y_1 = 1|\mathbf{x}_1, \mathbf{x}_2] &= \Phi_2(\boldsymbol{\beta}_1'\mathbf{x}_1, -\boldsymbol{\beta}_2'\mathbf{x}_2 - \delta, -\rho)\\
Pr[y_2 = 0, y_1 = 0|\mathbf{x}_1, \mathbf{x}_2] &= \Phi_2(-\boldsymbol{\beta}_1'\mathbf{x}_1, -\boldsymbol{\beta}_2'\mathbf{x}_2, \rho)
\end{aligned} \tag{5.11}$$

Given the probabilities in (5.11), the conditional mean for the correct appliance choice could then be written as

$$\begin{aligned}
\mathrm{E}[y_2|y_1 = 1, \mathbf{x}_1, \mathbf{x}_2] &= \frac{Pr[y_2 = 1, y_1 = 1|\mathbf{x}_1, \mathbf{x}_2]}{Pr[y_1 = 1|\mathbf{x}_1, \mathbf{x}_2]}\\
&= \frac{\Phi_2(\boldsymbol{\beta}_1'\mathbf{x}_1, \boldsymbol{\beta}_2'\mathbf{x}_2 + \delta, \rho)}{\Phi(\boldsymbol{\beta}_1'\mathbf{x}_1)}
\end{aligned} \tag{5.12}$$

[21] See Wilde (2000) and Greene (2018).
[22] See Maddala (1983, p. 123) for a proof and Greene (2018) for few extensions.

Moreover, the unconditional mean function can then be written as

$$\begin{aligned}
\mathrm{E}[y_2|\mathbf{x}_1,\mathbf{x}_2] = Pr[y_1 = 1|\mathbf{x}_1,\mathbf{x}_2] \cdot \mathrm{E}[y_2|y_1 = 1,\mathbf{x}_1,\mathbf{x}_2] \\
+ Pr[y_1 = 0|\mathbf{x}_1,\mathbf{x}_2] \cdot \mathrm{E}[y_2|y_1 = 0,\mathbf{x}_1,\mathbf{x}_2] \\
= Pr[y_2 = 1, y_1 = 1|\mathbf{x}_1,\mathbf{x}_2] + Pr[y_2 = 1, y_1 = 0|\mathbf{x}_1,\mathbf{x}_2] \\
= \Phi_2(\boldsymbol{\beta}_1'\mathbf{x}_1, \boldsymbol{\beta}_2'\mathbf{x}_2 + \delta, \rho) + \Phi_2(-\boldsymbol{\beta}_1'\mathbf{x}_1, \boldsymbol{\beta}_2'\mathbf{x}_2, -\rho)
\end{aligned} \tag{5.13}$$

In a non-linear model, marginal effects are more informative than coefficients, because they inform us how the outcome variable will change when an explanatory variable changes. The marginal effects can be calculated for each observation i or for any specific vector of the regressors. In this study, the marginal effects are calculated for the sample mean.

The expression for the marginal effects[23] could be derived following Greene (1998) and Kassouf and Hoffmann (2006). For a two equation model, one would obtain a *direct* effect for variables appearing on the right hand-side of the choice equation (i.e. $\mathbf{x}_2$) and an *indirect* effect for explanatory variables in the decision strategy equation (i.e. $\mathbf{x}_1$). The indirect effect on the correct choice occurs via the endogenous decision strategy variable which also appears on the right-hand side of the choice equation. The total effect is then the sum of the direct and the indirect effects.

There are different variable types to be considered, namely, the endogenous binary outcome y_1, binary explanatory variables in either (or both) equations, and continuous explanatory variables in either (or both) equations. The influence of using investment analysis as the decision strategy on the choice of the cost-efficient appliance can be calculated as its effect on the probability of the marginal distribution which is given by

$$M(y_1) = \Phi(\boldsymbol{\beta}_2'\mathbf{x}_2 + \delta) - \Phi(\boldsymbol{\beta}_2'\mathbf{x}_2) \tag{5.14}$$

The effect of an exogenous binary variable (say q) is calculated by comparing the effect on the outcome when this binary variable assumes a value 1 compared to when it has a value 0. The other variables are kept at their mean values. Let $\mathbf{q}_1$ represent the set of vectors $\mathbf{x}_1$ and $\mathbf{x}_2$ when $q = 1$ and other variables are at their means. Similarly, let $\mathbf{q}_0$ represent the set of the exogenous vectors in both equations when $q = 0$ and other variables are at their means values.

The total marginal effect of q could be thought as the sum of two parts, effect on those who have an optimization decision strategy in the first step ($y_1 = 1$) and an effect on those without an optimization decision strategy ($y_1 = 0$). This is equivalent to writing:

$$\begin{aligned}
M(q) = (Pr[y_2 = 1, y_1 = 1|\mathbf{q}_1] - Pr[y_2 = 1, y_1 = 1|\mathbf{q}_0]) \\
+ (Pr[y_2 = 1, y_1 = 0|\mathbf{q}_1] - Pr[y_2 = 1, y_1 = 0|\mathbf{q}_0])
\end{aligned} \tag{5.15}$$

Similarly, the effect of an exogenous continuous variable (say z) is calculated by computing the partial derivative of the unconditional mean function in equation (5.13) with respect to z. The somewhat complicated expression appears in Kassouf and Hoffmann (2006, p.115) and the analysis appears more generally in Greene (1996, 1998).

[23]As noted in Greene (2018) and Christofides et al. (1997), in a two-equation setting it is not always absolutely clear on what margins are the effects being calculated by the empirical analyst and/or estimation software. There exist more than one option in terms of choosing the margins at which effects could be calculated. Naturally, the choice of the margin might also depend upon the use case.

We are interested in calculating the impact of at least four variables of interest on the choice of decision strategy and in turn on the correct choice of the (cost-)efficient appliance — energy literacy, investment literacy, monetary treatment and the endogenous decision strategy to make an investment analysis. We have used NLOGIT for the model estimation and calculation of the marginal effects presented in this paper.[24]

5.5 Results

Below we present the estimation results for our two online randomized controlled trials. Three probit models were estimated for each of the two experiments for comparison purpose — the single equation probit (*Probit*), bivariate probit (*Biv. Probit*) and the recursive bivariate probit (*Rec. Biv. Probit*).[25] These models give us insights into the factors that influence the decision strategy and the identification of the appliance that minimizes total cost over the entire lifetime. Table 5.4 presents the empirical results from *Experiment 1*. Following this, Table 5.5 shows the results from *Experiment 2*. Finally we compare the results across the two experiments and present the estimated marginal effects for our quantities of interest, i.e. energy literacy, investment literacy, monetary treatment and investment analysis strategy on the identification of the cost-efficient appliances.[26]

Empirical results

Table 5.4 shows results of the three model specifications for the light bulb experiment. The slope coefficients in Table 5.4 are quite similar for the investment calculation equation across the three models. Differences are apparent in the appliance choice equation, particularly when comparing the first two models to the recursive bivariate probit. The correlation coefficient (ρ, shown as RHO(1,2) in the table) between the two error terms is significant only in the recursive bivariate setting.

Limiting the discussion to the recursive model which is our preferred framework, we observe a significant negative effect of gender and age (`AGE60P`) on choosing an investment analysis approach, and in turn on the identification of the cost-efficient appliance. University education, energy and investment literacy, and `TREATCHF` (i.e. getting the energy consumption information in monetary terms) –all appear to have a significant positive effect on the decision to perform an investment calculation. In the appliance choice equation, `AGE60P` has a significant and positive slope coefficient likely due to the fact that older respondents could have identified the cost-efficient light bulb via several other decision heuristics.

[24] A note on the software used for analysis: we noticed that the recursive bivariate model itself can be easily estimated by several econometric software programs (e.g., NLOGIT, STATA 13 and R). However, the calculation of the marginal effects is not at all straightforward. Of the three mentioned programs, we found that the inbuilt PARTIAL EFFECTS routine within NLOGIT was the only helpful and consistent tool that appears to correctly handle the computation of the marginal effects for different types of variables within the recursive bivariate model.

[25] Note that both bivariate settings assume non-linearity and joint normality for identification (there are no exclusion restrictions). We verify the joint normality assumption using Murphy's score test (Murphy, 2007) in all bivariate and recursive bivariate estimation. At 95%, the test rejects the joint normality assumption in the bivariate setting in experiment 2 but not in the recursive bivariate setting which is our preferred model.

[26] We also estimated other probit models to take into account the interaction between opting an investment calculation strategy and correctly answering the investment literacy question. The results obtained were on similar lines to those presented here. Note that in this paper, we make a distinction only in between an investment calculation approach and a heuristic approach rather than exploring the decision strategies in detail (which we acknowledge to be a related extension, one that dwells deeper into the decision making process itself).

Table 5.4: Results of Experiment 1 (robust standard errors in parentheses).

	Experiment 1: Light bulb (N = 1,958)		
Model	*Probit*	*Biv. Probit*	*Rec. Biv. Probit*
	Investment Calculation Equation ...		
Constant	-1.4462***	-1.4455***	-1.4301***
	(0.1404)	*(0.1399)*	*(0.1400)*
FEMALE	-0.2893***	-0.2907***	-0.2992***
	(0.0757)	*(0.0774)*	*(0.0771)*
AGE40_59	-0.0241	-0.0251	-0.0365
	(0.0862)	*(0.0873)*	*(0.0874)*
AGE60P	-0.3046***	-0.3060***	-0.3202***
	(0.0931)	*(0.0935)*	*(0.0936)*
OWNER	0.1414*	0.1413*	0.1394*
	(0.0727)	*(0.0744)*	*(0.0744)*
HHI6_12K	0.0706	0.0705	0.0743
	(0.0814)	*(0.0827)*	*(0.0825)*
HHI12K	0.1579	0.1582	0.1689
	(0.1087)	*(0.1110)*	*(0.1109)*
UNIEDU	0.1937***	0.1930***	0.1767**
	(0.0711)	*(0.0714)*	*(0.0699)*
ATTMORAL	-0.0548	-0.0549	-0.0525
	(0.0794)	*(0.0802)*	*(0.0801)*
ENLIT_IN	0.0451***	0.0448***	0.0439***
	(0.0120)	*(0.0123)*	*(0.0123)*
INVLIT	0.4938***	0.4972***	0.4979***
	(0.0792)	*(0.0787)*	*(0.0782)*
TREATCHF	0.3510***	0.3518***	0.3547***
	(0.0662)	*(0.0667)*	*(0.0666)*
	Appliance Choice Equation ...		
Constant	1.1966***	1.1837***	0.9775***
	(0.1958)	*(0.2045)*	*(0.2079)*
FEMALE	0.0843	0.0934	0.1898
	(0.1115)	*(0.1216)*	*(0.1157)*
AGE40_59	0.0600	0.0611	0.0705
	(0.1253)	*(0.1276)*	*(0.1178)*
AGE60P	0.1939	0.2020	0.2951**
	(0.1398)	*(0.1449)*	*(0.1362)*
OWNER	0.0866	0.0842	0.0311
	(0.1182)	*(0.1211)*	*(0.1122)*
HHI6_12K	0.0640	0.0595	0.0046
	(0.1176)	*(0.1293)*	*(0.1227)*
HHI12K	-0.0451	-0.0540	-0.1461
	(0.1570)	*(0.1659)*	*(0.1585)*
ITALSP	0.0242	0.0256	0.0619
	(0.1211)	*(0.1295)*	*(0.1170)*
ATTMORAL	0.1582	0.1584	0.1466
	(0.1162)	*(0.1271)*	*(0.1201)*
ATTCONCE	0.2238	0.2232	0.2243
	(0.2151)	*(0.2410)*	*(0.2208)*
ORDEFF	-0.1527	-0.1505	-0.1334
	(0.1005)	*(0.1107)*	*(0.1013)*
ENLIT_IN	0.0316*	0.0300*	0.0063
	(0.0187)	*(0.0181)*	*(0.0223)*
TREATCHF	0.2815***	0.2716**	0.1317
	(0.1017)	*(0.1108)*	*(0.1266)*
INVCALC	-0.0872	—	0.8725**
	(0.1212)	—	*(0.3586)*
RHO(1,2)	—	-0.0753	-0.5961***
	—	*(0.0772)*	*(0.2071)*

***, **, * ⇒ Significance at 1%, 5%, 10% level.

Furthermore, the coefficient on INVCALC is significantly positive which signifies a positive impact of choosing an optimization decision strategy on the probability to identify the cost-efficient appliance.

Table 5.5 shows the results from *Experiment 2*, the fridge experiment. The coefficients appear similar for the investment calculation equation across the three models and most of the significant effects are also more prominent in magnitude. Higher income levels are seen to be positively associated with the correct identification of the cost-efficient refrigerator in the probit and biprobit settings. The correlation coefficient is significant in both the bivariate and the recursive bivariate setting. We notice that most effects are stronger in *Experiment 2*, likely due to the fact that making a correct investment calculation was a necessary strategy to identify the cost-efficient refrigerator.

Within the recursive bivariate framework, we again find a significant negative effect of gender and age (AGE60P) on choosing an investment analysis strategy. University education has a positive effect. Energy literacy shows a significant positive effect in both equations. Investment literacy and monetary treatment both show a very strong effect on the decision to perform an investment calculation. TREATCHF also has a significant effect in the appliance choice equation now. Moreover, the coefficient on INVCALC is strong and significant highlighting the role of choosing an optimization decision strategy on the identification decision of the cost-efficient refrigerator.

