The role of smart meter feedback systems in changing household energy consumption in the Netherlands

Xujun Hu
910826370090
March 2017

MSc Thesis Environmental Policy Group

First reader: Prof.dr.ir. G (Gert) Spaargaren
Thesis Supervisor / Second reader: Robin Smale

Summary

While fossil fuel based energy consumption has generated great amount of greenhouse gas emissions that exacerbates climate change issues, smart meter feedback systems are expected to reduce households' energy consumption to mitigate this impact. Smart meter feedback systems are not mandates nor incentives for households to reduce their energy use, the potential of it to save energy is therefore up for debate.

This research investigates the effects of smart meter feedback systems in reducing household's energy consumption as nudges and the role of smart meter feedback in changing household energy consumption practices towards sustainability in the Netherlands. Document study on Dutch and international literatures as well as interviews are conducted as methods for this research. Smart meter feedback nudges: salient information, social norms, and commitment are all proved to be effective in reducing households' energy consumption. In the meantime, the different forms and delivering methods of the three nudges in real context differ in their effects on changing households' energy consumption. Their triggered household behavioral changes to save energy differ as well.

From the other perspective, smart meter feedback systems would change the current household energy consumption practices when introduced. Smart meter feedback manages to change the household energy consumption practices by changing its consisting elements: materials, competences & understandings, engagement and rules. Energy consumption information and unit price gives initial changes to materials and rules respectively. Social norms and commitment lead to initial changes in engagement. These initial changes are influenced by other elements in the energy consumption practices and in the meantime affect other elements. The initial changes also vary in themselves over time. This whole dynamic process of elements changing and influencing each other, determines sustainable change in the energy consumption practices to occur, fade, stabilize or never emerge after smart meter feedback systems being introduced.

Key words: Nudge, energy consumption practices, smart meter, in-home display, feedback

Table of Contents

List of abbreviations

ACM	Authority for Consumers & Markets
DECC	Department of Energy & Climate Change
DSO	Distribution system operators
EC	EU Commission
EMS	Energy Management Systems
GG	Government Gazette
GHGs	Greenhouse gases
GON	Government of the Netherlands
IHD	In-home display
IPCC	Intergovernmental Panel on Climate Change
KEMA	Keuring van Elektrotechnische Materialen te Arnhem
PBL	Netherlands Environmental Assessment Agency
ResCon	Research & consultancy
SER	Social and Economic Council
WEC	World Energy Council

List of tables and figures

Acknowledgements

This thesis cannot be successfully accomplished with the help of many people. I would like to give many thanks to these people here, who gave great much help to this thesis. First special thanks gives to Gert Spaargaren and Robin Smale, who have supervised my thesis. I always get valuable instructions and inspirations when discussing with them. And the thesis has been reformed many times after every-time discussion.

I would also like to thank people who offered me help, took my interviews or provided me with many valuable project documents. These include many Dutch households, contact persons from energy companies, experts in the field of smart meters. I give Mr. Henk Elburg from RVO my deep honor here. He has shared many valuable documents with me and introduced me to the smart meter expert meeting, from where I had further contacts with many experts in this field. Although because of time arrangement I didn't finally reach a research cooperation with Eneco and Quby, I would still like to thank Mr. Fonger Ypma from Eneco and Ms. Margriet van Lidth de Jeude from Quby, who showed great interests in my research topic and took time to discuss with me about cooperation possibilities.

Finally, I would like to thank my family and friends, who have given me unconditional support throughout this process.

1 Introduction

Climate change is one of the most essential environmental issues nowadays. It causes global warming, sea level raising, ocean acidification and other problems, which would have severe impacts on human and nature systems. The greenhouse gases (GHGs) discharged by fossil fuel based energy consumption have a major influence on this issue and the anthropogenic emissions has now reached to its historical highest point (IPCC, 2014).

The Netherlands, with its population of nearly 17 million people, had released GHGs equivalent to 198 million ton CO_2 in year 2014. To mitigate the impact from GHGs emissions, EU had announced its 2020 climate & energy package in order for a more smart, sustainable and inclusive growth. As agreed in this package, the Netherlands is responsible for 16% reduction of its GHGs emissions (Greenhouse gas emission reduction, 2009). And the Netherlands had developed its own approach for this responsibility. In 2013, The government of the Netherlands (GON) gathered forty-seven organizations to discuss and sign the Agreement on Energy for Sustainable Growth. In this overarching agreement for sustainable growth in the Netherlands, detailed goal had been made to reduce final energy consumption averaging 1.5% annually (SER, 2015). This reduction goal is also in line with the EU Energy Efficiency Directive (Energy efficiency, 2012).

Households play an important role in this emission and energy saving plan. While energy sector being responsible for the largest share of GHGs emissions in the Netherlands, households contribute to 19% of the total final energy consumption (EC, 2016). The energy consumption from households is the result of everyday activities using electricity as key resource, such as lighting, heating with air conditioner, cooking with electric stove, washing with washing machine, cleaning with cleaner, entertaining with TV, etc.

In order to reach the goal of emission reduction and energy efficiency improvement via households, the Dutch government started large scale roll-out of smart meters from year 2015. Smart meters were estimated to save 3.2% and 6.4% respectively for electricity with indirect feedback through home energy report and real time feedback through in-home display (KEMA, 2010). The roll-out is intended to cover 80% of all the Dutch households (Internal market in electricity, 2009). And the installation amount had already reached 1.5 million till 2015 July (Engerati, 2015).

Indeed, consumers are growing to be an important force to mitigate climate change issues. Not only because they contribute large amount of energy consumption, but also the great energy saving potential they have by changing their behaviors. At home, householders could directly change their behaviors to reduce energy consumption or switch energy consumption to off-peak times. All these actions could help reduce GHGs emissions generated from energy production and consumption.

Policy makers usually use mandate and market-based policy instruments to achieve policy goals. Smart meters and their consumption feedback systems, however, are not mandate nor incentive policy methods to change household energy consumption. There is no official energy saving command delivered by smart meters and their feedback systems. Also, smart meters and feedback systems themselves do not provide any rational benefits or losses to consumers. By simply providing information to consumers via consumption feedback mechanisms like home energy report, in-home display and web-based services (PC, Tablet, smart phones), smart meters are evaluated to be an effective way in reducing household energy consumption. The reasons why smart meter feedback systems would encourage energy savings from households are not clear yet. Because of the great potential in households to reduce their energy consumption, it is important to understand the role of smart meters in changing households' energy consumption and why smart meters can be effective in reducing household energy consumption.

Therefore, the aim of this research is to understand 'the role of smart meter energy consumption feedback systems in changing household energy consumption'. The main research question is formed as:

What is the role of smart meter feedback systems in changing household energy consumption?

Two sub research questions are developed based on the main research question.

(1) What are the effects of smart meter feedback on household energy consumption?

This part of research will evaluate the effects of smart meter feedback in changing household energy consumption. The results will be presented both in a quantitative way (meaning the consumption reduction percentage) and qualitative way (meaning the changing consumption behaviors to save energy).

The Netherlands Environmental Assessment Agency has done a research recently on smart meters. This research shows that smart meters do not meet its anticipated energy savings. And this research result has triggered wide discussion on the real potential of smart meters and their feedback mechanisms in reducing household's energy consumption (ECONOMIE, 2016). In many researches, smart meter feedback sometimes failed to reduce energy consumption in some of the households. Some researches show that the initial consumption reduction brought by smart meters would fade over time or could hardly persist (Van Dam, Bakker & van Hal, 2010; Stedin, 2013). Introducing smart meters would also facilitate formation of durable habits (Van Dam, Bakker & van Hal, 2010).

Before arriving at a certain energy saving after the intervention of smart meter feedback, these researches show a diverse change process of household energy consumption. To understand the role of smart meter feedback systems in changing household energy consumption, it is also important to understand the role of smart meter feedback during this process of change. Therefore, a further step would be taken to understand the role of smart meter feedback in the change process of household energy consumption. And to reveal how do consumption changes occur, fade, stabilize, or never emerge. The second part of research, therefore, would try to find out:

(2) How does household energy consumption change after the intervention of smart meter feedback and the role of smart meter feedback in it?

In the following text, Chapter 2 will elaborate on the concept of nudge and social practices, and how these two concepts work respectively as conceptual framework for answering the research questions. Research methods developed based on research questions and conceptual framework will be presented in Chapter 3, which mainly consists of interviews and literature studies. Chapter 4 and 5 are the main empirical findings of this research, while Chapter 4 gives answer to the first sub research question and Chapter 5 to the second. Chapter 6 will evaluate the empirical results and the theories used. Chapter 7 then goes to further discussion about the character, deficiency and potential of smart meter roll-outs in the Netherlands. The conclusion of this research will be made in Chapter 8 and recommendations on further research and possible measures are given in Chapter 9.

2 Conceptual framework

This chapter will introduce two main concepts in this research: nudge and practices. A brief explanation of nudge and its previous works to achieve sustainable energy consumption will be presented first. Followed by the reasons why nudge would help to understand the effects of smart meter feedback. And how nudge is involved in the smart meter feedback.

The practice theories will then be introduced and adapted for applying to describe energy consumption practices. A framework of the changing dynamics of energy consumption practices after the introduction of smart meters will be presented. This framework will be used to understand the changing dynamics of household energy consumption after the intervention of smart meter feedback.

2.1 Nudge

Smart meters and their consumption feedback systems, as discussed in the introduction chapter, are not mandate nor incentive policy methods to change household energy consumption. By simply providing information to consumers via consumption feedback mechanisms like home energy report, in-home display and web-based services (PC, Tablet, smart phones), smart meters are evaluated to be an effective way in reducing household energy consumption.

In order to better understand the '*the effects of smart meter feedback on household energy consumption'*, nudge is chosen as a perspective for this thesis. As defined by the Chief Executive of the Behavioural Insights Team, David Halpern, "A policy intervention intends to influence behavior but does not involve any incentive or sanction, mandate or regulation can be considered as nudge" (Halpern, 2015). It is "any aspect of the choice architecture that alters people's behavior in a predictable way without forbidding any potions or significantly changing their economic incentives" (Thaler & Sunstein, 2008).

Nudge works with bounded rational humans (Tversky & Kahneman, 1974). While traditional policy measures usually assume consumers to be rational, it is believed that people are not econs and are most often unrational (Thaler & Sunstein, 2008). Psychological effects would also determine people's behavior. This understanding helps to explain the fact that traditional mandate and market-based policy instruments are not always successful in directing the behavior of consumers. And it is even harder for traditional policy instruments to encourage positive actions than to ban negative behaviors (Halpern, 2015).

Applying different psychological effects to design effective policy, nudge developed diverse types. As one of the first researchers to raise the term nudge, Sunstein (2014) pointed out ten most important nudges: 1) default rules, 2) simplification, 3) uses of social norms, 4) increases in ease and convenience, 5) disclosure, 6) warnings and graphic, 7) pre-commitment strategies, 8) reminders, 9) eliciting implementation intentions, and 10) informing people of the nature and consequences of their own past choices.

Much researches have been done about the effects of different nudges in leading people towards more sustainable energy consumption. In a large scale randomized controlled trial conducted by Ebeling and Lotz (2015) in Germany, they proved the power of default rules. When green energy contract was opt-in option, there were only 7.2% people purchased it. Whereas, the percentage significantly increased to 69.1% when green contract was the default. In a research done in the United State, social norm was proved to be an effective tool to reduce household energy consumption (Schultz, Nolan, Cialdini, Goldstein & Griskevicius, 2007). People dramatically reduced their energy consumption when they knew their energy consumption were above the average in their neighborhoods. In UK, an intervention to make the energy cost salient also shown to be successful in changing people's consumption behavior (DECC, 2014).

Because of the non-mandate nor incentive nature of smart meter feedback as policy tool, smart meter feedback can be regarded as nudge to influence households' energy consumption (visualized in *Figure 1*). And smart meter feedback could also involve many different types of nudge to influence household energy consumption. By providing information to consumers, smart meters and feedback mechanisms attempt to make energy consumption amount and costs *salient*. Some of the feedback services also offer consumption comparison with similar or neighboring households. The comparison introduces *social influence* from peers to the households. Some smart meter feedback devices also provide the function of setting a personal consumption reduction goal. This is where *commitment* plays a role. These three different nudges, which were raised by nudge scientists before, are found within smart meter feedback in changing household energy consumption (Thaler & Sunstein, 2008; Halpern, 2015).

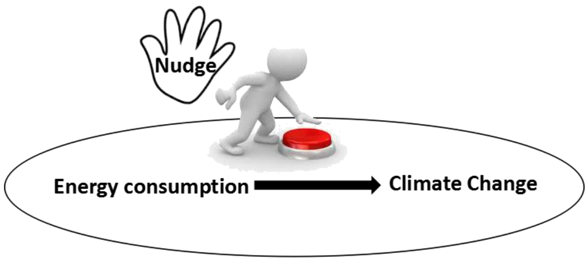


Figure 1. Nudging consumers to mitigate climate change issues

To better understand the effects and effectiveness of different smart meter feedback nudges in changing household energy consumption, the following research will investigate respectively on the effects of different smart meter feedback nudges. And the research results would serve for better design of effective smart meter feedback to encourage energy saving from households.

2.2 Energy saving behaviors

The investigation on household energy conservation behaviors can be divided into two categories: efficiency and curtailment behaviors. Efficiency behaviors are one-shot and require investment on energy efficient equipment, such as insulation, double glazing, and efficient appliances (Gardner & Stern, 2002; Fischer, 2008; Metcalf and Hassett, 1999). Curtailment behaviors involve repetitive and relatively simple efforts to reduce energy use.

Gardner & Stern (2002) consider the potential of efficiency behaviors to save energy is greater than that of curtailment behaviors. And normally, efficiency behaviors require one-shot effort and their effects would last in the long term effortlessly.

Wood and Newborough (2007) further identify different types of energy savings behaviors: on/off (e.g. turning off lights and appliances), energy frugality (reduce excessive consumption rate, e.g. turning down hot water flow), time frugality (save energy by time planning, e.g. turning off hotplate before meal is well cooked), fitting (e.g. full load operation and small hotplate for small pans), inter-appliance efficiency (achieve the same products by efficient appliance, e.g. preferring the toaster to the grill) and reasonable alternative (use non-energy consuming method, e.g. hanging clothes to dry rather than using the dryer).

The framework to understand the effects of smart meter feedback nudges on household energy consumption are therefore developed in the following graph (see *Figure 2*). The effects of smart meter feedback nudges are studied respectively by salient information, social norms and commitment. And the changing effects are paid attention to the energy savings and saving behaviors brought by smart meter feedback nudges.

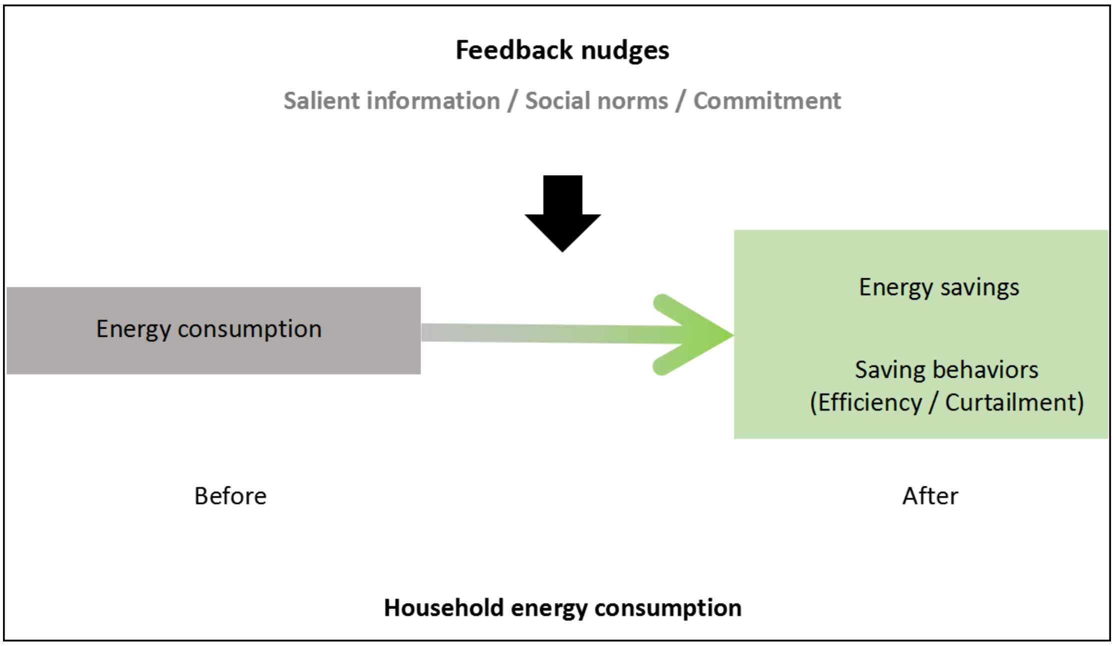


Figure 2. Smart meter feedback nudges changing household energy consumption

2.3 Practice theories

Practice theory is a different approach to understand the role of smart meter feedback in changing household energy consumption. While nudge theory helps to understand that different smart meter feedback measures leading to different saving results and behavioral changes, it is less able to answer the changing dynamic of energy consumption after the intervention of smart meter feedback.

Research has shown that smart meter feedback sometimes failed to reduce energy consumption in some households. And the initial consumption reduction brought by smart meters would fade over time or could hardly persist (Van Dam, Bakker & van Hal, 2010; Stedin, 2013). Introducing smart meters would also facilitate formation of durable habits (Van Dam, Bakker & van Hal, 2010). These phenomena can hardly be explained by nudge theory. And the role of smart meter feedback is not clear as well during this process.

