Empowering end users in the energy transition
An exploration of products and services to support changes in household energy management

Proefschrift

ter verkrijging van de graad van doctor
aan de Technische Universiteit Delft,
op gezag van de Rector Magnificus prof. ir. K.C.A.M. Luyben,
voorzitter van het College voor Promoties,
in het openbaar te verdedigen op vrijdag 19 september 2014 om 10.00 uur

door

Daphne Viviana GEELEN
Ingenieur Industrieel Ontwerpen
Geboren te Nijmegen

Dit proefschrift is goedgekeurd door de promotoren:
Prof. dr. A.H.M.E. Reinders
Prof. dr. D.V. Keyson

Samenstelling promotiecommissie:
Rector Magnificus, voorzitter
Prof. dr. A.H.M.E. Reinders, Technische Universiteit Delft, promotor
Prof. dr. D.V. Keyson, Technische Universiteit Delft, promotor
Dr. S.Darby, University of Oxford
Prof. dr. ir. G. Spaargaren, Wageningen Universiteit
Prof. dr. C.J.H. Midden, Technische Universiteit Eindhoven
Prof. dr. ir. P.M. Herder, Technische Universiteit Delft
Prof. dr. ir. J.C. Brezet, Technische Universiteit Delft
Prof. dr. P.J. Stappers, Technische Universiteit Delft, reservelid

This research has partly been funded by the IPIN subsidy program of the Ministry of Economic Affairs in The Netherlands.

Empowering end users in the energy transition - An exploration of products and services to support changes in household energy management
Thesis Delft University of Technology, Delft The Netherlands
Design for Sustainability Program publication nr. 26
ISBN 978-94-6186-357-7

Book design by Trekken Design (www.trekkendesign.com)
Printed by Impressed druk en print

Table of contents

1

Introduction

This chapter is based on the following publications:

Geelen, D., Reinders, A., Keyson, D., 2013. Empowering the end user in smart grids: Recommendations for the design of products and services. Energy Policy 61, 151–161.
Geelen, D., Keyson, D., 2012. USING ENERGY: Beyond individual approaches to influence energy behavior, in: Reinders, A., Diehl, J.C., Brezet, H. (Eds.), The Power of Design: Product Innovation in Sustainable Energy Technologies. Wiley.
Geelen, D., Scheepens, A., Kobus, C.B.A., Obinna, U., Mugge, R., Schoormans, J.P.L., Reinders, A., 2013. Smart energy households' field tests in The Netherlands with a design-driven approach, in: 4th European Innovative Smart Grid Technologies (ISGT) Conference. Copenhagen, Denmark.

1.1 Energy transition to a decentralized electricity system

Calls to mitigate climate change and current and anticipated constraints in energy resources continue to increase the pressure on society to improve energy efficiency and intensify the use of renewable energy sources. Hence goals set in national and international policies, such as the EU 20-20-20 directive (European Commission, 2010) strive to spearhead a transition of the current electric power system to a more efficient and sustainable one. Furthermore, end users of electricity are increasingly interested in using renewable energy. They employ micro-generators on their properties, such as PV solar panels, and also more frequently small wind turbines and micro-CHPs. They participate in energy cooperatives, e.g. by buying shares in wind turbines. As a result, the traditionally centralized system of electricity generation is becoming increasingly distributed by the integration of renewable energy sources (Ackermann et al., 2001; Alanne and Saari, 2006). The integration of renewable energy generation into the electricity supply system contributes to a lower dependency on fossil fuels, as well as lower CO2-equivalent emissions related to fossil fuel consumption. Additionally, distributed generation reduces transport losses in the electricity grid because long-distance transport can be minimized.

However, the intermittent nature of renewable energy sources, such as wind and solar power, poses a challenge to the reliability of the power system. The more renewable energy sources are connected to the electricity grid, the more critical the balancing of supply and demand becomes for

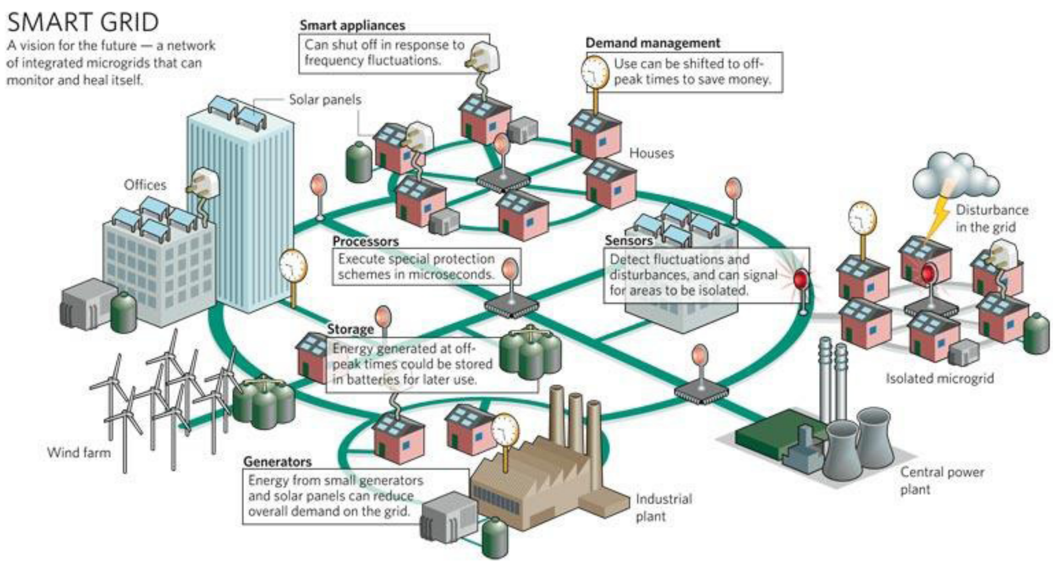


Figure 1: Representation of a smart grid (Marris, 2008). Reprinted by permission from Macmillan Publishers Ltd: Nature 454, 570–573, copyright 2008.

regulation of the power system. This critical balancing between supply and demand requires upgrading of the grid towards a more intelligent grid, generally referred to as a smart grid (Marris, 2008). The term smart grid refers to an electricity production and consumption infrastructure with distributed energy sources that is enhanced with information and communication technology (ICT) for improved monitoring and control of supply and demand balance in the electric power system. The smart grid is considered to be a requisite to accommodate an increasing amount of distributed and intermittent energy sources in electricity grids, as well as to reliably meet growing electricity demand (International Energy Agency, 2011). ICT plays an important role in smart grids by enabling monitoring and control of the energy flows in the grid at every level in the system, from large scale generation and transmission to the low voltage distribution networks in which residential end users are located (Marris, 2008; Wolsink, 2011), see also Figure 1.

1.2 Participation of end users in smart grids

A transition to smart grids thus allows consumers to play an active role in energy provision. Apart from being “normal consumers” who buy energy from an energy provider, consumers can choose to become producers of energy and thus participate in the energy market. In the context of this thesis, the terms “co-provision” and “co-provider” will be used to refer to the role of residential end users in contributing to balance supply and demand of electricity in smart grids. The term “co-provider” was introduced by van Vliet, Chappells and Shove (2005), who noticed a trend in which communities collaborate with utilities to reach solutions for water, waste and electricity management, as active contributors rather than only as consumers of resources.

Novel energy technology increasingly allows households to become producers of electricity through the use of micro-generators such as photovoltaic solar systems. Groups of households that formed local cooperatives to share micro-generator production are also emerging. Two examples from The Netherlands are Texel Energy (2013) and Grunneger Power (2013). These cooperatives aim to organize the production of local renewable energy and to balance supply and demand to optimize the use of locally produced energy. Also, energy stakeholders from the government and private sector try to involve residential end users in the supply and demand management of electricity in a smart grid, not only because they can become producers, but also because demand response (DR) by residential end users of electricity is considered a resource in the management of supply and demand (see e.g. Giordano 2011, International Energy Agency, 2011). Demand response refers to changes in electricity consumption by end users in response to supply conditions. For example, end users could permit utilities to automatically shut off their air-conditioning units or other appliances during peak demand periods provided that some financial incentives are offered. Also end users could be encouraged by utilities to use energy feedback systems.

Another example is the island of Bornholm in Denmark where a joint effort of local government and electricity companies and local industry are building a smart grid that may operate as a disconnected microgrid in the future (“EcoGrid,” 2013).

Van Vliet et al. (2005) described how the restructuring of these infrastructures stimulates utilities and end users to act together in order to establish environmentally sustainable systems. In the transition to smart grids, the challenge is to establish a sustainable system of energy provision in which local energy networks and co-providing end users operate in cooperation with larger scale utility companies. This implies a change in the technologies mediating between provision and consumption, a change in the roles that consumers play in the energy provision system, and, as a consequence, a change in energy-related behavior. In addition to using energy efficiently, households would ha ve to use electricity at appropriate times and in suitable amounts. Some would also generate electricity themselves. Moreover, in smart grids with advanced metering and energy feedback systems, households would additionally be able to trade electricity.

1.3 Problem statement

A transition to smart grids with residential end users as co-providers presents new opportunities for the different actors in the electric power system. With respect to the upcoming discussion on the role of end users, the question is how will the technological, as well as social, context of smart grids shape the role of residential end users as co-providers in the electric power system? Current energy products and services are still based on end users as buyers of electricity. Efforts to involve them in the energy transition are based on energy efficiency and address households as passive consumers rather than as participants in a (local) grid with other consumers and producers of energy. For example, residential end users are encouraged to save energy via information campaigns, rebates on energy-efficient appliances, periodic enhanced energy consumption and costs overviews, home energy monitors. Also self-production is stimulated, but more as an investment (via feed-in tariffs) and energy efficiency measures than as a means to contribute to the management of the electric power system.
The emerging role of end users is being investigated in several smart grid pilot projects. An overview of such projects in Europe is provided by Giordano et al. (2011). An inventory of smart grid projects worldwide revealed about 49 smart grid projects worldwide at the household level. The completed projects at this level generally involve the installation and testing of smart meters and advanced metering infrastructure (Obinna et al., 2013). With respect to active involvement of end users the dominant strategy for demand side management (DSM) is economic incentive through variable tariffs to stimulate behavioral change (Darby and McKenna, 2012). A threat posed towards the implementation of smart grids was observed by Verbong, Beemsterboer and Sengers (2012) in a tendency of stakeholders in the Dutch energy sector to focus on technological solutions and a predominant view that end user involvement should be based on economic incentives.
At present, smart grid pilot projects in distribution grids, at the neighborhood or household level, seem to consist in a top-down effort, driven by the technical implementation of systems that balance energy demand and supply. However, domestic demand response involves adoption of new technology and, as mentioned above, behavioral change by residential end users (see e.g. Darby and McKenna, 2012; Ehrhardt-Martinez et al., 2010).

1.4 Research framework

The research in this thesis is in the domain of design research. The overall aim of design research is to enable the development of more successful products and services (Blessing and Chakrabarti, 2009), in other words: to create value for end users. An earlier publication about several field studies in smart grid pilots in the Netherlands argues that a design-driven approach to research and development could offer such an integrated approach for product and service development in the energy sector (Geelen et al., 2013). A design-driven approach is multidisciplinary, integrating knowledge from, for example, engineering, natural, human and cultural sciences. A design-driven approach aims to combine 'top-down' implementation from a technical and economic perspective with end users' needs, perceptions and capabilities, or what could be called 'bottom-up' requirements. In this thesis the implementation of smart grids is viewed from a design perspective, by addressing the technological and the social context of residential electricity use in households equipped with smart grid technology.

Besides this design-driven approach, the theoretical framework in this thesis is mainly based on two perspectives on the role of products and services in shaping end user behavior towards sustainable resource consumption: (1) technology-behavior interaction and (2) social psychological models of behavioral change. The first perspective studies predominantly how technology influences behavior and how the interaction between technology and behavior affects the performance of a system, such as the balance in the electricity grid or the households' levels and patterns of electricity consumption and production. A conceptual framework was presented by Verbeek and Slob (2006) as a result of a collection of deliberations from different disciplines on how technology and user behavior influence each other. This framework suggests that the combined performance of technology and user is being influenced by the way in which a system is designed. In other words, contrary to the dominant approach in smart grid product development, when you design for a certain system performance, the design should address both user behavior and technology.

Social psychological models focus on the behavior of people and how it is influenced by both internal factors, e.g. attitude and motivation, and external factors, e.g. social norms. Generally, these models include factors of motivation, ability and opportunity that define whether a certain behavior occurs. The naming of the factors may differ (see Fogg, 2009; McKenzie-Mohr, 2011; Ölander and Thøgersen, 1995). With respect to design, the models suggest that, in addition to social influence, products and services can affect user behavior by providing ability and opportunities/incentives for behavioral change. Both perspectives acknowledge that user behavior takes place in a social and technological context, meaning that social influence by other people as well as other products, services or systems may affect user behavior and the way technology is used.

The field of sustainable design explores design strategies for sustainable household practices. For example Bhamra et al. (2011) and (2010) proposed design strategies. Kuijer (2014) looks for ways to include the broader social-technical context and achieve more fundamental changes by addressing social practices. The research framework in this thesis is not intended as an additional strategy, but draws from the strategies in the sense that the residential end users are studied in a social and technical context at the household and community levels.

The research framework in Figure 2 illustrates the approach taken in this thesis on the 'socio-technical system' under investigation. The framework is based on the concept that the interaction between technology and user

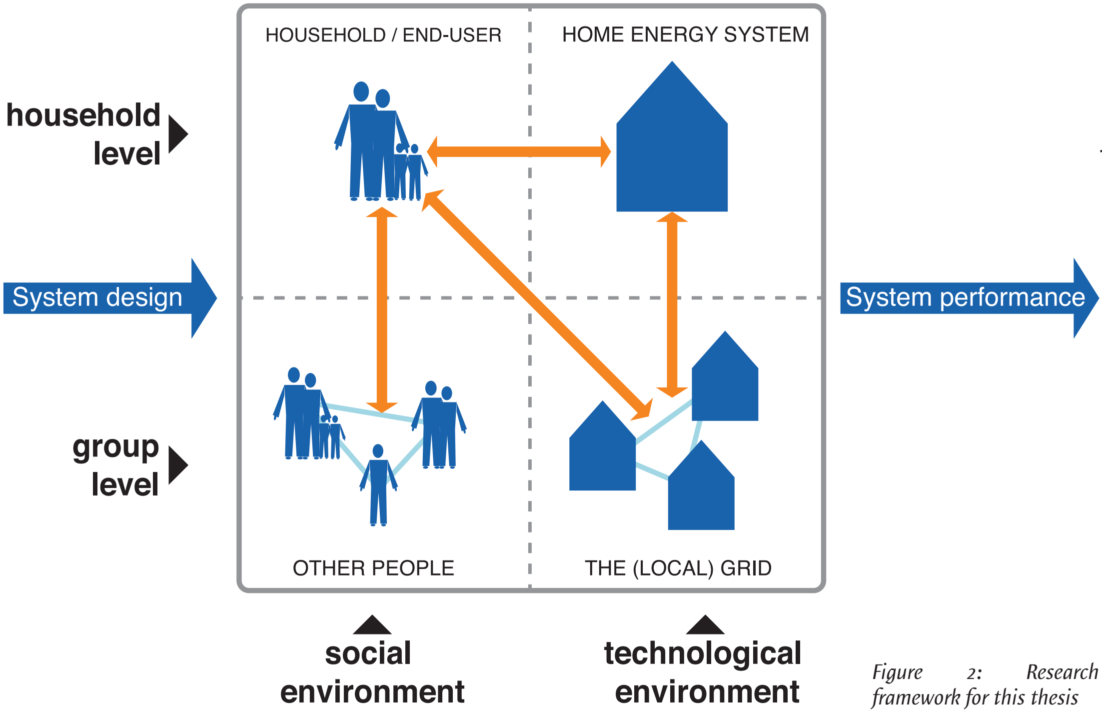


Figure 2: Research framework for this thesis

determines the performance of a socio-technical system, as described by Verbeek and Slob (2006). It focuses on how this performance is influenced by the relations between individual households and (a) the technology they use (in their home), (b) other people/households and (c) technology used by other stakeholders in the energy system, including the other households. Also (d) the relation between the technologies used at the household level and those used at the community level, i.e. in the local smart grid, is considered as part of the technological context that influences system performance. The performance within the socio-technical system is depicted as output. This performance is multifaceted, including energy consumption levels or changes therein as well as satisfaction of end users with a system or goals achievement by other stakeholders, e.g. grid balance for a network operator. The potential influence of design decisions on the performance of the system is depicted as input. For the purpose of this research the framework is limited to energy-related products and services at the household level, energy technology deployed in the local electricity grid, i.e. the distribution network, and to end users of those products and services in both households and community.