Summarizing the most important findings: We observe a positive and significant effect of energy literacy (ENLIT_IN) and investment literacy (INVLIT) on the choice of investment calculation as the decision strategy in both experiments. This supports *Hypothesis H1a* in that individuals with a higher cognitive ability are more likely to follow an optimization strategy rather than a heuristic strategy. Furthermore, the coefficient on INVCALC is significantly positive which signifies a positive impact of choosing an optimization decision strategy on the appliance choice step, which in turn supports *Hypothesis H2a*. All these effects are in particular found to be stronger in *Experiment 2*, wherein making an investment calculation was a necessary strategy to identify the cost-efficient appliance.

The effect of being in the treatment with monetary information on yearly electricity consumption is strong and highly significant in almost all model specifications thereby supporting *Hypotheses H1b and H2b*. As expected, the treatment effects are again stronger in the fridge experiment. No significant order effect is found in either experiment which indicates the absence of any bias due to the order of the presented appliance choices.

Marginal effects

In Table 5.6, we present the marginal effects at the sample means for the variables that are particularly important to verify our hypotheses. The marginal effects are computed for the two variables measuring energy and investment literacy, the dummy variable capturing the treatment effect of displaying yearly energy consumption in monetary terms, as well as the endogenous dummy variable of choosing an investment analysis decision strategy. We restrict the discussion to the reported results from our preferred model, which is the recursive bivariate probit.

It is shown that the fact that an individual is able to do complex calculations increases the probability to choose the most cost-efficient appliance by 2–3 percentage points in *Experiment 1* and by about 19–20 percentage points in *Experiment 2*. Similarly, an increase in an individual's energy literacy score (measured on a scale of 0 to 11) also increases the probability to choose the most cost-efficient appliance. The higher marginal effect in *Experiment 2* (3 percentage points) is likely due to the fact that in this

Table 5.5: Results of Experiment 2 (robust standard errors in parentheses).

	Experiment 2: Refrigerator (N = 877)		
Model	*Probit*	*Biv. Probit*	*Rec. Biv. Probit*
	Investment Calculation Equation …		
Constant	-1.5717***	-1.4353***	-1.5687***
	(0.2153)	*(0.2069)*	*(0.2179)*
FEMALE	-0.4838***	-0.4891***	-0.4692***
	(0.1222)	*(0.1259)*	*(0.1276)*
AGE40_59	-0.1949	-0.1845	-0.1996
	(0.1526)	*(0.1629)*	*(0.1577)*
AGE60P	-0.4837***	-0.4395***	-0.5539***
	(0.1634)	*(0.1628)*	*(0.1628)*
OWNER	0.0027	-0.0166	0.0609
	(0.1288)	*(0.1313)*	*(0.1343)*
HHI6_12K	0.1324	0.1814	0.0844
	(0.1286)	*(0.1290)*	*(0.1316)*
HHI12K	0.0676	0.1641	-0.0147
	(0.1816)	*(0.1817)*	*(0.1898)*
UNIEDU	0.2107*	0.0719	0.2739**
	(0.1181)	*(0.1100)*	*(0.1114)*
ATTMORAL	-0.0792	-0.0579	-0.0681
	(0.1198)	*(0.1231)*	*(0.1246)*
ENLIT_IN	0.0435**	0.0444**	0.0437**
	(0.0198)	*(0.0205)*	*(0.0203)*
INVLIT	0.6483***	0.4632***	0.6643***
	(0.1357)	*(0.1317)*	*(0.1361)*
TREATCHF	0.5730***	0.5661***	0.5467***
	(0.1107)	*(0.1144)*	*(0.1138)*
	Appliance Choice Equation …		
Constant	-1.6114***	-1.2912***	-1.6517***
	(0.2313)	*(0.2043)*	*(0.2157)*
FEMALE	-0.1941	-0.3845***	-0.0185
	(0.1240)	*(0.1208)*	*(0.1256)*
AGE40_59	-0.2425	-0.2736*	-0.1704
	(0.1619)	*(0.1541)*	*(0.1692)*
AGE60P	-0.1291	-0.3057*	0.0012
	(0.1659)	*(0.1570)*	*(0.1642)*
OWNER	-0.0104	-0.0009	0.0057
	(0.1309)	*(0.1258)*	*(0.1195)*
HHI6_12K	0.3297**	0.3849***	0.2004
	(0.1306)	*(0.1254)*	*(0.1287)*
HHI12K	0.4706***	0.5089***	0.3161*
	(0.1750)	*(0.1688)*	*(0.1635)*
FRENCHSP	0.0020	-0.0070	-0.0024
	(0.1202)	*(0.1054)*	*(0.1098)*
ATTMORAL	-0.2154*	-0.2002*	-0.1539
	(0.1212)	*(0.1154)*	*(0.1150)*
ATTCONCE	0.1825	0.1577	0.2165
	(0.2138)	*(0.1985)*	*(0.1903)*
ORDEFF	-0.0987	-0.0830	-0.0715
	(0.1119)	*(0.0994)*	*(0.1024)*
ENLIT_IN	0.0698***	0.0808***	0.0457**
	(0.0205)	*(0.0189)*	*(0.0200)*
TREATCHF	0.5299***	0.6885***	0.2971***
	(0.1144)	*(0.1074)*	*(0.1151)*
INVCALC	1.3794***	—	2.5436***
	(0.1284)	—	*(0.1657)*
RHO(1,2)	—	0.6633***	-0.8162***
	—	*(0.0524)*	*(0.1184)*

***, **, * ⇒ Significance at 1%, 5%, 10% level.

experiment, the most cost-efficient appliance could only be identified when comparing lifetime usage costs of both appliances, which requires some calculation. In *Experiment 1*, also the comparison of the power of the two light bulbs, their lifetime or the comparison of the energy-efficiency rating on the label lead to the choice of the most cost-efficient appliance. Hence, the ability to make complex calculations was less important here.

Table 5.6: Marginal effects (at means).

	Experiment 1: Light bulb			Experiment 2: Refrigerator		
Model	*Probit*[1]	*Biv. Probit*[2]	*Rec. Biv. Probit*[2]	*Probit*[1]	*Biv. Probit*[2]	*Rec. Biv. Probit*[2]
INVLIT	—	0.1289	0.0293	—	0.2148	0.1965
		(0.0188)	*(0.0133)*		*(0.0576)*	*(0.0576)*
ENLIT_IN	0.0030	0.0124	0.0032	0.0142	0.0009	0.0313
	(0.0018)	*(0.0033)*	*(0.0025)*	*(0.0041)*	*(0.0091)*	*(0.0079)*
TREATCHF	0.0267	0.0976	0.0360	0.1107	0.0935	0.2934
	(0.0096)	*(0.0182)*	*(0.0139)*	*(0.0241)*	*(0.0491)*	*(0.0524)*
INVCALC[3]	-0.0087	—	0.0777	0.4153	—	0.7786
	(0.0125)		*(0.0006)*	*(0.0441)*		*(0.0007)*

Robust standard error in parenthesis.
[1] Effects shown here are just for the appliance choice equation.
[2] Marginal effects of exogenous dummy variables are on those with `INVCALC=1`, i.e. the first part of the total effect in equation (5.15).
[3] For endogenous `INVCALC` in the recursive biprobit, marginal effects are calculated using equation (5.14).

For the same reason, also the marginal effects of providing the yearly energy consumption in monetary terms rather than physical units are much higher for *Experiment 2*. While the probability to choose the most cost-efficient light bulb increased by about 4 percentage points when the monetary information was displayed in the light bulb experiment, the probability increased by about 30 percentage points in the case of the refrigerator experiment. This result gives strong support for *Hypotheses H1b and H2b*, i.e. that the information on yearly energy costs strongly increases the chances that consumers choose the more (cost-)efficient appliance.

Lastly, the marginal effect of the endogenous investment calculation decision strategy variable is up to 8 percentage points in *Experiment 1* and up to 78 percentage points in *Experiment 2*. The strong impact supports our *Hypothesis H2a* that opting for optimization as the decision-making strategy has a positive impact on the probability to identify the most cost-efficient appliance.

5.6 Conclusion

In order to examine the role of information display, energy and investment literacy on the choice of electrical appliances of consumers, we have organized a household survey and conducted two online randomized controlled trials among households from three major Swiss urban areas. The first experiment was related to a choice between two light bulbs whereas the second experiment was concerned with making a choice between two refrigerators. The information collected from the survey was analyzed by estimating a series of (recursive) bivariate probit models in order to simultaneously model two binary variables which represent the two stage decision process explaining first the adoption of the decision strategy and then the identification of the cost-efficient appliance.

From the survey we observe that more than two-third of the consumers do not perform an investment calculation, which supports the view that a large part of the consumers are boundedly rational and prefer to use shortcuts instead of optimizing their expenditure. Further, from the econometric analysis we observe that displaying yearly energy consumption of appliances in estimated yearly energy cost rather than in physical units increases both the probability that consumers perform an investment analysis and that they identify the most (cost-)efficient appliances. Our results emphasize that informed and rational choices of appliances can be enhanced by the provision of monetary information on yearly energy consumption. Furthermore, we could show that individuals who possess energy-related knowledge and high cognitive abilities, captured by high levels of energy and investment literacy, were more likely to opt for optimization as the decision-making strategy which in turn positively influences the probability to identify the most cost-efficient appliance. It can therefore be concluded, that enhancing an individual's energy-related knowledge and the ability to make complex (investment) calculations seems to be one important prerequisite to empower consumers to make rational and informed energy-related choices.

From an energy policy point of view, the results suggest that an improvement in energy efficiency could be reached in three ways. First, with an obligation for the producers of electrical appliances to provide information on the future energy consumption of the product in the form of a monetary estimate. This could follow the example of the EnergyGuide label used in the United States that requires that on certain appliances an estimate of the annual operating energy cost is displayed (US-FTC, 2017). A second strategy would be to educate consumers about the energy consumption of different appliances and how to identify the most efficient appliances by means of brochures and energy literacy courses at schools. As a third strategy, decision support tools such as lifetime-cost-calculators could be provided in stores, mobile applications or through a web-page promoted by the government. All these measures would make use of the insights that energy and investment literacy as well as the display of monetary information seem to improve individual decisions when it comes to the identification of efficient household appliances.

Acknowledgements

We are grateful to the Swiss Federal Office of Energy (SFOE) for financial support. SFOE was not responsible for the study design, the collection, analysis and interpretation of data or in the writing of this article. The content does not necessarily represent the official views of SFOE. All omissions and remaining errors are our responsibility. Furthermore, we would like to thank the utilities who cooperated in sending out invitations to their customers to participate in our household survey. Comments from two anonymous referees as well as from participants of the 2016 Münster Energy Conference (MEC) and the 2016 IAEE Conference in Bergen are gratefully acknowledged.

6 Final conclusions and outlook

The mean persistent inefficiency in the analyzed samples of Swiss households is found to be around 22% whereas the transient inefficiency is found to be around 11% to 14%. The high persistent inefficiency points to structural problems faced by Swiss households in reducing their use of electricity.

The results also indicate a strong heterogeneity in residential electricity demand. Although several factors can influence the demand for electricity, and in turn the level of underlying persistent and transient efficiency, we focus on two important factors related to systematic behavioural shortcomings concerning the production and consumption of energy services. Attitudes and behaviours of the household members are very influential. In particular, a positive effect of energy-relate investment literacy and energy-saving behaviour in reducing household electricity consumption could be identified.

The level of energy-related investment literacy is found to be low among Swiss households. More than two thirds of Swiss consumers seem to rely on the use of simple decision-making heuristics rather than an assessment of the lifetime energy costs of various appliances before making a choice. This provides further evidence that individuals tend to be boundedly rational and might not tap the financial savings potential of energy efficiency investments without further support. Further, we observe that displaying yearly energy consumption of appliances in estimated yearly energy cost rather than in physical units increases both the probability that consumers perform an investment analysis and that they identify the appliance with lowest lifetime cost.

The project applied new methodological approaches to measure the level of efficiency in the use of electricity by Swiss households and provided new insights into its determinants. As presented in Chapter 3, the newly developed generalized true random effects model (GTREM) and a dis-aggregate panel dataset of electricity consumption in Swiss households were used for the first time to estimate the transient and persistent level of efficiency in the use of electricity among Swiss households. Only the GTREM allows to estimate the level of persistent and transient efficiency of an economic agent simultaneously. The GTREM recognizes that the level of productive efficiency can be split into these two components. The observed differences between the transient and persistent level of efficiency point out how important it is to distinguish between the two concepts.

From an energy policy point of view, the results suggest that an improvement in energy efficiency could be reached in three ways. First, with an obligation for the producers of electrical appliances to provide information on the future energy consumption of the product in the form of a monetary estimate. This could follow the example of the EnergyGuide label used in the United States that requires that on certain appliances an estimate of the annual operating energy cost is displayed (US-FTC, 2017). A second strategy would be to educate consumers about the energy consumption of different appliances and how to identify the most efficient appliances by means of brochures and energy literacy courses at schools. As a third strategy, policy measures that enhance an individual's energy-related knowledge and the ability to make complex (investment) calculations seems to be one important prerequisite to empower consumers to make rational and informed energy-related choices. Finally, decision support tools such as lifetime-cost-calculators could be provided in stores, mobile applications or through a web-page promoted by the government.

The clear distinction between the persistent and transient inefficiencies faced by households are again emphasized, as it may help to channel the relevant policy measures. For instance, energy policy measures that try to promote energy saving behavior (such as an information campaign) or try to increase the level of energy literacy (such as distribution of information leaflets and booklets among households) will probably have an impact on the level of transient efficiency. On the other hand, policy measures that try to improve the level of financial literacy (such as short courses training individuals in assessing investments or web-pages and mobile-apps that help to calculate the lifetime cost of appliances) could have an impact on the buying process of appliances, and therefore, on the level of persistent efficiency.