Taking practices as the unit of analysis, which consists of several elements, offers a suitable framework in understanding this dynamic changing process. Practice theory has been put forward by Reckwitz (2002), Schatzki (2002), Warde (2005) and Shove (2005) as a way to understand consumption in social sciences. As Reckwitz (2002) put it, social practice is "a routinized type of behavior which consists of several elements, interconnected to one other: forms of bodily activities, forms of mental activities, 'things' and their use, a background knowledge in the form of understanding, know-how, states of emotion and motivational knowledge". It is a coherent flow (social practice as entity) filled out by multitude single and unique actions (social practice as performance) (Reckwitz, 2002).

Practice is the unit of analysis, and it integrates both the elements from individual accounts for consumer choice and systematic perspectives on consumer behavior. Consumption in social practice theories, is not considered to be a practice itself, but rather a moment in almost every practice (Warde, 2005).

Agency is one of the major concepts in social practice theories. Most of the time, they are acting in a routinized, taken for granted and non-discursive way, as carriers of certain practices (Wilk, 2009; Welch and Warde, 2015). Meanwhile, they are also active participants reproducing social practices.

Material is another important concept for social practices. No matter whether Shove (2005) argued for an independent role of materials, or Schatzki (2002) regarded materials as constructed by participants, all practice theories assert that materials have an irreplaceable, co-constituting role in social practices. Materials like things, technologies and infrastructures are essential hardware for any social practice.

Therefore, social practice theory takes energy consumption as moments of energy consumption practices. Household energy consumption practices is a series of interconnected practices reproduced in the domestic arena with the help of energy as a key resource (Naus et al., 2014). The change in energy consumption after the intervention of smart meter feedback is actually the change in energy consumption practices (visualized in *Figure 3*).

To better apply social practice theories to energy consumption study, Gram-Hanssen (2011) compared different elements of practices from the point view of different scholars (see *Table 1*). She also developed four practices elements based on her study of Denmark household heat energy consumption. From the point view of the author, however, the elements developed by her is not so clear nor straightforward for analysis of this study.

Schatzki, 2002	Warde, 2005	Shove, 2005	Reckwitz, 2002
Practical understanding General understandings	Understandings	Competences	Body, Mind, The agent

Rules	Procedures		Structure/Process
Teleo-affective structures	Engagement	Meanings	Knowledge Discourse/Language
	Items of consumption	Products	Things

Table 1. Key elements in the understanding of practices

Source: Gram-Hanssen, 2011

Based on the works of these scholars, I first take the position that energy consumption is moments of energy consumption practices and to analyze energy consumption practices as the analysis unit. The elements I choose for analyzing energy consumption practices are: 1) rules of the practices, 2) meanings and engagement, 3) materials and, 4) understandings and competences (see *Figure 3*).

There are rules of energy consumption practices including "explicit rules of how to do things, what is allowed and what is not, but tacit knowledge or implicit rules are excluded" (Schatzki, 1996; Gram-Hanssen, 2010). In this research, special focus gives to the rules of variable electricity price during day and night time. Because this rule relates more closely to the energy savings in the Dutch households.

While energy consumption practices include meanings like life enjoyment, expenses saving or green orientation holding the practices together as normative views, more importantly is the engagement of householders with these meanings. More engaged with the meanings, more closely are the householders involved with the practices. Materials like smart meters, feedback mechanisms and information are definitely vital in this practices.

General understandings and competences is "about knowing what to do, and to identify and react to something" (Reckwitz, 2002; Gram-Hanssen, 2010). In the energy consumption practices, it includes for example to understand the information provided by smart meter feedback mechanisms. These four elements are together holding energy consumption practices.

This section applies social practice theory to investigating household energy consumption. While energy consumption is taken as moments of energy consumption practices, the practice consists of four elements. These elements holding the energy consumption practice together. And the four elements would change after the intervention of smart meter feedback. This framework helps to better understand the change process of household energy consumption after introducing smart meter feedback systems. It also helps to capture the role of smart meter feedback in this dynamic changing process.

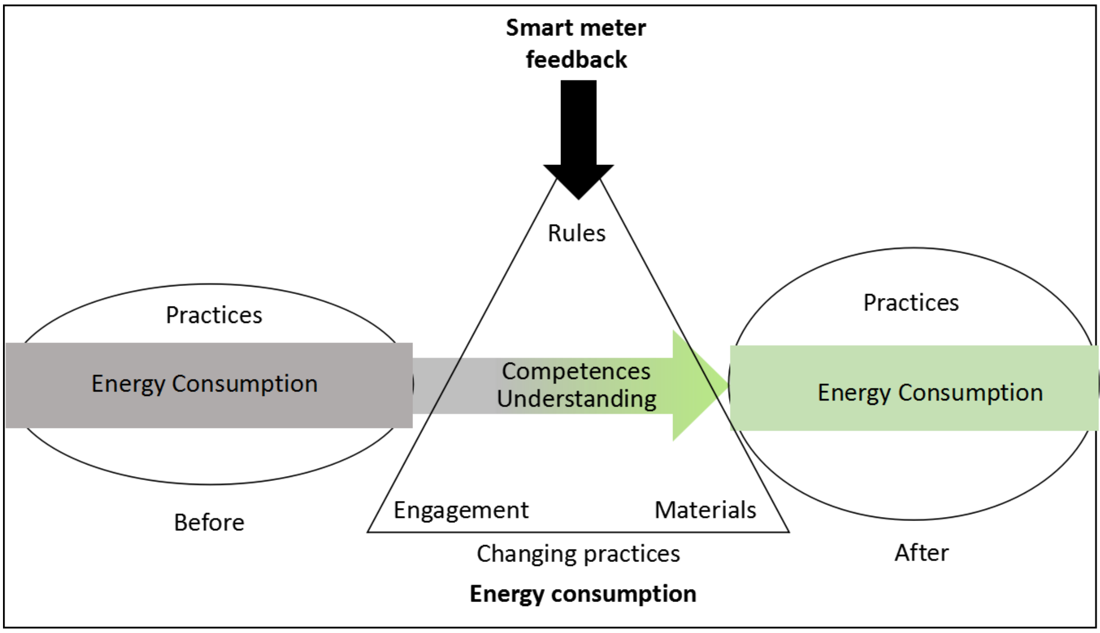


Figure 3. Changing energy consumption practices (1)

2.4 Practices changing dynamics

To better understand the change of the practices after introducing smart meter feedback into existing energy consumption practices, a model of smart meter feedback and practices interplay is further built below. It is a more zoomed-in graph of figure 3.

Smart meter feedback would change the different elements of household energy consumption practices after it being introduced. By bringing smart meters, feedback devices and information, smart meter feedback add new *materials* to existing practices. Showing electricity price variation during the day, feedback enhance the electricity pricing *rules* in the practices. And information provided by the feedback requires *understanding and competences* to make use of it. Social norms involved in the smart meter feedback are engaging householders to reduce energy consumption as a brand new *engagement*, for example a tendency to reduce energy consumption would emerge when knowing their own consumption is above peer average.

Smart meter feedback could change the elements in the energy consumption practices by introducing new things to or influencing different elements of the practices (see *Figure 4*). The change in these elements would vary in themselves over time. Further, these elements themselves are holding practices together. Therefore, they are very interconnected with each other. These elements would also interact with and alter each other as well.

When introducing smart meter feedback to existing practices, there is a starting point of one or several elements to change. This impact from feedback to energy consumption practices elements could be one shot or long last. The beginning changes in one or more elements start to interact with, impact, or being influenced by other elements. The initial influence on other elements would then trigger more changes. And finally, the practices start to stabilize turning more sustainable or remaining the same (see *Figure 4*). This whole dynamic after the intervention of smart meter feedback determines the energy consumption changes to occur, fade, stabilize, or never emerge.

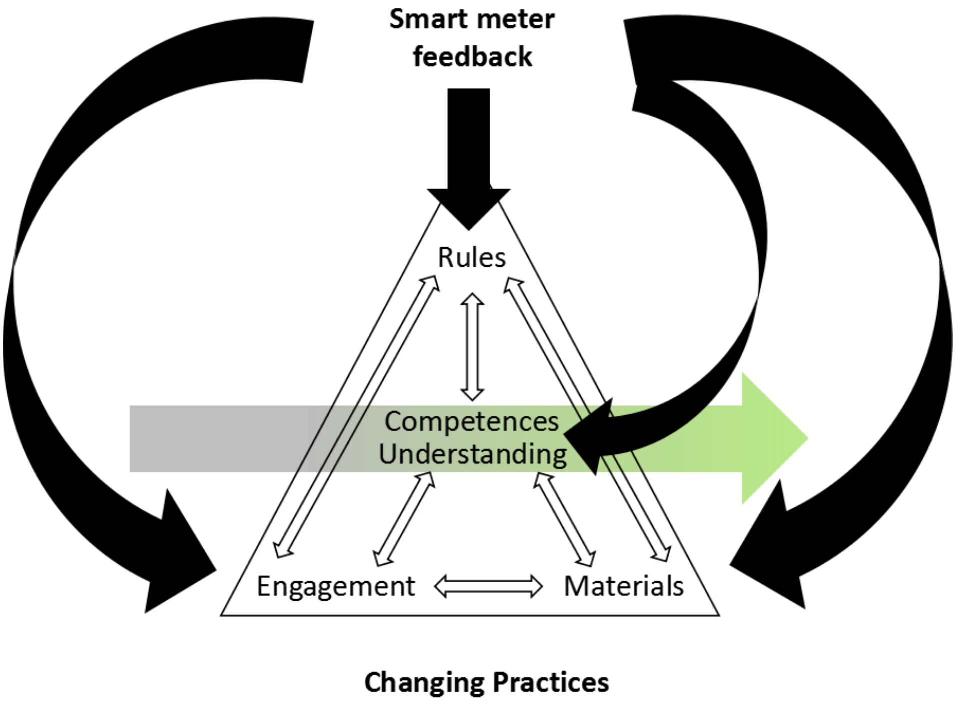


Figure 4. Changing energy consumption practices (2)

3 Methods

3.1 Project analysis

In order to understand '*the role of smart meter feedback systems in changing household energy consumption'*, project reports and peer-review papers on smart meter feedback are collected. This research gives a specific attention to smart meter feedback in the Dutch context, therefore projects conducted in the Netherlands are gathered as many as possible. Some international projects are also consulted as an extension to gain more insights on smart meter feedback and to link Dutch experiences with international context.

Various search engines (e.g. google, google scholar, Global Search Wur) were used to search for relevant projects. Further, reference lists of relevant articles were used to locate more materials. For projects that did not have available report access online, organizations or people in charge of these projects were contacted for the reports. Apart from desk study, experts in the field of smart meters were interviewed to expend the knowledge on more smart meter feedback projects conducted before. The experts would also share relevant project materials with me. Some of the experts were contacted directly via email. While, contacts with many experts were built via attending the smart meter expert meeting on 10 Nov 2016. I did many face-to-face interviews with experts who attended the meeting and continued contacting with them via email. In total I interviewed 8 experts in the field of smart meters. For many project reports that were in Dutch only, google translate is used as a tool to translate the text.

This search resulted in a total of 17 projects for detailed analysis (listed in *Table 2*). These projects are selected because they all studied the effects of smart meter feedback on household energy savings. All the projects had researched the energy saving percentage relating to smart meter feedback. Some of the projects also studied corresponding behavior changes to save energy. These all help to understand the sub-research question (1) "*What are the effects of smart meter feedback on household energy consumption?"*.

These projects are classified according to different smart meter feedback nudges involved in their studies. This helps to understand the effects of different smart meter feedback nudges separately. Projects 1-9 reveal the effects of *salient* nudge, while projects 10-12 show the effects of *social norms*. Effects of *commitment* were demonstrated in projects 13-17. Within *salient* nudge, there were observed different forms of performing *salient* in the real context: home energy report, in-home display and web-based services. And their effects in changing households' energy consumption differ. Projects 1-9 were therefore further divided according to the different salient forms involved in their studies.

Order	Project	Source
1	Small scale roll-out	Elburg, 2014
2	Nuon	PowerPlay, 2009
3	TU Delft	Van Dam, Bakker & van Hal, 2010
4	Toon	Ramondt, 2016
5	West Orange	Noort & Ossenbruggen, 2011
6	Enexis	Enexis, 2014
7	Stedin	Stedin, 2013
8	Oxxio	ResCon, 2011
9	Energy Warriors	Liander, 2014
10	Opower 1	Allcott, 2009
11	Opower 2	Ayres, 2012
12	Comparison	Schultz et al., 2015
13	Utrecht	Van Houwelingen & Van Raaij, 1989
14	Eindhoven	McCalley, 2002
15	Setting goal	Harding & Hsiaw, 2014
16	Ambitious goal	Mosler & Gutscher, 2004
17	Easy goal	Becker, 1978

Table 2. Overview of studied projects

Apart from investigating on the energy saving percentage and corresponding changing behaviors, some of the projects listed above also studied other changes during the process which relates to the elements change of energy consumption practices. These projects are further selected to get knowledge for the second sub-research question "*How does household energy consumption change after the intervention of smart meter feedback and the role of smart meter feedback in it?*". For the interest of this study, the analysis of these projects first focus on the initial changes that smart meter feedback introduced to the existing energy consumption practices. And then how the initial element changes of energy consumption practices affect and being influenced by other elements within the practices. This part of analysis would give a clue on the energy consumption changes to occur, fade, stabilize, or never emerge after the intervention of smart meter feedback.

3.2 Interviews

Interviews are conducted with 5 Dutch households and 6 Dutch energy suppliers. 5 households are contacted because one of whose family member is my friend. The interview with households is to get general knowledge of their understandings of their energy use.

For choosing energy suppliers, the list of all the energy suppliers in the Netherlands is first generated from the website https://www.energievergelijken.nl/en. The websites of these energy suppliers are then consulted to see whether they offer services on smart meter feedback. The suppliers who provide smart meter feedback services are then contacted via calling, email and their official social media account to get general knowledge of energy feedback in the Netherlands.

These companies are contacted also because of part of the research planning to study energy consumption practices change via household interviews, who are customers of these companies and receive smart meter feedback. However, due to time matching issues, this part of research plan was not conducted.

4 Effects of smart meter feedback nudges

This chapter starts to present the empirical findings of this research. Smart meter feedback mechanisms as them being diversified in the market, could involve many different nudges and various forms of one certain nudge in real context. Smart meters feedback mechanisms are firstly making information about energy consumption amount and costs *salient* to consumers. And there are various forms exist to make information salient: home energy report, in-home display and web-based services (PC, Tablet, smart phones). The various forms differ in how information are presented and approached by consumers.

Some of the feedback services introduce *social norms* when consumption comparison is offered with similar or neighboring households. Feedback mechanisms are sometimes bind with goal setting of households on their energy reduction amount. This is where *commitment* plays a role. Based on literature and project analysis, this chapter will present the effects of different nudges and their various forms in changing households energy consumption quantitatively (meaning the consumption reduction percentage resulted from feedback nudges) and qualitatively (meaning the changing consumption behavior to save energy). And to give an answer to the first sub-research question: *What are the effects of smart meter feedback on household energy consumption?*

4.1 Nudging with salient energy information

The most straightforward thing smart meter feedback mechanisms bring is the information about electricity consumption. Electricity consumption seems for many households as a double-blind thing. Unlike gas consumption, it is hard to directly sense the consumption of electricity. Electricity consumption is invisible and untouchable, consumed indirectly via different energy services. Besides that, households could allow their energy suppliers to charge energy bills automatically through their bank accounts monthly (Interview with energy suppliers 1-6, 26 Sep 2016). Therefore, households can easily lose perception on their electricity consumption amount as well as consumption costs. Let alone most people cannot make any sense of the abstract power unit kwh.

Revealing the hidden electricity consumption and costs, smart meter feedback mechanisms bring salient information to households. It works as a constant reminder of energy use. Also, households learn their electricity consumption amount and patterns with these information (Lynham, Nita, Saijo, & Tarui, 2015). There are different forms in delivering information, including home energy report, in-home display and web-based services. Each of the form differs in which information are chosen and how the information is designed, organized and approached to households. The following section will present the effects of salient information in reducing electricity consumption carried in various forms.

4.1.1 Home energy report

After the installation of smart meters, households in the Netherlands will receive home energy report bi-monthly as required in legal regulation. 'The Home Energy Report Decree' stipulates that "The report must provide insight into the actual consumption at actual energy prices and must compare this to previous consumption periods and to comparable end users." (GG, 2011). Eight power distribution system operator (DSO) companies are responsible for collecting data from smart meters, while energy supplier companies are in charge of designing and delivering home energy reports (Interview with R. Martens from Stedin and Netbeheer nerderland, 10 Nov 2016). Below is one example of home energy report in Dutch.

Omdat je een slimme meter hebt, ontvang je een tweemaandelijks overzicht van jouw verbruik, eventuele opwek en de kosten op je adres...... Het betreft een indicatief overzicht van je energieverbruik, ter voorkoming van verrassingen op de jaarnota.

Je verbruik

	Deze periode	Vorig jaar
Periode	01-05-2016 - 01-07-2016	01-05-2015 - 01-07-2015
Elektra T1 (kWh)	220	n.v.t.
Elektra T2 (kWh)	135	n.v.t.
Gas (m^3)	162	n.v.t.

Je teruglevering

	Deze periode	Vorig jaar
Periode	01-05-2016 - 01-07-2016	01-05-2015 - 01-07-2015
Elektra T1 (kWh)	0	n.v.t.
Elektra T2 (kWh)	0	n.v.t.

Als je zelf energie opwekt, lever je ook energie terug. Het bovenstaande overzicht toont de teruggeleverde energie over de afgelopen periode en dezelfde periode een jaar eerder. Als de voorgaande periode niet gevuld is, zijn er onvoldoende historische gegevens beschikbaar.

Je geschatte jaarverbruik

Elektra T1 (kWh)	1800
Elektra T2 (kWh)	1200
Gas (m^3)	1420

Op basis van het historische verbruik op je woning, wordt door de netbeheerder een geschat jaarverbruik bepaald. Je maandbedrag wordt berekend aan de hand van dit geschatte jaarverbruik. Het geschatte jaarverbruik kan wijzigen naar aanleiding van je jaarnota of tussentijdse afrekening.