A related framework was used by Van Dam (2013) in her research on Home Energy Management Systems (HEMS). The framework describes the relations between end user, HEMS, other persons and other products in a household. While the framework used by Van Dam focuses on the relations in a household for detailed insight in the use of HEMS, the framework used in this thesis extends beyond the household level by including relations with other households and shared technology at group or local grid level, in order to investigate the potential of products and services that are available at the community level.

1.5 Research questions and research approach

The main objective of the research in this thesis is to infer insights for the design of products and services that can empower end users in a role as co-providers in smart grids.

This objective was translated in the following overall research questions:

1. *In what ways can products and services support end users in taking up a co-provider role in a smart grid context?*
2. *What are the implications for the design of smart grid related products and services for supporting end users end users in a co-provider role?*

The research questions were addressed with a literature review of currently applied smart grid technologies and field studies to investigate two cases of households equipped with smart energy technology. Both cases involve the implementation of technology that was new for the household and that aimed at one or more aspects of co-providing end user behavior. The field studies were carried out in pilot projects initiated by companies who are developing novel smart grid products and services. The research into the cases is exploratory and qualitative in nature, because of the newness of the topic and the set-up of the pilot projects. Specific research questions and approach were defined per field study and will be explained in the chapters about the specific studies. Considering the design-driven approach of the research, the end user's experiences of the implemented system in relation to the potential role as a co-provider was central to the research in each case. This was investigated with respect to user experiences with the implemented technology and effects on household electricity consumption behavior; the user's needs and ability to influence the electricity consumption pattern; and the role interaction with other people may play in facilitating co-provision. A graphic overview of the thesis is given in Figure 4.
Chapter 2 presents an exploration based on literature study of what becoming a co-provider means for home energy management, in terms of energy related behavior. We discuss how end user behavioral change may be facilitated and evaluate to what extent the categories of technologies that are considered for smart home energy systems enable end users to adjust their home energy management behavior (or energy related behavior) to a co-provider role. Chapter 2 thus focuses on the interaction between households and their home energy systems, but at the same time explores how the interaction with other people and with the local grid may help shape end users' role as co-providers.
In Chapter 3 the relations 'end user-technology' and 'end user-other people' is investigated via the evaluation of a product-service combination that combines energy feedback with competition between households in the so-called Energy Battle.
Chapters 4 to Chapter 7 relate to the smart grid demonstration project PowerMatching City in Groningen, The Netherlands. In this pilot project the end user relation to the home energy system, the local smart grid, as well as other people in the smart grid, were investigated. Chapter 4 provides a description of the smart energy system that was implemented and a description of the sample of households participating in the demonstration

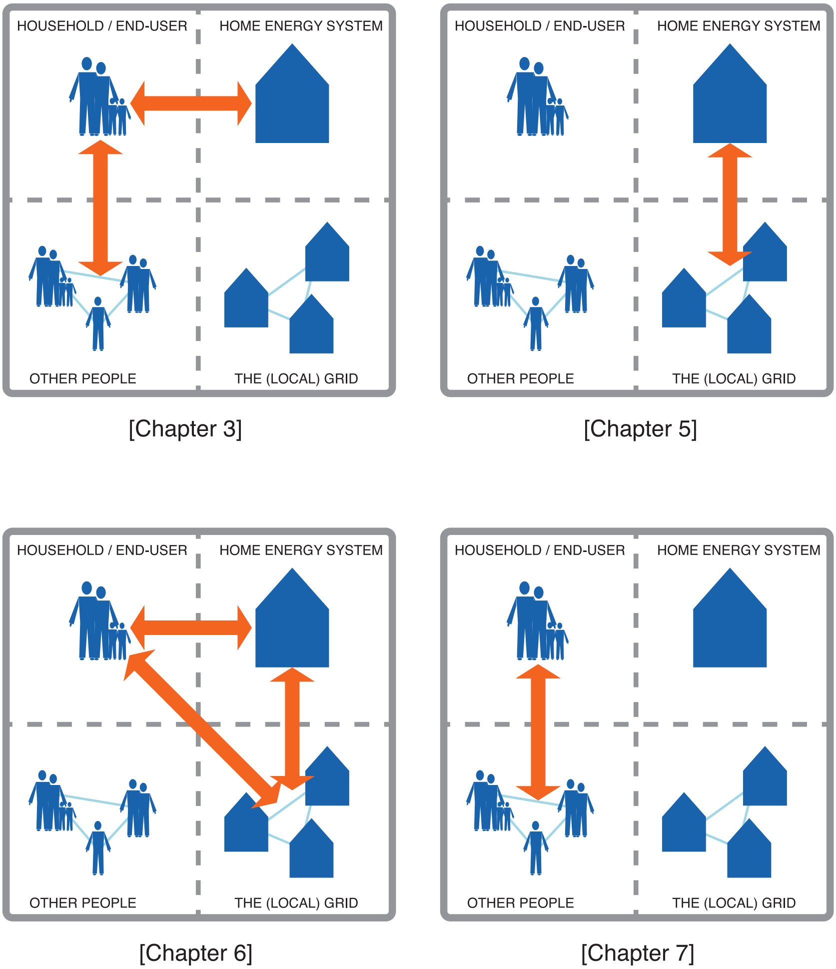


Figure 3: Relations addressed in Chapters 3, 5, 6 and 7

project. Chapter 5 addresses the performance of the technical system via the analysis of electricity data measurements in order to gain insight into the energy balance within the smart grid according to different seasons and different home energy systems. This chapter does not directly investigate one of the relations in the framework, but provides insights that can be used for optimization of overall smart energy system performance by adjustments in the interactions between end user, home energy system and smart energy system. Chapter 6 then looks into the relation between end user and home/smart energy system, by evaluating the end users' experiences with the system in relation to their goals, expectations and possibilities for interaction with the technical home energy system.
Chapter 7 addresses the relation between end users and other participants in a local smart energy system, or in other words: the relation between participants in a local smart grid. The potential of fostering social interaction to support a co-provider role was explored by means of a community web portal.

Finally, in Chapter 8 the findings of each study are brought together in order to present general conclusions. Furthermore the research limitations, contributions to knowledge and practice and recommendations for future research are discussed.

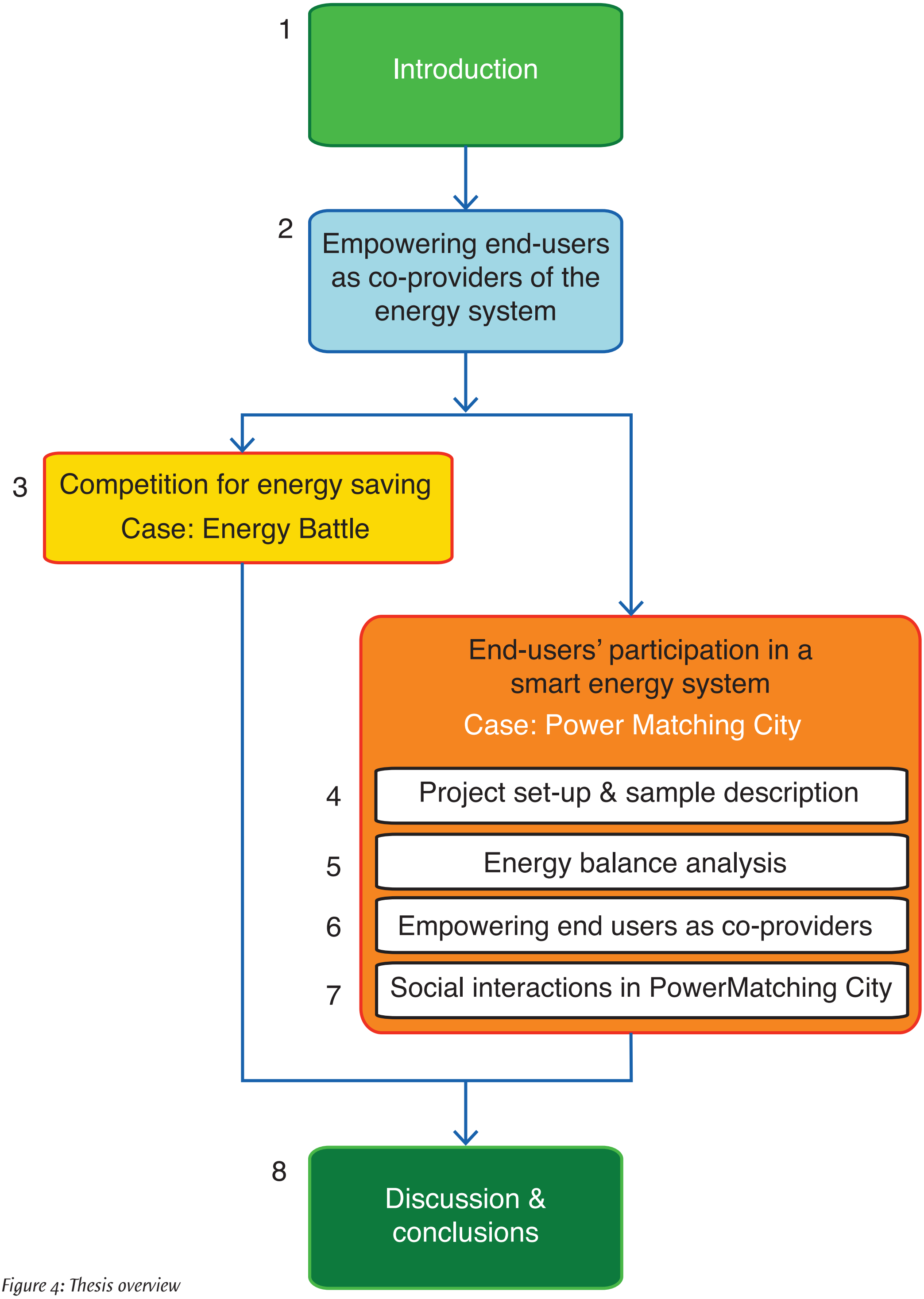


Figure 4: Thesis overview

2

Empowering the end user in smart grids: Current status and insights from literature

This chapter is based on:
Geelen, D., Reinders, A., Keyson, D., 2013. Empowering the end user in smart grids: Recommendations for the design of products and services. Energy Policy 61, 151–161.

2.1 Introduction

In the previous chapter was proposed that a transition to smart grids makes it possible for end users to become active participants in the energy management of the electric power system. This chapter builds on literature review to discuss how household energy management in a co-providing household differs from a mere energy consuming household and to what extent current categories of products and services enable end users to become co-providers in the electric power system. First the implications of a co-provider role for household energy management are addressed in section 2.2. Section 2.3 discusses the relevance of addressing behavioral change in addition to technological improvements in order to achieve household energy management geared towards co-provision. In section 2.4 the effects of current smart grid products and services on household energy behavior are discussed based on the aspects of co-provision defined in section 2.2, resulting in the proposal of a model that connects technical performance with end user behavior and that suggests an integral approach to designing products and services for households. Based on the reflection of current products and services and complementary findings in the literature, recommendations were formulated for product and service designers. These are presented in section 2.5. Finally, in section 2.6 an overall conclusion is presented and future research needs are discussed, some of which are addressed in the field studies presented in this thesis.

2.2 Co-provision: Beyond efficient energy use in households

Currently household energy management is geared toward using energy efficiently. The expression "efficient energy use" throughout this thesis refers to the effort expended by users in a household to reduce energy consumption and the extent to which energy efficient appliances[1] are utilized. The transition to smart grids, whereby end users shift to a co-provider role, suggests that household energy management not only concerns efficient energy use, but also includes demand response and production of electricity. Household energy management in a distributed and smart grid would then be geared towards:

1. *Using electricity efficiently.*
2. *Planning electricity consumption for, or shifting to, moments that are favorable for the energy system, such as when renewable energy is locally available or when overall demand in the system is low. This also includes avoiding consumption of electricity at times of peak demand in the system.*
3. *Producing electricity when it is favorable for the local grid, for example via a micro-cogeneration unit.*
4. *Trading self-produced electricity that is surplus to household needs.*

The combination of these four aspects makes household energy management more complex than when it is limited to the case of "efficient energy use".

1 Energy efficiency of appliances refers to the energy that is required to provide a given service, such as to heat a room to 20 °C or to boil a liter of water. The lower the energy consumption, the more efficient the appliance is. In general, efficient energy use is independent of the conditions of energy supply and demand in the electricity grid.

If end users are to become co-providers, they will have to be empowered in relation to the four aspects. Past research on stimulating changes in energy related behavior has typically focused on efficient energy use and addressed households in their role as passive consumers rather than as co-providers (see e.g. the reviews by Abrahamse et al., 2005; Fischer, 2008; Lopes et al., 2012). Little is known yet on how to shape active participation of residential end users in smart grids and thus how to support them in achieving the role of co-providers.