Implementing these policy measures together with the promotion through subsidies of in-home energy audits and other measures, e.g., based on nudges and social norms, may help in achieving improvements in the level of efficiency in the use of electricity. Nonetheless, the inherent bounded rationality within consumers could undermine the impact of an ecological tax aiming to internalize external costs, i.e. even if an energy or CO_2-tax made electricity more costly - and hence investments in energy efficiency more viable - boundedly rational consumers would probably not make these investments because they would still not be (cognitively) able to take future cost savings into account when choosing an appliance. Moreover, the presence of bounded rational consumers could also justify instruments such as efficiency-related regulations and standards for electrical appliances.

Future research should investigate further into the determinants of the level of efficiency of Swiss households, and in particular the relation between the contributions of changes in behavior, attitudes and literacy and the contribution of a renewed appliance stock on the observed levels of energy efficiency. Moreover, randomized controlled trials (RCT) should be implemented to field-test the impact that online support tools such as calculators and mobile-apps can have on the choice of more efficient appliances.

Next steps

The insights from this project have motivated us to further examine the concepts related to energy-related financial literacy, its socio-economic determinants, and the role it plays in investment decisions related to adoption of energy-efficient household appliances, investments into energy saving technologies, and renovation of building envelope. With that in mind, in the future we would be very interested to explore the role of energy-related financial literacy in the building and transport sectors in Switzerland.

As part of a recent European project "PENNY" (Psychological social & financial barriers to energy efficiency), we have collected household level data from several European countries and are clearly defining the concept of energy-related financial literacy. We measure this aspect of literacy and are studying the impact of energy-related literacy and socio-economic determinants on the adoption of electrical appliances.

The discussion on investments into energy-efficient appliances is perhaps even more far-reaching within the context of developing countries where the economic growth has brought consumers closer to appliances and devices of their liking. The same is true within the rapidly increasing mobility markets in developing economies. Switching from diesel and gasoline to electric cars and motorbikes has been envisaged as one of the essential solutions to many of the related environmental problems but adoption has been lacking. In this context, role of energy-related financial literacy is crucial and it could stimulate adoption of newer and cleaner technologies. We have plans to explore further research on these topics and we are, e.g., currently working out feasibility analysis of a project in Nepal and India.

7 Publications

Below is a list of publications and working papers written within the project.

Journal articles

- Blasch, J., Boogen, N., Filippini, M., and Kumar, N. (2017a). Explaining electricity demand and the role of energy and investment literacy on end-use efficiency of Swiss households. *Energy Economics*, 68 (S):89–102 - https://doi.org/10.1016/j.eneco.2017.12.004

- Blasch, J., Filippini, M., and Kumar, N. (2017b). Boundedly rational consumers, energy and investment literacy, and the display of information on household appliances. *Resource and Energy Economics*, (In Press) - https://doi.org/10.1016/j.reseneeco.2017.06.001

- Boogen, N. (2017). Estimating the potential for electricity savings in households. *Energy Economics*, 63:288–300 - https://doi.org/10.1016/j.eneco.2017.02.008

Working papers (already published as journal articles)

- Blasch, J., Boogen, N., Filippini, M., and Kumar, N. (2016). Boundedly rational consumers, energy and investment literacy, and the display of information on household appliances, *CER-ETH Economics Working Paper Series*, No. 16/249 - https://doi.org/10.3929/ethz-a-010656875

- Blasch, J., Filippini, M., and Kumar, N. (2017). The role of energy and investment literacy for residential electricity demand and end-use efficiency, *CER-ETH Economics Working Paper Series*, No. 17/269 - https://doi.org/10.3929/ethz-a-010870845

References

Aigner, D., Lovell, C., and Schmidt, P. (1977). Formulation and estimation of stochastic frontier production function models. *Journal of Econometrics*, 6(1):21–37.

Alberini, A., Banfi, S., and Ramseier, C. (2013). Energy efficiency investments in the home: Swiss homeowners and expectations about future energy prices. *The Energy Journal*, 34(1):49–86.

Alberini, A. and Filippini, M. (2011). Response of residential electricity demand to price: The effect of measurement error. *Energy Economics*, 33(5):889–895.

Alberini, A. and Filippini, M. (2018). Transient and persistent energy efficiency in the US residential sector: Evidence from household-level data. *Energy Efficiency*, 11(3):589–601.

Allcott, H. and Greenstone, M. (2012). Is There an Energy Efficiency Gap? *Journal of Economic Perspectives*, 26(1):3–28.

Allcott, H. and Taubinsky, D. (2015). Evaluating behaviorally motivated policy: Experiment evidence from the lightbulb market. *American Economic Review*, 105(8):2501–2538.

Anderson, C. and Claxton, J. (1982). Barriers to consumer choice of energy efficient products. *Journal of Consumer Research*, 9:163–170.

ASHRAE (2001). *2001 ASHRAE handbook: Fundamentals.* American Society of Heating Refrigerating and Air-Conditioning Engineers, Atlanta.

Attari, S., DeKay, M., Davidson, C., and Bruine de Bruin, W. (2010). Public perceptions of energy consumption and savings. *PNAS*, 107(37):16054–16059.

Battese, G. E. and Coelli, T. J. (1995). A model for technical inefficiency effects in a stochastic frontier production function for panel data. *Empirical Economics*, 20(2):325–332.

BFE (2015). Schweizerische gesamtenergiestatistik 2014. Technical report, Bundesamt für Energie - BFE.

Bhattacharyya, S. C. (2011). *Energy Economics Concepts, Issues, Markets and Governance*. Springer-Verlag.

Blasch, J., Boogen, N., Daminato, C., and Filippini, M. (2018). Empower the consumer! Energy-related financial literacy and its socioeconomic determinants. *CER-ETH Economics Working Paper Series*, No. 18/289.

Blasch, J., Boogen, N., Filippini, M., and Kumar, N. (2017a). Explaining electricity demand and the role of energy and investment literacy on end-use efficiency of Swiss households. *Energy Economics*, 68 (S):89–102.

Blasch, J., Filippini, M., and Kumar, N. (2017b). Boundedly rational consumers, energy and investment literacy, and the display of information on household appliances. *Resource and Energy Economics*, (In Press).

Boogen, N. (2017). Estimating the potential for electricity savings in households. *Energy Economics*, 63:288–300.

Boogen, N., Datta, S., and Filippini, M. (2015). An Evaluation of the Impact of Energy Efficiency Policies on Residential Electricity Demand in Switzerland – Schlussbericht zu Handes des BFE. Technical report.

Boyd, G. A. (2008). Estimating Plant Level Energy Efficiency with a Stochastic Frontier. *The Energy Journal*, 29(2):23–43.

Brent, D. A. and Ward, M. (2017). Energy Efficiency and Financial Literacy. *Department of Economics Working Paper Series, Louisiana State University*.

Broberg, T. and Kazukauskas, A. (2015). Inefficiencies in Residential Use of Energy - A Critical Overview of Literature and Energy Efficiency Policies in the EU. *International Review of Environmental and Resource Economics*, 8(2):225–279.

Brounen, D., Kok, N., and Quigley, J. M. (2013). Energy literacy, awareness, and conservation behavior of residential households. *Energy Economics*, 38:42–50.

Brown, M. and Graf, R. (2013). Financial Literacy and Retirement Planning in Switzerland. *Numeracy*, 6(2).

Brown, M. and Popkin, J. (1962). A Measure of Technological Change and Returns to Scale. *The Review of Economics and Statistics*, 44(4):402. 00092.

Bruderer Enzler, H., Diekmann, A., and Meyer, R. (2014). Subjective discount rates in the general population and their predictive power for energy saving behavior. *Energy Policy*, 65:524 – 540.

Burnett, N. J. (1997). Gender Economics Courses in Liberal Arts Colleges. *The Journal of Economic Education*, 28(4):369–376.

Butler, J. S. and Moffitt, R. (1982). A Computationally Efficient Quadrature Procedure for the One-Factor Multinomial Probit Model. *Econometrica*, 50(3):761.

Carley, S. (2012). Energy Demand-Side Management: New Perspectives for a New Era. *Journal of Policy Analysis and Management*, 31(1):6–32.

Chambers, R. (1988). *Applied Production Analysis*. Cambridge University Press.

Chiang, A. C. (1984). *Fundamental methods of mathematical economics*. McGraw-Hill.

Christofides, L. N., Stengos, T., and Swidinsky, R. (1997). On the calculation of marginal effects in the bivariate probit model. *Economics Letters*, 54(3):203–208.

Coelli, T., Perelman, S., and Romano, E. (1999). Accounting for Environmental Influences in Stochastic Frontier Models: With Application to International Airlines. *Journal of Productivity Analysis*, 11(3):251–273.

Coller, M. and Williams, M. B. (1999). Eliciting individual discount rates. *Experimental Economics*, 2(2):107–127.

Colombi, R., Kumbhakar, S. C., Martini, G., and Vittadini, G. (2014). Closed-skew normality in stochastic frontiers with individual effects and long/short-run efficiency. *Journal of Productivity Analysis*, 42(2):123–136.

Conlisk, J. (1988). Optimization cost. *Journal of Economic Behavior & Organization*, 9(3):213 – 228.

Deaton, A. and Muellbauer, J. (1980a). An Almost Ideal Demand System. *The American Economic Review*, 70(3):312–326.

Deaton, A. and Muellbauer, J. (1980b). *Economics and consumer behavior*. Cambridge University Press, Cambridge.

Deutsch, M. (2010). The effect of life-cycle cost disclosure on consumer behavior: evidence from a field experiment with cooling appliances. *Energy Efficiency*, 3:303–315.

DeWaters, J. E. and Powers, S. E. (2011). Energy literacy of secondary students in New York State (USA): A measure of knowledge, affect, and behavior. *Energy Policy*, 39(3):1699–1710.

Dillman, D. A., Smyth, J. D., and Christian, L. M. (2009). *Internet, Mail and Mixed-Mode Surveys: The Tailored Design Method*. Wiley: Hoboken, NJ, 3rd edition.

Electricity Commission of the Swiss Government (2017). Die kantonalen Strompreise im Vergleich (Comparison of cantonal electricity prices). Published online: https://www.strompreis.elcom.admin.ch/Map/ShowSwissMap.aspx (04.04.2017).

Energy Information Administration (1999). Annual Energy Review 1999. http://www.eia.gov/totalenergy/data/annual/archive/038499.pdf, accessed December 2015.

Epper, T., Fehr-Duda, H., and Schubert, R. (2011). Energy-using durables: The role of time discounting in investment decisions. Swiss Federal Office of Energy, Publication No. 290417.

Evans, J., Filippini, M., and Hunt, L. (2013). The contribution of energy efficiency towards meeting CO2 targets. In Fouquet, R., editor, *Chapter 8 in*, pages 175–223. UK and, Cheltenham.

Farrell, M. J. (1957). The Measurement of Productive Efficiency. *Journal of the Royal Statistical Society. Series A (General)*, 120(3):253–81.

Farsi, M. and Filippini, M. (2009). Efficiency Measurement in the Electricity and Gas Distribution Sectors?, Chapter 25 in. In Evans, J. and Hunt, L., editors, *International Handbook on the Economics of Energy*, pages 598–623. UK and, Cheltenham.

Filippini, M. and Greene, W. (2016). Persistent and transient productive inefficiency: a maximum simulated likelihood approach. *Journal of Productivity Analysis*, 45(2):187–196.

Filippini, M. and Hunt, L. C. (2011). Energy Demand and Energy Efficiency in the OECD Countries: A Stochastic Demand Frontier Approach. *The Energy Journal*, 32(2):59–80.

Filippini, M. and Hunt, L. C. (2012). US residential energy demand and energy efficiency: A stochastic demand frontier approach. *Energy Economics*, 34(5):1484–1491.

Filippini, M. and Hunt, L. C. (2015). Measurement of energy efficiency based on economic foundations. *Energy Economics*, 52:S5–S16.

Filippini, M., Hunt, L. C., and Zorić, J. (2014). Impact of energy policy instruments on the estimated level of underlying energy efficiency in the EU residential sector. *Energy Policy*, 69:73–81.

Flaig, G. (1990). Household production and the short-and long-run demand for electricity. *Energy Economics*, 12(2):116–121.

Frederiks, E. R., Stenner, K., and Hobman, E. V. (2015). Household energy use: Applying behavioural economics to understand consumer decision-making and behaviour. *Renewable and Sustainable Energy Reviews*, 41:1385–1394.

Gerarden, T., Newell, R., and Stavins, R. (2015). Deconstructing the Energy-Efficiency Gap: Conceptual Frameworks and Evidence. *American Economic Review*, 105(5):183–186.

Gillingham, K., Newell, R., and Palmer, K. (2006). Energy Efficiency Policies: A Restropective Examination. *Annual Review of Energy and the Environment*, 31:161–192.

Gillingham, K., Newell, R. G., and Palmer, K. (2009). Energy Efficiency Economics and Policy. *Annual Review of Resource Economics*, 1(1):597–620.

Greene, W. (2005a). Fixed and random effects in stochastic frontier models. *Journal of Productivity Analysis*, 23:7–32.

Greene, W. (2005b). Reconsidering Heterogeneity in Panel Data Estimators of the Stochastic Frontier Model. *Journal of Econometrics*, 126:269–303.