Indicatieve kosten

	Netto verbruik	Tarief	Kosten deze periode	Kosten Vorig jaar
Elektra T1	220	€ 0,1392	€ 30,62	n.v.t.
Elektra T2	135	€ 0,1498	€ 20,22	n.v.t.
Gas	162	€ 0,4580	€ 74,19	n.v.t.

Dit zijn indicatieve kosten gebaseerd op de laatst geldende kwartaaltarieven van de afgelopen periode. De jaarnota wordt gebaseerd op de door de netbeheerder vastgestelde meterstanden en alle van toepassing zijnde kosten. Er kunnen dus kleine verschillen optreden tussen wat je hier ziet en de bedragen op de jaarnota.

(name of energy supplier) rekent met de huidige energietarieven inclusief huidige energiebelasting, ODE, GvO/CO_2-compensatie, opslagen, btw en netwerkkosten, maar zonder vastrecht.

Figure 5. Example of home energy report

In 2010, The Ministry of Economic Affairs had instructed KEMA to conduct a cost-benefit analysis on smart meter roll-outs. In their analysis, KEMA estimated smart meter with home energy report (indirect feedback as they name it) would allow Dutch households to achieve an average persistent reduction in energy consumption of 3.2 % for electricity (KEMA, 2010).

From 2012 to 2013, the Dutch government started a small scale roll-out of 500,000 smart meters (GON, 2016). The small scale roll-out received acceptance of more than 98 percent consumers (ACM, 2014). From 2015 onwards, the Dutch government officially started large scale roll-out of smart meters to cover 80% of households in the Netherlands.

Energy saving achieved

The effects of home energy report were first evaluated in the small scale roll-out program. The evaluation report shows that households who received home energy report consumed only an average of 0.6% less electricity per year, compared to household without smart meters (Elburg, 2014).

Name	Participants	Savings
Small scale roll-out evaluation	670 households	0.6%

Table 3. Electricity savings by home energy report in small scale roll-out

One of the reasons for the relatively low savings would due to the fact that home energy report is not powerful enough to make information salient to households in real life. As the evaluation report of small scale roll-out also shows relatively few households were aware of receiving bi-monthly home energy report. Many of them did not know about the home energy report. And some of them thought they were receiving an advertisement or spam. One year after the small scale roll-out started, only one third (32 %) of the households were aware that they were receiving home energy report.

The evaluation report investigated different methods in delivering home energy report. There were three ways: letter, email+pdf, and email+web-link. The awareness of households receiving home energy reports through regular mails was significantly higher than those who received through website links. The actual use of the home energy report was also higher when reports were sent by mail than email with pdf attachment or website link (Elburg, 2014).

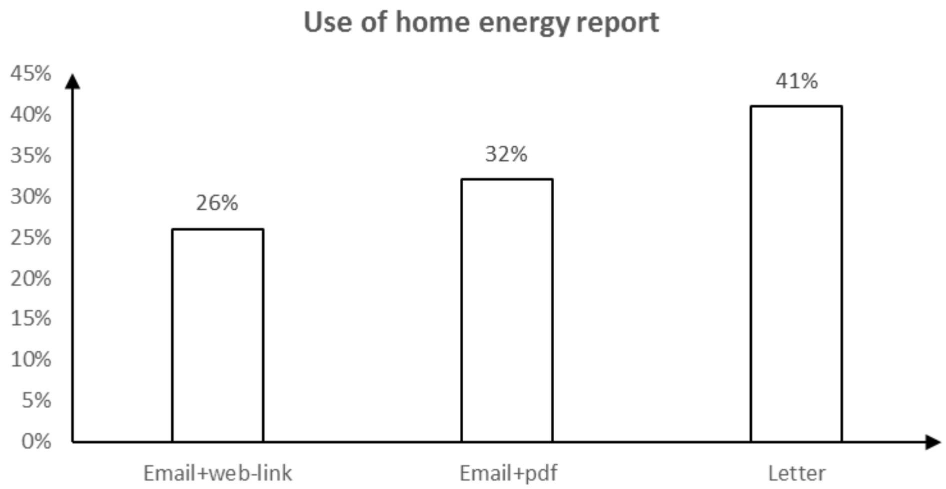


Figure 6. Use of home energy report receiving from different methods (%, n=418)

Source: Elburg, 2014

This result clearly shows different ways of making information salient vary in their effects on getting households aware and make use of the information. This difference ultimately leads to different saving consequences. The reasons for the effects of 'letter' over 'email+pdf' and 'email+web-link' are not clear yet. Mails are sent to home, while to check emails people need to open computer and applications first. And people receive much less mails than emails each day. Unlike emails being digital, mails are materialized. All these characteristics would make mails more approachable and hard to be disregarded. While checking emails takes people's effort. With large amount of emails received every day, they can easily be regarded as spam and be deleted. The real reasoning behind the differences between these various salient methods, however, needs further exploration and research.

Behavioral changes for energy saving

Gardner & Stern (2002) consider the potential of efficiency behaviors to save energy is greater than that of curtailment behaviors. And normally, efficiency behaviors require one-shot effort and their effects would last in the long term effortlessly. Although the average household energy savings are identified insignificant with home energy report, there are still behavioral changes found in many households to reduce their energy consumption. As discovered by the evaluation survey, bi-monthly home energy reports lead to more efficiency behaviors, like putting up weather strips, replacing to energy-saving light bulbs (Elburg, 2014). This may result from long-term consumption feedback triggering households to think of long-term saving strategies.

4.1.2 In-home display

Apart from required home-energy report, in-home display is another form of making information salient to consumers. Unlike in the United Kingdom, there is no combined roll-out of smart meters and displays in the Netherlands. The Netherlands government has decided to let market in charge of display services (Interview with H. Elburg from RVO, 3 Nov 2016). Households in the Netherlands, therefore, can choose to purchase energy management devices according to their own interest. These displays could be installed at home and consulted conveniently (see *Figure 7* as a sample).

Similar with home energy report, in-home display presents information about energy consumption and costs. While home energy report provides information on an aggregated bi-monthly basis. In-home display could provide more frequently updated consumption information, from monthly up to weekly, daily and even real time. Due to technical limits, the highest frequency of meter reading is 10 seconds for electricity via the P1 port (Elburg, 2014). Even though, this frequency is still sufficient to provide users with real time electricity consumption data. And as many international literatures suggested, the more frequent and immediate the feedback is, the greater impacts are on consumption reduction (Darby, 2006; Abrahamse, Steg, Vlek, & Rothengatter, 2005; Fischer, 2008).

Figure 7. Example of in-home display (Eneco Toon)

In the national cost-benefit analysis, KEMA estimated that Dutch households could save an average of 6.4 % for electricity with real-time feedback through an in-home display (KEMA, 2010). The following text brings together various studies on in-home displays to show the effects of in-home displays on households' electricity savings and according behavioral change.

Energy saving achieved

To see the effects of in-home displays, three studies are further elaborated in the following text. In the three studies, electricity savings are compared between group with in-home display and control group without displays. Table 4 gives a brief overview of these three projects.

Name	Period	Participants	Savings
Nuon	4 months	40 households	6%
TU Delft	15 months	54 households	4.7%, 7.9%
Toon	1, 2years	5473, 5309 households	2.6, 3.2%

Table 4. Effects of displays in reducing household electricity consumption

Nuon

In 2009, energy supplier Nuon in cooperation with Eindhoven University of Technology conducted a trial research on consumers with smart meter and real-time in-home energy display (PowerPlay, 2009). The small-scale experiment took place in Arnhem. All of the households had smart meters installed in their houses. Apart from that, half households received a real-time energy display and the others did not. After four months, group with displays managed to achieve considerably more energy saving (average of 9% for electricity) compare with those don't have displays (3% for electricity). Also worth noticing that higher portion of the group with displays had saved their consumption.

Certainly that social-demographic characteristics, attitudes and housing states of households will influence their energy consumption and saving. To eliminate these effects, this research selects both groups to be equal in terms of family composition, living environment and environmental incentives. Both groups were also given the same instructions and recommendations to ensure the comparability of their energy savings.

Many studies have learnt that the initial savings will lost in the long term when novelty effects fade away, people's behavior went back to before and displays were drift to the background (Allcott and Rogers, 2014; Van Dam, Bakker & van Hal, 2010). To learn the effects of displays in reducing household electricity consumption, it is therefore important to bring in a longer study (more than four months).

TU Delft

From 2008 to 2009, researchers from Delft University of Technology did a 11 months follow up study after initial 4 months' trial initiated by several commercial parties (Van Dam, Bakker & van Hal, 2010; Van Dam, 2013). In the beginning four months, all the households are offered displays. They achieved average 7.8% electricity savings after the initial trial. They then split into two groups, one kept the displays and the other one returned (in exchange for € 25). The group, who no longer kept their displays, experienced a decrease in their electricity savings from initial 3.9% to negative -1.0%. Group, who kept the displays, still maintained an average 4.6% savings. Households, who developed their habits of checking the displays once a day, even remained a 7.8% electricity saving after 15 months.

The effects of displays in reducing electricity consumption are not so solid in this research because households had the option to keep or return the displays. Therefore, the characteristics of households also influence the different saving outcomes. However, it is fair to say that displays are playing a role in reducing household electricity consumption for those kept the displays even in the long run.

It is important to point out that in both of the projects, Hawthorne effect is playing a role. Households are recruited when they are informed. They are also aware that their electricity consumption is being observed. The results from 'TU Delft' can somewhat lessen the possible effects from Hawthorne effect since the following 11-month observation is unknown to the households.

Moreover, people who are interested in joining the projects can be different from general public, also known as "volunteer bias" (Davis and Krishnamurti, 2013). Therefore, the savings and study results may not be valid for generalization. In order to eliminate the influence of Hawthorne effects and the specific characteristics of participants, the third study is introduced here.

<u>Toon</u>

Toon is one the most widespread in-home energy displays in the Netherlands. Since it was first introduced in year 2012, it has been offered to over 200,000 Dutch households. In 2015, Amsterdam University worked together with Eneco (Energy supplier and Toon retailer) and Quby (Toon developer) to evaluate the energy saving effects achieved by Toon (Ramondt, 2016). From these 200,000 households, several household characteristics were controlled to reduce assignment endogeneity bias. And over 5,300 households were selected to be treatment group. The treatment group was then distinguished into two: one-year and two-year billing after installation of Toon. Each group was matched with 15 times control households. Their yearly billing data was used for analysis.

From this large sample size and real context evaluation, Toon was estimated to save household electricity consumption for 2.6% after one-year installation. And the savings were 3.2% after two-year installation. The savings effect seems cumulatively increasing over years. This suggests after initial period after installation, savings would persist under continued treatment (Darby, 2006; Fischer, 2008).

While compared to the previous two studies, the saving effects of displays is relatively low in this evaluation. As suggested by the researcher, the lower savings could be caused by unexplained endogeneity. For example, there can be a considerable portion of control households possessing solar panels, while there is none in the treatment group. Or households who are more interested in acquiring Toon might be "gadget-loving", so they also tend to purchase more electronic appliances (Ramondt, 2016).

The three studies evaluated the saving effects of displays under different time span: 4 months, 15 months, 1 and 2 years. In the initial period after installation, households decreased in their electricity consumption. This saving effects faded to some extent as time went. However, under continued treatment, the savings started to persist and accumulate over the years.

Behavioral changes for energy saving

While in-home displays have clear effects on households' electricity consumption reduction, it is more interesting to know what specific behaviors are triggered after the installation of in-home displays, which leads to the consumption reduction. This part takes together four projects conducted in different years with different participants' size to get insights about household behavioral changes.

Name	Time	Participants
TU Delft	2008-2009	54 households
West Orange	2010	397 households
Enexis	2011-2012	900 households
Stedin	2013	127 households (low rental segment)

Table 5. Overview of projects on display triggered behavioral changes

As discussed in the previous text, household energy conservation behaviors can be divided into two categories: efficiency and curtailment behaviors. Efficiency behaviors are one-shot and requires investment (Gardner & Stern, 2002; Fischer, 2008; Metcalf and Hassett, 1999). Curtailment behaviors involve repetitive and relatively simple efforts, which include six different types: on/off, energy frugality, time frugality, fitting, inter-appliance efficiency and reasonable alternative (Wood and Newborough, 2007).

<u>TU Delft</u>

In the TU Delft research conducted from 2008 to 2009, households achieved 4.6% and 7.9% reductions after 15 months. Researchers found the most common responses to save energy were on/off (curtailment) behaviors. Households switch off unnecessary lighting and standby appliances. They also use less appliances, which might be replaced by reasonable alternatives.

There were also efficiency behaviors found within many households. Mostly, more efficient light bulbs are substituted for compact fluorescent lights (CFLs) and light-emitting diodes (LED). Less often, some households would buy new energy-saving appliances mainly washing machines, refrigerators and freezers (Van Dam, Bakker & van Hal, 2010).

<u>West Orange</u>

In 2010, nine parties in the Netherlands: IBM, AIM Amsterdam Innovation Motor, Cisco, Home Automation Europe, Liander, Nuon, Universiteit van Amsterdam, Ymere and FarWest, actively conducted a pilot study called West Orange. This study is based in the context of

Amsterdam Smart City. 397 households are involved in this project by receiving in home displays offered by the research team (Noort & Ossenbruggen, 2011). These households achieved 4.5 % electricity consumption reduction compared to control group without smart meters.

Similar with what was found in the TU Delft research, West Orange researchers found out the savings were mostly on/off (curtailment) behaviors. These are simple behavioral changes that required little or no investment of time or money. The most applied measures are: turning lights off when no one present, pull chargers after use, do not leave appliances on standby. These households also started planning for longer-term (efficiency) investments like purchasing energy efficient appliances. However, the actual buying behaviors are rarely observed.

Enexis

From 2011 and 2012, Enexis conducted a 24-month study amongst approximately 900 home owners. Quite similar with other projects, most energy savings measures taken by households are on/off (curtailment) behaviors. The most often taken measures are switching lights off in the empty room, avoiding stand-by. There are also inter-appliance (curtailment) behaviors like use air-drying laundry rather than tumble-dryer. There are time frugality behaviors observed that households cut down their showering time. Efficiency behaviors such as insulation were hardly taken into consideration (Enexis, 2014).

Stedin

In 2013, a special study was conducted by grid operator Stedin, Rotterdam housing corporation Woonbron involving 140 households in the low rental segment called PowerPlayer. Active users, who still use the Power Player daily to several times a month after 9 months after installation, achieved 7.9% energy savings.

Their most frequently taken savings measures were turning down the thermostat, turning heat off in unused rooms, switching lights off in unused areas and unplugging chargeable devices from outlets, avoiding stand-by mode. These measures are falling into the category on/off (curtailment). Many households also cut down their showering time, categorized as time frugality behavior. Efficiency measures directing at energy savings, however, were not or hardly taken into consideration.

The above described four studies, are conducted in different years with diverse sample sizes and even include special low rental segment group. The behavior changes found in the four studies have many in common. Most saving measures taken are curtailment behaviors, especially on/off. People switch off lights, appliances, thermostats, standby appliances not in use. Some of the households also are also engaged in inter-appliance and time frugality behaviors, like using air-drying laundry rather than tumble-dryer, cutting down appliances use and shower time. Whether they have changed to reasonable non-energy consuming alternatives is unknown. These curtailment behaviors require little or no time and money investment, contributing to energy saving immediately.

Efficiency behaviors are only found in one of the studies, where switching energy-intense light bulbs is the most often targeted. Households sometimes start planning for switching to energy-efficiency appliances, but the actual purchasing is rare. Install insulation or double glazing, are rarely taken into their consideration.

Compared with home energy report, in-home displays are more likely to trigger curtailment behaviors, which require little effort and save energy immediately. It might have something to do with its immediate feedback characteristics. People are directed to their consumption at the moment and respond to reduce the moment consumption. While people learn their long-term aggregated consumption from home energy report and make saving decision from another perspective. Because the aggregated energy consumption and costs are in another monetary magnitude than the immediate consumption and costs, people can invest more efforts and money to improve their energy efficiency in another magnitude. From the point view of PBL, this is also because consumers under valuate energy bills and over valuate investment (Interview with K. Vringer from PBL, 10 Nov 2016).

4.1.3 Web-based services

With the fast development of technology and economy, the ownership of smartphone in the Netherlands has reached 87% in 2016 and still has potential to increase. The percentage of laptop computers and tablets ownership are stabilized around 75% and 60% respectively (Deloitte, 2016). The tremendous penetration of mobile devices gives great platform for the development of smart meter web-based services.

Compared with in-home displays, web-based feedback services are cheaper for consumers to access. Sometimes even freely offered by their energy suppliers (See *Figure 8* as an example). It often contains more detailed information and sophisticated analysis. Therefore, it can usually provide its users with more insights. Delivered without hardware, these software offers are much easier for updating.

Figure 8. Example of web-based services (Oxxio)

Energy saving achieved

In order to learn the effects of rapid developing smart meter web-based services, the following text will focus on two pilots. One of them uses personal webpage to give consumption feedback to consumers via PC and laptop. The other project, while, develops application to give feedback via mobile phones.

Name	Participants	Medium	Savings
Oxxio	2,513 households	PC/laptop	1.5%
Energy Warriors	330 households	Phone	3%

Table 6. Overview of projects on smart meter web-based services

<u>Oxxio</u>

Join forces with research and consultancy agency Rescon and the Universities of Amsterdam and Maastricht, energy supplier Oxxio conducted a trial research on smart meter with online webpage in 2008. This web service is called MijnOxxio. It provides information about households' (historical) energy consumption, rates and costs. 2,513 Oxxio's clients were studied for a two-year period (ResCon, 2011).

The researchers found out households who used the webpage, saved an average of 1.5% electricity consumption compared to other Oxxio clients, who are not using the website but have smart meters.