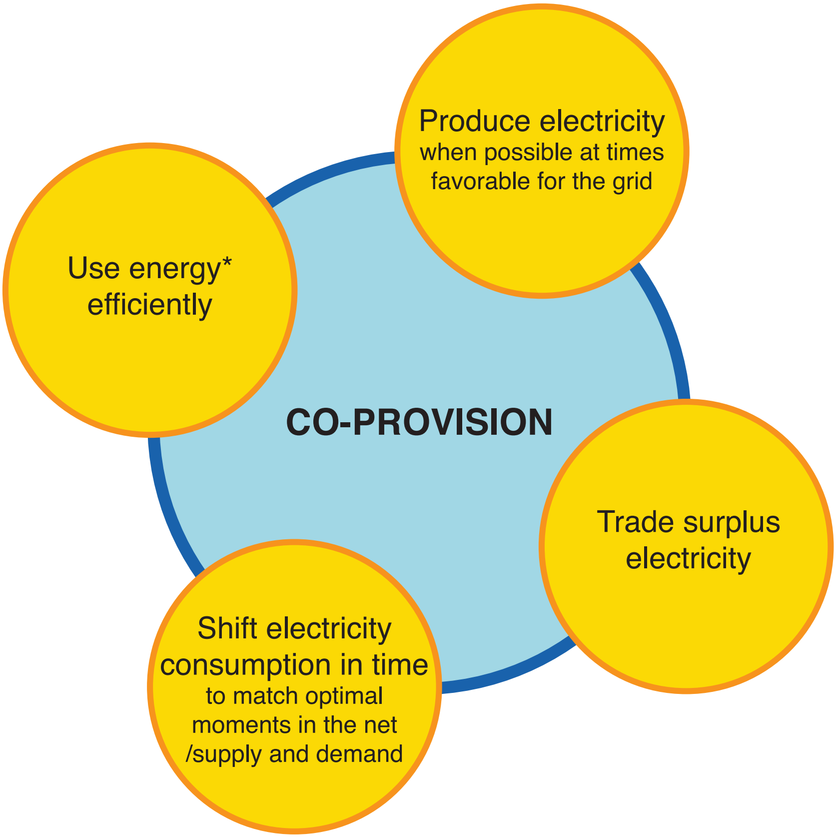


Figure 5 Aspects of co-provision in home energy management

**The term energy is used instead of electricity to include gas consumption, as it may constitute a major part of a household's consumption. Additionally, gas can be used for electricity production, as in the case of combined heat and power generation.*

2.3 Supporting changes through technology and behavior

Household electricity consumption and production results from the technologies and services people use, as well as from the behavior of people themselves. The reliance on, and energy consumption of, heating and cooling equipment and home appliances depends on several factors, among which local climate, type of housing, cultural background and household income.

Technological improvements can significantly influence electricity consumption. For instance, it was estimated that electricity consumption by ICT and consumer electronics could be reduced by about 50% given the use of the best available technologies and by about 30%, given a minimum investment cost, maximum benefit scenario (Eichhammer et al., 2009; Ellis and Jolland, 2009). At the same time, differences in behaviors among end users have been found to contribute to the variability in household's energy consumption levels (Lutzenhiser, 1993; Sanquist et al., 2012). Sanquist et al.

(2012) found that more than 40% of electricity consumption in households is attributable to lifestyle factors. Guerra-Santin and Itard (2010) found that approximately 12% of the variation in energy use for space heating could be explained by occupant behavior. Similarly, Dietz et al. (2009) estimated that approximately 20% reduction in household carbon emissions could be achieved through behavioral changes.

When household members do not understand how to efficiently utilize a technology or how to adjust their behavior accordingly, the potential impact on energy reduction may be lost through 'wrong' usage of equipment. For example, using an air-conditioner on a hot day while the windows are open would result in higher electricity consumption. Rebound effects may also occur, meaning that potential energy savings as a result of technical improvements are not achieved due to behavioral changes that counteract the energy saving potential (Sorrell, 2007). Direct rebound effect occurs for instance when end users replace light bulbs for more efficient ones and then leave the lights on longer. Another example here would be the case of end users who take advantage of increased comfort afforded by a new more energy-efficient heating system by heating more rooms. Studies have shown that households with programmable thermostats and balanced ventilation, i.e. a ventilation system where air supply and exhaust consist of approximately equal quantities of fresh outside air and polluted inside air respectively, tended to heat more rooms and use the heating system for more hours than households with manual thermostats and mechanical exhaust ventilation (Guerra-Santin and Itard, 2010).

Summarizing, the introduction of energy efficient technology into the household may theoretically lead to changes in energy consumption, but when behavior in the household is not aligned, potential energy savings may not be realized. This does not imply that end users should always have to adjust their behavior to technology. Technology should also fit end user needs, wishes and abilities. Technology and behavior thus have to complement each other.

In relation to the four aspects of household energy management that are introduced by a shift to a co-provider role in smart grids, it is also important that technology and behavior complement each other. For example, an automated system could decide when to turn on a heat pump or dishwasher, or when to sell excess produced energy. End users would nevertheless have to understand, and be able to operate in line with, how the technology functions and adjust it to match their needs.

The intentional design of products and services for co-providers can play a part in shaping home energy management by creating a synergy between technological possibilities and the needs, wishes and abilities of end users. Alongside ongoing technical developments increasing theoretical and applied knowledge exists on how product design can affect behavior (see e.g. Groot-Marcus et al., 2006; Lockton et al., 2010; Zachrisson and Boks, 2012).

2.4 Current products and services for the residential end users

As described above, household energy consumption and production is tied to a combination of technology and end user behavior. In a smart grid in which end users are expected to play a more active role in the management of the electric power system, products and services would have to support

end users in their role as co-providers.
Over the past years, several pilot projects have been initiated that deploy smart grid products and services in households with the aim to enable households to take part in the management of the electric power grid. The following categories of smart grid products and services can currently be discerned from the end user perspective:

- *Micro-generators*
- *Storage systems*
- *Smart appliances*
- *Smart meters*
- *Time variable prices and contracts*
- *Energy monitoring and control systems*

In the following section, each of the categories of smart grid products and services is considered in terms of how energy related behavior might be shaped in relation to the four aspects of co-provision (i.e., consuming, planning, producing and trading). A summary is provided in Table 1.
Figure 6 depicts a framework for an electricity grid with distributed generation at the household and community levels. The figure schematically shows how the categories of smart grid products and services can be viewed across the household and community levels. Balance between supply and demand can be achieved at each level, aggregating demand and supply from lower levels. For simplicity the 'main' grid is depicted as the higher level after the community level, though additional levels and interconnections may exist in reality.

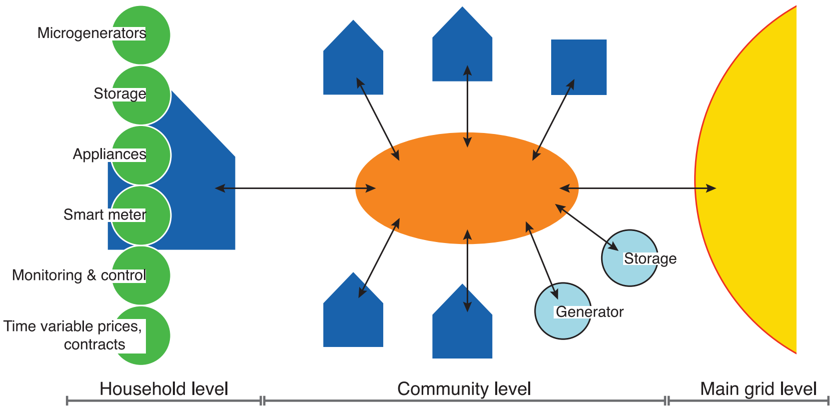


Figure 6: Schematic overview of the categories of products and services per level.

2.4.1 Micro-generation

Micro-generation technologies allow households to produce their own electricity. Examples are photovoltaic solar panels, micro-cogeneration units and small wind turbines. A micro-cogeneration unit is a particular type of micro-generator, in the sense that it is a heating system with high efficiency, producing electricity as a by-product of the heat it generates based on fossil fuel or biomass.
To make optimum use of micro-generation installations within a household, energy consumption should be matched to the periods of production.

Otherwise the surplus electricity is fed into the grid, and thus sold, via a feed-in tariff scheme or similar mechanism. Alternatively, when the energy demand in the network can be rapidly covered by household-based micro-generation to solve network imbalance, a network operator may send an automated request to the households to deliver electricity. The PowerMatching City project has tested this concept. Separate households are aggregated to form a so-called virtual power plant (VPP). The micro-cogeneration units are prompted to produce electricity and deliver it to the electricity grid based on the PowerMatcher coordination mechanism, which coordinates the matching of supply and demand in the smart grid. The heat produced by the micro-cogeneration unit is used directly in the household or is stored in hot water tanks for later (Bliek et al., 2010).

Micro-generation and delivery of surplus energy can also take place at the community level in which apartment blocks, neighborhoods or towns may utilize a collective electricity generation unit for local energy supply. The matching of supply and demand then takes place at the community level, rather than at the household level. Generation at the community level via medium-sized generators can be more favorable in terms of efficiency and costs (Fox-Penner, 2010). The organization of shared micro-generation capacity however brings along extra organizational and legal issues.

The extent to which micro-generators has been shown to trigger changes in end user energy behavior varies between studies. Bergman and Eyre (2011) point out that “possible behavior after installation may range from misuse, disappointment/disillusionment and rebound effects, through fit-and-forget (no change), to increased energy awareness, indirect benefits and double dividends”. A study in the UK by Keirstead (2007) showed that the installation of photovoltaic solar energy systems led to 6% savings over the overall household electricity consumption, as well as load shifting to times of peak generation by the solar panels. This study also indicated that monitoring devices displaying the output of the photovoltaic solar system facilitated such behavioral changes by increasing awareness (Keirstead, 2007). Dobbyn and Thomas (2005) found positive, though not universal, effects in terms of awareness and behavioral change following the installation of micro-generators. When information was given about what times of day were best for making use of solar energy, households were found to shift consumption towards these hours (Herrmann et al., 2008; Kobus et al., 2012). In short, visibility of micro-generation systems in terms of physical presence or energy information appears to be an important factor in influencing user behavior.

2.4.2 Energy storage systems

Energy storage systems enable households to use energy at different times than when it was actually produced or purchased from the grid. Surplus energy can be stored as electrical energy in batteries and as heat in hot water tanks or storage heaters.

In the case of electrical storage, electricity can be delivered to, and drawn from, the grid at favorable times in terms of system balance and prices. Additionally, a household can avoid buying electricity from the main grid, for example during peak hours by using previously produced (and stored) electricity. As with micro-generation, storage can also be organized as a shared or collective facility.

Electrical storage in batteries is not yet very common in households due to the related costs. Electric mobility is often mentioned in relation to electrical storage at the household level. The batteries of an electric vehicle can be charged with surplus electricity from micro-generation or from the grid during off-peak hours. When required, the car batteries can deliver power to the household or to the local grid. This concept is known as vehicle-to-grid (V2G) (Mullan et al., 2012).

In homes with electric heating, storage heaters are sometimes used to take advantage of periods of low electricity prices, i.e. usually at night. A storage heater uses the electricity to heat a material, such as refractory bricks. The heat is released slowly. The rate of heat release from the storage heater may be accelerated by the use of fans controlled via a thermostat. Heat storage thus allows end users to separate periods of electricity consumption from times when home heating is desired.

Heat is also often stored by heating water in tanks. The heat generally serves the supply of hot tap water and hot water circulating in a central heating system. For example, in the first group of houses in PowerMatching City, heat generated by the heating systems, being a hybrid heat pump system or a micro-cogeneration unit, is stored in hot water tanks (Bliek et al., 2010). This enables the home energy system to produce the required heat for the household at times favorable for operation of the smart grid.

The interaction of the end users with storage technologies and the effects on user behavior could be similar to the case of micro-generation. Storage technologies are typically concealed in the house and are not visible to the residents. Information about the performance of the system, such as the state of charge, would be needed to bring the storage system to the foreground. Further research is needed to examine the effect of energy storage on end user behavior.

2.4.3 Smart appliances

Smart appliances can be programmed and communicate with energy management systems about appropriate hours to operate. Appliances for which the time of operation can be shifted and that consume a high amount of energy are most suitable for 'smart' operation. For example, white goods such as dishwashers, washing machines and refrigerators, as well as heating systems such as heat pumps, micro-cogeneration units and ventilation systems can be considered here.

Smart appliances can decide for themselves or based on a trigger signal when is the best time to operate. The timing of the trigger signals may depend on the service that is contracted at a utility company, based for example, on tariffs, availability of local renewable energy sources or power system frequency. The demand response of appliances may depend on factors such as convenience and safety, reducing flexibility in activation times. While a heat pump may be activated at any time that energy can be stored, clean clothing may be desired at a rather fixed time.

White goods, such as dishwashers and washing machines, generally have a user interface through which one can control and plan when the appliance starts working in order to determine optimal results for the end user (e.g. clean clothes at a given hour) and the management of the energy system. Heating system installations generally do not have such a user interface. The interaction takes place through a thermostat or via a more elaborate home energy management system.

An elaborate home energy management system could also make remote control of white goods possible. The pilot project 'Jouw Energiemoment' ('Your energy moment') does this for example[2]. The energy management system developed in this project predicts the best moments for energy consumption. The smart washing machine proposes a time for its operation based on this information. On a display in the living room end users can see the best times for energy use and can adjust the washing machine's planned schedule.

Because smart appliances have only recently become available, research results about their effects on household energy behavior are not yet available. Studies on smart appliances have focused on drivers and barriers for adoption (Mert and Tritthart, 2009; Paetz et al., 2012). Their effects have been studied as part of a system in combination with other smart grid technologies, particularly energy management systems (see e.g. Kobus et al., 2012; Paetz et al., 2012).

2.4.4 Smart meters

The term smart meter refers to digital electricity meters that accurately measure consumption and production of electricity and communicate these data to the energy supplier. The 'smart' aspect of these meters is basically the ability to communicate the data they measure. As such they are part of the 'Advanced Metering Infrastructure' (AMI) of a smart grid in which the status and electricity flows are measured at several points in the system.

Currently, smart meters are predominantly used by energy suppliers for more automated and accurate billing. Smart meters can however also be connected to home energy management systems via communication protocols. The information communicated by smart meters concerns energy flows and price signals. A smart meter, and the related infrastructure, thus enables the end user to take part in the smart grid by measuring electricity flows and communication with other devices about energy use and tariffs. In terms of user interaction with the energy system, direct interaction does not take place at the smart meter itself. The smart meter alone is not a device with which the end user interacts. It therefore has little effect on energy related behavior (Darby, 2010). An intermediary product or service that displays energy feedback information would be required.

2.4.5 Dynamic pricing and contracting

Dynamic pricing, also referred to as time-variable pricing, provides an other opportunity to involve the end users in the management of the smart grid. The idea behind dynamic pricing is that the varying costs of electricity provision are conveyed to the end users, who then pay for, and get a sense of, the real cost of energy provision at the time they request it (Faruqui et al., 2010). The energy market already works with dynamic prices based on the situation in the grid, but does not transfer it to residential end users. In The Netherlands, for example, the energy price is either a flat rate or only

2 Information about the projects can be found online: www.jouwenergiemoment.nl

differentiated between day and night consumption. The introduction of smart grid technology allows for more accurate measurement of residential energy consumption via smart metering and as a result for dynamic pricing schemes. The underlying premise for introducing dynamic pricing is that variation in the tariffs, and informing end users about these variations, stimulates load shifting. Furthermore it can provide incentives for trading energy, for example by selling energy produced by a micro-cogeneration unit when prices are high.

Several studies have shown that households adjust their electricity consumption patterns with time-varying tariffs. They tend to shift the use of appliances to lower-priced times. Faruqui et al. (2010) found that the effect of load shifting was reinforced in combination with an in-home display providing feedback. They also observed that the amount of cost saving was reinforced when a combination of an in-home display and a prepaid electricity program was in place. In addition to load shifting, reductions in overall energy consumption may occur. A study by the Irish Commission for Energy Regulation found that peak usage was reduced by 8.8% and overall usage by 2.5% (CER, 2011). Nemtzow et al. (2007) report about 3 to 4% overall reduction of overall electricity consumption.

The introduction of dynamic pricing requires energy providers to reconsider their business models. It can be expected that contracts with energy suppliers will show various options, based on different pricing schemes relating to different types of consumers (see e.g. Owen and Ward, 2010). It may however be limiting to only focus on pricing schemes. While some end users will be interested in lowest costs, for others different motivations may be dominant, such as comfort and environmental concerns. As highlighted in a review by Breukers and Van Mourik (2013), the response of end users to dynamic pricing differs per end user segment. To stimulate co-providing behavior, business propositions thus have to differentiate on more than price alone.