Greene, W. (2008). The econometric approach to efficiency analysis. In Fried, H. O., Lovell, C. A. K., and Schmidt, S. S., editors, *Chapter 2 in The Measurement of Productive Efficiency and Productivity*, pages 92–250. Oxford University Press.

Greene, W. H. (1996). Marginal Effects in the Bivariate Probit Model. Technical report, New York University, Leonard N. Stern School of Business, Department of Economics.

Greene, W. H. (1998). Gender Economics Courses in Liberal Arts Colleges: Further Results. *The Journal of Economic Education*, 29(4):291–300.

Greene, W. H. (2012). *NLOGIT 5*. Econometric Software, Inc., Plainview, New York. www.nlogit.com.

Greene, W. H. (2018). *Econometric analysis*. Pearson, New York, eighth edition.

Groves, R. M., Fowler, F. J., Couper, M. P., Lepkowski, J. M., Singer, E., and Tourangeau, R. (2004). *Survey Methodology*. Wiley, Hoboken N.J.

Harrison, G. W., Lau, M. I., and Williams, M. B. (2002). Estimating individual discount rates in denmark: A field experiment. *American Economic Review*, 92(5):1606–1617.

Hausman, J. A. (1979). Individual discount rates and the purchase and utilization of energy-using durables. *The Bell Journal of Economics*, 10(1):33–54.

Heinzle, S. L. (2012). Disclosure of energy operating cost information: A silver bullet for overcoming the energy-efficiency gap? *Journal of Consumer Policy*, 35(1):43–64.

Hille, S., Geiger, C., and Loock, M. (2015). Camouflaging environmental impact through relative rating: the case of eco-labels for cars. In *Conference Proceedings of the 2nd SCCER CREST Conference 2015 - On the implementation of the energy transition: The impact of Economic, Environmental and Political Action*, pages 69–74.

Houde, S. (2014). How consumers respond to environmental certification and the value of energy information. Working paper, NBER.

Howarth, R. B. and Sanstad, A. H. (1995). Discount rates and energy efficiency. *Contemporary Economic Policy*, 13:101–109.

Hunt, L. C., Ninomiya, Y., and Judge, G. (2003). Modelling underlying energy demand trends. In *Energy in a Competitive Market: Essays in Honour of Colin Robinson*, chapter 9, pages 140–174. Edward Elgar Publishing.

Huntington, H. (1994). Been top down so long it looks like bottom up to me. *Energy Policy*, 22:833–838.

Jones, A. M. (2007). *Applied econometrics for health economists: a practical guide*. Radcliffe, Oxford, 2. ed edition.

Kassouf, A. L. and Hoffmann, R. (2006). Work-Related Injuries Involving Children and Adolescents: Application of a Recursive Bivariate Probit Model. *Brazilian Review of Econometrics*, 26(1):105–126.

Kopp, R. (1981). The Measurement of Productive Efficiency: A Reconsideration. *The Quarterly Journal of Economics*, 96(3):477–503.

Kumbhakar, S. C. and Hjalmarsson, L. (1995). Labour-use efficiency in Swedish social insurance offices. *Journal of Applied Econometrics*, 10(1):33–47.

Kumbhakar, S. C., Lien, G., and Hardaker, J. B. (2014). Technical efficiency in competing panel data models: a study of Norwegian grain farming. *Journal of Productivity Analysis*, 41(2):321–337.

Kumbhakar, S. C. and Lovell, C. A. K. (2003). *Stochastic Frontier Analysis*. Cambridge University Press.

Kumbhakar, S. C. and Tsionas, E. G. (2012). Firm Heterogeneity, Persistent and transient Technical Inefficiency: A generalized True Random Effects model. *Journal of Applied Econometrics*, 29:110–132.

Lin, B. and Wang, X. (2014). Technology gap and China's regional energy efficiency: A parametric metafrontier approach. *Energy Policy*, 72:87–96.

Lusardi, A. and Mitchell, O. S. (2007). Baby Boomer retirement security: The roles of planning, financial literacy, and housing wealth. *Journal of Monetary Economics*, 54(1):205–224.

Lusardi, A. and Mitchell, O. S. (2009). Financial literacy: Evidence and implications for financial education. *Trends and issues*.

Maddala, G. S. (1983). *Limited-dependent and qualitative variables in econometrics*. Cambridge University Press, Cambridge [Cambridgeshire]; New York.

Martínez-Espiñeira, R. and Lyssenko, N. (2011). Correcting for the endogeneity of pro-environment behavioral choices in contingent valuation. *Ecological Economics*, 70(8):1435–1439.

McNeill, D. and Wilkie, W. (1979). Public policy and consumer information: Impact of the new energy labels. *Journal of Consumer Research*, 6:1–11.

Mills, B. and Schleich, J. (2010). What's driving energy efficient appliance label awareness and purchase propensity? *Energy Policy*, 38:814–825.

Mills, B. and Schleich, J. (2012). Residential energy-efficient technology adoption, energy conservation, knowledge, and attitudes: An analysis of European countries. *Energy Policy*, 49:616–628.

Min, J., Azevedo, I. L., Michalek, J., and de Bruin, W. B. (2014). Labeling energy cost on light bulbs lowers implicit discount rates. *Ecological Economics*, 97:42 – 50.

Murillo-Zamorano, L. (2004). Economic Efficiency and Frontier Techniques. *Journal of Economic Surveys*, 18(1):33–77.

Murphy, A. (2007). Score tests of normality in bivariate probit models. *Economics Letters*, 95(3):374–379.

Muth, R. F. (1966). Household production and consumer demand functions. *Econometrica: Journal of the Econometric Society*, 34(3):699–708.

Nadel, S. and Geller, H. (1996). Utility DSM: What have we learned? Where are we going? *Energy Policy*, 24(4):289–302.

Nair, G., Gustavsson, L., and Mahapatra, K. (2010). Factors influencing energy efficiency investments in existing swedish residential buildings. *Energy Policy*, 38(6):2956–2963. The Role of Trust in Managing Uncertainties in the Transition to a Sustainable Energy Economy, Special Section with Regular Papers.

Newell, R. and Siikamäki, J. (2013). Nudging energy efficiency behavior: The role of information labels. Discussion Paper RFF DP 13-17, Resources for the Future.

Patterson, M. (1996). What is energy efficiency? Concepts, indicators and methodological issues. *Energy Policy*, 24:377–390.

Pérez-Urdiales, M. and García-Valiñas, M. A. (2016). Efficient water-using technologies and habits: A disaggregated analysis in the water sector. *Ecological Economics*, 128:117–129.

Pingle, M. (2015). *Real-world decision making: an encyclopedia of behavioral economics*, chapter Decision Cost, pages 86–88. Greenwood.

Pitt, M. and Lee, L. (1981). The measurement and sources of technical inefficiency in the Indonesian weaving industry. *Journal of Development Economics*, 9:43–64.

Reinhard, S., Lovell, C. A. K., and Thijssen, G. (1999). Econometric estimation of technical and environmental efficiency: an application to Dutch dairy farms. *American Journal of Agricultural Economics*, 81(1):44–60.

Sallee, J. M. (2014). Rational inattention and energy efficiency. *The Journal of Law and Economics*, 57(3):781–820.

Sanstad, A. H. and Howarth, R. B. (1994a). Consumer rationality and energy efficiency. *Proceedings of the ACEEE 1994 Summer Study on Energy Efficiency in Buildings*, pages 175–183.

Sanstad, A. H. and Howarth, R. B. (1994b). 'Normal' markets, market imperfections and energy efficiency. *Energy Policy*, 22(10):811–818.

Scott, S. (1997). Household energy efficiency in Ireland: A replication study of ownership of energy saving items. *Energy Economics*, 19(2):187–208.

Shi, L. (2014). *Econometric analyses of renewable energy promotion*. Diss., Dept. of Forest Economics, Swedish University of Agricultural Sciences.

SIA (1982). *SIA Standard 381/3: heating degree-days in Switzerland*. Swiss Society of Engineers and Architects, Zürich. http://www.sia.ch/en/the-sia/.

Simon, H. (1959). Theories of decision-making in economics and behavioral sciences. *The American Economic Review*, 49(3):253–283.

Terza, J. V., Basu, A., and Rathouz, P. J. (2008). Two-stage residual inclusion estimation: addressing endogeneity in health econometric modeling. *Journal of Health Economics*, 27(3):531–543.

Todorova, T. (2010). *Problems Book to Accompany Mathematics for Economists*. John Wiley & Sons.

Train, K. (1985). Discount rates in consumers' energy-related decisions: A review of the literature. *Energy*, 10(12):1243 – 1253.

US-FTC (2017). Shopping for Home Appliances? Use the EnergyGuide Label. Published online: https://www.consumer.ftc.gov/articles/0072-shopping-home-appliances-use-energyguide-label (04.04.2017).

Varian, H. R. (1992). *Microeconomic Analysis*. W.W. Norton.

VSE (2011). Vse household survey 2011.

Waechter, S., Sütterlin, B., and Siegrist, M. (2015). Desired and undesired effects of energy labels - an eye-tracking study. *PLoS ONE*, 10(7):1–26.

Weyman-Jones, T., Boucinha, J. M., and Inácio, C. F. (2015). Measuring electric energy efficiency in Portuguese households: a tool for energy policy. *Management of Environmental Quality: An International Journal*, 26(3):407–422.

Wilde, J. (2000). Identification of multiple equation probit models with endogenous dummy regressors. *Economics Letters*, 69(3):309–312.

Wilson, C. and Dowlatabadi, H. (2007). Models of decision making and residential energy use. *Annual Review of Environment and Resources*, 32:169–203.

Zhou, P., Ang, B., and Zhou, D. (2012). Measuring economy-wide energy efficiency performance: A parametric frontier approach. *Applied Energy*, 90(1):196–200.

Zografakis, N., Menegaki, A. N., and Tsagarakis, K. P. (2008). Effective education for energy efficiency. *Energy Policy*, 36(8):3226–3232.

Appendices

A Appendix for Chapter 2

We include here some simple comparisons related to energy consumption behaviour across different Swiss utilities in our sample. Note that the comparison tables comprises of only those households for which we have consumption data available.[1] Moreover this number differs considerably across the different utilities, ranging from a sample of 276 households for one utility to 1'276 households for another.

Electricity consumption

Electricity consumption per capita

To get an overview of the typical electricity consumption characteristic among the households across different utilities, we provide here a table with the median value of the electricity consumption per head living in single-family houses or multi-family houses over 2010 - 2014 (Table 1).

Table 1: Per capita electricity consumption (median value in kWh) in 2010 - 2014.

Year	Utility-A	Utility-B	Utility-C	Utility-D	Utility-E	Utility-F	Utility-G	Utility-H
Single Family Households (SFH)								
2010	3'083.0	1'603.5	1'841.0	1'366.5	1'795.7	–	13'360.4	1'593.1
2011	2'848.0	1'582.5	1'786.5	1'337.2	2'158.0	1'528.8	10'351.5	1'507.0
2012	2'774.5	1'607.0	1'773.5	1'416.9	2'003.5	1'152.5	9'867.3	1'398.0
2013	2'820.0	1'554.5	1'850.5	1'293.7	2'172.8	2'413.8	14'253.3	1'563.3
2014	2'693.8	1'480.6	1'830.0	1'388.2	2'095.3	1'573.0	11'905.9	1'464.0
Multi Family Households (MFH)								
2010	1'886.8	1'189.5	1'229.5	1'205.0	860.8	–	6'876.0	932.0
2011	1'770.4	1'222.5	1'185.5	1'199.7	1'324.0	890.5	6'891.0	934.3
2012	1'686.8	1'200.0	1'179.0	1'198.2	1'100.0	763.0	6'817.1	953.3
2013	1'602.0	1'101.8	1'178.0	1'066.0	1'039.5	1'381.8	8'799.8	898.0
2014	1'437.0	1'075.8	1'112.8	1'141.0	1'069.6	992.0	6'512.0	837.5

Electricity consumption per m^2

Table 2 shows the comparison across utilities in term of the median value of the electricity consumption per square metres of living space in single-family and multi-family houses over 2010 - 2014.

[1] 8 out of 9 participating utilities presented here since we have not yet received the consumption data for one utility.

Table 2: Electricity consumption per m^2 (median value in kWh/m^2) in 2010 - 2014.

Year	Utility-A	Utility-B	Utility-C	Utility-D	Utility-E	Utility-F	Utility-G	Utility-H
Single Family Households (SFH)								
2010	48.4	29.0	34.4	26.5	31.9	–	152.8	28.3
2011	42.8	26.9	33.1	24.5	38.7	25.0	136.9	28.1
2012	42.3	27.8	31.8	24.3	34.5	21.1	142.6	26.5
2013	43.3	25.9	31.8	22.1	34.1	37.4	201.0	27.3
2014	40.8	24.4	31.3	24.0	35.7	23.5	146.0	27.1
Multi Family Households (MFH)								
2010	30.2	22.7	27.7	23.8	21.9	–	134.3	22.4
2011	28.5	22.8	25.3	22.7	29.2	16.8	129.7	22.7
2012	26.6	21.9	24.8	22.5	24.4	14.9	126.6	21.8
2013	25.1	21.1	24.3	19.5	22.6	25.5	164.4	20.9
2014	23.2	20.7	24.0	21.5	22.8	18.6	126.7	19.9

Gas consumption

Gas consumption per capita

To get an idea about the typical gas consumption characteristic among the *single-family households* across different utilities, we provide here a table with the median value of the gas consumption per head living in single-family houses over 2010 - 2014 (Table 3).