<u>Energy Warriors</u>

In 2012 and 2013, network operator Liander conducted a 12-months study named Energy Warrior. a feedback tool for smart phones, named 'Energy Warrior'. About 330 residents in the city of Arnhem were involved in this study. An app was developed to provide electricity consumption both in energy units and costs. It also gave historical consumption comparison or reference group comparison. The involved households were mainly with higher income, education and environmental motivation. These households showed an average saving in electricity consumption of 3%, compared to their forecast consumption based on their historical data (Liander, 2014).

There are savings observed in the two project presented above. However, when compared with the saving effects of in-home displays, the saving potential of smart meter web-based services are not as equal or more. The advantage of IHD in reducing household electricity consumption has also been recognized by many main stakeholders (Interview with K. Vringer from PBL, 10 Nov 2016; Interview with E. Honig from Consumentenbond, 10 Nov 2016). As pointed out by many researchers, though the web-based feedback is doing better in graphic presentation and analysis, it needs more commitment and discipline for households to persist using. Before getting the information, two steps are required to open the device first and then the relevant application. Researchers also found that the attention of households on web services waned most (Elburg, 2014). This might also result from that physical in-home displays would serve as a physical reminder, whereas apps are less visible.

Behavioral changes for energy saving

<u>Energy Warriors</u>

When it comes to behavior changes triggered by web-based feedback, the qualitative survey conducted by energy warriors project finds a relatively low effect on energy-saving behaviors. Only 18 % of the households took energy saving measures because of the provided app. Most measures were curtailment behaviors. Efficiency behaviors were hardly taken into consideration (Liander, 2014).

Oxxio

In Oxxio research, however, researchers found more efficiency behaviors stimulated by the webpage feedback. Compared with the non-users, the participated households practice efficiency behaviors like invest in high-efficiency appliances, double glazing and insulation (ResCon, 2011).

It is not clear yet why different web-based feedback would stimulate different type of behaviors. Due to the insignificant saving effects and behavioral change influence, the web-based feedback has on households, the differences in behavioral change type could also result from group variances or different experimental conditions. Because of the limits of web-based feedback in engaging households using them, the effects of web services in reducing household electricity consumption remains to be seen.

4.2 Nudging with social norms

Social norm is one of the most effective nudges (Halpern, 2015; Sunstein, 2014). This results from humans being influenced frequently by others. The influence comes from information conveyed from others of what might be best for them and peer pressure (Thaler & Sunstein, 2008). People learn quickly from other people's actions or thoughts, and they usually benefit from it (Foster & Rosenzweig, 1995; Conley & Udry, 2010). This shapes a 'believe in wisdom of crowds' mindset that encourages people to follow from what others are doing (Allcott & Mullainathan, 2010). And they feel uncomfortable not doing so (Banerjee, 1992).

Social learning effects and peer pressure could largely change people's consumption behaviors and decisions (Mobius, Niehaus, & Rosenblat, 2005; Duflo & Saez, 2002; Beshears, Choi, Madrian & Milkman, 2015). And it has been proved by many studies that information on social norms can make people conserving more energy (Goldstein, Cialdini, & Griskevicius 2008).

While saving energy saves costs for households, it also reduces the environmental damage caused by energy use. And people are more likely to contribute for public goods while knowing others are doing so (Frey & Meier, 2004; Shang & Croson, 2008). Or when people's behavior are exposed to public conditions (Alpizer, Carlsson & Johansson-Stenman, 2008).

Energy saving achieved

In the Netherlands, great attention has been paid to the influence of social norms in reducing households' energy consumption. In 'The Home Energy Report Decree', it stipulates that "The report … must compare actual consumption at actual energy prices to comparable end users." (GG, 2011). The website 'energy managers [energieverbruiksmanagers]' developed by Milieucentraal, where most in-home displays and web-based products are listed and presented, 29 products are sorted under providing consumption compare with others [eigen verbruik kunnen vergelijken met anderen] (Milieu centraal, 2016). The application of social norms on smart meter feedback products are flourishing.

Despite the fact that many smart meter feedback mechanisms are currently providing information on comparison with similar or neighboring households, the effects of social norms with smart meter feedback in reducing households' energy consumption has hardly been studied separately in the Netherlands.

One of the most well-known example of social norms in influencing energy consumption is the company called OPOWER in the United States. It started as a program called OPOWER. The program is implemented as a randomized controlled natural field experiment. Treatment group receives Home Energy Reports including their electricity consumption and comparison to a hundred nearest households with comparable house size. This study shows a 1.9-2.0 percent electricity savings in the treatment households compared to the control group (Allcott, 2009).

Ayres (2012) analyzed another large-scale, random-assigned field experiments together with OPOWER in the Sacramento Municipal Utility District. Utility companies supplied households with electricity in the district. After receiving the Home Energy Reports containing neighborhood comparison information, the consumption of households reduced by 2.1%.

Another study done by Schultz, Estrada, Schmitt, Sokoloski, Silva-Send (2015), where three treatment groups receiving 'KW consumption', 'KW consumption + cost', and 'KW consumption + social comparison and norm' respectively via in home displays. Only the group receiving information on 'KW consumption + social comparison and norm' achieved 7% reduction compared to the control group over three-month experimental period.

Behavioral changes for energy saving

Allcott (2009) did a survey to investigate the effects of the Home Energy Report in changing households' behaviors. From the survey, it shows households increasing many curtailment behaviors after receiving the Reports. The most practiced behaviors fall into the on/off category: such as turning off lights and unplugging standby appliances.

"Boomerang effect" was observed in the social norm intervention (Schultz, Nolan, Cialdini, Goldstein, & Griskeviciu, 2007; Clee and Wicklund, 1980; Ringold, 2002). It suggests social norm would influence more on the high consumption households. Low consumption group would be influenced less since they knew their consumption being less than the normal. Schultz et al. (2007) then introduced "injunctive social norms" together with "descriptive social norms", which boosted the saving effects on low consumption households.

There was also decay in savings between the point of receiving two Home Energy Report. Especially for the treatment group who received Reports quarterly (Allcott, 2009). But this "action and backsliding" cycle attenuates over time (Allcott & Rogers, 2014).

The effects of social norms would persist. It has been proved, if the Report discontinued after two-year treatment, the effects would be persistent. On the other hand, however, the behavior changes are also hard to habituate. The letter reengaged the households into saving behaviors when sent to them. And this reminding or motivating effects still work even after two-year continued treatment (Allcott, 2009, 2014).

4.3 Nudging through commitment

Commitment is thought, oral or written promise to change one's behavior (Abrahamse, 2005). It often links to a qualitative (e.g. to reduce energy use) or quantitative (e.g. to save energy by 10%) goal. When a commitment is made, personal norm starts to play a role. This is the reason why people usually tend to fulfill their commitment. Psychologists interpret this mysterious power as being consistency (Cialdini, 1987). While many economists argue committing to a goal is same with setting a personal reference point (Heath, 1999). The power of commitment has been demonstrated by great many scholars (Cialdini, 1987; Moriarty, 1975).

Commitment and goal setting nudges has also been applied in the field of smart meters and energy savings (Van Dam, 2013). Many smart meter projects often provide energy consumption feedback to households together with letting the households set a reduction goal in the beginning of the project (Liander, 2014). The results of saving energy are significant. The following text is going to present the projects applying the strategy of commitment and learn the effects of commitment more in depth.

Energy saving achieved

Van Houwelingen and Van Raaij (1989) was one of the first to apply commitment strategy in household energy consumption savings. 325 households were chosen in a new town of Utrecht. These households were situated in identical rental homes and were most middle-class. One group of people were assigned to treatment 1, where households agreed to achieve 10 percent energy saving and received feedback on their progress. They also received information on energy conservation. There were treatment group 4 households, who only received information on energy conservation. The information provided to both households were the same.

After the experiment period, group setting reduction goal had achieved 12.3 percent of energy saving. While the group only receiving conservation information reduced by 4.3 percent, the commitment group saved significantly higher amount of energy. Both groups were recruited when informed and both groups knew their energy consumption being observed during the experimental period. It is therefore able to distinguish the existing effects of commitment in changing households' energy consumption amount.

In a similar vein, McCalley (2002) did an experiment applying commitment on appliance specific energy consumption. Washing machine was used as the specific electricity consuming appliances. 100 residents in Eindhoven were recruited in this experiment. They were randomly assigned to experimental groups. One of the group received feedback and set a saving goal themselves. One group only received feedback without setting a personal goal. And one group received neither feedback nor set a goal as the baseline control.

After the experiment, researchers found a 21.9% energy saving compared to the control group. While the group only receiving feedback without setting a goal had no significant difference in energy use compared with the control group.

This evidence is also supported by many international experiences (Becker, 1978; Harding & Hsiaw, 2014). In their research, Harding and Hsiaw (2014) found setting goals could help consumers to achieve on average 4 percent of energy savings. While consumers who set realistic goals could achieve persistently 11% more savings than those who set low or unrealistic high goals. This is also evidenced in the research by Mosler and Gutscher (2004). They found that too unambitious goals would discourage households to make saving efforts further. Becker (1978) in his research also found that easy goals didn't help households with energy savings.

The study on the effects of commitment on energy savings, however, are mostly quantitative researches. Therefore, the behavior change related to energy savings triggered by committing to a goal can hardly be revealed. The effects of commitment, though, is pretty powerful as shown in the previous studies.

5 Smart meter feedback in changing practices

The previous chapter has described the effects of three smart meter feedback nudges: salient information, social norms and commitment in reducing household's energy consumption amount and changing their consumption behaviors.

Energy savings and behavioral changes occur after the intervention of different smart meter feedback (PowerPlay, 2009; Ayres, 2012; Van Houwelingen and Van Raaij, 1989). Meanwhile, many projects show faded saving effects and behaviors over time by either under continuous interventions or between two intervention points (Van Dam, Bakker & van Hal, 2010; Allcott, 2009). With continuous stimulates over long term, however, the effects of smart meter feedback seem stabilize (Ramondt, 2016; Allcott, 2009). These dynamic changes of household energy consumption over time implies a more complex process after the introduction of smart meter feedback.

In order to better understand this dynamic process on consumption changes to occur, fade, stabilize, or never emerge, this chapter presents the analysis results with the help of smart meter feedback and practices interplay framework developed in Chapter 2. And to give an answer to the second sub-research question "*How does household energy consumption change after the intervention of smart meter feedback and the role of smart meter feedback in it?*".

The introduced smart meter feedback would change different elements of the existing energy consumption practices. And the initial change of these elements would also trigger changes in and being influenced by other elements. This dynamic process then determines the changes in energy savings to occur, fade, stabilize, or never emerge. The following sections will show the initial changes that smart meter feedback bring to the elements of existing energy consumption practices: materials, engagement, and rules. And how these initial changing in these elements changes over time, affects other elements and being influenced by other elements.

5.1 Changing materials

This first section will describe the change in materials brought by smart meter feedback. Smart meter feedback changes the 'materials' element of the existing energy consumption practices by bringing new materials into the practices: smart meters, feedback things and salient energy information. This initial changes in the materials would attract householders to it. And the engagement with the new materials will change the householders in the energy consumption practices and to engage more householders with more frequent saving behaviors. The changing relation of householders with the newly introduced materials over time, however, would change the initial number of householders and their frequency in conducting energy saving behaviors.

The newly introduced materials would also be influenced by other elements in the practices: mainly competences & understandings and engagement. This influence will be further elaborated in the following sections. This influence would affect the relation of householders with the newly introduced materials positively or negatively. Newly introduced materials would also alter other elements in the energy consumption practices. This influence on the other elements will change the relation of the householders with the whole practices and the amount and frequency of them conducting energy saving behaviors.

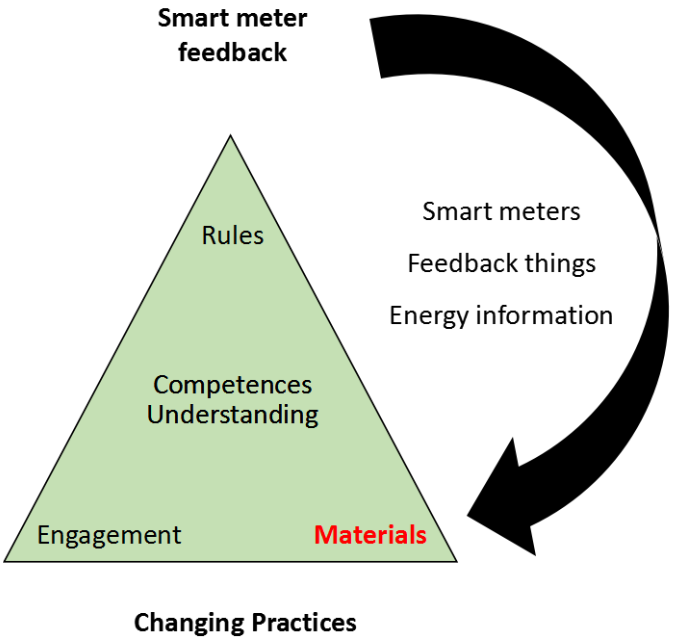


Figure 9. Smart meter feedback changing materials

5.1.1 Householders engaged with materials

The newly added 'materials' would attract householders to different extent. The engagement of householders with the materials changes over time. And for different householders, the change trend differs.

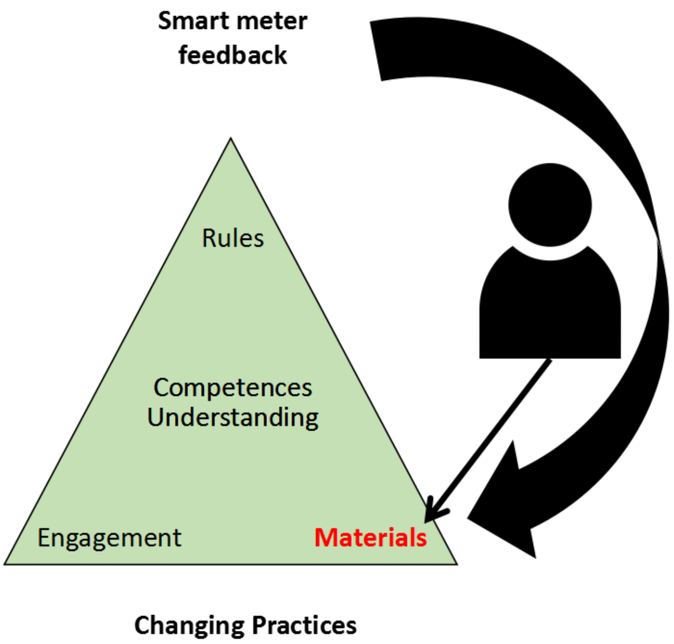


Figure 10. Householders engaged with materials

In the West Orange project, introducing the new materials engaged 99% of all the households (see *Figure 11*). The effects of engagement are remarkable. The consultancy of the materials, however, varies in the beginning of the project. Even though, 61% of all the households use it more than several times a week (Noort & Ossenbruggen, 2011).

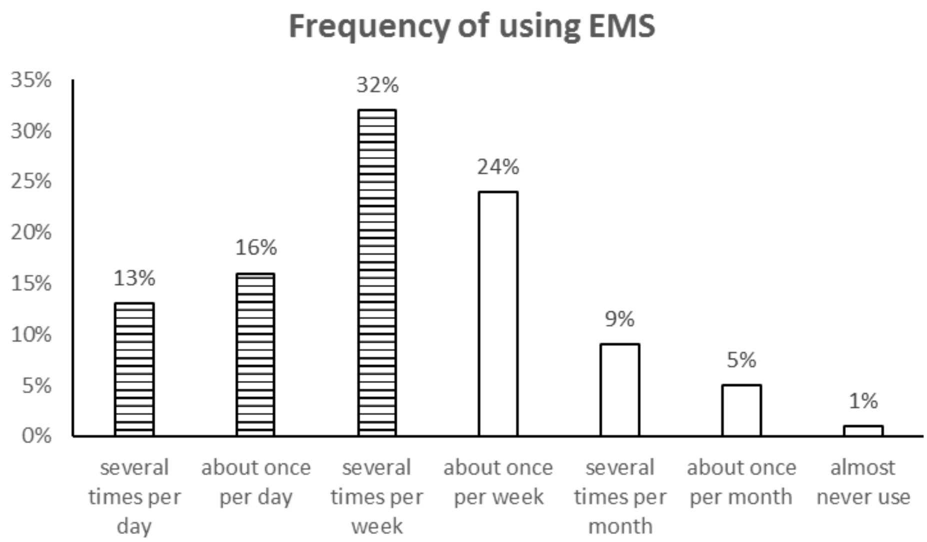


Figure 11. Frequency of using EMS

Source: Noort & Ossenbruggen, 2011

The same engagement effects of introducing new materials can also be found in Stedin project (Stedin, 2013). One month after installation of in-home display, more than 92% of all the households are engaged with the displays (see *Figure 12*). Similarly, while there are differences of using Powerplay, there are more than 70% of all the households use it more than several times a week.

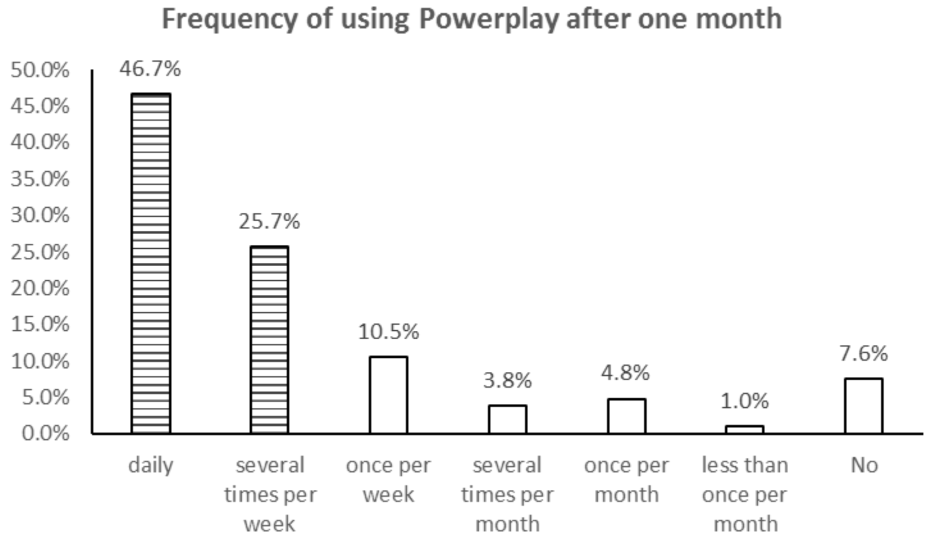


Figure 12. Frequency of using Powerplay

Source: Stedin, 2013

However, the engagement with the materials fades. The researchers found in West Orange project that the consulting of the in-home displays declined as time went. And there was hardly any click after 30 weeks.