2.4.6 Energy monitoring and control systems

Monitoring and control by residential end users

The technologies discussed in the above sections provide little or no means of interaction between end user and home energy system. Intermediary devices can facilitate interaction between end users and technology. Van Dam refers to such devices as Home Energy Management Systems (HEMS), and describes them as "intermediary devices that can visualize, monitor and/or manage domestic gas and/or electricity consumption. Their main purpose is to give users direct and accessible insight into their energy consumption" (Van Dam et al., 2010).

Most research and development of HEMS has taken place in the context of energy saving and to a lesser extent of energy production and control of appliances (Spagnolli et al., 2011; Van Dam et al., 2010). In terms of empowering end users, they support the efficient energy use aspect of co-provision.

Research on energy consumption feedback has been ongoing since the early 1970s. In review studies comparing results of feedback programs it was concluded that feedback on energy consumption could stimulate reduction of energy consumption. Ehrhardt-Martinez, Donnelly, and Laitner (2010) found that the average reduction for different types of feedback ranged from 4 to 12%. Considering HEMS, real-time feedback via in-home displays generally appears to be more effective than other means of feedback, which is less visible and direct (Ehrhardt-Martinez et al., 2010; Stromback et al., 2011). At the same time, effects on energy consumption were found to be strongly dependent on the design of a program, which not only concerns the form of feedback but also factors such as participant characteristics, duration of the program and the forms of communication that are utilized to involve participants in the program. A program was found to be more likely to be successful when the designers managed to meet the needs of the end users, thereby ensuring end user engagement with the program (Stromback et al., 2011).

While HEMS typically only provide energy feedback information, they have the potential to help end users achieve goals by monitoring progress towards a given goal, 5% electricity savings for example, and by providing tips to achieve that goal (Spagnolli et al., 2011). HEMS could also provide information related to the four aspects of co-provision, such as home energy production, dynamic prices, and the demand-supply status in a smart grid. Furthermore, HEMS can be designed to enable end users to switch smart appliances on/off or to adjust their settings (e.g. thermostat settings). Further research into the potential effects of HEMS with such extended functionality on energy behavior is required. Limited research results are available, such as from Faruqui et al. (2010) who found a reinforcing effect of in-home displays on load-shifting behavior based on dynamic pricing. Kobus et al. (2012) observed that energy behavior was influenced by the presence of an energy management system to control home appliance activation times in combination with the availability of photovoltaic solar energy.

In a smart grid, supply and demand management will take place on a local level. Energy information and control across electricity producers and consumers in a community could be made available. This would result in energy management systems that provide not only information on individual households, but also provide energy feedback at the community level and about the performance of related individual households. Literature on energy saving behavior has shown that comparative feedback in relation to the energy consumption levels of related households can be effective. Though, end users may differ in the degree to which they are interested and could be influenced by comparative feedback between households (Fischer, 2008). The potential of knowing the consumption levels of neighbors was highlighted in the feedback program design of OPOWER, which combines comparison between similar households with social-normative messages and energy saving tips in monthly energy bills (Allcott, 2011).

Smart energy technology makes it possible to make comparisons more accurate and based on several characteristics. There is an increasing amount of applications that involve social media allowing people to share and compare their energy consumption with other end users along several parameters. One can also choose the group of people or community with whom to share information. Furthermore, the applications increasingly make use of challenges to achieve household-level goals as well as competitions between households (Foster et al., 2010; Geelen et al., 2012; Petersen et al., 2007).

Automation of monitoring and control

In a smart grid with time-based variable pricing, the management of energy consumption and production can become rather complex for a household. End users' appliance operation may have to be planned ahead in order to take advantage of forecasted tariffs or may even have to react to prices that vary throughout the day in a matter of minutes. To facilitate such complexity, home energy management is becoming increasingly automated. The infrastructure of a smart energy system makes such automation possible and can thereby support end users in their role as co-providers. For example, in the PowerMatching City demonstration project (Bliek et al., 2010), the energy flows in the local smart grid are managed via the PowerMatcher, which is an agent-based algorithm that automatically coordinates the matching of supply and demand based on market mechanisms, while taking user preferences into account. User preferences include thermostat settings for space heating and the operation modes of the smart dishwashers and washing machines. Based on informal interviews conducted with households by the PowerMatching City project team, it would appear that while the PowerMatcher system automatically anticipates and reacts to the supply and demand conditions in the smart grid, end users are missing a sense of control and energy feedback that enables them to adjust their energy related behavior. Several end users reported that they wanted to change their behavior in order to lower their energy consumption or utilize the electricity that is produced in PowerMatching City, but felt insufficiently enabled to do so. This issue is addressed in more detail in Chapter 6.
A second example of a system that uses automation to control appliances is 'Jouw Energiemoment' (see also section 2.4.3). In comparison to PowerMatching City, the system operation is more visible to the end user via a HEMS with a user interface that enables the end users to plan the use of their smart appliance based on their own preferences in combination with day-ahead predictions of tariffs and the availability of locally produced energy. Kobus et al. (2012) found that such a system could support end users to consciously shift loads in time.
In short, HEMS could enable end users to interact with the automated energy systems and support the shift from energy consumer towards an active role as co-provider. A balance would have to be struck between automation and autonomy of the end user in the management of the energy system.

2.4.7 Summary and findings

Table 1 provides an overview of the products and services that were described above. The table summarizes:

- *Examples of smart energy products and services per category*
- *The type of co-providing behavior that is facilitated*
- *Main findings from literature on the effect of smart energy products and services on energy related behavior.*

The overview illustrates that the single elements of a smart energy system cannot be seen independently from each other. The extent to which co-provision is enabled depends on the combination of products and services that are implemented to form a smart energy system. In the background, in terms of the end user's perception, are 'core technologies' that produce, store or consume energy and the automated or semi-automated systems that manage the energy flows. Intermediary products and services are required to enable end users to interact with the household energy system for monitoring and control. Other services or incentives can further influence the interaction with a smart energy system, as in the case of variable tariffs and automated control. Figure 7 depicts the relation between the aforementioned elements as layers that can be included in smart energy system design. From the center outward, the products or services become less focused on technical functionality and more on user behavior or engagement with the energy system. An additional layer is added concerning the facilitation of change processes, which are addressed in the next section.

The overview of smart grid products and services for end users also shows that little is known still about the effects on end user behavior in the context of co-provision. The available research publications often focus on specific aspects of the system rather than the system as a whole. Furthermore, product and service development, and as a consequence the related research, has typically focused on empowering end users with technical solutions and financial incentives. These strategies are however limited in their ways to involve end users in co-provision. Further development and exploration of products and services are needed to address cognitive and social aspects to empower residential end users in becoming co-providers. In the next section three design directions for product and service development are discussed.

2.5 Design recommendations

To complement the ongoing development of products and services in smart grid deployment, three design directions are proposed which could potentially empower end users in becoming co-providers, namely: (1) designing interaction between end users and smart energy systems, (2)

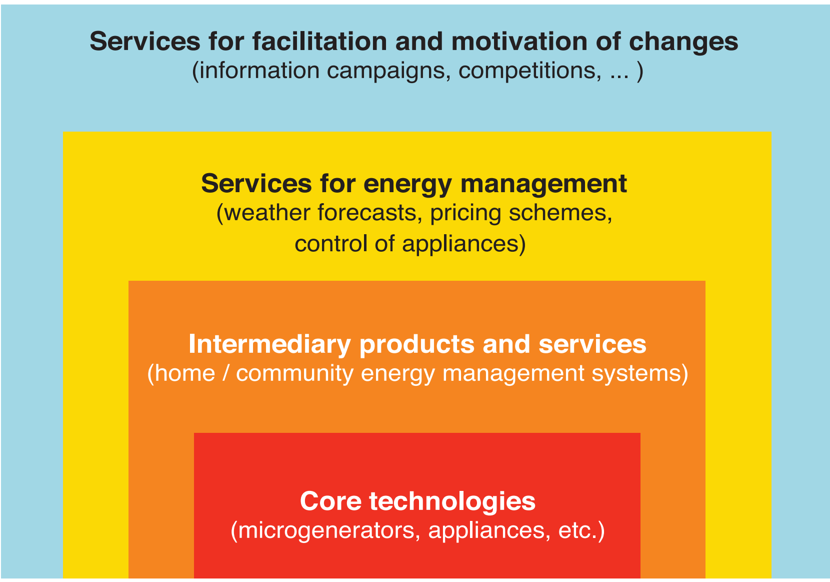


Figure 7: Relation between products and services making co-provision possible

guiding processes of behavioral change, and (3) enabling community-based facilitation and initiatives to stimulate local management of supply and demand. Following the description of the directions design recommendations are given.

2.5.1 Supporting user interaction in a smart energy system

Creating awareness of household energy consumption and production patterns is important to enable end users to achieve their energy related goals and to act in ways that optimize benefits for both end user and technical system. Interaction with the household energy system can be enabled with a HEMS, as discussed in section 2.4.6. A HEMS could provide insight into how the home energy system operates and support end users in their household energy management concerning the four aspects of co-provision by households in smart grids. Since current HEMS typically focus on reducing energy consumption, additional functionality would have to be developed to empower end users in achieving goals related to their role as co-providers.
In addition to interaction with the energy system at the household level, HEMSs could provide information about electricity flows at higher levels in the electric power system. Particularly, information at the community or neighborhood level may be useful to empower end users to contribute to balancing demand and supply within the local smart grid of which they are a part. Moreover, information at the community level can include shared facilities, such as a wind turbine or a co-generator providing heat and electricity for an entire community. In this way, end users can gain insight on how their household energy management contributes to the management of supply and demand in the electric power system.

Design recommendations:

- *Provide insights into the technical operation of a smart home energy system via HEMSs. A HEMS should enable end users to understand the decisions being made by the home energy system, such as when the dishwasher will be turned o n. Based on this insight, the end users can take action to match their own needs and goals with those of the electric power system. Several principles on the design of HEMSs have been defined by Fischer (2008); Kobus et al. (2012); Spagnolli et al. (2011) and Van Dam (2013).*
- *Deploy goal-driven interfaces rather than displays with only energy consumption and production feedback to enable end users to make trade-offs and interact with smart energy systems (Geelen and Keyson, 2012). A goal-driven interface aims to provide the mechanisms for end users to achieve certain goals. For example, the user may wish to fully charge a car battery at a certain time of the day to access the lowest possible cost. A goal-driven interface should provide actionable feedback such that a user can understand to what degree a given goal is being met and what changes in behavior might be required to meet that goal. In the case of charging a car battery, the system may suggest to allow for more time or to accept a lower charge level in order to avoid higher charging costs.*

- *Relate energy feedback information to the electric power system at the community or even higher levels, such as a city, to enable end users to gain insight and react to the situation in the electricity grid. For new business models such insight may be a requisite and part of the value proposition to the end users. Community level feedback could also enable end users to coordinate energy production and consumption with other households. For example, a neighbor may indicate when his or her photovoltaic solar energy is going to be available.*

2.5.2 Guiding processes of behavioral change

Behavioral change facilitation strategies from the social sciences could be applied in product and service development in order to enable end users to transition from being passive consumers to become co-providers. The adoption of innovations is a social process of communication and learning in which people gradually become familiar with an innovation and decide whether or not to adopt it (Rogers, 2003). The adoption of the role of co-providers, accompanied by the implementation of related products and services can be considered such a process. In supporting this process, residential end users will first need to become aware of the ongoing transition to smart grids and what it could mean for their home energy management. Then they can choose certain products and services that enable them to become co-providers. This adoption process can be facilitated in several ways, for example by media campaigns and communication with experts or peers. Products and services can also be utilized in this process, as for example computer simulations of a smart grid environment or games explaining the reasons behind, and consequences of, smart grid deployment (e.g. Costa, 2011).

Once end users have been provided with smart grid products and services, they may have to change their behavior in order to utilize the system in ways that are favorable for both the household and the electric power system. For example, an end user who usually does the laundry at night would, following implementation of a smart energy system, be able to benefit from lower electricity tariffs during daytime because of local photovoltaic solar energy production. To do so, the end user would have to adjust his or her routines and plan to use the washing machine during the day.

In changing behavior, end users go through several stages, starting with becoming aware that one has to or wants to make a change, followed by finding out how to change, implementing and then consolidating changes (Dahlstrand and Biel, 1997; Verplanken and Wood, 2006). Interventions to stimulate behavioral change should include multiple strategies based on education and information, incentives and community-based approaches. Education and information can increase knowledge and skills to adopt a certain behavior. Incentives can lower barriers to action (e.g. Gardner and Stern, 1996). Community-based approaches take advantage of the influence that other people may have on one's behavior, through the formation of social norms, comparison with others, learning from peers and cooperation (Gardner and Stern, 1996; Rogers, 2003; Wilson and Dowlatabadi, 2007). Intrinsic motivators such as cooperation and competition can be leveraged in interventions that take the social context of energy behavior into account (Breukers et al., 2011; Gardner and Stern, 1996; Heiskanen et al., 2010).

Categories	Examples	Type of co-providing behavior involved (Consumption/ production/ timing / trading)	Product, service or combination	Impact on behavior
Microgenerators	*Electricity:* • Photovoltaic solar system • Wind turbine *Electricity and heat:* • Micro-cogeneration unit • Fuel cell	• Production • Timing, when the microgenerator is controllable, e.g. a micro-cogeneration unit • Trading excess electricity generation Intermediary technology required for visualization & interaction	Product	- Awareness of electricity production and consumption. - Willingness to turn on appliances when producing electricity. Though this is not a universal effect. - Visibility of the installation is important for awareness.
Energy storage systems	*Heat storage:* 1. Hot water storage in home 2. Storage heaters 3. Shared storage on building or local community level *Electricity storage:* • Batteries • Hydrogen (immature technology)	• Production, based on stored energy • Timing • Trading Intermediary technology required for visualization & interaction	Product	- Effect can be expected to be similar as for micro-generation.
Smart appliances	- Micro-cogeneration units - Heat pumps - Air conditioners - Dishwashers - Washing machines - Clothes dryers - Freezers / refrigerators	- Consumption - Timing Intermediary technology can complement usability.	Product	• In combination with intermediary devices supports load-shifting. • For acceptance, certain level of control is required
Smart/digital meters	• Electricity meters frequency ranges from seconds to day intervals and variation in measurement minor units (e.g. Wh vs. kWh) • Gas meters • Meters that allow for breakdown to appliance level (usually part of a monitoring and control system, e.g. Plugwise)	Supportive due to measurement and signals transmission for: • Timing • Trading Makes monitoring & control possible (as intermediary) Intermediary technology required for visualization & interaction	Product-service combination (operates in background)	• Does not stimulate behavioral changes without intermediary devices, like HEMS that visualize energy flows.
Time varying pricing	• Time-of-use (TOU) • Critical Peak Pricing (CPP) • Real time pricing (RTP) Contracts may allow control of appliances, e.g. air-conditioning	Supporting: • Timing • Trading Intermediary technology required for visualization & interaction	Service	• Shifting of electricity consumption (timing) takes place, resulting in lower electricity use during peak periods. Rebound may occur with higher consumption in low-priced periods. • Dynamic pricing in combination with in-home displays reinforces shifting.
Energy monitoring and control systems	• Electricity monitoring systems, ranging from household aggregate to breakdown at appliance level. • Gas measurement - often combined with 'smart thermostat'	As intermediary technology can support: • Consumption • Production • Timing • Trading Energy monitoring and control systems doing so	Product-service combination	• Stimulates awareness. • Has potential to stimulate savings due to increased insight • HEMS as in-home display appear most effective • Differentiation necessary, 'one size does not fit all'. So different forms of feedback interaction and visualization required for different target groups.
Home automation for smart energy use	• PowerMatching City energy services gateway • Steering of air-conditioning	• Consumption, by smart appliances • Production, when controllable • Timing • Trading	Product-service combination (operates in background)	- Fully automated system without feedback information appears not to support co-providing behavior.