Table 3: Per capita gas consumption (median value in kWh) in single-family houses in 2010 - 2014.

Year	Utility-A	Utility-B	Utility-C	Utility-D	Utility-E	Utility-F	Utility-G	Utility-H
2010	10’269.0	6’670.5	7’027.0	7’213.9	–	–	7’655.4	–
2011	6’822.5	6’275.1	6’496.0	6’279.0	–	2’979.5	8’043.5	–
2012	7’592.1	5’994.5	6’355.1	7’507.5	–	4’062.2	25’238.1	–
2013	8’926.0	6’489.5	7’295.2	7’973.7	–	7’273.6	30’073.4	–
2014	6’704.5	6’042.2	6’714.7	7’567.0	–	3’501.6	18’894.0	–

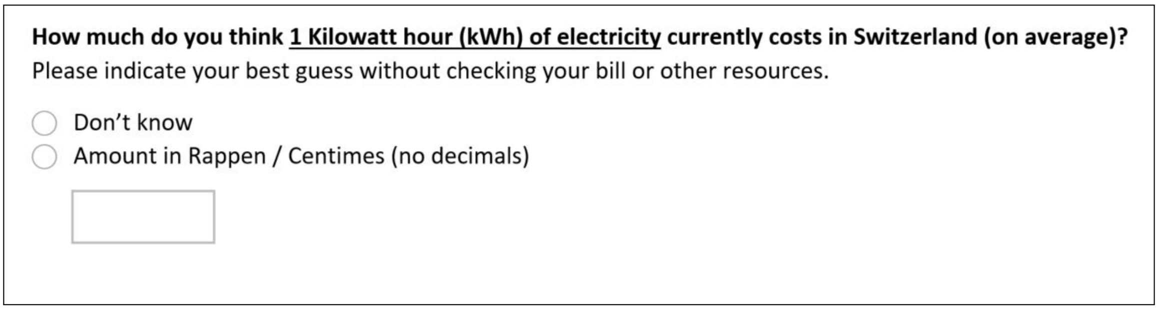
Gas consumption per m^2

Table 4 shows the comparison across utilities in term of the median value of the gas consumption per square metres of living space in single-family houses over 2010 - 2014.

Table 4: Gas consumption per m^2 (median value in kWh/m^2) in single-family houses in 2010 - 2014.

Year	Utility-A	Utility-B	Utility-C	Utility-D	Utility-E	Utility-F	Utility-G	Utility-H
2010	165.5	119.3	132.9	156.2	–	–	103.4	–
2011	102.9	114.4	117.4	130.1	–	58.5	110.5	–
2012	110.0	113.5	115.5	142.1	–	80.1	367.1	–
2013	125.9	117.5	129.6	129.1	–	130.7	397.9	–
2014	99.8	101.0	120.8	118.2	–	78.3	257.6	–

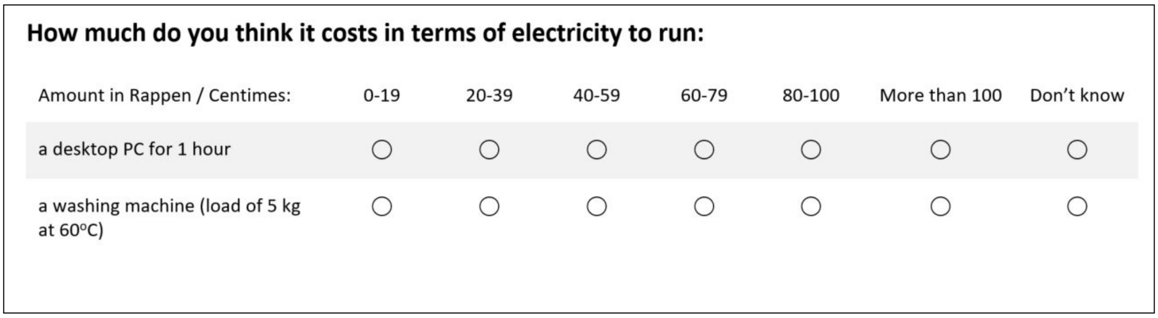
B Appendix for Chapter 3



How much do you think 1 Kilowatt hour (kWh) of electricity currently costs in Switzerland (on average)?
Please indicate your best guess without checking your bill or other resources.

- ○ Don't know
- ○ Amount in Rappen / Centimes (no decimals)

Figure 1: Energy-related literacy question on the price of 1 kWh of electricity.



How much do you think it costs in terms of electricity to run:

Amount in Rappen / Centimes:	0-19	20-39	40-59	60-79	80-100	More than 100	Don't know
a desktop PC for 1 hour	○	○	○	○	○	○	○
a washing machine (load of 5 kg at 60°C)	○	○	○	○	○	○	○

Figure 2: Energy-related literacy questions on monetary cost of energy services.

In the following pairs, which of the two consumes more electricity?

Pair 1:

- ○ Bringing 1 litre of water to a boil in an average pot with lid
- ○ Running a washing machine with a load of 5kg at 60°C
- ○ Both consume about the same
- ○ Don't know

Pair 2:

- ○ Bringing 1 litre of water to a boil in an average pot with lid
- ○ Bringing 1 litre of water to a boil in an electric kettle
- ○ Both consume about the same
- ○ Don't know

Pair 3:

- ○ Running a desktop PC for 1 hour
- ○ Running a laptop for 1 hour
- ○ Both consume about the same
- ○ Don't know

Figure 3: Energy-related literacy questions on comparison of electricity consumption of appliances.

Let's say you have 200 CHF in a savings account. The account earns 10% interest per year.
How much would you have in the account at the end of 2 years?

- ○ 220 CHF
- ○ 240 CHF
- ○ 242 CHF
- ○ 204 CHF
- ○ Don't know

Figure 4: Survey question on mathematical/investment literacy.

How regularly do you and other members of your household perform the following activities in your daily life?

	Never	Rarely	Sometimes	Very often	Always	Don't know	N/A
Running only full loads when using the washing machine	○	○	○	○	○	○	○
Washing clothes using 30°C or less rather than higher temperatures	○	○	○	○	○	○	○
Completely switching off electronic devices (TV, computer) [no standby]	○	○	○	○	○	○	○
Choosing different program of dishwasher depending on level of dirtiness of the dishes	○	○	○	○	○	○	○

Figure 5: Survey questions on energy-saving behaviour.

Table 5: Comparison of basic demographic characteristics of the six urban areas.

	Biel/Bienne		**Lucerne**		**Bellinzona**		**Lugano**		**Winterthur**		**Aarau**	
	Sample (N=877)	*SSV*	*Sample (N=1,375)*	*SSV*	*Sample (N=583)*	*SSV*	*Sample (N=1,406)*	*SSV*	*Sample (N=739)*	*SSV*	*Sample (N=826)*	*SSV*
Share of females (%)	52.61	51.19	51.39	52.07	51.06	52.88	51.69	51.85	50.35	50.91	50.35	51.13
Share of population by age (%)												
young (0-19 years)	17.15	19.09	13.08	15.66	25.96	18.48	20.04	17.57	20.44	19.69	19.11	16.86
adult (20-64 years)	62.04	62.21	63.82	64.93	62.25	60.77	63.24	60.68	65.11	64.05	58.92	64.72
elderly (65+ years)	20.81	18.69	23.10	19.41	11.79	20.75	16.72	21.75	14.45	16.26	21.97	18.42
Mean household size	2.18	2.10	2.09	1.90	2.60	2.10	2.40	2.00	2.31	2.20	2.43	2.00
Dwelling (mean values)												
living space per head (m^2)	51.63	38.00	52.44	45.00	52.62	44.00	54.19	46.00	49.10	43.00	62.36	48.00
people per room	0.57	0.66	0.57	0.58	0.65	0.61	0.63	0.62	0.61	0.61	0.53	0.55

Data at city level from 2015.

Data source: Swiss cities association (Schweizerischer Städteverband/SSV).

Table 6: Descriptive statistics over 2010 – 2014 (Unbalanced panel of 1, 994 households).

Households →	**Year = 2010 (1065)**		**Year = 2011 (1568)**		**Year = 2012 (1729)**		**Year = 2013 (1972)**		**Year = 2014 (1961)**	
	Mean	*Std.Dev.*	*Mean*	*Std.Dev.*	*Mean*	*Std.Dev.*	*Mean*	*Std.Dev.*	*Mean*	*Std.Dev.*
Q_E	3629.26	2467.77	3136.85	2270.76	3002.00	2360.20	3130.14	2331.90	2935.53	2214.20
MP_AVG	17.84	2.66	19.00	2.52	18.65	2.78	18.42	2.29	19.17	2.02
HHSIZE	2.57	1.29	2.42	1.20	2.36	1.18	2.30	1.16	2.28	1.14
INC6K	0.30	0.46	0.30	0.46	0.30	0.46	0.30	0.46	0.30	0.46
INC6_12K	0.52	0.50	0.52	0.50	0.52	0.50	0.51	0.50	0.51	0.50
INC12K	0.18	0.38	0.18	0.38	0.18	0.39	0.18	0.39	0.19	0.39
HDD	3310.85	302.85	2779.06	196.58	3046.15	272.51	3191.46	342.13	2562.07	240.46
CDD	209.81	82.45	170.47	79.66	200.37	98.00	215.88	70.59	106.00	44.36
IS_SFH	0.38	0.49	0.30	0.46	0.29	0.45	0.27	0.44	0.27	0.44
SQM	129.92	56.45	123.55	54.48	122.60	54.54	120.36	53.54	120.49	53.67
BLT1940	0.19	0.39	0.19	0.39	0.19	0.39	0.18	0.39	0.18	0.39
BLT1970	0.25	0.44	0.27	0.44	0.26	0.44	0.27	0.44	0.27	0.44
BLT2000	0.41	0.49	0.38	0.49	0.37	0.48	0.36	0.48	0.36	0.48
BLT2015	0.15	0.36	0.15	0.36	0.18	0.38	0.19	0.39	0.19	0.39
MINERGIE	0.06	0.23	0.06	0.24	0.07	0.26	0.08	0.28	0.08	0.28
WABS5TO8	0.08	0.27	0.08	0.27	0.08	0.27	0.08	0.27	0.08	0.27
HAS_FR2	0.22	0.41	0.20	0.40	0.19	0.39	0.18	0.38	0.18	0.38
HAS_FREE	0.59	0.49	0.54	0.50	0.52	0.50	0.50	0.50	0.50	0.50
NONE_APP	0.63	0.48	0.69	0.46	0.69	0.46	0.70	0.46	0.70	0.46
COOKEL	0.89	0.31	0.89	0.31	0.89	0.31	0.90	0.30	0.90	0.30
LUG	0.34	0.48	0.26	0.44	0.25	0.43	0.25	0.43	0.25	0.43
AAR	0.14	0.35	0.10	0.31	0.11	0.31	0.11	0.31	0.10	0.31
WINT	0.16	0.37	0.12	0.33	0.13	0.33	0.13	0.33	0.13	0.33
BIEL	0.25	0.44	0.18	0.38	0.18	0.38	0.16	0.37	0.17	0.37
LUZ	–	–	0.26	0.44	0.26	0.44	0.28	0.45	0.28	0.45
BELL	0.10	0.30	0.07	0.26	0.08	0.26	0.08	0.27	0.08	0.28
UNIV	0.34	0.48	0.35	0.48	0.36	0.48	0.38	0.48	0.37	0.48
UNIV_PAR	0.15	0.36	0.16	0.37	0.17	0.38	0.18	0.39	0.18	0.39

Table 7: Comparison of estimation results with older methods.