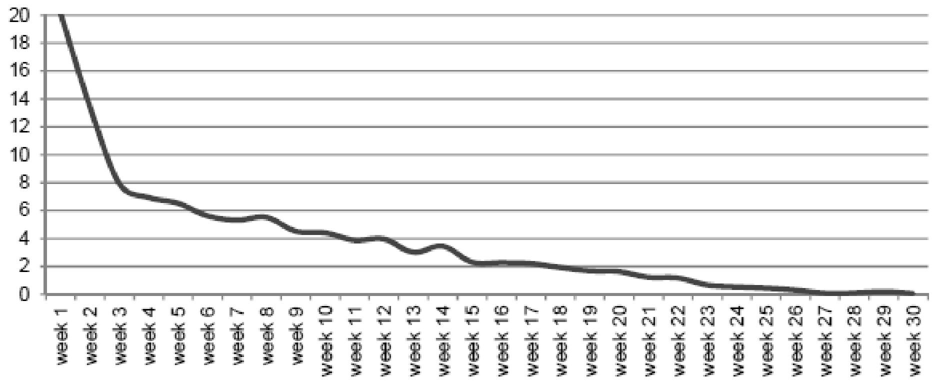


Figure 13. Frequency of using EMS over time

Source: Noort & Ossenbruggen, 2011

The similar trend was observed in the Stedin project (see *Figure 14*). Nine month after the installation of in-home displays, the consultation of the displays decreased dramatically. However, different from the West Orange project, the use of the displays did not drop to hardly any click. More than half of the households still used the displays more than once a month.

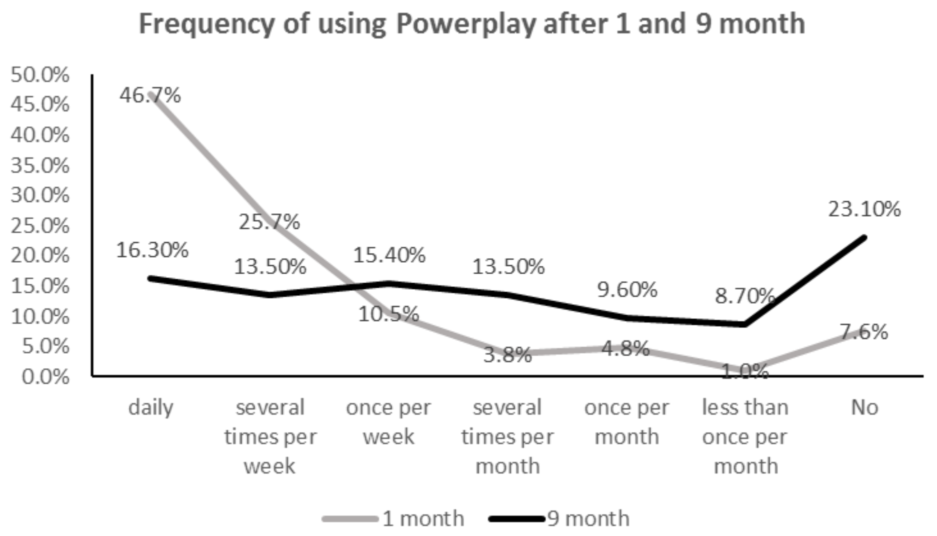


Figure 14. Frequency of using Powerplay after 1 and 9 month

Source: Stedin, 2013

The faded engagement with newly introduced materials are not only seen in the materialized but also virtual materials. In the Energy Warriors project, the frequency of using the energy management app dropped during the experimental period. At the end of 12-month projects, around two-third of the households used the app only once a month or less (Liander, 2014).

Although in most of the smart meter projects, where new materials are introduced, usage of the materials drops as the experimental time goes by. There are still many households keep using the materials. In the Oxxio project, which introduced new materials via website, had three-quarters of the experimental group still making use of their personal websites after a year (ResCon, 2011). There are also many active users of the materials after a long period of time (Stedin, 2013). Therefore, the newly introduced materials have built up a new link with householders to different degrees.

5.1.2 Relation between engagement with materials and saving behaviors

There is a relation between householders using smart meter feedback and the extent that they are involved in the energy saving behaviors. As Van Dam (2010) has found in the TU Delft project that 14 out of 26 households, who have chosen to keep the displays after initial experimental period, developed habits of checking the displays more than once a day. This group of households also performed better in their energy savings. They saved electricity use by 7.8% after 15 months. The group of households, who did not develop habits of checking the displays daily only achieved 1.7 percent of saving. The group of households, who returned their displays after the initial 4-month experimental period, even experienced a negative 0.9% electricity saving.

This indicate a strong relationship between engagement with materials and engagement with saving behaviors in the energy consumption practices. The more often materials are used, the more savings are achieved.

The same results can be seen in the Stedin (2013) research. After 9-month study, the researchers distinguish active users and non-active users. Active users are those who still use the Powerplay displays from daily to several times a month. This group of households consist more than half of the experimental households. They saved 7.9% of their electricity use at the end of the experimental period.

The non-active users, who use the Powerplay displays once a month or ever less, experienced a -0.1% electricity saving. Interestingly, there are no difference of the active users and non-active users in their age, income, house types, resident years, number of family members, proportion of immigrants, and variable consumption. They even have no differences in their motivation and attitude for energy conservation.

This indicates the developed engagement with materials, in other words, checking habits of displays, alone influences the engagement of households in the saving behaviors in the energy consumption practices. The reasons for why there are differences in checking frequency developed by different households are not clear yet.

5.1.3 Engagement with materials influenced by competences & understandings

The extent of householders making use of smart meter feedback is at the same time influenced by competences and understandings. There has been found no difference of the active users and non-active users in their age, income, house types, resident years, number of family members, proportion of immigrants, and variable consumption. However, there is one significant difference between the group of active households and non-active households in the Stedin project (Stedin, 2013). 80% of the households in the active group found the displays easy for operating. While only 50% of the households in the non-active group found the displays easy to use.

This indicates that the engagement of households with materials have something to do with required competences and understandings. Less equipped competences and understandings will influence the use frequency of, therefore, the engagement with the materials.

Apart from influencing the extent that householders consulting the smart meter feedback, competences and understandings alone can also influence the engagement of households with the saving behaviors in the practices. While 80% of the households in the active group found the displays easy for operating. The top savers in the Stedin project, found the Powerplay displays easy for everyone in the households to use. Moreover, they also know more about how to save energy.

Therefore, competences and understandings can support the engagement with materials, and at the same time, influence the engagement with saving behaviors in the practices independently (visualized in *Figure 15*).

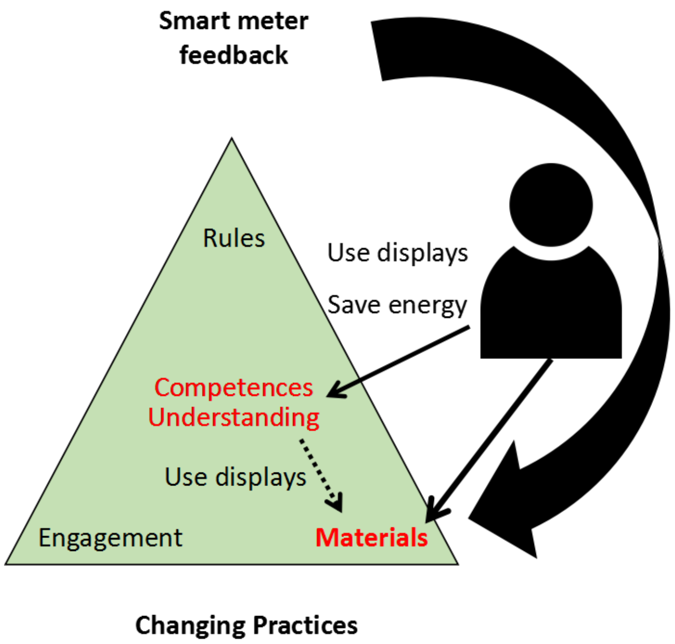


Figure 15. Engagement with materials influenced by competences & understandings

The importance of required competences and understandings to engage households into saving behaviors in the consumption practices, reflects the importance of material medium and material designs. As is revealed by the Computer and internet use trend report [Trendrapport Computer en Internetgebruik] (University of Twente, 2011), around 40 % of the 65+ individuals and 17 % of minimal educated people do not or hardly know how to use the internet. To better recruit these people into the saving behaviors in the practices, simpler electricity displays would be a more successful initial step.

Moreover, it's also important to keep the materials more comprehensive and easy. As most respondents from the Stedin (2013) project highly appreciated the car dashboard resembling for electricity use well understood for them. And three-quarter of the households would not like to see more added features of the displays. In the survey done by consumentenbond, 28% percent of the population considers easy and convenience a really important thing for them when comes to electricity conservation (Interview with E. Honig from Consumentenbond, 10 Nov 2016).

5.1.4 Engagement with materials influenced by pre-exist engagement

The relation between smart meter feedback and householders can not only be influenced by competences and understandings. Pre-exist engagement also plays a role in the extent that householders using smart meter feedback. The extent of consulting smart meter feedback materials would result from pre-exist engagement of monitoring energy use and having feedback.

Vereniging Eigen Huis, the national home owners' association, had conducted a research from 2011 to 2012 together with DSO Liander on the user experiences of households with real-time displays and web portals. From the study, the researchers found a pre-existing need for households to monitor their electricity consumption (Ruigrok Netpanel, 2012).

The same phenomenon was also found in many other projects: West Orange, Enexis and Stedin. The researchers found in the West Orange project that there pre-exists electricity consumption monitoring need for consumers (Noort & Ossenbruggen, 2011). Enexis project participants also expressed a pre-existing need for real-time consumption feedback (Enexis, 2014).

In the Stedin project, 75% of the households even considered the Powerplayer displays a missing link to access their consumption information. This activates their interest in obtaining information and their engagement with the displays (Stedin, 2013).

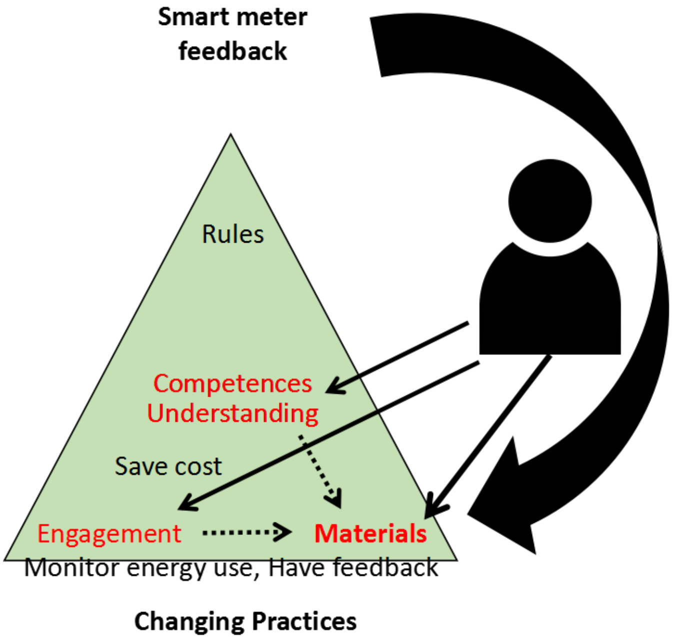


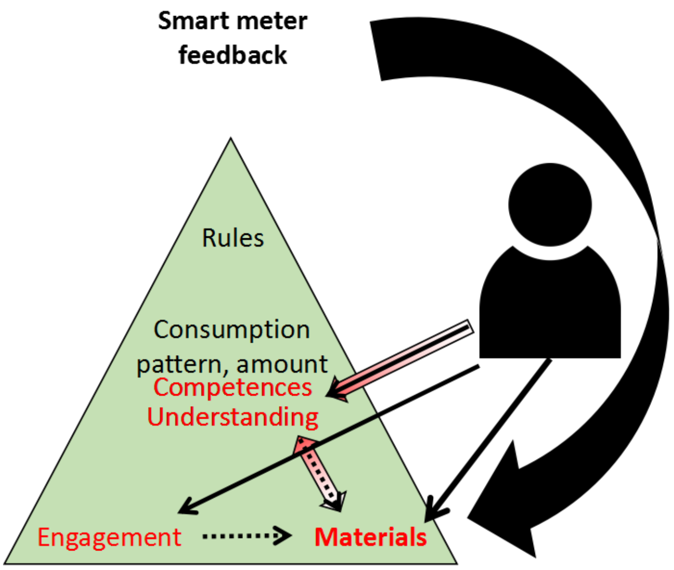
Figure 16. Pre-exist engagement for monitor

The pre-exist engagement of saving cost can also work independently in engaging households into saving behaviors in the practices. As was shown in the Stedin project, one of differences between top savers and active users is that the top savers consider it is important to save electricity (Stedin, 2013).

This engagement, however, limits on the economic concerns of the households. That is to say, their engagement with the saving behaviors in the practices is mainly reducing their energy bills and costs. The households don't really feel responsible for the environment.

5.1.5 Activating competences & understandings from materials

Changing in the element 'materials' can be influenced by the two elements in the energy consumption practices 'competences and understandings' and 'engagement'. At the same time, it can also influence and alter the two elements. Introducing of the materials in to existing energy consumption practices can activate competences and understandings. This effect is distinguished by Lynham et al. (2015) as learning effect besides the reminding function of materials.



Changing Practices

Figure 17. Activating competences & understandings

The Nuon project has found the participate households started to understand their electricity consumption patterns better. The households therefore, felt less need for consulting the displays daily (PowerPlay, 2009). The engagement with materials, hence, has transformed to competences and understandings to some extent.

The same evidence can be found in the West Orange project (Noort & Ossenbruggen, 2011). The households have more insights into their own electricity consumption amount. They also get more understanding on the energy consumption of each individual device. Moreover, the households got a sense of the energy cost of standby appliances.

Lynham et al. (2015) think the engagement of the households into the saving behaviors in the practices is resulted completely from the what they have learned from the materials. That is to say, the transformed competences and understandings from materials plays the key role. They demonstrate this argument by conducting an experiment, where "saliency group" received an IHD for two months while "learning group" only kept the IHD for the first of the two months. In their research, the "saliency group" does not outperform the "learning group". They then concluded that the learning effect is much stronger than the saliency effect.

Despite the fact, I don't find the argument of Lynham et al. (2015) very convincing. On one hand, one month without IHD is not long enough for the reminding effect to fade away. On the other, there are many evidences on the relation between frequency of using IHD with electricity savings (Noort & Ossenbruggen, 2011; Stedin, 2013). Therefore, the saliency effect does play an important role. Moreover, in Allcott and Roger's study (2014), households still respond to feedback materials even after two years' time.

It is, however, true that there is backsliding in using frequency after the initial period when materials are introduced. Some of the engagement with materials transformed into competences and understandings (PowerPlay, 2009). And for some households, the engagement just faded (Noort & Ossenbruggen, 2011; Stedin, 2013). The formulated competences and understandings can be more stable than the stimulus from materials. And the knowledge acquired from the materials, helps with the engagement of households into electricity saving behaviors in the practices. New energy use behaviors and habits would then follow (Allcott and Rogers, 2014).

5.1.6 Activating engagement from materials

Apart from influencing the element 'competences and understandings', the initial change in the 'materials' can also influence the element 'engagement'. Being reminded of their electricity consumption, can not only let households learn their consumption patterns but also enhance the saving engagement in the practices. The evidence of engagement of saving energy being promoted by displays can be seen in the Nuon project (Power Play, 2009). The researchers found a significantly increased willingness to reduce energy demand.

The enhanced saving engagement as discussed in section 5.1.4, can contribute to the increased engagement of householders with the saving behaviors in the consumption practices.

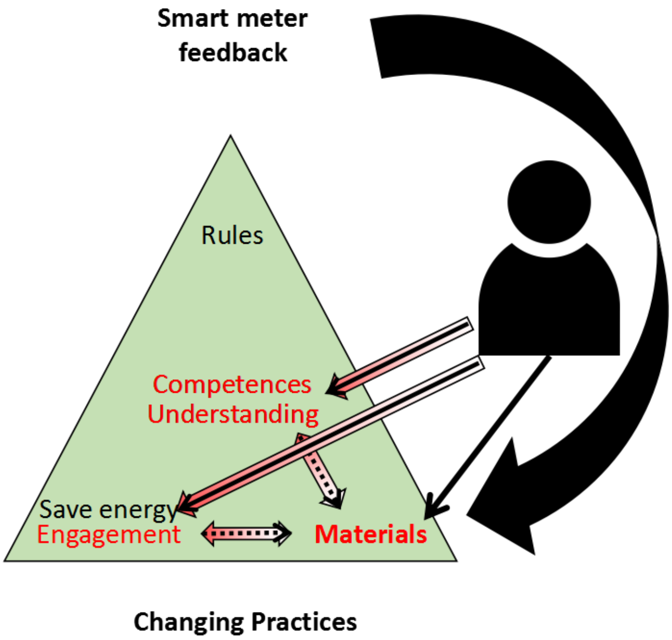


Figure 18. Activating engagement

When households start engaged in the saving behaviors, their saving engagement can also be strengthened. This is also explained as 'internalization of behavior' (Van Houwelingen and Van Raaij, 1989). When the doings of saving energy take place, the energy saving engagement enhanced at the same time. This was interpreted by psychologist as 'self-perception' effect (Bem, 1976). Householders will adapt their attitude to be accordant when they are reproducing certain behaviors. After the reproducing process, the attitude remained or the engagement enhanced.