Table 1: Categories of products and services in a smart energy system, as currently considered

Design recommendations:

- *Use awareness-creating interventions to facilitate the adoption of a co-provider role and related smart energy products and services. This can be in the form of services linked to the deployment of new products. An example here could be a game about the concept of smart grids and changes for households in the transition to smart grids (Costa, 2011).*
- *Combine temporary interventions that relate to the stages of a behavioral change process with products and services that are already in the home, such as home energy management systems and contracts with energy suppliers. An example here would be an energy competition, which is facilitated by a home energy management system (Geelen et al., 2012; Gustafsson et al., 2009).*
- *Make use of community-based approaches in interventions, for example by facilitating interaction between end users, making social norms explicit and stimulate cooperative activities or challenges within a community.*

2.5.3 Supporting community management of resources

The goal of a community management approach is to support end users in their role as co-providers by leveraging the social fabric of connected households within a smart grid. The influence of the community on household energy practices was reviewed by Gardner and Stern (1996) and f urther examined by Heiskanen et al. (2010).

Wolsink (2011) argued that for the deployment of smart grids with distributed power generation, community management of resources would be useful in facilitating the end users' transition to the role of co-provider. Governance at the community level could support the development of solutions that fit local circumstances, in terms of end user needs as well as technological possibilities. Energy cooperatives are a form of organization for the management of community resources. End users in cooperatives are generally involved in organizing their energy provision. For example, joint investment in photovoltaic solar systems may be accompanied by agreements on how to distribute the financial gains from the electricity produced by the cooperative.

Key to community management approaches and behavior change is the notion of social innovation. Jégou and Manzini (2008) described it as follows: "The term social innovation refers to changes in the way individuals or communities act to solve a problem or generate new opportunities. Social innovations are driven more by changes in behavior than by changes in technology or the market. They typically emerge from bottom-up rather than top-down processes". Communities can develop ways to fulfill the needs in their daily life by organizing themselves differently. Jégou and Manzini (2008) gave the example of a community that due to a lack of safe roads and proper public transport organized a 'walking bus'. Parents took turns in walking a group of children to school. An additional example of a community-led initiative would be the joint purchase of photovoltaic solar systems and investments at the community level. Product and service design for such initiatives, such as a website in support of the organization of an initiative, can lead to the adoption of solutions by a broader public.

In order to establish a sustainable society, Jégou and Manzini (2008) argued that designers should rather than just translating new technology for end users, learn from them for new directions of technology development. This approach is similar to the recommendation by Gardner and Stern to include end users in design of an intervention program (1996), while placing more emphasis on the development of collaborative communities and activities as a change agent, rather than on end users residing in a community. With regard to electricity supply and demand management, requirements and solutions of energy cooperatives could provide directions for development of smart grid related product and services.

Design recommendations:

- *Develop products and services that make community management of the energy system possible. For example, insight and control can be provided for electricity supply and demand at the community level by 'community energy management systems' (CEMS) in addition to home energy management systems (HEMS) for individual households. Also electricity exchange or payment mechanisms that support local trading of electricity could be developed. Products and services for community management would have to be flexible in their set-up to enable customization to specific energy needs and organizational preferences of communities.*
- *Develop products and services that stimulate or facilitate communication among end users. Home energy management systems could for instance, be equipped with a discussion or messaging functionality. The communication functionality can enable the development of a collaborative environment. Interaction among end users could include: (a) asking and giving advice on energy related to the use of energy products and services (b) comparing and discussing energy consumption and production levels, (c) exchanging ideas for improvement of smart energy systems, including new community initiatives, and (d) initiating organizational structures to facilitate a smart grid community. The communication methods that are suitable for a particular group of end users vary with the context. Ideally, community-based systems should be self-sustaining in the sense that eventually an external mediator is not required to keep community-based initiatives running. Designers should thus carefully consider how community-based activities are structured and how best to involve end users in developments, so as to increase the chance of end users becoming co-providers and engaged at the community level.*

2.6 Conclusion

Current discourse on smart grid deployment suggests that residential end users are expected to play a more active role as co-providers in the electric power system. In this chapter the extent to which current smart grid-related products and services support residential end users in a co-providing role was examined, based on a literature review and existing smart grid pilot projects.

The overview of smart grid related products and services showed that product and service development to involve end users in smart grid operation has typically focused on technical solutions and financial incentives. Past research on energy-related behavior suggests that behavioral aspects and social context for residential end users as co-providers have to be taken into account more in product and service development to ensure the adoption of smart products and services. Also previous research appears to have focused more on specific parts of household energy systems, rather than on integrated energy systems at the household or community level.

A number of design recommendations falling under three directions were proposed, namely (a) interaction between end user and energy system, (b) approaches to stimulating behavioral change, and (c) community management and initiatives. Product and service designers should play a bridging role between policy makers and technology developers, while facilitating the involvement of end users in the design process. This will require designers to consider the needs of co-providers in designing smart products and services while looking beyond the functionality provided by current household energy systems.

As developments in smart grids continue, along with the emergence of residential end users as active co-providers, lessons from smart grid projects related to end user perception and behavior should be leveraged to inform the next generation of smart grid products and services. Further exploration in field research is therefore required as to the products and services that are able to foster a co-providing role. Involvement of end users in product and service development is central to ensuring their potential future role as co-providers in the electric power system.

In the following chapters, field studies for two pilot projects are presented. The product-service combinations studied in those pilot projects address one or more of the proposed design directions. The study of Energy Battle focuses on stimulating behavioral change and the role of social context therein. The studies into PowerMatching City are more focused on the interaction between end user and energy system on the one hand, and the potential role of the social interaction in actively engaging end users as co-providers rather than passive consumers.

3

Energy Battle: Exploring the use of a game to stimulate energy saving

This chapter is based on:
Geelen, D., Keyson, D., Boess, S., Brezet, H., 2012. Exploring the use of a game to stimulate energy saving in households. Journal of Design Research 10, 102–120.

3.1 Introduction

In the previous chapter we proposed that a shift to co-provision in households involves behavioral change in combination with technology that enables co-provision in households. This chapter presents a study about a specific case of design for sustainable behavior, namely a serious game aimed at energy saving in households called Energy Battle. The game creates a social context that can motivate end users to change energy behavior and supports end users as they change their behavior with energy feedback information. The game was developed by Shifft, a communication consultancy in cooperation with graduation students of Delft University of Technology, Faculty of Industrial Design Engineering. The study presented in this chapter concerns a pilot test of Energy Battle in student households. The goal of the study was to explore which role the game and its elements played in facilitating energy saving behavior. This chapter first addresses theory about behavior and behavior change in section 3.2, followed by a review of the potential role of games in section 3.3. The design of Energy Battle will be explained in section 3.4. The research approach and results are discussed in section 3.5 and 3.6 respectively. The chapter concludes in section 3.7 with a discussion of the main findings concerning the effects of the Energy Battle in the short and long term and implications for future game design.

3.2 Explaining and stimulating behavior change

There is a vast body of literature about behavior and behavior change in the social sciences. In the field of social psychology, several models have been developed to explain behavior and behavior change. Most of the models focus on the individual and internal factors determining behavior. Consumer behavior however is largely influenced by external factors, such as social norms and the availability of resources. In a literature review, Jackson (2005) pointed out that few models attempt to include both internal and external factors that determine behavior. An example of a model that integrates both internal and external factors is the Motivation-Opportunity-Ability (MOA) model of consumer behavior, developed by Ölander and Thøgersen (1995). It has been applied to empirical studies successfully (Jackson, 2005). As shown in Figure 8, the model defines three main components that influence behavior: motivation, ability and opportunity. The motivational component motivation is based on the model of Ajzen and Fishbein (1980) as it is a popular approach, but Ölander and Thøgersen suggest that the factor could also be filled in with other models for motivation.
The expected outcomes of a given behavior drive motivation, which in turn influences the attitudes towards that behavior and the intention to actually perform it. Additionally, the intention to perform certain behaviors is influenced by social norms concerning the behavior. This social norm refers to the subjective norm of the Theory of Reasoned Action, which is a person's perception of how others think one should or should not act (Ajzen and Fishbein, 1980). The factors ability and opportunity facilitate the step from intention to actually performing the behavior. Ability to perform the behavior is based on knowledge about how to perform it as well as habits which 'shortcut' the intentional process. Opportunities are contextual circumstances (external factors) that make performance of a behavior

convenient or can trigger a certain behavior, for instance the placement of waste containers close to someone's home.

A model that is closely related to the MOA model, is the Fogg Behavior Model (Fogg, 2009), which is intended to support the design practice in stimulating certain behaviors. This model states that the higher motivation and ability are, the more likely it is that a person performs the target behavior (Figure 9). Note that ability in this model not only relates to habits and knowledge, but also to contextual factors which in the MOA model are considered part of the opportunity component. Triggers can be used to increase ability and/or motivation. Examples of triggers are the alarm of a kitchen timer or a message that you should return books to the library. A trigger in the Fogg Behavior Model is comparable to 'opportunity' in the MOA model. Both refer to changes in contextual circumstances. According to Fogg, triggers and ability are easier to address than motivation. Triggers are to be used first to stimulate certain behaviors. If that is not sufficient, one has to focus on improving ability.

Most people have a positive attitude towards saving energy. Positive attitudes towards the behavior however do not provide a clear prediction that the behavior will actually be performed (Ölander and Thøgersen, 1995). Stern (2000) addressed the effect of contextual factors on behavior. Contextual factors can include a variety of external influences such as incentives, physical capabilities and constraints, interpersonal influences, institutional and legal factors, public policy support. Stern implied that when the context effect is small or neutral, the attitude of the user plays a significant role. Attitude, however, has little influence on behavior, when it is strongly influenced by the context. A similar approach was proposed by Zachrisson (2012) for product design. He argued that for the intended behavior to occur, the user has to have a positive or neutral attitude towards the behavior.

This influence of context relates to the opportunity-element in the MOA-model, that facilitates certain target behavior. Gardner and Stern (1996) stated that incentives can be very effective in changing behavior. A characteristic of incentives, however, is that when they are removed the behavior is often not maintained.

Habits are part of the ability factor in both the MOA-model and the Fogg Behavior Model. Habits strongly determine the behavior of people. Therefore interventions aimed at changing behavior, will have to address habitual behavior as well as intentional behavior. According to Verplanken and Wood (2006, p. 100), to successfully change old habits and establish new ones, interventions must: "*(1) change the context cues that trigger existing habits, (2) establish incentives and intentions that encourage new actions, and (3) promote repetition of new actions in stable circumstances*". This is in the same line as the apparent consensus that behavioral change involves the 'unfreezing' of existing behavioral patterns and the elaboration of new alternatives, as observed by Jackson (2005) referring to Lewin (1951), Spaargaren and Van Vliet (2000) and Biel and Thögersen (2007).

Feedback information about energy consumption has shown to be an effective means to enable people to change their energy consumption behavior. The information provides the Opportunity to perform a behavior, and at the same time supports the development of task knowledge, the second element of Ability.

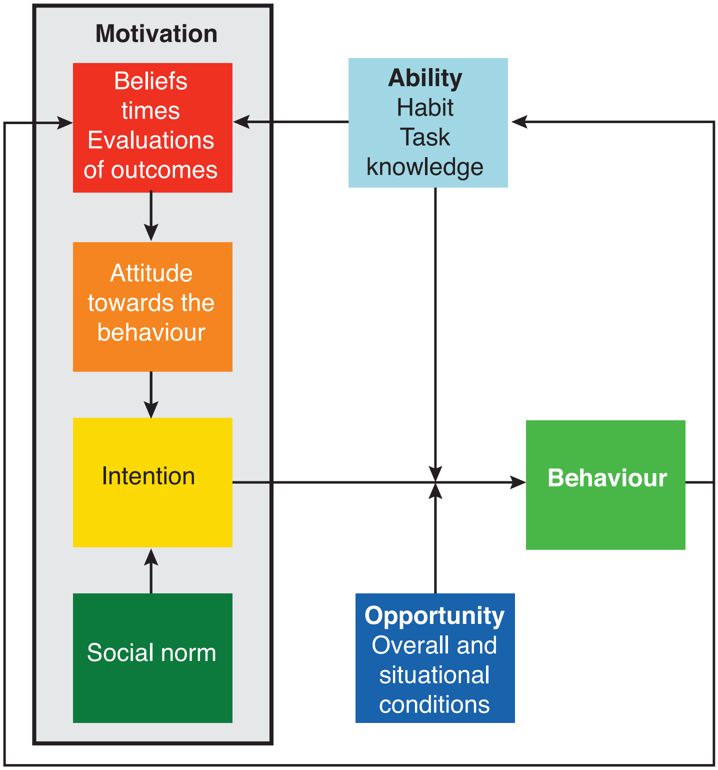


Figure 8: The motivation-ability-opportunity-behavior model (Ölander and Thøgersen, 1995)

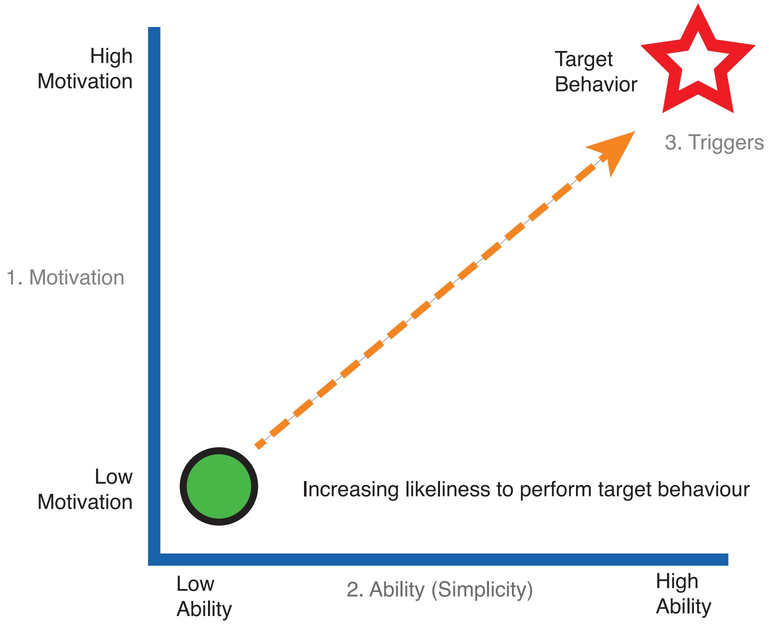


Figure 9: Fogg Behavior Model (Fogg, 2009)

As the reviews by Abrahamse et al. (2005) and Fischer (2008) showed, there have been numerous interventions using feedback to stimulate energy saving. Basic requirements for feedback are that it has to be given frequently, over a long period of time and should enable users to see the consequences of their activities (e.g. the effect of using the washing machine).