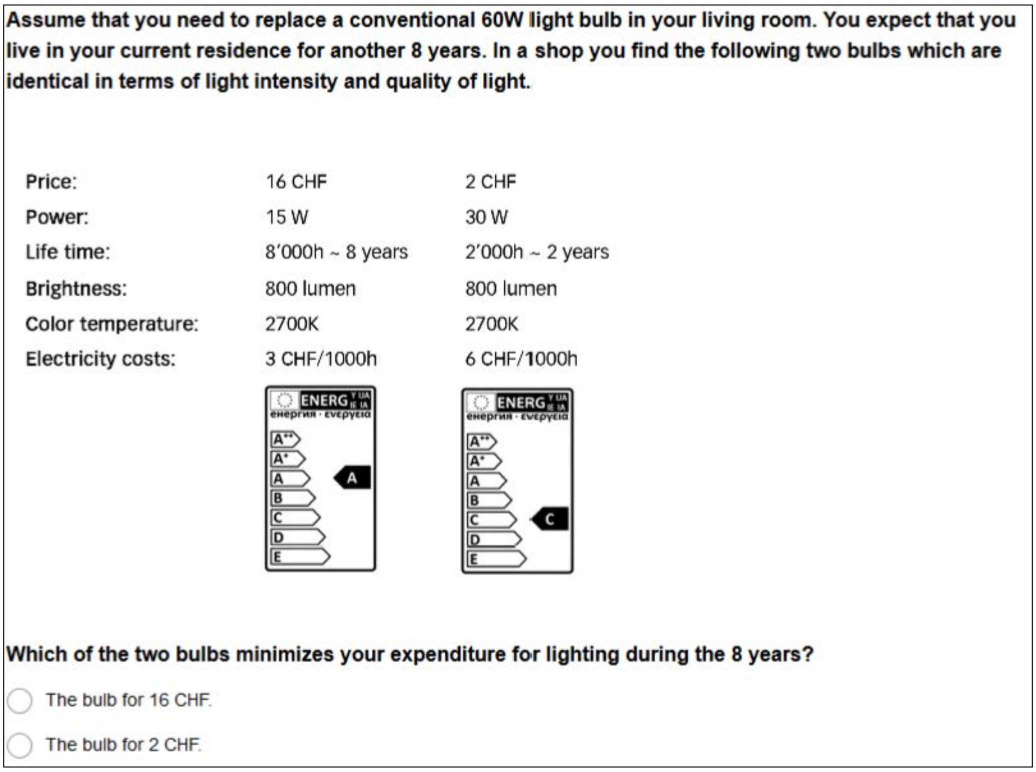
	REM		TREM		GTREM	
	Estimate	*t ratio*	*Estimate*	*t ratio*	*Estimate*	*t ratio*
LNP_E	-0.1848	-3.25	-0.3250	-9.19	-0.3032	-8.31
IS_SFH	0.1718	9.09	0.1561	21.96	0.1674	23.03
LN_HS	0.4131	21.89	0.3433	31.63	0.3472	31.26
LN_SQM	0.3086	13.82	0.3654	41.95	0.3921	44.40
HAS_YOUN	-0.0969	-5.08	-0.0479	-6.13	-0.0449	-5.66
HAS_ELDE	-0.0053	-0.37	0.0383	6.79	0.0346	5.98
INC6_12K	-0.0017	-0.14	-0.0103	-1.74	-0.0119	-2.01
INC12K	-0.0032	-0.18	-0.0158	-1.83	-0.0180	-2.07
BLT1970	0.0267	1.57	-0.0684	-9.02	-0.0773	-10.06
BLT2000	0.1163	6.62	0.0665	9.24	0.0440	5.99
BLT2015	0.1007	4.12	-0.0459	-5.08	-0.0558	-6.15
MINERGIE	0.0636	2.27	0.0299	2.97	0.0185	1.83
WABS5TO8	-0.1536	-7.78	-0.1221	-13.80	-0.1506	-16.89
HAS_FR2	0.0871	6.02	0.0912	13.83	0.1042	15.48
HAS_FREE	0.1421	10.46	0.1263	23.69	0.1126	20.63
NONE_APP	-0.0790	-6.06	-0.0661	-11.88	-0.0767	-13.46
LNMEALS	0.0502	3.16	0.0072	1.18	0.0021	0.35
LNDISH	0.1490	12.56	0.1325	32.37	0.1151	28.06
LNWASHIN	0.1162	12.87	0.1115	32.31	0.1009	28.58
LNENTT	0.1318	10.07	0.1566	37.49	0.1708	40.58
COOKEL	0.1332	7.11	0.1263	15.40	0.0957	11.44
LNHDD	-0.0934	-0.80	-0.1742	-1.59	-0.1051	-0.95
LNCDD	0.2009	4.14	0.2263	4.92	0.1923	4.15
AAR	0.1793	6.01	0.0455	2.35	0.0559	2.85
WINT	0.0003	0.01	-0.1850	-4.67	-0.1312	-3.29
BIEL	0.0741	2.24	0.0854	3.55	0.0768	3.16
LUZ	0.0974	3.96	-0.0487	-2.97	-0.0514	-3.09
BELL	-0.2005	-2.65	-0.3043	-4.65	-0.2524	-3.85
UNIV	-0.0429	-3.42	-0.0413	-7.56	-0.0144	-2.60
UNIV_PAR	-0.0968	-6.55	0.0092	1.36	-0.0185	-2.69
LNBEHAV	-0.0934	-5.55	-0.0281	-4.29	-0.0227	-3.39
LNENLIT2	-0.0093	-0.92	-0.0085	-2.16	-0.0126	-3.20
INVLIT	-0.0651	-4.72	-0.1231	-23.11	-0.1137	-20.57
T	-0.1216	-5.14	-0.1317	-6.00	-0.1190	-5.30
T*T	0.0236	5.95	0.0253	6.86	0.0230	6.11
α	4.9545	6.24	6.4229	8.79	5.6722	7.89
λ	3.0095	29.07	0.1200	0.20	0.7553	18.47
σ_u	0.6670	53.16	—	—	—	—
σ_w	—	—	0.4002	174.42	0.3960	165.44
$\sigma_{(v+u)}$	—	—	0.2185	21.53	0.2542	87.09
σ_h	—	—	—	—	0.5411	31.83
Observations:	8295		8295		8295	
Log-likelihood	-1708.60		-1654.91		-1735.77	

Table 8: Comparison of efficiencies.

	Median	*Mean*	*Std. Dev.*	*Minimum*	*Maximum*
REM	0.585	0.595	0.185	0.049	0.987
TREM	0.979	0.979	0.001	0.968	0.988
GTREM (Transient)	0.894	0.892	0.026	0.634	0.974
GTREM (Persistent)	0.785	0.784	0.013	0.394	0.841

Correlation between TREM and GTREM (Transient) = 0.931.
Correlation between REM and GTREM (Persistent) = 0.397.

C Appendix for Chapter 5



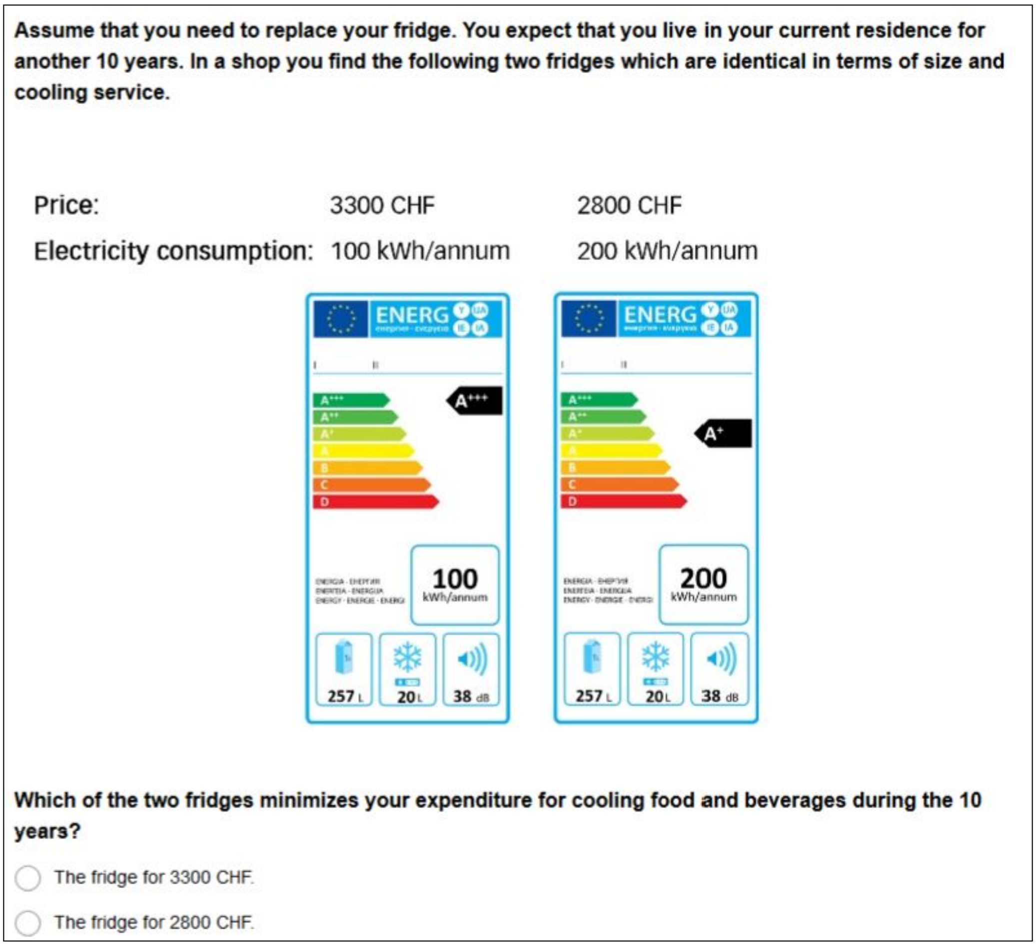
Assume that you need to replace a conventional 60W light bulb in your living room. You expect that you live in your current residence for another 8 years. In a shop you find the following two bulbs which are identical in terms of light intensity and quality of light.

Price:	16 CHF	2 CHF
Power:	15 W	30 W
Life time:	8'000h ~ 8 years	2'000h ~ 2 years
Brightness:	800 lumen	800 lumen
Color temperature:	2700K	2700K
Electricity costs:	3 CHF/1000h	6 CHF/1000h

Which of the two bulbs minimizes your expenditure for lighting during the 8 years?

- The bulb for 16 CHF.
- The bulb for 2 CHF.

Figure 6: The light bulb question as presented in *Experiment 1* (the example with display of energy consumption in monetary units (CHF) shown here).

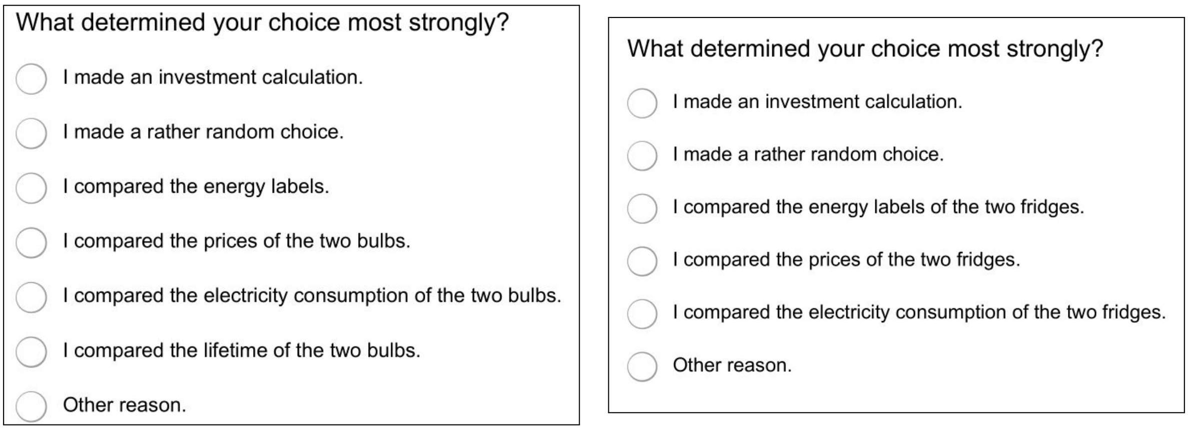

Assume that you need to replace your fridge. You expect that you live in your current residence for another 10 years. In a shop you find the following two fridges which are identical in terms of size and cooling service.

Price:	3300 CHF	2800 CHF
Electricity consumption:	100 kWh/annum	200 kWh/annum

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

- The fridge for 3300 CHF.
- The fridge for 2800 CHF.

Figure 7: The refrigerator question as presented in *Experiment 2* (the example with display of energy consumption in physical units (kWh) shown here).


What determined your choice most strongly?

- I made an investment calculation.
- I made a rather random choice.
- I compared the energy labels.
- I compared the prices of the two bulbs.
- I compared the electricity consumption of the two bulbs.
- I compared the lifetime of the two bulbs.
- Other reason.

What determined your choice most strongly?

- I made an investment calculation.
- I made a rather random choice.
- I compared the energy labels of the two fridges.
- I compared the prices of the two fridges.
- I compared the electricity consumption of the two fridges.
- Other reason.

(a) Experiment 1 - Light bulb

(b) Experiment 2 - Refrigerator

Figure 8: The decision strategy debriefing questions as presented in the two experiments.

D Survey questionnaire

Below we provide a copy of the questionnaire used for the survey.

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Willkommen

Sehr geehrter Teilnehmer, sehr geehrte Teilnehmerin

Dieser Fragebogen wurde vom *Centre for Energy Policy and Economics* (CEPE) der ETH Zürich (Eidgenössische Technische Hochschule Zürich) im Rahmen eines Forschungsprojektes zum Thema Energienutzung in Schweizer Haushalten entwickelt. Das Projekt wird vom Schweizer Bundesamt für Energie (BFE) gefördert.

Für das vollständige Ausfüllen des Fragebogens werden Sie etwa 15-20 Minuten benötigen. Bitte füllen Sie den Fragebogen ohne Unterbrechung aus. Es ist leider nicht möglich, die Antworten zwischenzuspeichern und den Fragebogen zu einem späteren Zeitpunkt zu beenden. Das CEPE der ETH Zürich garantiert Ihnen, dass alle Ihre Angaben anonym und vertraulich behandelt werden. Sie werden nur in statistischer Form zum Zweck der wissenschaftlichen Analyse von Forschern des CEPE genutzt werden.

Wir verlosen unter allen Teilnehmern 30 mal eine Smartbox "Happy Day" im Wert von je 50 Franken. Die Gewinner werden aus allen Teilnehmern zufällig ausgewählt. Die Preise werden vom NAME_VERSORGER versandt. Zusätzlich enthält der Fragebogen einige Wissensfragen zum Thema Energieverbrauch, zu denen Sie am Ende der Umfrage die korrekten Antworten erhalten.

Besten Dank für Ihre Teilnahme an dieser Umfrage!

Das Projektteam des CEPE der ETH Zürich

* *

- [ ] Ich bin mit den Teilnahmebedingungen einverstanden.

1

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Kundennummer

*

Bitte geben Sie Ihre Kundennummer ein [X Ziffern], wie in der Musterrechnung unten zu sehen:

2

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Qualifikation für die Umfrage

*

Bezieht sich die von Ihnen eingegebene Kundennummer auf Ihren Hauptwohnsitz?