5.2 Changing engagement

Smart meter feedback does not only change the element 'materials' by introducing new materials: smart meter, feedback things and salient energy information to the existing energy consumption practices. As described before, smart meter feedback can also enhance the engagement to save energy costs in the energy consumption practices. The engagement of environmental concerns, however, does not appear successful in engaging households into the saving behaviors in the consumption practices.

Apart from introducing new materials and activating engagement from materials, smart meter feedback can also change the 'engagement' element of the consumption practices through by bring new engagement in to the existing energy consumption practices. The newly added engagement will attract householders who are more concerned with these motivations to reproduce the energy saving behaviors in the practices (see *Figure 19*). As identified in the chapter 4, the new engagement brought by smart meter feedback are social norms and commitment.

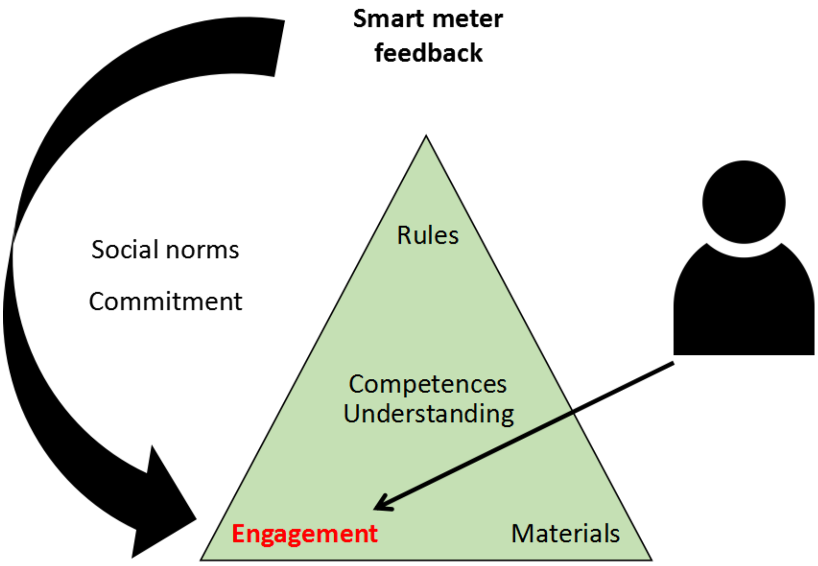


Figure 19. Smart meter feedback changing engagement

5.2.1 Householders engaged with social norms

Introducing the engagement 'social norms' into the existing energy consumption practices can increase the reproduction of electricity saving behaviors. As shown in the Opower study, the introduction of social norms has engaged households to reduce their electricity use by 1.9-2.1% (Allcott, 2009; Ayres, 2012). In the research done by Schultz et al. (2015), the result is even more remarkable. The saving effects reached 7%.

There are differences in how the social norms are formed. "Descriptive social norms" would engage households who have higher electricity consumption better, while the lower electricity consumption households will less likely be engaged. This phenomenon is also described as "boomerang effect" (Schultz et al., 2007; Clee and Wicklund, 1980; Ringold, 2002).

"Injunctive social norms", which encourages the lower consumption households, would better engage them into the reproduction of saving behaviors. It therefore would boost the savings of low consumption households (Schultz et al., 2007).

Similar with engagement with materials, the engagement with social norms of householders varies as time goes by. After the initial great attraction, the effects of social norms then waned. When intervened again, social norms would still have effects in engaging households into the saving behaviors. The effects would decay again. But this cycle would attenuate over time. The every-time introduction of social norms would accumulate gradually on its effects in engaging households into the saving behaviors (visualized in *Figure 20*).

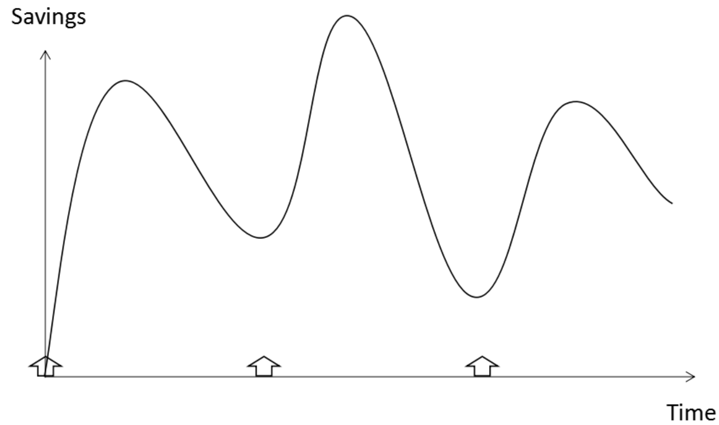


Figure 20. Engagement with social norms

The evidence can be seen in work done by Allcott (2014). Both the quarterly and monthly treated group shows a boost in saving when social norms intervened. Between every two treatment points, there was a decay in the reproduction of saving behaviors. The decay attenuates over time. And the engagement effects of social norms persist. And when the social norm report discontinued after two years, the effects were still relevant persist.

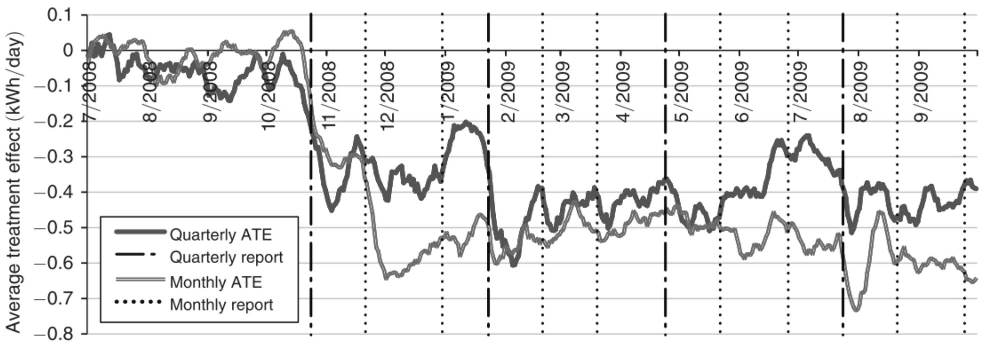


Figure 21. Treatment effect of social norms

Source: Allcott, 2014

5.2.2 Householders engaged with commitment

Apart from social norms, many scholars have in their projects also introduced commitment into exisitng energy consumption practices. The effects of commitment in engaging households into saving behaviors in the practices is prominent (Becker, 1978; Van

Houwelingen and Van Raaij, 1989; McCalley, 2002; Mosler and Gutscher, 2004; Harding & Hsiaw, 2014).

Unlike introducing of materials and social norms to the consumption practices, once households are linked to the commitment, the engagement of households with commitment persist. During the experimental period, there shows a continuous saving of the electricity. This means the reproduction of saving behaviors in the practices are more often.

As can be seen in the figure below, the engagement effects continue to accumulate till experiment period 2 (Van Houwelingen and Van Raaij, 1989). However, when the experimental condition cancels, as shown from the experiment period 2 to post-experimental period, the practices of the experimental group goes back to before again. Each of the experimental and post-experimental period lasts for one year.

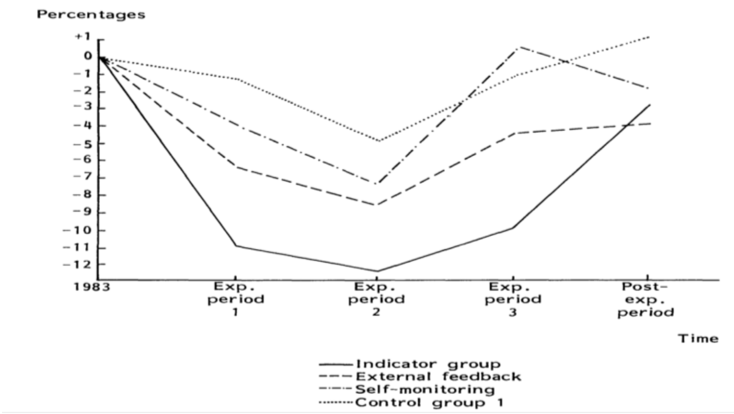


Figure 22. Engagement with commitment

Source: Van Houwelingen and Van Raaij, 1989

It indicated that unlike the persistant engagement of social norms, the engagement of commitment disappeared when households are no longer linked to a commit. The newly introduced commitment engagement hardly influenced other elements nor transformed the entire practices. It was similar with the case of introducing materials. When the newly introduced materials are no longer available in the practices, the engagement of the householders with the new materials disappear as well.

5.3 Changing rules

Introducing smart meter feedback can also change the element 'rules' in the energy consumption practices. For many energy suppliers, they bid different prices for domestic peak and off-peak electricity use. This is the rule in the energy consumption practices. Most of the time, this variable pricing rule is to some extent known by the consumers. But the exact price and corresponding hours are somewhat hidden in the existing energy consumption practices. Consumers cannot tell clearly about their electricity prices and variations in different hours. This fact there exists variable electricity price also sometimes fades from their memories (Interview with households 1-5, 4 Sep 2016).

Smart meter feedback also provides information on the variable electricity price throughout the day. This changes the elements 'rules' in the consumption practices by enhancing the pricing rules in the existing practices. And consumers are therefore more aware of this rule.

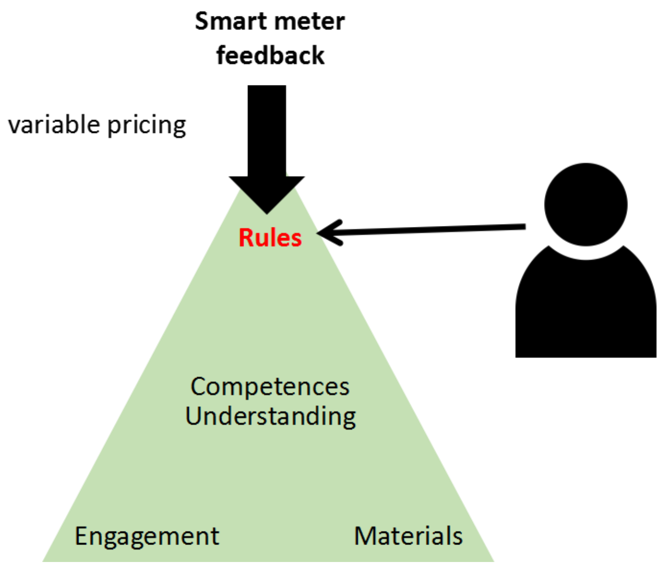


Figure 23. Smart meter feedback changing rules

Many researchers have studied the effects of enhancing the pricing rules in existing consumption practices (Jessoe & Rapson, 2014; Ida, Ito, & Tanaka, 2013; Wolak, 2011; Sexton, Johnson, & Konakayama, 1987; Heberlein & Warriner, 1983). From their research, enhancing variable pricing rules in the energy consumption practices seems do not have a close link with engaging households with behaviors of saving overall energy consumption in the practices. There is no observed conservation in the overall electricity consumption.

Enhancing the variable pricing rules, did however contribute to shifting households' electricity use from peak to off-peak hours. The higher difference of the prices is; the more shifts are observed. This is also one type valuable behavior changes in the energy consumption practices to reduce GHGs emissions. The shifted use would match the electricity production time from renewable solar energy. And it can also reduce the energy demand in peak hours, when more GHGs intense sources will be needed to produce sufficient energy. However, the shifting time use behaviors is not the main interest of this research. But it would still be very valuable for further researches.

This chapter has presented the changing process of household energy consumption after the intervention of smart meter feedback. The smart meter feedback could bring initial change in different elements of the practices, especially rules, materials, and engagement. The initial changes in these elements are being influenced by other elements and influence other elements at the same time. Change in the materials can be influenced by 'competences and understandings' and 'engagement'. It can also change these two elements. These complex dynamic of consumption change determines the extent that householders are engaged with energy saving behaviors in the practices. And also how this engagement with saving behaviors change over time. The whole dynamic of consumption change gives explanation to the consumption savings to occur, fade, stabilize or never emerge after the intervention of smart meter feedback.

6 Evaluation

Although nudge and practice theory are different approaches to understand household energy consumption, both nudge and practice theories give nice perspectives to understand 'the role of smart meter feedback systems in changing household energy consumption'. While nudge theory helps to reveal changing effects after the intervention of different smart meter feedback methods, practice theories give more insights into to the dynamic changing process of household energy consumption after smart meter feedback are introduced.

Contributions from nudge theory

With the help of nudge theory, the effects and effectiveness of different smart meter feedback methods in reducing households' energy consumption are clearly revealed. Although smart meter feedback systems do not involve any mandate or incentive, they are proved to be successful in achieving energy savings by nudging households.

As identified in the previous research, the current smart meter feedback involves three different types of nudges: salient information, social norms and commitment. These nudges have been proved helpful to make energy consumption sustainable in many cases (Ebeling and Lotz, 2015; Schultz et al., 2007). From the study results of this research, the three nudges have also worked effectively with smart meter feedback systems in achieving household energy savings.

Nudging, while works with bounded rational humans (Tversky & Kahneman, 1974), is not a specific touchable or seeable entity. Each nudge has different ways of design in real context. This leads to the different effects resulted from different forms of nudges. For example, while in-home displays and home energy report are both salient information nudge, the effects of in-home displays in reducing households' energy consumption is much greater than home energy report.

Nudge theory does not have a clear explanation on this difference. The transforming from nudges to a concrete method is described by Halpern (2015) as incremental radical. In order to maximize the effects of nudges in real context, experiments are needed to test the effects of different concrete methods. One successful design in a specific case can hardly be generalized to other cases. The effects of different designs are also hard to be predicted.

While in-home displays, web-based services, and home energy report are all proved to be successful in reducing households' energy consumption from previous studies, nudges have already found effective concrete method in smart meter feedback systems to achieve energy saving.

Contributions from practice theories

Applying nudge theory to this case has certainly give a great perspective in understanding the effects of smart meter feedback in energy savings. The smart meter feedback and practices interplay framework, further helps to understand the changing process of household energy consumption after the intervention of smart meter feedback.

When the elements of the existing energy consumption practices are changed by smart meter feedback, the newly changed elements start to engage householders into energy saving behaviors. The changes in materials by smart meter feedback devices (information) and engagement by social norms & commitment have a close link to the engagement with saving behaviors. This explains the sustainable change in the consumption practices to occur. While the engagement with the newly change elements faded, the householders conduct less energy saving behaviors. It helps to explain the faded sustainable change in the energy consumption practices. The faded engagement with newly introduced smart meter feedback devices and information, for example, results in the faded energy savings.

The engagement with newly changed elements would also persist. For example, the engagement with social norms accumulate over time. And the initial change of one element would affect other elements in the practices. Newly introduced energy information, for example, activates competences & understandings of energy consumption patterns and engagement to save energy bills. The persist engagement with the changed element and triggered changes in other elements all contribute to the saving effects to stabilize.

The initial changes in the elements are also influenced by other elements. For instance, the absence of competences & understandings in making use of the information would hinder the engagement with newly introduced materials. This impeditive effects sometimes are so strong that the engagement with newly introducing salient information can hardly be built. The sustainable changes in the existing consumption practices therefore never emerge. Withdraw the engagement from the practices, salient information and commitment especially, can result in the saving effects to fade away completely.

The interplay of smart meter feedback and practices, therefore, gives a great framework to understand the changing process of the household energy consumption after the intervention of smart meter feedback. It can be understood better why sustainable changes of household energy consumption occur, fade, stabilize or never emerge in different cases.

Differences between nudge and practice theories

Nudge theory is developed from psychological and political sciences (Thaler & Sunstein, 2008). The aim of developing nudge is to reach a policy goal with the help of influencing people psychologically. Therefore, people's behaviors can be altered positively with little capital investment from government.

Nudge focuses on developing effective intervention methods with psychological effects. And the attention of nudge research is paid much to the final results after the policy interventions (Halpern, 2015). Since people are the main objects to be influenced in nudge theory, the final changes after nudging are also brought by human beings either in themselves or their influences on the outside environment.

Practice theories, however, are developed from social sciences. Rather than focusing on individual people, practice theories take the practices as the main analysis objects. Compared with nudge theory, practice theories take individual as well as systematic perspectives into account. Apart from the psychological aspects, the description of practices includes also external rules, materials, conscious motivations, competences and understandings.

Both nudge and practice theory consider that human beings only have limited rational choice and behaviors can be contextual. But from there, the two theories go in different directions.

Nudge seeks to influence those sometimes irrational choices through intelligently designing 'choice infrastructure' in key locations through for example social norms. 'Information' and 'design' are key ways to get people to change behaviors with nudge. The weakness of nudge is that nudges can stop working after a while (e.g. people stop using smart meter feedback information after a while). And nudge did not give a clear insight into the changing process if the process is complexed. The strength of nudge, however, is the ability to concretely make design recommendations, among other things.

Practice theory is more accurate in understanding energy consumption & conservation, because these are typically routine behaviors better characterized as routines than as series of choices. Practice theory would focus more on new skills, understandings, motivations can be created through smart meter feedback. However, it is less clear how to translate practice theory insights into policy recommendations (weakness).

For this research, nudge theory provides an interesting angle to explain and study the effects of smart meter feedback to reduce household energy consumption. And this theory is able to distinguish and reveal the effects from different smart meter feedback nudges. The research results would serve more conveniently for future design of smart meter feedback.

Practice theories, on the other hand, offer a framework to present the changing dynamic of household energy consumption after the intervention of smart meter feedback. Apart from final reduction results from smart meter feedback, practice theories help to explain why do the consumption reduction changes occur, fade, stabilize over time or never emerge.