It is not enough to simply present the feedback information, it should be presented in such a way that it motivates action (Wood and Newborough, 2007). Or as McCalley and Midden (2002) found: feedback is only effective when it helps to achieve one of the user's goals. Thus feedback has to be a tool that enables reaching a goal.

In a similar way, tips will only be effective when they help users to fulfill a goal. While feedback only gives information about the results of (energy saving) activities, tips provide knowledge about how to save energy.

Based on the theory presented above, one may expect the Energy Battle to have a strong effect on energy saving behavior. The contextual circumstances are changed (Opportunity) and the Ability to perform the behavior is improved with feedback information and tips. The question is however, to what extent behavior changes will be maintained after completion of the Energy Battle.

3.3 Games to stimulate energy saving

Games can be considered as a specific type of intervention to stimulate behavior. Playing a game allows people to step outside of the ordinary (Caillois and Barash, 1962; Huizinga, 1949). They typically let people do things differently than normal, to stretch the boundaries of the imaginable. When games are designed with the aim of education or training, they are referred to as serious games. The same principles as for normal games apply for the development of serious games, with the addition that they have to fulfill learning goals, rather than just entertain.

Games tap into intrinsic motivation. They are inherently engaging. Fogg (2003) argued that intrinsic motivation is powerful in persuading people to perform certain actions. Intrinsic motivation is a type of energizing force that arises directly from an activity or situation. Malone and Lepper (1987) defined seven types of intrinsic motivation: fantasy, curiosity, control, challenge, competition, cooperation and recognition.

Considering that changes in contextual circumstances may stimulate behavior change, as discussed in the previous section, games could offer a means to change circumstances in an engaging way. By stepping out of the ordinary situation into a game context, they have the potential to let persons 'unfreeze' their existing behavioral patterns and 'refreeze' different behaviors while or after playing.

There has been limited research so far about games as a form of intervention for saving electricity. Four studies are discussed here.

Petersen et al. (2007) described a student dormitory competition. During the experiment, the authors introduced feedback, educational information and an incentive. In the two weeks of the competition, overall electricity use dropped by 32%, whereby use in dormitories that received weekly feedback based on meter reading dropped by 31% and in dormitories that received web-based real-time feedback it dropped by 55%. The authors do not report on energy consumption trends following the competition. The incentive to participate was provided in the form of an ice cream party for the winning dormitories. Hardly anyone attended this party. This suggests that the motivation to participate was based on the competition, rather than the final prize.

Odom et al. (2008) organized an energy and water saving competition in 10 student dormitories with the aim to test the visualization of web-based information. The result of the competition was *"an estimated combined avoidance of 33,008 kilowatt hours (KWh) of electricity and 724,322 gallons of water compared to baseline consumption of the previous three years"* (Odom et al., 2008, p. 1). They found social motivation to be a key component for success of the competition. They suggested that to motivate energy saving behavior, social motivation should take first priority along with the provision of concrete suggestions on how to save energy.

Whereas the two dormitory competitions were relatively simple in terms of game design, the following games apply mechanisms that are used for computer games, for instance by letting the players take on special roles. Power Agent is a mobile game in which the players are special agents fulfilling missions for energy related behavior (Gustafsson et al., 2009). Teenagers from different families form a team and competed with teams on other locations. The players had to fulfill missions once a week that were unlocked via a game on their cell phone. This game also allowed them to gain tips for energy saving related to the mission. The missions were function related, e.g. cooking or heating. It was found that up to 50% per mission was saved. Family members participated indirectly, and with varying degrees of enthusiasm. The teams reported to have undertaken activities that infringed their comfort. One of the families even made a structural change to the house by modifying the heating installation. Social interaction in the form of peer pressure from the team members and the cooperation of family members were reported to be highly motivating. Long-term effect on energy consumption was not measured.

Power Exchange (Bång et al., 2009) was also a mobile phone game for teenagers. The design was based on the findings of the Power Agent trial. The hypothesis was that more casual game play and real time feedback based on a real time sensor system could stimulate longer lasting effects. The players were represented as avatars. There were four modes of interaction. Two of them focused on saving energy, which was represented in the state of the habitat of the avatar and a position in a ranking (a pile) of avatars. The two other modes concerned learning about appliances, which took place through duels with other players. The players were not guided in their energy saving as in the Power Agent game, though they could gain insight by playing duels. The game was played for one week. In the 10 weeks that followed, energy consumption continued to be monitored. On average the consumption in this period was 14% lower in the player group than in the control group. The researchers concluded that the Power Explorer trial showed indications for a long term effect on energy consumption, a significantly positive attitude change towards energy savings, the forming of energy saving strategies in the form of new habits and less extreme energy saving energy measures compared to the trial with Power Agent.

Although the studies described here were exploratory in nature, some lessons can be learnt. The dormitory studies show that competition between households based on feedback, real-time as well as weekly, can be effective in stimulating high-energy savings. The findings suggest

that prizes may not be the main incentives for participating, but that the contextual situation, including the competition between and cooperation within households, are likely key motivating aspects of playing the game.
Games can provoke extreme behaviors that infringe on comfort. The Power Explorer study suggested that a casual game might not induce very extreme energy saving behaviors, but that changes in behavior are maintained and habits changed. Apart from the Power Explorer study, none of the studies reported on the long-term effects on energy consumption behavior.
These few studies of games aimed at changing energy consumption behavior show that games have the potential to stimulate behavior change. However, there still is little empirical evidence about how games can be used as an engaging means to stimulate changes in energy consumption behavior.

3.4 Energy Battle

The Energy Battle is a serious game developed by Shifft, a spin-off company of Delft University of Technology. An initial version of the game was tested with student households and focused only on electricity consumption. The choice for this target group was of pragmatic nature. A student housing association agreed to provide the necessary access to the energy meters of the student houses. Furthermore, students tend to be eager to participate in gaming events. The current study was seen as a means to provide input towards a next version of Energy Battle aimed at families with children, while also including electricity, gas and water consumption.
The Energy Battle targeted electricity consumption in several ways, namely: (a) by providing general information about electricity consumption of household devices, (b) making electricity consumption visible via feedback (c) rewarding electricity savings during the game (Versluis, 2008).
The participating houses were provided with an energy meter and access to an online platform. The energy meter, a Wattson (DIY Kyoto, 2010) provided direct feedback on power consumption (Figure 3). Furthermore it stored data on the consumption over time, which after uploading was displayed via the Dashboard (see Figure 4). The players were instructed to upload the data themselves.

The online platform consisted of:

- *A 'Dashboard' displaying electricity consumption over time; per day and per hour (Figure 4),*
- *Tips about electricity saving,*
- *Ranking of all the teams,*
- *A game with building blocks (Figure 5). By saving energy the teams gained credits that could be used to buy building blocks. The more a team would save, the bigger and nicer a structure they were able to build.*

The main goal of the game was to save as much energy as possible. A secondary goal was to build a nice structure with the building blocks. The prize for the team that saved the most energy compared to the baseline measurement was € 750 in kitchen appliances. The team with the most creative structure in the online game won €250 worth of dining vouchers.

This creativity prize aimed to stimulate playing the building blocks game on the online platform.

The Energy Battle was executed in three phases:

1. *Two weeks of baseline measurement. Two weeks before the start of the competition the energy meters were installed in the houses to measure energy consumption. The residents were not able to access the meter during this time.*
2. *Four weeks of competition. At the start the participants received information about how to use the energy meter and how to log on to the website. During the competition the households received e-mails to further stimulate participation. After four weeks the two winners were announced.*
3. *Follow-up measurement. In the month following the competition the energy meter remained in the household for follow-up measurement to monitor the levels of energy consumption after the competition.*

3.5 Research approach

The main research questions that were considered for the Energy Battle were:
What are the motivating factors for participating in the Energy Battle?
How much saving would be achieved during the energy battle?
What activities for saving behavior would be developed by the teams?
What role would the specific game elements serve in the motivating and in enabling increased energy saving behavior?
If people change their behavior, would it be sustained following the completion of the game?

Figure 10: Energy meter Wattson. (image by DIY Kyoto)

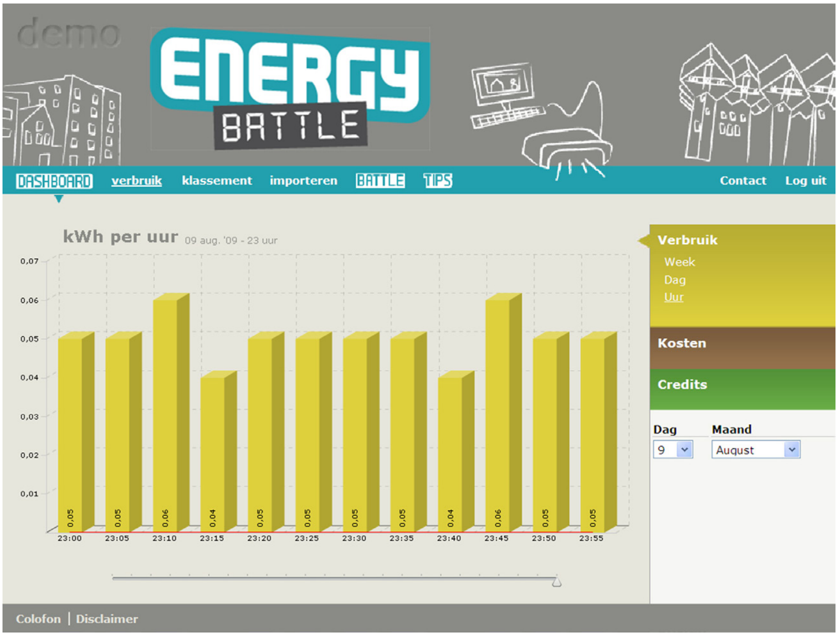


Figure 11: Dashboard, electricity consumption (image by Shifft)

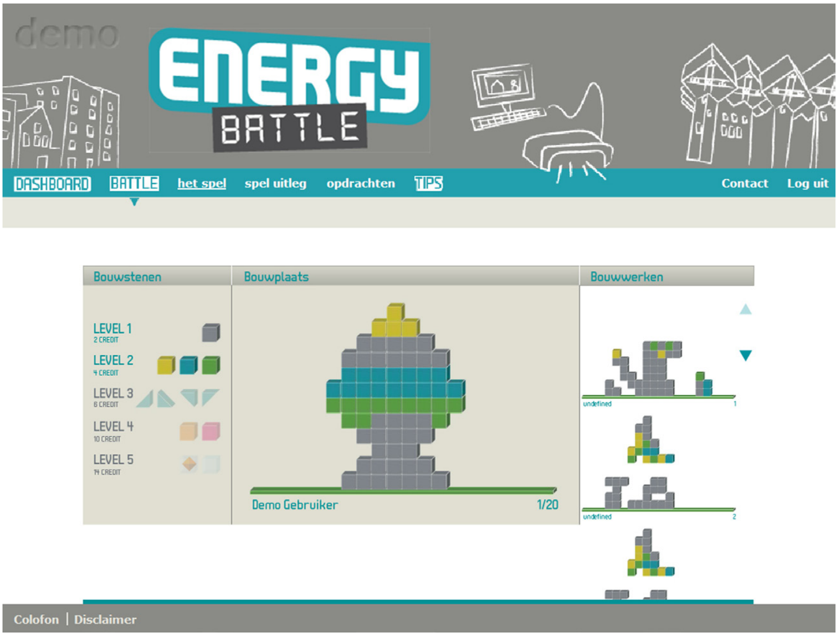


Figure 12: Online game over time (image by Shifft)

The game elements in question 4 refer to: direct feedback, feedback over time, tips, prizes, ranking, game with building blocks and teamwork.

Since the researchers only became involved after completion of the game, the research started with an analysis of the data that were collected by the organizers of the Energy Battle: the electricity consumption data and the answers to an online questionnaire held by the organizers directly after the pilot. Since this questionnaire did not provide a lot of insight about motivation and ability, nor long-term effects, complementary semi-structured interviews were held. These interviews addressed the role of the elements of the Energy Battle and the motivation and ability of the participants both as individuals and as a team. The interviews were held eight months after the Energy Battle, thus also providing insight in the long-term effect of the competition.

3.6 Results

Twenty households (teams) in the city of Rotterdam in the Netherlands participated in the game. The households consisted of two to five members and were located in three different buildings of a housing association. They were invited to sign up via posters in their buildings, followed up by personal communication by Shifft, the organizers of the Energy Battle. Of the 20 households that initially started in the competition, 17 uploaded the measurement data to be included in the ranking of the competition. The remaining 3 either were not able to upload the data or had lost interest in participating. The questionnaire was sent to individuals in the teams. 17 questionnaires were filled in and returned, representing 16 households (2 respondents from the same team).

It was difficult to find respondents for the interviews. Many people had already moved or could not make time for the interview. Four interviews were held with people from teams with both high and low amounts of saving; of these, two were with members of the same household. (Respondent 1, team N, 14th place in the final ranking; respondent 2, team E, 5th place; respondent 3, team G, 7th place; respondent 4, team G, 7th place).

3.6.1 Main reasons for participating

Both the prizes and the energy savings were important incentives for participating. In the questionnaire more respondents answered that the awards were more important than the energy saving itself (9 and 7 respectively). Due to the small sample size one cannot conclude that the prospect of the prizes was a stronger motivator.

In the complementary interviews another reason was mentioned: curiosity for learning about energy consumption in the home. Respondent 1 stated: *“ … we thought that it was not very probable that we’d win the competition. But in the end…a reason may have been that we wanted to see if we could achieve some results”*.

The team of respondent 2 (team E) was only interested in winning the prize: “At that time we were still very much into cooking and trying out recipes. You could win kitchen appliances, that stimulated us a lot.” This team was among the households that saved the most electricity.

3.6.2 Achieved energy savings

The amount of savings in electricity use was 24% overall, with the highest being 45%. Figure 13 shows the amount of saving per household. Seven of the teams reached savings of 30% or more, and only 4 households did not save more than 10%. Figure 14 shows the average amount of electricity consumption per day and per person for each household.

Overall, the reasons for participation do not appear to influence the amount of savings. The teams are equally represented in the higher saving categories (> 30%).