- Ja
- Nein

* **Sind Sie eine der Personen in Ihrem Haushalt, die die Kaufentscheidungen trifft und/oder die Rechnungen bezahlt?**

(z.B. im Hinblick auf Ausgaben für Möbel, Haushaltsgeräte, Telefon- und Stromrechnung)

- Ja
- Nein

* **Wohnten Sie bereits vor dem 1. Januar 2015 in Ihrer derzeitigen Wohnung/in Ihrem derzeitigen Haus?**

- Ja
- Nein

3

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Ihr Hauptwohnsitz

*

Welche der folgenden Kategorien trifft auf Ihren Hauptwohnsitz am ehesten zu?

- Freistehendes Einfamilienhaus
- Doppelhaushälfte (Doppelhaus mit zwei separaten Eingängen)
- Reihenhaus
- Wohnung in einem Mehrfamilienhaus

* **Sind Sie oder ein anderes Haushaltsmitglied Eigentümer oder Mieter Ihres Wohnobjektes?**

- Eigentümer
- Mieter

Seit wann wohnen Sie in Ihrer derzeitigen Wohnung/in Ihrem derzeitigen Haus?

Bitte wählen Sie das Einzugsjahr und, falls möglich, auch den Monat (optional).

	Jahr	Monat
Einzugsdatum:		

Wie lautet Ihre Postleitzahl?

5

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Ihr Haus

*
Wie viele Quadratmeter hat Ihr Haus?
Bitte runden Sie jeweils auf den nächsten ganzen Zehner.

* **Wie viele Zimmer des folgenden Typs hat Ihr Haus?**

	0	1	2	3	4	5	6 oder mehr
Zimmer (Schlaf-, Wohn-, Ess-, Arbeitszimmer)	○	○	○	○	○	○	○
Küche	○	○	○	○	○	○	○
Badezimmer, Toilette	○	○	○	○	○	○	○
Andere Zimmer (z.B. Estrich, Keller, Garage, Wintergarten)	○	○	○	○	○	○	○

* **In welchem Jahrzehnt wurde Ihr Haus ursprünglich gebaut?**

- ○ vor 1940
- ○ 1940 - 1950
- ○ 1951 - 1960
- ○ 1961 - 1970
- ○ 1971 - 1980
- ○ 1981 - 1990
- ○ 1991 - 2000
- ○ 2001 - 2010
- ○ 2011 oder später
- ○ Weiss nicht

6

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Bauperiode

Wenn Sie es nicht genau wissen: In welchem der folgenden Zeiträume wurde das Haus ursprünglich gebaut?

- ○ vor 1940
- ○ zwischen 1940 - 1970
- ○ zwischen 1971 - 2000
- ○ 2001 oder später
- ○ Weiss nicht

7

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Ihr Haus

*
Welchen Energieträger nutzen Sie primär zum <u>Heizen Ihrer Wohnräume</u>?

- ○ Heizöl
- ○ Gas
- ○ Elektrizität
- ○ Holz
- ○ Wärmepumpe
- ○ Solarwärme
- ○ Fernwärme
- ○ Andere
- ○ Weiss nicht

Verwenden Sie eine <u>zweite</u>, ergänzende Energiequelle zum Heizen Ihrer Wohnräume?

- ○ Nein
- ○ Ja, und zwar (bitte geben Sie eine der zur Auswahl stehenden Quellen an)

*
Welchen Energieträger nutzen Sie primär zur <u>Erzeugung von Warmwasser</u>?

- ○ Heizöl
- ○ Gas
- ○ Elektrizität
- ○ Holz
- ○ Wärmepumpe
- ○ Solarwärme
- ○ Fernwärme
- ○ Andere
- ○ Weiss nicht

Verwenden Sie eine <u>zweite</u>, ergänzende Energiequelle zur Erzeugung von Warmwasser?

- ○ Nein
- ○ Ja, und zwar (bitte geben Sie eine der zur Auswahl stehenden Quellen an)

8

*
Welchen Energieträger nutzen Sie primär <u>zum Kochen</u>?

- ○ Elektrizität
- ○ Gas
- ○ Andere
- ○ Weiss nicht

9

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Ihr Haus

Entspricht Ihr Haus dem Minergie-Standard?

- Ja
- Nein
- Weiss nicht

* **Wurde Ihr Haus seit dem Jahr 2000 energetisch saniert?**
(z.B. Ersatz der Fenster oder des Dachs, Wärmedämmung der Fassade, Austausch des Heizsystems)

- Ja
- Nein
- Weiss nicht

10

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Energetische Sanierung

Welche Art energetischer Sanierung wurde durchgeführt? In welchem Jahr?
Wählen Sie 'nicht zutreffend', falls keine solche Renovation durchgeführt wurde.

	2015	2014	2013	2012	2011	2010	vor 2010	Nicht zutreffend
Ersatz von Fenstern und/oder Türen	○	○	○	○	○	○	○	○
Wärmedämmung des Dachs	○	○	○	○	○	○	○	○
Wärmedämmung der Fassade	○	○	○	○	○	○	○	○
Neues Heizsystem für Raumwärme	○	○	○	○	○	○	○	○
Neues Heizsystem für Warmwasser	○	○	○	○	○	○	○	○
Andere	○	○	○	○	○	○	○	○

Falls Sie Ihr Heizsystem gewechselt haben:

Welche Energiequelle nutzten Sie vor dem Wechsel des Heizsystems?

	Energiequelle
Heizung der Wohnräume	
Erzeugung von Warmwasser	

11

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Ihre Wohnung

*
Wie viele Quadratmeter hat Ihre Wohnung?
Bitte runden Sie jeweils auf den nächsten ganzen Zehner.

* **Wie viele Zimmer des folgenden Typs hat Ihre Wohnung?**

	0	1	2	3	4	5	6 oder mehr
Zimmer (Schlaf-, Wohn-, Ess-, Arbeitszimmer)	○	○	○	○	○	○	○
Küche	○	○	○	○	○	○	○
Badezimmer, Toilette	○	○	○	○	○	○	○

Wie hoch ist die monatliche Miete für Ihre Wohnung?

12

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Ihre Wohnung

*
Wann wurde das Haus, in dem sich Ihre Wohnung befindet, ursprünglich gebaut?

- vor 1940
- zwischen 1940 - 1970
- zwischen 1971 - 2000
- 2001 oder später
- Weiss nicht

Wie gross ist dieses Haus?

- Kleines Mehrfamilienhaus (weniger als 6 Wohnungen)
- Mittleres Mehrfamilienhaus (6 - 12 Wohnungen)
- Grosses Mehrfamilienhaus (mehr als 12 Wohnungen)

Entspricht dieses Haus dem Minergie-Standard?

- Ja
- Nein
- Weiss nicht

13

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Ihre Wohnung

*
Haben Sie in Ihrer Wohnung ein eigenes System zum Heizen Ihrer Wohnräume, unabhängig vom Rest des Gebäudes?
(z.B. elektrischer Speicherofen oder kleiner Gasboiler in Küche oder Badezimmer)

- Ja, elektrisch
- Ja, mit Gas betrieben
- Ja, mit einer anderen Energiequelle betrieben
- Nein
- Weiss nicht

* **Haben Sie in Ihrer Wohnung ein eigenes System zur Erzeugung von Warmwasser, unabhängig vom Rest des Gebäudes?**
(z.B. elektrischer Boiler oder Gasboiler in Küche oder Badezimmer)

- Ja, elektrisch
- Ja, mit Gas betrieben
- Ja, mit einer anderen Energiequelle betrieben
- Nein
- Weiss nicht

* **Welchen Energieträger nutzen Sie primär zum Kochen?**

- Elektrizität
- Gas
- Anderen
- Weiss nicht

14

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Haushaltszusammensetzung

*
Wie viele Personen lebten in den vergangenen 5 Jahren regelmässig in Ihrem Haushalt?
Beginnend ab dem Jahr Ihres Einzugs in Ihr derzeitiges Wohnobjekt.

	1	2	3	4	5	6 oder mehr
2014	○	○	○	○	○	○
2013	○	○	○	○	○	○
2012	○	○	○	○	○	○
2011	○	○	○	○	○	○
2010	○	○	○	○	○	○

* **Wie viele Personen der folgenden Altersgruppen lebten Ende 2014 in Ihrem Haushalt?**

	Keine	1	2	3	4 oder mehr
Kinder/Teenager bis 19 Jahre:	○	○	○	○	○
Erwachsene zwischen 20 und 64 Jahren:	○	○	○	○	○
Senioren ab 65 Jahren:	○	○	○	○	○

* **Wie viele weibliche und männliche Personen lebten Ende 2014 in Ihrem Haushalt?**

	Keine	1	2	3	4 oder mehr
Weiblich	○	○	○	○	○
Männlich	○	○	○	○	○

15

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Belegung Ihrer Wohnung/Ihres Hauses

Wie viele Wochen pro Jahr ist Ihre Wohnung/Ihr Haus in einem durchschnittlichen Jahr nicht bewohnt?
(z.B. aufgrund von längeren beruflichen Einsätzen, Urlaubsreisen oder Aufenthalten in Ferien- oder Zweitwohnsitzen)

- bis zu 1 Woche
- bis zu 5 Wochen
- bis zu 8 Wochen
- mehr als 8 Wochen

Wie viele Tage pro Woche ist Ihre Wohnung/Ihr Haus nicht bewohnt?
(z.B. aufgrund von regelmässigen beruflichen Reisen oder regelmässigen Wochenendreisen)

- 0 Tage
- 1 bis 3 Tage
- 4 oder mehr Tage

16

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Reduktion des Energieverbrauchs

*
Wie sehr stimmen Sie den folgenden Aussagen zu oder nicht zu?

	Stimme gar nicht zu	Stimme nicht zu	Unentschieden	Stimme zu	Stimme vollkommen zu
Ich fühle mich moralisch verpflichtet, meinen Energieverbrauch zu reduzieren.	○	○	○	○	○
Solange andere nicht das gleiche tun, bin ich nicht bereit meinen Energieverbrauch zu reduzieren.	○	○	○	○	○
Zum Schutz der Umwelt bin ich bereit Einschränkungen in meinem Lebensstil hinzunehmen.	○	○	○	○	○

17

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Haushaltsgeräte

Nun haben Sie bereits 35 % der Fragen beantwortet.

Kochen

* Haben Sie folgende Geräte in Ihrem Haushalt? Falls ja, wie alt sind diese Geräte?

Kochherd

* **Backofen**

* **Wie viele warme Mahlzeiten bereiten Sie und/oder andere Mitglieder Ihres Haushaltes in einer typischen Woche zu?**

	Anzahl pro Woche
Gekochte Mittagessen	
Gekochte Abendessen	

18

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Haushaltsgeräte

Haben Sie diese Geräte in den vergangenen fünf Jahren neu hinzugefügt oder ersetzt?

	Keine Veränderung	Ersetzt	Neu hinzugefügt	Weiss nicht / Nicht zutreffend
Kochherd				
Backofen				

Falls eines oder mehrere dieser Geräte neu hinzugefügt oder ersetzt wurden:

In welchem Jahr?

	Jahr
Kochherd	
Backofen	

19

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Haushaltsgeräte

Kühlen und Gefrieren

Kühlschrank (mit oder ohne Gefrierfach) — Kühl-Gefrier-Kombination

* Haben Sie folgende Geräte in Ihrem Haushalt? Falls ja, wie alt sind diese Geräte?

Kühlschrank (mit oder ohne Gefrierfach):

...Falls ja, ist es eine Kühl-Gefrier-Kombination? (2 Türen)

- Ja
- Nein

* **Zusätzlicher Kühlschrank (mit oder ohne Gefrierfach):**

...Falls ja, ist es eine Kühl-Gefrier-Kombination? (2 Türen)

- Ja
- Nein

* **Separater Tiefkühler:**

20

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Haushaltsgeräte

Haben Sie diese Geräte in den vergangenen fünf Jahren neu hinzugefügt oder ersetzt?

	Keine Änderung	Ersetzt	Neu hinzugefügt	Weiss nicht / Nicht zutreffend
Kühlschrank				
Zusätzlicher Kühlschrank				
Separater Tiefkühler				

Falls eines oder mehrere dieser Geräte neu hinzugefügt oder ersetzt wurden:

In welchem Jahr?

	Jahr
Kühlschrank	
Zusätzlicher Kühlschrank	
Separater Tiefkühler	

21

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Haushaltsgeräte

Geschirrspüler

* **Haben Sie in Ihrem Haushalt einen Geschirrspüler? Falls ja, wie alt ist dieser?**

* **Wie häufig benutzen Sie und/oder andere Mitglieder Ihres Haushaltes den Geschirrspüler in einer typischen Woche?**

22

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Haushaltsgeräte

Haben Sie den Geschirrspüler in den vergangenen fünf Jahren neu hinzugefügt oder ersetzt?

- Keine Änderung
- Neu hinzugefügt
- Ersetzt
- Weiss nicht

Falls der Geschirrspüler neu hinzugefügt oder ersetzt wurde:

In welchem Jahr?

23

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Haushaltsgeräte

Waschen und Trocknen

* **Haben Sie eine Waschmaschine und/oder einen Wäschetrockner, der über Ihre Stromrechnung abgerechnet wird?**
(d.h. Gerät in Ihrer Wohnung/Ihrem Haus (nicht gemeinsam genutzt) oder Gerät, dass bei Benutzung auf Ihren Stromzähler umgeschalten wird)

- Ja
- Nein

24

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Haushaltsgeräte

Waschen und Trocknen

* **Haben Sie folgende Geräte in Ihrem Haushalt? Falls ja, wie alt sind diese Geräte?**

Waschmaschine:

* **Wäschetrockner:**

* **Wie häufig benutzen Sie und/oder andere Mitglieder Ihres Haushaltesin einer typischen Woche die folgenden Geräte?**

	Anzahl Ladungen pro Woche
Waschmaschine	
Wäschetrockner	

25

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Haushaltsgeräte

Haben Sie diese Geräte in den vergangenen fünf Jahren neu hinzugefügt oder ersetzt?