Connections between nudge and practice theories

While nudge focuses on introducing outside interventions into the existing household energy consumption, practice theories offer the image of complex changing dynamics of household energy consumption. Nudge theory presents the effects from different smart meter feedback nudges. And future policies can be developed in a way to encourage effective intervention designs. Practice theories, on the other hand, reveal the changing dynamics after the intervention of smart meter feedback and the role of smart meter feedback in it. From the research results from practice theories, we get to know when sustainable changes in energy consumption are enhanced or when are hindered. Future policies can, therefore, be designed to support the changing dynamic towards more positive outcomes.

The research results from these two theories both provide solutions to improve the energy consumption reduction from smart meter feedback. Nudge provide solutions on applying effective smart meter feedback nudges into smart meter feedback designs, and practice theories provide solutions on improving the supportive methods during the changing process. From two directions, these two theories are able to generate a more integrated picture of the role of smart meter feedback in changing household energy consumption and possible improvement methods.

7 Discussion

Non-combined roll out

While this paper discussed much on the effects of smart meter feedback systems in reducing household electricity consumption, the effects of smart meters in reducing electricity use are amplified only when combined with feedback mechanisms. Without feedback mechanisms, smart meters are only serving the energy suppliers with accurate and remote electricity consumption reads. Its effects in reducing household electricity consumption are not utilized.

Many consumers in UK even take in-home displays as smart meters in their daily conservations, even when those consumers are employees from energy companies (Interview with D. Palmer from Smart Energy GB, 10 Nov 2016). The same can be observed in pilot projects conducted in the Netherlands (Elburg, 2014). In their mind, consumers think in-home displays are smart meters. It's hard for consumers to distinguish them, because smart meters are most of the time installed out of their sight. And it is the in-home displays that provide information to households.

Since GON had decided to roll out smart meters without binding in-home displays, there are many debates on this (ECONOMIE, 2016). When it is up to consumers to decide whether to purchase an in-home display (effective feedback device), the effects of smart meters in reducing household electricity consumption are limited. GON is quite aware of the disadvantage of non-binding roll out. Whereas, they hope this strategy would save governmental cost and provide complete competitive market environment for IHD innovation (Interview with K. Vringer from PBL, 10 Nov 2016).

While Netherlands Environmental Assessment Agency (PBL) hopes that energy companies and suppliers of smart meters will do more to convince consumers about the value of purchasing a display (ECONOMIE, 2016), the main concern of the Ministry of Economic Affairs has also shifted to researching the acceptable price of IHD for consumers (Interview with H. Elburg from RVO, 3 Nov 2016).

Deficiency of smart meter feedback

Yet, there are many questioning on the effects of smart meter feedback. Some argue that one of the reasons for limited electricity reduction from smart meter feedback mechanisms is that the feedback does not give appliance specific information (ECONOMIE, 2016). From the previous analysis, it is true that specific appliance feedback is one of the key factor influencing the engagement of households with materials, also saving behaviors in the practices. There are also many other factors in engaging households better with materials. And there are also other elements: engaging with social norms and commitment would contribute to engaging households with electricity saving behaviors in the practices. Therefore, while admitting appliance specific feedback is one factor that would influence the effects of smart meter feedback on electricity savings, it is not a dominating factor.

Potential of reducing electricity use

Some people doubt about the potential of smart meter feedback as electricity consumption is of limited concern of households. This results from electricity costs being a limited share of households' expenses. While, the average Dutch households' electricity consumption is 3291 kWh per year (WEC, 2014), the average electricity cost is around 0.18 euros per kWh in the Netherlands (Eurostat, 2016). A simple calculation comes that the average electricity cost for a Dutch household is 579 euros per year. Compares to the average income and living expenses in the Netherlands, the electricity costs indeed shares a limited number of households' expenditure. Main stakeholders in the field of smart meters also consider that consumers don't concern about energy conservation (Interview with K. Vringer from PBL, 10 Nov 2016; interview with M. Lamers from twinstone, 10 Nov 2016).

This might lead to the fact that even with the similar house conditions, the energy consumption amount between different households can vary up to three times (Gram-Hanssen, 2010). Meanwhile, the big differences give great potential for smart meter feedback in reducing household electricity consumption.

First glimpse of the electricity usage distribution in the Netherlands may not provide a clear clue on the potential of households' electricity savings. However, Sonderegger (1978) had in his research, reported that 33% of home energy use is attributable to user behavior in the United States. And Verhallen and Van Raaij (1981) had reported 26% energy use accounting on household behaviors for the Netherlands. Only by saving energy for space heating, households could save up to 10% of their overall energy consumption (Darby, 2001; Wilhite & Ling, 1992).

It had also been reported that the majority of Dutch households were well-insulated and had more double glazing than most other European countries. And if the house were built since the early 1990s, there were also more stringent energy efficiency standards than most European countries (Ramondt, 2016). This might limit the potential reduction degree of household electricity consumption from smart meter feedback.

However, from the below distribution figure we can imaging that only by finding an alternative non-energy consuming method for Dryer alone, can reduce the household electricity consumption by 6%. The potential of smart meter feedback in reducing household electricity consumption, is therefore, promising.

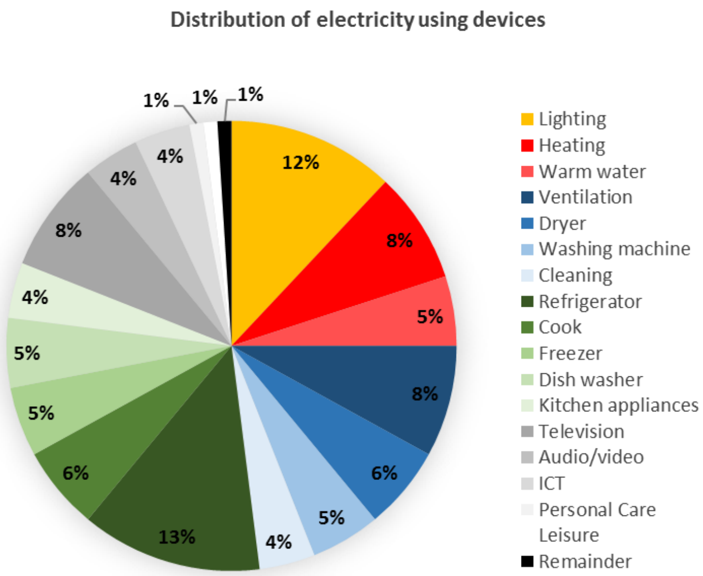


Figure 24. Distribution of electricity using devices

Source: ECN, Energie-Nederland, & Netbeheer Nederland, 2016

Applying default

The power of default nudges has been recognized by plenty of leading scholars (Halpern, 2015; Thaler & Sunstein, 2008). It has also been applied to the field of promoting sustainable energy consumption. Examples are defaulting people to green energy contract (Ebeling and Lotz, 2015). The percentage of people signing green energy contract increased from 7.2% to 69.1% when it was the default option.

Default has also been applied to reduce energy use in working environment (Brown, Johnstone, Haščič, Vong, & Barascud, 2013). By setting a 1 °C decrease default on the thermostat, leads to a final reduction in the chosen thermostat setting by 0.38 °C.

Default has great potential in reducing household electricity consumption while introduced to the energy consumption practices. The evidence can be seen in the research on Toon (Ramondt, 2016). Because of the default function of Toon thermostat, households achieve significantly more gas saving. The Toon thermostat can be automatically turned down during away hours, at night time, or even by proximity sensing.

There is, however hardly any applications of default nudge into the field of domestic electricity conservation. Ample room is therefore left for exploring this opportunity.

8 Conclusion

While fossil fuel based energy consumption has generated great amount of greenhouse gas emissions that exacerbates climate change issues, smart meter feedback systems are expected to reduce households' energy consumption to mitigate this impact. However, smart meter feedback systems are not mandate or incentive policy methods to change household energy consumption. Therefore, how do smart meter feedback manage to reduce household energy consumption is unknown.

This research investigates the effects of smart meter feedback systems, with the help of both nudge and practice theories. While nudge theory helps to reveal changing effects after the intervention of different smart meter feedback methods, practice theories give more insights into to the dynamic changing process of household energy consumption after smart meter feedback are introduced. Document study on Dutch and international literatures about smart meter feedback and interviews on smart meter users and experts are conducted as methods for this research.

The effects of smart meter feedback in changing household energy consumption are revealed with the help of nudge theory. Smart meter feedback involves many different nudges, which makes it successful in changing household energy consumption. Smart meter feedback nudges: salient information, social norms, and commitment all contribute to the households' energy savings. The energy reduction effects and triggered behavioral changes, however, differs among different nudges and their forms in real context.

Salient information has three different forms in real context: home energy report, in-home display and web-based services. Home energy report also has different delivering methods to households. The different forms and delivering methods all make a difference in changing households' energy consumption. As investigated from many projects in previous text, in-home display is shown to be the most effective form to make information salient as well as to reduce households' energy use. It managed to reduce households' electricity use by 6% after the initial 4-month period after installation. This saving effects faded to some extent over time and remained a saving of 4.7% after a long term of 15 months. However, under continued treatment, the savings started to persist and accumulate over the years.

The effects of web-based services, however, are not as great as in-home displays. It achieved 1.5% saving with PC/laptop webpages and 3% with smartphone applications. Although the web-based feedback is doing better in graphic presentation and analysis, it is less visible compared to in-home displays and needs more commitment and discipline for households to persist using.

Home energy report turns out to be the least effective salient information form in real context. It can be easily ignored or regarded as an advertisement or spam. Home energy report only achieved a saving of 0.6%. The study of home energy report, however, shows that the delivering methods also makes a big difference in making households aware of receiving the report and make use it.

The three different forms of salient energy information in real context also differs in the behavioral changes they trigger. In-home displays are more likely to trigger curtailment behaviors, especially on/off, which require little effort and save energy immediately. Home energy report, however, leads to more efficiency behaviors, like replacing to energy-saving light bulbs. This difference may result from the different feedback characteristics of the two forms. While in-home display feedback has an immediate and daily character, home energy report gives more aggregated information with longer period. Web-based services would give rise to either efficiency behaviors or curtailment behaviors in different projects. Because of its limited reduction effects, the difference in behavioral changes may also result from participate group or experimental condition.

Social norms also have prominent effects in reducing households' energy consumption. It takes place when comparison of neighboring energy consumption is given. The effects evaluated in real context has reached 1.9-2.1% savings. And under smaller sample size experimental conditions, this saving effects achieved 7%. The behavioral changes brought by social norms are mainly on/off curtailment behaviors. Social norms also have two different forms in real context: injunctive social norms and descriptive social norms. While descriptive social norms are successful in reducing the energy consumption of the relative higher consumption group, injunctive social norms encourage the relative lower consumption group to remain or reduce their energy use as well.

The effects of commitment in reducing households' energy consumption are remarkable. When households commit to an energy saving goal, the commitment nudge starts to play a role. Commitment effect achieved an 8% reduction in regular energy use condition and 21.9% in an appliance specific condition. It is, however, important to commit to more realistic goals. Too ambitious or easy goals both do not help with reduction in energy use. While committing to realistic goals would reach a higher energy saving.

Smart meter feedback has clear effects in reducing households' energy consumption and triggering saving behaviors. However, there are also dynamic changes of household energy consumption after the introduction of smart meter feedback. The energy consumption of households would if emerge, increase, fade or stabilize. Practice theory gives a great framework to understand this dynamic changing process. And also the role of smart meter feedback in it. It can be understood better why sustainable changes of household energy consumption occur, fade, stabilize or never emerge in different cases and period of time.

Smart meter feedback changes the 'materials', 'engagement' and 'rules' elements of the existing energy consumption practices. The changes in these elements could engage more householders to energy saving behaviors more frequently.

Smart meter feedback could bring for example energy information and devices, which are practice materials. The new materials that smart meter feedback bring to the existing energy consumption practices engage most households in the very beginning, and this gives rise to great amount of saving behaviors. There is a close relationship of households with the newly introduced materials and sustainable change in the energy consumption practices. As the frequency of consulting salient information faded in the practices over time, the sustainable change of energy saving in the practices fades.

The relationship between households with the new materials, is also influenced by the elements 'competences & understandings' and 'engagement' in the practices. This means the frequency of householders using energy information and feedback devices can be influenced by their capability of operating and interpreting them. While existing 'competences & understandings' could support the relationship between households and new materials, lack 'competences & understandings' would hinder this process. Pre-exist engagement of monitoring energy use and having feedback would also support the relationship between households and the new materials. In other words, householders would consult more often of the information if they wish to. The two elements 'competences & understandings' and 'engagement' could also work independently in engaging households into saving behaviors and leading to sustainable change in the consumption practices.

The newly introduced materials 'salient information' can not only be influenced by 'competences & understandings' and 'engagement', it can also change the two elements. Households understand their electricity consumption patterns and amount after consulting the salient energy information. The frequency of consulting salient information decreases because of this learning effects, and this can be regarded as the materials transformed to competences and understandings. 'Engagement' to save energy and bills can also be activated after households consulting the salient energy consumption information.

Apart from the change in materials that smart meter feedback brings, feedback also change the 'engagement' element by introducing new engagement into the existing energy consumption practices. The newly introduced engagement: social norms and commitment can involve households into energy saving behaviors. And this leads to sustainable change in the practices. Unlike sustainable change under changing materials, the sustainable change brought by social norms accumulates under continuous stimulates over long term and faded sustainable change is only observed among the two treatment points. The sustainable change under commitment nudge persist after one-time intervention.

The changes in the element ‘rules’ brought by salient variable electricity price, while triggers time-shifting energy use behaviors, does not contribute to the savings behaviors of overall energy conservation.

Smart meter feedback effectively reduces household energy consumption by involving different kind of nudge. And the effects of nudges differ according to their different forms in real context. Sustainable change to save energy occurs when smart meter feedback changes the elements ‘engagement’ of householders and new ‘materials’. The initial changes vary in themselves over time. They also influence other elements in the practices and being influenced by other elements at the same time. These dynamics determine the sustainable change in the energy consumption practices to be hindered, enhanced or stabilized.

9 Recommendations

Performing effective nudge forms

Nudging, while proved to be effective from previous research in reducing households’ energy consumption, differs in its effects with different performing forms in real context. Different forms of salient information: home energy report, in-home display and web-based services are different in letting households make use of them. Even different ways of delivering the information makes a difference. This results in the different saving effects. Similarly, different forms of social norms and commitment also lead to different saving results. Therefore, it is important to perform more effective nudge forms when applying nudges to reduce energy use. There are many key factors in designing effective nudging forms in real context that can be applied in future designs.

<u>Make the nudge information more approachable for consumers</u>

As shown in the previous chapters, more approachable letter feedback is used more often than emails or web-links. Similarly, in-home displays are more effective than web-based services, which is less visible and requires more discipline for use. The Enexis (2014) project shows displays were used more often than web-based service. During the experimental period, most users (70 %) consulted the displays more often, even daily, compared to the web-based services being used only on average once a month. To design nudge information more approachable for consumers in real context can hence better release the effects from nudges to reduce households’ energy consumption.

<u>To nudge continuously</u>

To exert nudges for a long term is important for its effects to reduce households’ energy consumption. As shown in the previous study, the effects of salient information and social norms persist and accumulate over long time period. When the salient information nudges and commitment are withdrawn from the practices, the pervious saving effects faded completely. Fischer (2008) also suggested in his review that long term feedback would contribute to the formation of saving behaviors. A review in the Nordic countries also found that longer duration the trial was, more persistent the effects were (Henryson, Håkansson, & Pyrko, 2000).

Combining nudges

The effects of the three different nudges has been studied separately in the previous research. And it has been identified that each of them are effective in reducing households' energy consumption. To provide salient information is the main focus in current smart meter roll-outs. For future application to improve the effects of smart meter in reducing households' energy consumption, it would be a good attempt to combine the three nudges in smart meter feedback systems. Whether the savings effects of the three nudges would add up is not clear yet. However, study by Abrahamse (2005) shows that combinations of interventions can be especially effective in reducing energy use.

Build up competences and understandings

The changes in elements that smart meter feedback bring to the existing energy consumption practices are identified to be effective in engaging households into saving behaviors. The initial changes triggered by smart meter feedback can also be influenced by other elements in the practices. The element 'competences and understandings' can support the engagement with the newly introduced 'materials' on one hand, and hinder on the other.

The 'competences and understandings' to understand the information provided is vitally important. On one hand, it is necessary to keep the information medium simple for operation and information easy to be interpreted. On the other, it is also important to help households with learning to interpret and make use of the information. The recent research done by Hargreaves, Wilson and Hauxwell-Baldwin (2017) also shows that smart technologies require householders to adapt and familiarize. Otherwise, it would limit their use.

The moment of installing smart meters is shown to be vital in building up the 'competences and understandings' (Darby, 2006). However, this opportunity is not well utilized in the Netherlands. The regular way of installing a smart meter is to send a letter first informing households about the installation and the installation stuff will go to install the smart meters in short time with no explain and education (Interview with R. Martens from Stedin and Netbeheer nerderland, 10 Nov 2016).

To add short explanation and education section when installing smart meters and displays can be a valuable attempt to further increase the saving effects of smart meters. To provide instructions and possible strategies for households to save energy is also a nice way to build up 'competences and understandings' in the energy consumption practices.

Build up engagement to save cost

There are many campaigns to raise the awareness of households on environmental issues. There are also some display designs to show reduction of the greenhouse gas emissions from energy savings. The underlying assumption is that the increased engagement of householders with environmental concerns, the more likely the saving behaviors will be conducted. However, from the study of this research, the existing or increased engagement of environmental concerns do not contribute to the conduction of energy saving behaviors.

The engagement of householders with saving energy bills and costs, however, are more likely to engage householders into energy saving behaviors. While people respond stronger to loses (Tversky & Kahneman, 1974), the smart meter feedback can be designed in a way to emphasis the monetary loses by energy consumption.

References

Abrahamse, W., Steg, L., Vlek, C., & Rothengatter, T. (2005). A review of intervention studies aimed at household energy conservation. *Journal of environmental psychology*, *25*(3), 273-291.