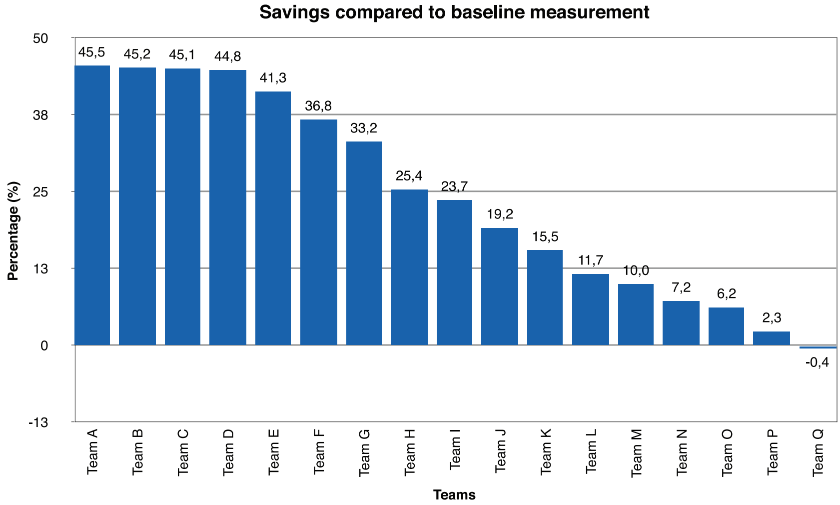


Figure 13: Amount of savings (in %), relative to the baseline measurement

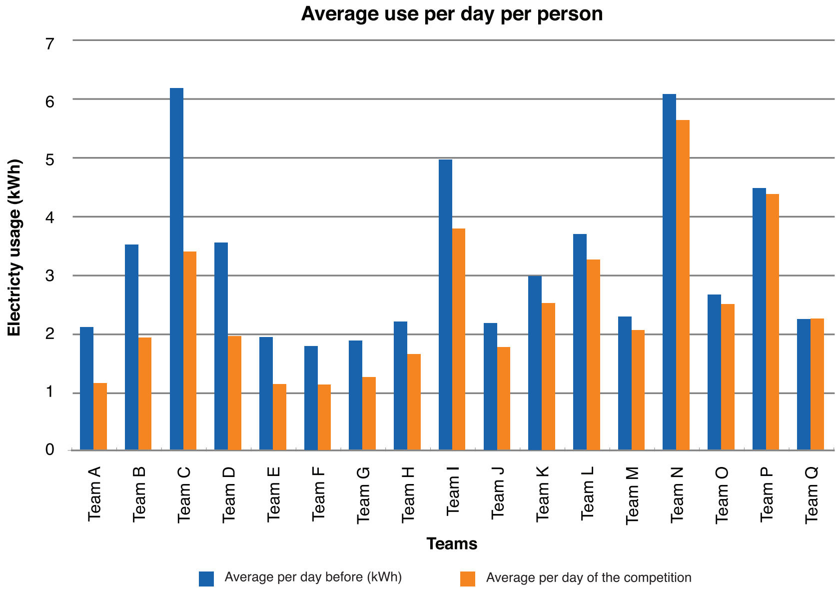


Figure 14: Energy consumption per person per day before (baseline) and during the Energy Battle

3.6.3 Energy saving activities

The respondents to the questionnaire were asked to list what they had done to save energy. It was an open question. The researcher coded the answers. Table 1 shows a crosstab of the activities and the amount of energy saving.

The most frequently mentioned measure was turning off lights, indicated by 13 of the 15 participants. Turning off lights was followed by lower use or different usage of media, less PC or less TV. One respondent mentioned that they substituted watching TV for listening to the radio. Measures involving cooking were mentioned a lot (6 out of 15), mainly related to the electric kettle in terms of boiling less water and direct usage of the hot water. Turning off and unplugging devices to avoid stand-by current was mentioned by 4 out of 15. Turning off the refrigerator (2 out of 15) can be considered a more extreme measure, since it involves the risk of spoiling

	Missing*	< 0 %	0 - 15 %	15-30 %	30 - 46 %	Total
Lights (turning off / saving bulbs)	1	1	2	3	7	14
Cooking/kettle	1	0	1	0	4	6
Media	1	0	1	3	2	7
Social activities	0	0	0	0	2	2
No standby/unplug	0	0	0	0	4	4
Turn off refrigerator	0	0	1	0	1	2
Personal care	0	0	0	0	1	1
Total respondents	1	1	2	3	8	15

* Measurement data was not available for this team

Table 1: Energy saving measures. The percentages stand for the amount of savings achieved, divided into four categories.

food. High electricity-consuming products such as washing machines and tumble dryers were not reported in the activities.

Remarkable are the social activities that led to energy saving. Respondents, who usually eat dinner separately, reported having dinner together. They would thus cook in one batch for all housemates instead of each housemate cooking separately. They also reported decreasing time spent at home to use less electricity. Furthermore, when looking at the cross-tabulation on the amount of measures taken and the amount of saving it can be seen that, not surprisingly, those who saved most took the most measures.

The responses to the questionnaire provided insight into how much the energy saving activities infringed on their comfort. Most respondents indicated that they had done more to save energy than they found acceptable for comfortable living (8 out of 15, 2 missing). However, 5 out of 15 indicated they could go on like this forever. Of the respondents in the households with the highest savings, 30 to 46%, most responded that they did more than desirable to live comfortably (5 out of 8 in this category), while the other 3 indicated that they could have continued comfortably at the achieved level of savings. This could mean that a lot of saving is possible without perceiving a (too big) loss of comfort. It could also mean that the game motivated the teams to do more than is comfortable. To illustrate how the measures influenced daily life: Team E, of respondent 2, explained in the interview how they did far more than what they considered comfortable. They had agreed to have only one computer turned on at a time, meaning that they shared and coordinated computer use. Watching TV was banned. Furthermore they cooked dinner together, instead of cooking separately, and had dinner by candlelight only.

3.6.4 Role of elements in savings

There are a number of elements that can be discerned from the Energy Battle: direct feedback, feedback over time, tips, prizes, ranking, game with building blocks and teamwork. The questionnaire addressed some of these elements. During additional interviews the respondents were explicitly asked to share their opinions about the elements of the Energy Battle.

Wattson – direct feedback

The Wattson energy meter was used as a tool to help save energy. The direct feedback was used to find out how much power appliances consumed. The respondents reported that the direct feedback of the meter provided insight for, and motivation to, use less electricity. Furthermore the respondents stated that the meter drew attention (respondent 1 and 4). In the case of respondent 1, even visiting friends were drawn to the meter and asked for demonstrations.
The game participants indicated via the questionnaire that, given the energy meter, the dashboard and the prizes, both the energy meter and the prizes were the main motivators to save electricity (7 and 6 resp. of 15 valid responses).

Dashboard – feedback over time

The questionnaire results do not provide a clear answer to whether the over time feedback on the 'dashboard' was useful. In the interviews the respondents on the one hand said it had been very useful: *"very good because it showed us that we should use less"* (respondent 2). On the other hand, there were teams that had problems with uploading the information and as a result could not use the information (respondent 3).

Tips

While 6 respondents indicated that the tips helped them save energy, 6 (of 15) did not have an opinion. This means that they did not see the tips or did not use them, as two of the interview transcripts point out (respondents 2 and 4), or they did not find them helpful. The responses to the questionnaire suggest that the tips contributed to higher energy savings, because respondents stating that the tips were useful for saving energy were from households that saved more than 30%.
In the interviews we found that the tips helped to discover how to save energy. Respondent 1 for example said that a question about the vacuum cleaner made him try it and look at the energy consumption on the energy meter. As a consequence he now uses the vacuum cleaner less and began using a crumb sweeper instead.

Prizes

While some participants took part in the activities for, and remained driven by, the chance of winning the prize, others were mainly interested in gaining more insight into energy consumption and saving energy. The questionnaire results suggest a 50/50 split. When choosing among the energy meter, the dashboard and the prizes, both energy meter and prizes ranked as most attractive (7 and 6 responses respectively out of a total of 15 valid responses).
Ranking
The ranking remained important as long as the teams still had a chance at winning. According to Versluis (Personal communication, 2009) and the responses to the questionnaire, once a given team's ranking dropped as to preclude any chance at winning, the team lost its motivation to save

energy. There were also households that did not pay a lot of attention to the ranking since they were only interested in how their own household could save energy.

Game with building blocks

The questionnaire results indicate that the building blocks game was both challenging and motivating to save energy. However, the interviews cannot confirm the findings of the questionnaire:
The building blocks game was *"not really important. We wanted the other prize, but we won on this element"* (respondent 2). Her team won the originality prize for nicest construction. Respondent 1 stated: *"...especially in the beginning, we had very little points so we could not really build something. So it was not a motivator"*.

Teamwork

The questionnaire did not address teamwork as an influential factor for the energy saving activities in the Energy Battle. Versluis (Personal communication, 2009) indicated that teams that saved a lot of energy were coordinating their activities. The team members of respondent 2, which ranked second, had agreed to have dinner together and not to use more than one computer at a time. Housemates thus had to coordinate computer use. *"We stimulated each other to turn off the lights and used each other's computer"*. Furthermore she said *"It was quite funny and cozy, because for a few nights we had been sitting together with candles. It made our house quite cozy"*.
Teamwork could also include consensus about reducing time spent at home. According to respondent 2, and to her annoyance, the members of the winning team were hardly at home.
In other teams agreements were not reached explicitly. The team simply discussed their individual findings with each other (respondent 1 and 3). Discussion with the other team members was considered useful: *"The best [about the Energy Battle] was that we were now consciously talking about it, although we did not work on it together so much"* [due to different working hours] (respondent 3).
Respondent 1: *"We did not really work on strategies ... It just started, that was also my idea, just see how it goes and whether it is of any use to us. In the end it simply is fun to see how the energy consumption regulates itself."* Respondent 1 and one of his housemates, wanted to involve a less energy conscious household member to encourage him/her to become more conscious about energy use.

3.6.5 Energy consumption after the Energy Battle

Directly after the Energy Battle, the energy meter remained in the households for a month. Figure 7 shows the relative energy savings after one month. Unfortunately, these data could not be retrieved for all the teams.

Two teams continued to lower their electricity consumption (team L and N). In 4 of the 10 monitored households electricity consumption rose, but

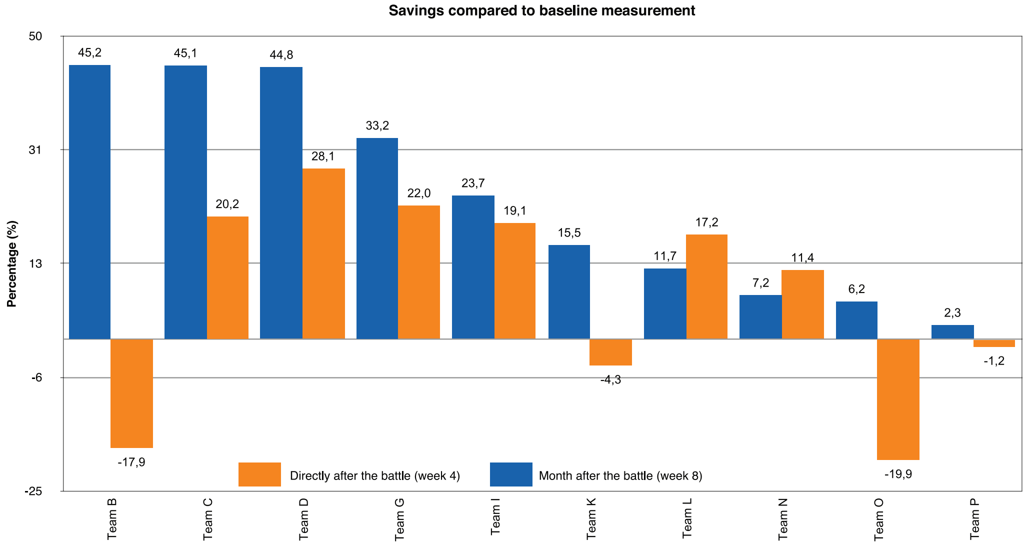


Figure 15: Energy saving directly after and one month after the Energy Battle compared to baseline data (in %).

still remained below the level of before Energy Battle. Two households (team K and P) have a difference in electricity consumption level before and after the game of less than 5%. This can be considered as returning to the baseline level. Finally two teams (B and O) use more electricity than before the Energy Battle.
Overall the expectation whether the electricity consumption level would stay below the baseline level was moderate. The responses were 6 times 'I don't think so', 7 times 'maybe a little', twice 'for sure' (15 valid responses). Which is comparable to the results above.

3.6.6 Eight months later...

The additional interviews held eight months after the Energy Battle ended, provide insights into the effects of the Energy Battle over a longer term.
The energy meter was still in the households of respondent 1 and 2. In the house of respondent 2 they had disconnected the energy meter when the official measurements were over. In the house of respondent 1 the energy meter was still working. He mentioned looking at it, but he also indicated that he had not retrieved the historical feedback data stored in the device.
In terms of energy behavior the interviews indicate that some things have changed, due to the Energy Battle. Respondents say to be more conscious about switching off lights (respondent 2), boiling less water in the kettle and use the water right away instead of reheating it later (respondent 1, 4).
The team that actively saved energy via extreme measures (respondent 2 of team E) indicated that they maybe were more conscious about their electricity consumption behavior and that some habits had been developed:
"I am sure that after the Energy Battle we unconsciously took it [energy saving] into account. You did not really think about it, but did turn off the lights or so...Now I always turn off my computer...yeah, I don't know...I am not doing it consciously... and considering what I answered to your questions... we did not really consider saving energy anymore."
Those that did not take it to the extreme (respondents 1, 3 and 4) indicated that they maintained all the behaviors they had adopted or changed during the Energy Battle:

"I try to continue as much as possible with what we started then" (respondent 1).

"During the Energy Battle we did hardly anything different than now" (respondent 4).

None of the interviewees could tell how much their electricity consumption was at that time. They only guessed that, based on the changes in their behavior, consumption would be lower than, or equal to, the level before the Energy Battle.

In terms of insight into electricity consumption, the respondents indicated that it had either stayed the same or improved. With respect to discussing the topic of energy consumption amongst the team members: they stopped doing it once the competition had ended.

3.7 Conclusions

This study is based on a small sample size in a particular target group. Therefore it is not possible to draw generalizable conclusions concerning the impact of the Energy Battle on energy consumption behavior. The study did nevertheless provide insight in the role the game and its elements play in motivation for, and the ability to, perform energy saving behavior.

3.7.1 Motivations to participate

To answer the first research question: Among the reasons for participating in the Energy Battle both receiving the prizes and gaining insight into energy saving dominated. This difference in motivation did not appear to influence the teams' energy savings results. This suggests that even when people participate for reasons other than energy saving, a behavior change can be maintained in the longer term.

3.7.2 During the game

The amount of energy saving (research question 2) was 23% on average, with more than half of the teams saving more than 30%. The activities undertaken to reach these savings are mainly related to lighting, media use and cooking. Only one respondent mentioned vacuum cleaning (after a cue from the Energy Battle). No one mentioned measures related to washing machine, tumble dryer or dish washer; appliances that have quite an impact on the electricity consumption of a household. At least a washing machine must have been present in the households. This result suggests that the game design should include guidance to explore all energy saving options. Concerning the role of the game elements, the feedback from the energy meter and the prizes turned out to be most motivating elements for energy saving during the game. This coincides with the two most mentioned reasons for participating: learning about energy saving and winning the prizes.

The feedback via Wattson and Dashboard increased the task knowledge of the participants, as was expected from the literature research. In the first month following the Energy Battle, the teams were still able to read consumption data on the energy meter. The interviews indicate that the feedback was hardly used after completion of the Energy Battle. Apparently the game context during the Energy Battle was more influential for energy saving than the actual ability to achieve it. This coincides with the findings of McCalley and Midden (2002), that feedback only works when it helps the users to achieve a goal. When energy feedback remains accessible following interventions such as the Energy Battle, it may be useful to consider how an intervention can provide follow-up goals or stimulate the users to set goals.

The extent to which the tips contributed to task knowledge could not be verified. In future game design, attention should be given as to how tips may contribute to behavior change in a game context and what effect different types of tips have. The tips can for example be used to better guide the energy saving activities.
The ranking, and thereby chance of winning a prize, affected the motivation to save energy during the Energy Battle. Motivation to save energy was high when teams expected to have a good chance to win the game. The motivation dropped however when there was no chance of winning anymore. Further research into game design should consider how the participants could be motivated throughout the game. Apart from the winning prize, some form of reward for all other participants should be considered.