	Keine Änderung	Ersetzt	Neu hinzugefügt	Weiss nicht / Nicht zutreffend
Waschmaschine	○	○	○	○
Wäschetrockner	○	○	○	○

Falls eines oder mehrere dieser Geräte neu hinzugefügt oder ersetzt wurden:

In welchem Jahr?

	Jahr
Waschmaschine	
Wäschetrockner	

26

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Elektrogeräte

Fernsehen

*** Wie viele Röhren- und Flachbildschirmfernseher wurden in Ihrem Haushalt in den folgenden Jahren genutzt?**
Beginnend mit dem Jahr Ihres Einzugs in Ihr derzeitiges Wohnobjekt.

Röhrenfernseher:

	0	1	2	3 oder mehr
2014	○	○	○	○
2013	○	○	○	○
2012	○	○	○	○
2011	○	○	○	○
2010	○	○	○	○

*** Flachbildschirmfernseher:**

	0	1	2	3 oder mehr
2014	○	○	○	○
2013	○	○	○	○
2012	○	○	○	○
2011	○	○	○	○
2010	○	○	○	○

27

Wie viele Stunden pro Tag laufen im Durchschnitt in Ihrem Haushalt die TV-Geräte?
Bitte zählen Sie die Nutzung aller Geräte zusammen (z.B. ein Flachbildschirmfernseher läuft 3 Stunden und ein Röhrenfernseher läuft 2 Stunden; die gesamte Nutzung der TV-Geräte beträgt 5 Stunden).

28

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Elektrogeräte

Computer

*** Wie viele Desktop PCs und Laptops wurden in den folgenden Jahren in Ihrem Haushalt genutzt?**
Beginnend mit dem Jahr Ihres Einzugs in Ihr derzeitiges Wohnobjekt.

Desktop PCs:

	0	1	2	3 oder mehr
2014	○	○	○	○
2013	○	○	○	○
2012	○	○	○	○
2011	○	○	○	○
2010	○	○	○	○

*** Laptops:**

	0	1	2	3 oder mehr
2014	○	○	○	○
2013	○	○	○	○
2012	○	○	○	○
2011	○	○	○	○
2010	○	○	○	○

Wie viele Stunden pro Tag laufen im Durchschnitt in Ihrem Haushalt die Desktop PCs und Laptops?
Bitte zählen Sie bei paralleler Nutzung mehrerer Geräte die Gesamtzahl der Stunden zusammen.

29

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Beleuchtung

Beleuchtung

* **Wie hoch ist der Anteil folgender Leuchtmittel an der Gesamtzahl aller Leuchtmittel in Ihrem Haushalt?**

	Null	Weniger als die Hälfte	Etwa die Hälfte	Mehr als die Hälfte	Alle	Weiss nicht
...herkömmliche Leuchtmittel (inkl. Glühlampen, Halogen)	○	○	○	○	○	○
...Energiesparlampen (inkl. Leuchtstofflampen)	○	○	○	○	○	○
...LED-Lampen und -Bänder	○	○	○	○	○	○
...Leuchtstoffröhren (inkl. Halogenröhren)	○	○	○	○	○	○

30

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Wärme / Warmwasser

Wärme / Warmwasser

Wie häufig wird die Dusche in Ihrem Haushalt im Durchschnitt pro Woche benutzt?

Bitte addieren Sie die Gesamtzahl Duschen aller Haushaltsmitglieder.

Welche Temperatur haben Sie während der Wintermonate in Ihrem Wohnzimmer?

Welche der folgenden Objekte/Geräte haben Sie?

Mehrere Antworten möglich.

- ☐ Heimkino
- ☐ Sauna
- ☐ Klimaanlage
- ☐ Elektroauto/Hybridauto
- ☐ Solarium
- ☐ Infrarot-Heizstrahler/-gerät
- ☐ Swimming pool
- ☐ Wasserbett
- ☐ Keines dieser Objekte/Geräte
- ☐ Whirlpool/Jacuzzi
- ☐ Aquarium / Terrarium

31

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Energienutzung im Alltag

Nun haben Sie bereits 70 % der Fragen beantwortet.

* **Wie häufig führen Sie und/oder andere Mitglieder Ihres Haushalts im Alltag die folgenden Aktivitäten durch?**

	Nie	Selten	Manchmal	Sehr oft	Immer	Weiss nicht	Nicht zutreffend
Die Waschmaschine bei jedem Waschgang möglichst voll befüllen.	○	○	○	○	○	○	○
Die Wäsche bei 30°C oder weniger anstatt bei höheren Temperaturen waschen.	○	○	○	○	○	○	○
Elektrogeräte wie Fernseher oder Computer komplett abschalten [kein Standby]	○	○	○	○	○	○	○
Wahl des Geschirrspül-Programms je nach Verschmutzungsgrad des Geschirrs.	○	○	○	○	○	○	○
Bevorzugte Nutzung bestimmter Geräte zu Zeiten mit Niedertarif, z.B. Waschmaschine.	○	○	○	○	○	○	○

32

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Energienutzung im Alltag

*

Haben Sie oder andere Mitglieder Ihres Haushalts seit 2010 eines der folgenden Angebote Ihres Energieversorgers oder Ihrer Gemeinde wahrgenommen?

	Ja	Nein	Weiss nicht
Energieberatung bei Ihnen zu Hause	○	○	○
Preisnachlass beim Kauf energieeffizienter Elektrogeräte	○	○	○
Online-Anwendung, die es Ihnen ermöglicht, Ihren Energieverbrauch regelmässig zu dokumentieren und zu überwachen	○	○	○
"Smart meter", der es Ihnen ermöglicht, Ihren Stromverbrauch in Echtzeit zu verfolgen	○	○	○
Förderung für Investitionen in Energieeffizienzmassnahmen (Kredit, Steuergutschrift, Zuschuss)	○	○	○

33

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Ausgaben für Energie

Was denken Sie, wie viel haben Sie gemäss Ihrer letzten Jahres-Stromabrechnung im vergangenen Jahr, d.h. über einen Zeitraum von 12 Monaten, für Strom ausgegeben?
Bitte geben Sie eine Schätzung an ohne auf der Rechnung nachzusehen.

- ○ Weiss nicht / nicht zutreffend
- ○ Betrag in Fr. (auf Zehner gerundet)

34

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Ausgaben für Energie

Auf den folgenden Seiten stellen wir einige Quiz-ähnliche Fragen, bei denen es um Stromverbrauch und Stromkosten geht. Die korrekten Antworten erhalten Sie am Ende der Umfrage.

Wieviel kostet Ihres Wissens nach 1 Kilowattstunde (kWh) Strom in der Schweiz (im Durchschnitt)?
Bitte geben Sie eine Schätzung an ohne auf Ihrer Rechnung oder anderswo nachzusehen.

- ○ Weiss nicht
- ○ Betrag in Rappen (keine Dezimalstellen)

Was denken Sie, welche Stromkosten verursachen die folgenden Aktivitäten?

	Betrag in Rappen
Nutzung eines Desktop PCs für 1 Stunde	
Waschgang mit einer Beladung von 5kg bei 60°C	

35

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Vergleich verschiedener Aktivitäten

Vergleichen Sie die folgenden Aktivitäten: Welche Aktivität benötigt mehr Strom?

Vergleich 1:

- ○ 1 Liter Wasser in einem gewöhnlichen Topf mit Deckel zum Kochen bringen
- ○ Ein Waschgang mit einer Beladung von 5kg bei 60°C
- ○ Beide benötigen gleich viel
- ○ Weiss nicht

Vergleich 2:

- ○ 1 Liter Wasser in einem gewöhnlichen Topf mit Deckel zum Kochen bringen
- ○ 1 Liter Wasser in einem elektrischen Wasserkocher zum Kochen bringen
- ○ Beide benötigen gleich viel
- ○ Weiss nicht

Vergleich 3:

- ○ Nutzung eines Desktop-PCs für eine Stunde
- ○ Nutzung eines Laptops für eine Stunde
- ○ Beide benötigen gleich viel
- ○ Weiss nicht

36

Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Investitionsentscheidungen

Stellen Sie sich nun vor, sie haben 200 Franken auf einem Sparkonto. Sie erhalten pro Jahr 10% Zinsen auf dieses Sparkonto.
Wie hoch wäre der Kontostand nach zwei Jahren?

- ○ 204 Fr.
- ○ 220 Fr.
- ○ 240 Fr.
- ○ 242 Fr.
- ○ Weiss nicht

37

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Zu Ihnen

Nun haben Sie bereits 90 % der Fragen beantwortet.

*** Was ist Ihr Geschlecht?**

- Weiblich
- Männlich

*** Wie alt sind Sie?**

- 19 oder jünger
- 20-29
- 30-39
- 40-49
- 50-59
- 60 oder älter

*** Welche Konstellation beschreibt Ihren Haushaltstyp am besten?**

- Ein-Personen-Haushalt
- Ein-Personen-Haushalt mit einem oder mehreren Kindern
- Paarhaushalt ohne Kinder
- Paarhaushalt mit einem oder mehreren Kindern
- Anderer (z.B. Wohngemeinschaft)

44

*** Welcher ist Ihr höchster Bildungsabschluss?**

- Obligatorische Schulbildung
- Berufliche Grundbildung, z.B. Eidg. Berufsattest, Fähigkeitszeugnis
- Gymnasiale Maturität, Fach-, Berufsmaturität; Fachmittelschulausweis (FMS)
- Abschluss einer Höheren Fach- oder Technikerschule, z.B. Eidg. Diplom, Fachausweis; Diplom HF
- Abschluss einer Hochschule (Universität, ETH, Fachhochschule, Pädagogischen Hochschule)
- Anderer

In welchem Jahr haben Sie Ihren höchsten Bildungsabschluss erworben?

*** Welcher ist derzeit Ihr hauptsächlicher beruflicher Status?**

- Angestellt (Vollzeit)
- Angestellt (Teilzeit)
- Selbstständig / Freelancer
- Arbeitssuchend
- In Ausbildung
- Hausfrau / Hausmann
- Rentner/in
- Anderer

45

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Zu Ihrer(m) Partner(in)

*****
Welcher ist der höchste Bildungsabschluss Ihres Partners/Ihrer Partnerin?

- Obligatorische Schulbildung
- Berufliche Grundbildung, z.B. Eidg. Berufsattest, Fähigkeitszeugnis
- Gymnasiale Maturität, Fach-, Berufsmaturität; Fachmittelschulausweis (FMS)
- Abschluss einer Höheren Fach- oder Technikerschule, z.B. Eidg. Diplom, Fachausweis; Diplom HF
- Abschluss einer Hochschule (Universität, ETH, Fachhochschule, Pädagogischen Hochschule)
- Anderer

*** Welcher ist derzeit der hauptsächliche berufliche Status Ihres Partners/Ihrer Partnerin?**

- Angestellt (Vollzeit)
- Angestellt (Teilzeit)
- Selbstständig / Freelancer
- Arbeitssuchend
- In Ausbildung
- Hausfrau / Hausmann
- Rentner/in
- Anderer

46

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Zu Ihnen

Wie hoch war das monatliche Bruttoeinkommen Ihres Haushalts in den folgenden Jahren? (in Fr.)
Bitte addieren Sie die Bruttoeinkommen aller Haushaltsmitglieder.

	bis zu 4'500	4'501 - 6'000	6'001 - 9'000	9'001 - 12'000	mehr als 12'000	Keine Antwort / Weiss nicht
2014						
2013						
2012						
2011						
2010						

47

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Zu Ihnen

In welcher geographischen Region sind Sie überwiegend aufgewachsen?

- ◯ Schweiz
- ◯ Europa (ausserhalb Schweiz)
- ◯ Nordamerika
- ◯ Zentral- und Südamerika
- ◯ Afrika
- ◯ Asien
- ◯ Australien, Neuseeland und Ozeanien
- ◯ Andere

Haben Sie innerhalb der letzten 12 Monate mindestens einmal an eine Umweltorganisation gespendet?
(z.B. Greenpeace, WWF, myclimate etc.)

- ◯ Ja
- ◯ Nein

48

cepe
Centre for Energy Policy and Economics
Swiss Federal Institutes of Technology

Energienutzung in Schweizer Haushalten

Einwilligung

Im Rahmen unserer Untersuchung würden wir gerne Ihren Energieversorger bitten, uns Angaben zu Ihrem Elektrizitätsverbrauch (und allfälligem Gasverbrauch), zu Ihren jährlichen Ausgaben für Strom (und Gas) und Ihrer Tarifwahl während der letzten 5 Jahre zu übermitteln.*

Die Auswertung dieser Daten erfolgt vollständig anonym und lässt keinerlei Rückschlüsse auf einzelne Teilnehmer zu. Das CEPE der ETH Zürich garantiert Ihnen, dass Ihre Daten vertraulich behandelt werden, geschützt sind und nur in anonymisierter Form zu Forschungszwecken verwendet werden.

*** * Stimmen Sie zu, dass Ihr Energieversorger uns diese Informationen übermitteln darf?**

- ◯ Ja, ich stimme zu
- ◯ Nein, ich stimme nicht zu

49