Allcott. (2009). *Social Norms and Energy Conservation*. Retrieved from http://ceepr.mit.edu/files/papers/2009-014.pdf.

Allcott, H., & Mullainathan, S. (2010). Behavior and energy policy. *Science*, *327*(5970), 1204-1205.

Allcott, H., & Rogers, T. (2014). The short-run and long-run effects of behavioral interventions: Experimental evidence from energy conservation. *The American Economic Review*, 104(10), 3003-3037.

Alpizar, F., Carlsson, F., & Johansson-Stenman, O. (2008). Anonymity, reciprocity, and conformity: Evidence from voluntary contributions to a national park in Costa Rica. *Journal of Public Economics*, *92*(5), 1047-1060.

Authority for Consumers & Markets (ACM). (2014). *Introduction of smart meter is progressing well*. Retrieved from https://www.acm.nl/en/publications/publication/12806/Introduction-of-smart-meter-is-progressing-well/.

Ayres, I., Raseman, S., & Shih, A. (2012). Evidence from two large field experiments that peer comparison feedback can reduce residential energy usage. *Journal of Law, Economics, and Organization*, ews020.

Banerjee, A. V. (1992). A simple model of herd behavior. *The Quarterly Journal of Economics*, 797-817.

Becker, L. J. (1978). Joint effect of feedback and goal setting on performance: A field study of residential energy conservation. *Journal of applied psychology*, *63*(4), 428.

Bem, D. J. (1967). Self-perception: An alternative interpretation of cognitive dissonance phenomena. *Psychological review*, *74*(3), 183.

Beshears, J., Choi, J. J., Laibson, D., Madrian, B. C., & Milkman, K. L. (2015). The effect of providing peer information on retirement savings decisions. *The Journal of finance*, *70*(3), 1161-1201.

Brown, Z., Johnstone, N., Haščič, I., Vong, L., & Barascud, F. (2013). Testing the effect of defaults on the thermostat settings of OECD employees. *Energy Economics*, *39*, 128-134.

Cialdini, R. B. (1987). *Influence*: the psychology of persuasion. NY, USA: HarperCollins.

Clee, M. A., & Wicklund, R. A. (1980). Consumer behavior and psychological reactance. *Journal of Consumer Research*, *6*(4), 389-405.

Conley, T. G., & Udry, C. R. (2010). Learning about a new technology: Pineapple in Ghana. *The American Economic Review*, *100*(1), 35-69.

Darby, S. (2001). Making it obvious: designing feedback into energy consumption. In *Energy efficiency in household appliances and lighting*, 685-696.

Darby, S. (2006). *The effectiveness of feedback on energy consumption. A Review for DEFRA of the Literature on Metering, Billing and direct Displays*. Oxford: Environmental Change Institute, University of Oxford.

Davis, A. L., & Krishnamurti, T. (2013). The problems and solutions of predicting participation in energy efficiency programs. *Applied energy*, 111, 277-287.

Decision No 406/2009/EC of the European Parliament and of the Council of 23 April 2009 on the effort of Member States to reduce their greenhouse gas emissions to meet the Community's greenhouse gas emission reduction commitments up to 2020. OJ L 140, 5.6.2009, p. 136–148.

Department of Energy & Climate Change (DECC). (2014). *Evaluation of the DECC/John Lewis energy labelling trial.* Retrieved from https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/350282/John_Lewis_trial_report_010914FINAL.pdf.

Deloitte. (2016). *Global Mobile Consumer Survey 2016 - NL Edition*. Retrieved from https://www2.deloitte.com/content/dam/Deloitte/nl/Documents/technology-media-telecommunications/deloitte-nl-tmt-global-mobile-consumer-survey-2016.pdf

Directive 2009/72/EC of the European Parliament and of the Council of 13 July 2009 concerning common rules for the internal market in electricity and repealing Directive 2003/54/EC (Text with EEA relevance), Official Journal of the European Union, 14.8.2009. L 211/ p. 91.

Directive 2012/27/EU of the European Parliament and of the Council of 25 October 2012 on energy efficiency, amending Directives 2009/125/EC and 2010/30/EU and repealing Directives 2004/8/EC and 2006/32/EC Text with EEA relevance. OJ L 315, 14.11.2012, p. 1–56.

Duflo, E., & Saez, E. (2002). *The role of information and social interactions in retirement plan decisions: Evidence from a randomized experiment* (No. w8885). National Bureau of Economic Research.
Ebeling, F., & Lotz, S. (2015). Domestic uptake of green energy promoted by opt-out tariffs. *Nature Climate Change*, 5, 868–871.
ECN, Energie-Nederland, & Netbeheer Nederland. (2016). *Energy trends 2016 [Energietrends 2016]*. Retrieved from https://issuu.com/aandagt/docs/energietrends2016
ECONOMIE. (2016, Nov 19). *Smart energy meter saves little [Slimme energiemeter bespaart maar weinig]*. Retrived from http://nos.nl/artikel/2143894-slimme-energiemeter-bespaart-maar-weinig.html
Elburg, H.V. (2014). *Dutch Energy Savings Monitor for the Smart Meter*. Retrieved from http://english.rvo.nl/sites/default/files/2014/06/Dutch%20Smart%20Meter%20Energy%20savings%20Monitor%20final%20version.pdf.
Enexis. (2014). Smart energy savings [Slim besparen op energie]. Final report on researching the effects of using the smart meter in combination with different feedback systems [Eindrapportage onderzoek effecten gebruik slimme meter in combinatie met verschillende feedbackystemen]
Engerati. (2015). *Netherlands Smart Meter Rollout Goes Large-Scale*. Retrieved from http://www.engerati.com/article/netherlands-smart-meter-rollout-goes-large-scale.
EU Commission. (2016). *Energy datasheets: EU-28 countries*. Retrieved from https://ec.europa.eu/energy/en/data-analysis/country.
EU Commission. (2016). *EUROPE 2020: A strategy for smart, sustainable and inclusive growth*. Retrieved from http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=COM:2010:2020:FIN:EN:PDF.
Eurostat. (2016). *Electricity prices for domestic consumers - bi-annual data (from 2007 onwards) [nrg_pc_204]*. Retrieved from http://appsso.eurostat.ec.europa.eu/nui/submitViewTableAction.do.
Fischer, C. (2008). Feedback on household electricity consumption: a tool for saving energy?. *Energy efficiency*, 1(1), 79-104.
Foster, A. D., & Rosenzweig, M. R. (1995). Learning by doing and learning from others: Human capital and technical change in agriculture. *Journal of political Economy*, 1176-1209.
Frey, B. S., & Meier, S. (2004). Social comparisons and pro-social behavior: Testing" conditional cooperation" in a field experiment. *The American Economic Review*, *94*(5), 1717-1722.
Gardner, G. T., & Stern, P. C. (2002). *Environmental Problems and Human Behavior.* Boston: Pearson.
Goldstein, N., Cialdini, R., & Griskevicius, V. (2008). A room with a viewpoint: Using norm-based appeals to motivate conservation behaviors in a hotel setting. *Journal of Consumer Research*, 35(3), 472-482.
Government Gazette (GG). (2000). *Law for the protection of personal information [Wet Bescherming Persoonsgegevens]*. Retrieved from http://wetten.overheid.nl/BWBR0011468/2016-01-01.
Government Gazette (GG). (2011). *Home Energy Report Decree*. Retrieved from http://wetten.overheid.nl/BWBR0029673/2012-01-01.
Government of the Netherlands (GON). (2016). *What is a smart meter*. Retrieved from https://www.government.nl/topics/smart-meters/contents/what-is-a-smart-meter.
Gram-Hanssen, K. (2010). Residential heat comfort practices: understanding users. *Building Research & Information*, *38*(2), 175-186.
Gram-Hanssen, K. (2011). Understanding change and continuity in residential energy consumption. *Journal of Consumer Culture*, *11*(1), 61-78.
Halpern, D. (2015). *Inside the nudge unit*. London, England: WH Allen.
Harding, M. and Hsiaw, A. (2014). Goal setting and energy conservation. Journal of Economic Behavior & Organization, 107:209–227.
Hargreaves, T., Nye, M., & Burgess, J. (2010). Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors. *Energy policy*, 38(10), 6111-6119.
Hargreaves, T., Wilson, C., & Hauxwell-Baldwin, R. (2017). Learning to live in a smart home. *BUILDING RESEARCH & INFORMATION,* 1-13.
Heath, C., Larrick, R. P., & Wu, G. (1999). Goals as reference points. *Cognitive psychology*, *38*(1), 79-109.
Heberlein, T. A., & Warriner, G. K. (1983). The influence of price and attitude on shifting residential

electricity consumption from on-to off-peak periods. *Journal of Economic Psychology*, *4*(1), 107-130.
Henryson, J., Håkansson, T., & Pyrko, J. (2000). Energy efficiency in buildings through information–Swedish perspective. *Energy policy*, *28*(3), 169-180.
Ida, T., Ito, K., & Tanaka, M. (2013). Using dynamic electricity pricing to address energy crises: Evidence from randomized field experiments. *36th Annual NBER Summer Institute, Cambridge, MA, USA*.
IPCC. (2014). *Climate Change 2014: Synthesis Report*. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change [Core Writing Team, R.K. Pachauri and L.A. Meyer (eds.)]. IPCC, Geneva, Switzerland, 151 pp.
Jessoe, K., & Rapson, D. (2014). Knowledge is (less) power: Experimental evidence from residential energy use. *The American Economic Review*, *104*(4), 1417-1438.
KEMA. (2010). *Smart meters in the Netherlands: Revised financial analysis and policy advice*. Retrieved from https://www.rijksoverheid.nl/documenten/rapporten/2010/10/25/smart-meters-in-the-netherlands.
Liander. (2014). Energy Warriors [Energiekrijgers]. Final report on researching the effects of using the smart meter in combination with energy feedback through smart phones [Eindrapportage onderzoek effecten gebruik slimme meter in combinatie met een energie feedback via smart phone]
Lynham, J., Nitta, K., Saijo, T., & Tarui, N. (2015). Why does real-time information reduce energy consumption?. *Energy Economics*, 54, 173-181.
McCalley, L. T., & Midden, C. J. (2002). Energy conservation through product-integrated feedback: The roles of goal-setting and social orientation. *Journal of economic psychology*, *23*(5), 589-603.
Metcalf, G. E. and Hassett, K. A. (1999). Measuring the energy savings from home improvement investments: evidence from monthly billing data. *Review of economics and statistics*, 81(3), 516–528.
Milieu centraal. (2016). *Energieverbruiksmanagers*. Retrieved from https://www.energieverbruiksmanagers.nl.
Mobius, M. M., Niehaus, P., & Rosenblat, T. S. (2005). Social learning and consumer demand. *Harvard University, mimeograph. December*.
Moriarty, T. (1975). Crime, commitment, and the responsive bystander: Two field experiments. *Journal of Personality and Social Psychology*, *31*(2), 370.
Mosler, H.-J., & Gutscher, H. (2004). Die Förderung von Energiesparverhalten durch Kombination von instruierter Selbstverbreitung mit Interventionsinstrumenten. [Promoting Energy Conserving Behaviour by Combining Instructed Self-Diffusion with Intervention Instruments]. *Umweltpsychologie*, 8(1), 50–65.
Noort, H. & Ossenbruggen, R.V. (2011). West Orange. Save energy with EMS [*Energie besparen met het EMS*], results of in-home pilot 2010 – 2011 [*Resultaten in-home pilot 2010 – 2011*]. Participants in this pilot were IBM, Amsterdam Innovation Motor, CISCO, Home Automation Europe, Liander, Nuon, University of Amsterdam, Ymere and FarWest.
PowerPlay pilot 2008/2009, Nuon / NL Agency / TU Eindhoven / Home Automation Europe and UC Partners, May 2009.
Ramondt, D. (2016). Energy savings from smart thermostats with energy displays. Available at SSRN: https://ssrn.com/abstract=2745144
Reckwitz, A. (2002). Toward a theory of social practices a development in culturalist theorizing. *European journal of social theory*, *5*(2), 243-263.
Research & consultancy (ResCon). (2011). Customised energy advice through the use of smart meters [Energieadvies op maat via gebruik van slimme meters].
Ringold, D. J. (2002). Boomerang effects in response to public health interventions: Some unintended consequences in the alcoholic beverage market. *Journal of Consumer Policy*, *25*(1), 27-63.
Ruigrok Netpanel. (2012). The smart meter put to the test [De slimme meter op de proef gesteld].
Schatzki, T.R. (1996). *Social Practices*. *A Wittgensteinian Approach to Human Activity and the Social.* Cambridge: Cambridge University Press.
Schatzki T.R. (2002). *The Site of the Social. A Philosophical Account of the Constitution of Social Life and Change*. Pennsylvania: Pennsylvania State University Press.
Schultz, P. W., Nolan, J. M., Cialdini, R. B., Goldstein, N. J., & Griskevicius, V. (2007). The constructive, destructive, and reconstructive power of social norms. *Psychological science*, *18*(5), 429-434.

Sexton, R. J., Johnson, N. B., & Konakayama, A. (1987). Consumer response to continuous-display electricity-use monitors in a time-of-use pricing experiment. *Journal of Consumer Research*, *14*(1), 55-62.Shang, J., & Croson, R. (2009). A field experiment in charitable contribution: The impact of social information on the voluntary provision of public goods. *The Economic Journal*, *119*(540), 1422-1439.

Shove, E., & Pantzar, M. (2005). Consumers, Producers and Practices Understanding the invention and reinvention of Nordic walking. *Journal of consumer culture*, *5*(1), 43-64.

Social and Economic Council (SER). (2015). *The Agreement of Energy for Sustainable Growth: a policy in practice*. Retrieved from http://www.energieakkoordser.nl/~/media/files/energieakkoord/publiciteit/agreement-on-energy-policy-in-practice.ashx.

Sonderegger, R. C. (1978). Movers and stayers: the resident's contribution to variation across houses in energy consumption for space heating. *Energy and Buildings*, *1*(3), 313-324.

Stedin. (2013). REPORTING "THE RESIDENTALS ENERGY MANAGER" Energy saving by behavior in Rotterdam – Ijsselmonde [RAPPORTAGE “DE BEWONERALS ENERGIEMANAGER” Energiebesparing door gedragsverandering in Rotterdam - IJsselmonde].

Thaler, R.H. & Sunstein, C.R. *Nudge: Improving Decisions About Health, Wealth, and Happiness*. New Haven and London: Yale University Press.

Tversky, A. & Kahneman, D. (1974). Judgement under uncertainity: heuristics and biases. *Science,* 185(4157), 1124-1131.

Ueno, T., Inada, R., Saeki, O., & Tsuji, K. (2005). Effectiveness of displaying energy consumption data in residential houses. Analysis on how the residents respond. In Proceedings of the 2005 summer study of the European Council for an energy efficient economy (pp. 1289–1299). Stockholm: ECEEE.

University of Twente, Centre for e-Government studies. (2011). Trend report on computer and internet use 2011, a Dutch and European perspective [Trendrapport computer en internetgebruik 2011, een Nederlands en Europees perspectief]. Final report for the Ministry of Economic Affairs.

Van Dam, S. (2013). *Smart energy management for households*. TU Delft.

Van Dam, S., Bakker, C. A., & Van Hal, J. D. M. (2010). Home energy monitors: impact over the medium-term. *Building Research & Information*, 38(5), 458-469.

Van Houwelingen, J. H., & Van Raaij, W. F. (1989). The effect of goal-setting and daily electronic feedback on in-home energy use. *Journal of consumer research*, *16*(1), 98-105.

Verhallen, T. M., & Van Raaij, W. F. (1981). Household behavior and the use of natural gas for home heating. *Journal of Consumer Research*, *8*(3), 253-257.

Warde, A. (2005). Consumption and theories of practice. *Journal of consumer culture*, *5*(2), 131-153.

Welch, D., & Warde, A. (2015). Theories of practice and sustainable consumption. *Handbook of Research on Sustainable Consumption*, 84-100.

Wilhite, H., & Ling, R. (1992). The effects of better billing feedback on electrical consumption: A preliminary report. *Proceedings of ACEEE 1992 summer study on energy efficiency in buildings* (Vol. 10) (pp. 173–175).

Wilk, R. (2009). The edge of agency: routines, habits and volition. *Time, consumption and everyday life: Practice, materiality and culture*, 143-156.

Wolak, F. A. (2011). Do residential customers respond to hourly prices? Evidence from a dynamic pricing experiment. *The American Economic Review*, *101*(3), 83-87.

Wood, G. and Newborough, M. (2007). Influencing user behaviour with energy information display systems for intelligent homes. *International journal of energy research*, 31(1), 56–78.

World Energy Council (WEC). (2014). *Average electricity consumption per electrified household*. Retrieved from https://www.wec-indicators.enerdata.eu/household-electricity-use.html.

Appendix: List of interviews

Time	Name	Organization
4 Sep 2016	Household 1	
4 Sep 2016	Household 2	
4 Sep 2016	Household 3	
4 Sep 2016	Household 4	
4 Sep 2016	Household 5	
26 Sep 2016	Energy supplier 1	Qurrent
26 Sep 2016	Energy supplier 2	Essent
26 Sep 2016	Energy supplier 3	E.on
26 Sep 2016	Energy supplier 4	Eneco
26 Sep 2016	Energy supplier 5	Delta
26 Sep 2016	Energy supplier 6	Oxxio
3 Nov 2016	Henk Elburg	RVO
10 Nov 2016	Rob Martens	Stedin & Netbeheer Nederland
10 Nov 2016	Dennis Palmer	Smart Energy GB
10 Nov 2016	Erik Honig	Consumentenbond
10 Nov 2016	Michiel Lamers	Twinstone
10 Nov 2016	Kees Vringer	PBL
10 Nov 2016	Fonger Ypma	Eneco
23 Dec 2016	Maarten Eeke van der Veen	Vereniging Eigen Huis