It is not clear what role the building blocks game played in stimulating behavior change due to the mixed results from the questionnaire and the interviews. While energy saving enabled participants to play the game, energy saving could be achieved without playing the game. This online game thus has to be really engaging for participants to play it or playing the game should contribute to the energy saving goals of the players. Further research has to look at how to better integrate such a game in the overall game dynamics of the Energy Battle.

Cooperation between team members and the competition with other teams influenced the motivation to play the game and thus save energy. The Energy Battle used these intrinsic motivators in a very basic, though successful, manner. Further research could look into different ways to use intrinsic motivators for energy related behavior.

3.7.3 Energy consumption behavior in the long term

The study yielded mixed results on the energy consumption trends after the game. Six out of ten households stayed below baseline level, while others returned to baseline level or even consumed more.
In general, it appears that the lower levels of energy consumption were not maintained in the month after the pilot, because the competition and social influence among household members were removed and the teams ceased to perform activities that were not considered comfortable. For example, sharing one computer at the time is hard to keep up, when most household members have their own and use it frequently.
During the Energy Battle the teams took extreme measures that infringed their comfort. We could not find out what the effect was of extreme measures on behavior change in the long term. Bång et al. (2009) suggest that casual game play with less extreme behavior has more effect in the long term. Unfortunately they did not present data comparing long-term behavior from extreme vs. casual behavior changes. Further research

should look into the effects of stimulating extreme behaviors versus casual behavior during a game, both for long-term energy savings as for game play.

Concerning habits, the interviews suggest that new habits were formed, even in a team that was not interested in energy saving. This indicates that a game can be effective in changing habits. The change in context of the energy consuming behavior appears to have been sufficient to break habitual behavior and encourage new behavior. For behavior that was often performed, such as switching of lighting, unplugging adapters and putting on the kettle with less water, the repetition may have been sufficient and long enough to transform habits.
Maintaining behavior over a long period is a critical factor for using games as interventions to change behavior. Further research is necessary to explore in what ways a game can support long-term behavior change. Using gaming as part of a broader long-term program of products and services (with or without game elements) could be a way to provide a context and stimuli that facilitate energy saving behavior, or sustainable behavior in a broader sense, in the long term.

The test of the Energy Battle in student households demonstrates the potential for creating insight among households on how to save energy and the formation of new habits. The next step would be to make a translation of the findings from this study to tailor the Energy Battle for other target groups, such as families with children. Furthermore, in light of the facilitation of households in a co-provider role, it would be necessary to consider how a game design will need to change to stimulate the aspects of household energy management beyond energy saving, i.e. shifting consumption, producing electricity when favorable for the system and trading surplus produced electricity. Co-provision related energy behavior is more complex than energy saving only, and suggests that different game mechanics are required that include a contribution at household or community level to the balancing of supply and demand in the local grid. Instead of stimulating competition between community members, a cooperative approach aimed at achieving common goals for balancing supply and demand in a smart grid community may be more effective at community level. Competition could then still be used to motivate changes, but between communities rather than between households.

Main results and design implications of this chapter

Main results

- *With respect to the layer model, the Energy Battle can be seen as a service to motivate changes (the outer layer of the model) which also includes intermediary products: an energy meter and a website with energy feedback.*
- *To engage end users in behavioral changes concerning their household energy management, the combination of feedback and competition in the Energy Battle was successful, mostly in the short term. There were indications of minor habit changes.*
- *The feedback provided by the energy meter and website offered end users the opportunity to assess their electricity consumption levels and undertake action to lower their consumption, whilst the competition with other households, a form of social comparison, provided an incentive to save energy. Furthermore, the game context of the Energy Battle seems to appeal to intrinsic motivation for cooperation within the households and competition between households. The actual behavioral changes appear to also have contributed to participants' propensity for energy saving, with knowledge, know-how and changes in habitual behavior.*
- *Revision of the game design is required for adaption to other target groups and higher impacts on energy related behavior and energy saving.*

Implications for product- and service design

- **Long-term effects:** *The achievement of long-term effects needs to be considered in the design of a game, for example by fostering habit formation and development of know-how.*
- **Guidance of energy related behavior changes:** *To achieve high impact saving, guidance of behavioral change is recommendable, for example through tips, assignments and design of the feedback to focus attention. This will be relevant for a smart grid context in which household energy management goes beyond energy saving and becomes more complex.*
- **Actions are to be meaningful:** *When the actions are meaningful, households remain motivated to perform a certain behavior. For example, interest in winning the prize versus interest in the potential for energy saving provides different bases for an energy saving behavior to be meaningful. In Energy Battle, teams who lost the opportunity to win and had no particular interest in energy saving stopped energy saving activities.*
- **Inclusion of heating energy:** *In the Netherlands heating constitutes the major part of household energy consumption and it is recommendable this consumption is included in a game for energy saving. This would mean that gas consumption should be included.*
- **Social dynamics:** *Take social dynamics in households and between households into account and consider using them to leverage the impact of the game.*
- **Games as part of broader programs:** *A game context can temporarily boast energy saving activities. Using gaming as part of a broader long-term program of products and services (with or without game elements) could be a way to provide a context and stimuli that facilitate energy saving behavior, or sustainable behavior in a broader sense, in the long term.*

4

A smart grid in practice: PowerMatching City

4.1 Introduction

In Hoogkerk, The Netherlands, a smart grid pilot project, PowerMatching City, was running in which smart energy technology was installed in real households. Thereby the households were technically as well as socially connected in a smart energy system. In contrast to Energy Battle, which was a temporary intervention focused on behavioral change, PowerMatching City presented a structural change in the households by replacing heating systems and appliances to enable co-provision in households. This smart grid pilot project was selected for this thesis because of it's integral design for a local smart energy system that aimed to optimize supply and demand balancing with respect to goals of network operators, energy providers and households. It provided the opportunity to study experiences of households with smart grid technology in a real life setting and during several years of use. Three field studies were carried out in PowerMatching City for this thesis. They are discussed in Chapters 5, 6 and 7. This chapter describes the set-up of the pilot project and the sample of participating households.

The PowerMatching City pilot (PMC) started in 2007 as one of the pilot locations of INTEGRAL, a European project under the 6th Framework program, with a consortium of companies and research institutes[1]. The main goal of the project was to design and deploy a smart energy system in which supply and demand are coordinated at distribution grid level, including real households and with 'off-the-shelf' technology. The term smart energy system refers specifically to a power system that includes distributed energy production and ICT technologies that enable demand response of appliances for supply and demand matching. It is used instead of 'smart grid', which can have different meanings depending on the context.

In the first phase of the project PowerMatching City involved 22 households that were connected in a smart energy system and therefore equipped with smart energy technology. Research in the first phase of the pilot focused mainly on demonstrating the technical functioning of the system with respect to the multiple optimization goals that were defined (see section 4.2). In first instance, the smart energy system design was intended to automate co-provision as much as possible. It was however recognized that insight into end users' experiences related to their participation in the smart energy system was needed for further development of products and services related to smart grids.

In January 2011 the first phase of the project officially ended and a transition took place to a second phase starting in September 2011. In the transition period the author joined the project. The project activities in this period were minimal and aimed at maintaining the smart energy system and keeping the households involved. End user research was included in the second phase of the project 'PowerMatching City II', run by a consortium of Dutch partners, partly the same partners as in the INTEGRAL project, co-financed by the IPIN subsidy from the Dutch government. In this phase a second group of households was added to the smart energy system. Lessons learnt with the implementation of the smart energy system in the first group of households provided input for the extension of the smart energy system with additional households and for further end user research concerning

1 For more information see: www.integral-eu.com

products and services for households participating in a smart grid.
The studies presented in this thesis address the end user side of the smart energy system. They relate to the households participating in the first phase of PowerMatching City as the technology implemented for the second phase only became operational in autumn 2013. Where possible, findings are complemented with initial insights from the on-going research in phase 2.

The research in PowerMatching City is based on three complementary research goals, each addressing a different aspect of how co-provision by the households is enabled in the smart energy system. Each goal will be addressed in, Chapters 5, 6 and 7 respectively. The goals are to:

1. *Gain insight into the balance between energy consumption and production at household and cluster levels, in order to identify differences in performance between seasons and heating systems as well as to gain insight into the potential for end user behavior to contribute to energy balancing.*
2. *Evaluate to what extent the smart grid products and services in PowerMatching City empower the end users to assume a co-provider role in the smart energy system.*
3. *Explore the interest in, and potential for, social interaction among the participants in the smart energy system for engaging with home energy management.*

The questions address what happened in the smart energy system at the household level, concerning, on the one hand, energy consumption and production in the cluster of households and, on the other hand, the experiences, needs of and potential for the households' members as co-providers in the smart grid (Questions 2 and 3). The findings presented in the following chapters point out that although the households were enabled for co-provision from a technology point-of-view, the empowerment of the end users could be organized differently to optimize the potential for matching of supply and demand that takes place in the smart energy system.
The study of PowerMatching City was design-driven, which means end users represented a starting point to gain insight for the development of products and services that match their needs, wishes and possibilities, as opposed to expecting end users to comply with the needs and possibilities of technology (Geelen et al., 2013). Furthermore, the study into PowerMatching City was of an exploratory nature because the smart energy system implemented in PowerMatching City was under continuous development and consisted of a small amount of participating households. The research took place in practice, thus interventions and data collection were adjusted to the situation 'in the field'. This meant that the research had to adjust to changing circumstances and to make use of the common project approach to organizing meetings and other communication.
The sample of 22 participating households was too small for statistical testing. The sample was not representative of households in the Netherlands as described in section 4.3. Because of the newness of the research field, the project nevertheless provided a valuable opportunity to gain insights for future product and service development at the household level.

The research methods used for the study included:

1. *Quantitative analysis of energy consumption and production. This part of the study made use of the available monitoring data related to the energy consumption and production in the cluster of households.*
2. *Qualitative field study into the extent to which end users were taking part in the smart energy system as co-providers, as well as the role of social interaction in the community of participating households. This study involved methods such as interviews, focus groups, co-design activities and questionnaires.*

A clarification of terms is necessary here, as the group of households is referred to as a cluster of households as well as a community of households. The term cluster refers to the households connected to each other in the virtual electricity network of PowerMatching City and is thus related to the technical system. The term community refers to the social context of a group of households with individuals that participate in the project and interact with each other. A more detailed description of the utilized methods follows in the following chapters addressing the corresponding research questions. An overview of the research activities is included in appendix A.
This chapter continues with a description of the pilot project in relation to the implemented system in Section 4.2 and a description of the sample of participating households in Section 4.3. Followed by a conclusion. Next, in Chapter 5 the first research question about the energy production and consumption balance in the cluster is addressed. Chapter 6 addresses the second question about the extent to which the end users in PowerMatching City were empowered as co-providers by the implemented technologies. The third question about social interaction in the community of households is addressed in Chapter 7.

4.2 PowerMatching City system design

PowerMatching City consists of a cluster of connected households within a smart energy system. In this thesis, the combination of the components at the household level will be referred to as the 'home energy system' to differentiate from the 'smart energy system' which refers to the overall system in which the households are connected. In addition to the 22 home energy systems, several other devices are included in the smart energy system, such as electric vehicles used by a utility company, a wind turbine and a number of simulated households.

The smart energy system is designed to achieve several goals, related to different stakeholders in the electric power system (Bliek et al., 2011, 2010):

- *Capacity management for the distribution system operator (DSO) and transmission system operator (TSO). For the project, this is focused on the reduction of peak loads.*
- *Commercial optimization for electricity companies trading on the energy market. To support the balance between energy production and demand in the energy market, the production and demand in the*

distribution grid can be influenced, for example smooth peak power demand and avoid dispatch of costly reserve production plants. For the project, the cluster of households can be controlled as a Virtual Power Plant (VPP).

- *Integration of renewable energy sources. The coordination mechanism has to take care to valorize generated renewable energy from wind and solar and take care to minimize imbalance due to the intermittency of these sources. This can be done for example by stimulating demand from the households in the cluster.*
- *In-home optimization for cost-effective use of energy by end users. With respect to recovering investments made in renewable sources, the coordination mechanism aims prioritizing in-home consumption of produced electricity when market (sales) prices are low and delivery of electricity to the grid when market prices are high.*

The description of these goals indicates the complexity of operating a smart energy system. The different goals for stakeholders in the electric power system, from residential end user to commercial energy provider, means that trade-offs have to be made continuously to negotiate and achieve the goals that are set in the project. The goals are based on the technical and financial considerations that govern the management of the electric power system.
Since the research in this thesis focuses on household energy management,

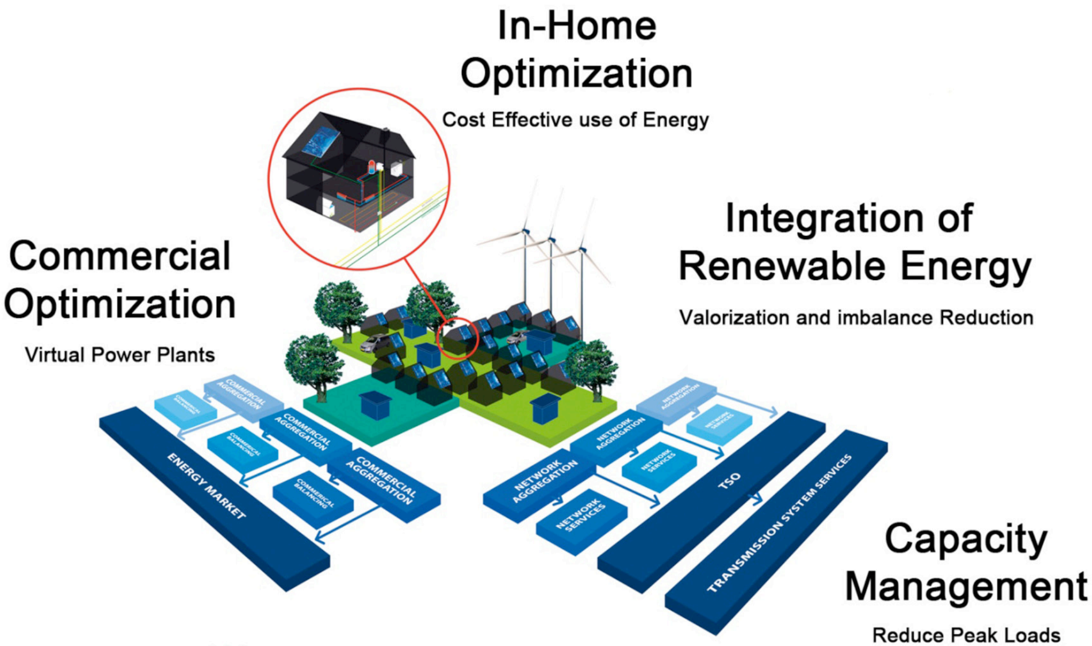


Figure 16 Impression of the smart energy system of PowerMatching City and its optimization goals.

the description here is limited to the home energy systems with which end users interact. The main components of the home energy system are:

a. An automatic coordination mechanism, named PowerMatcher
b. Heating systems
c. Smart household appliances
d. Renewable energy sources
e. A user interface.

These components are described in more detail in the following sections, of which most information about system specifications are taken from Bliek et al. (2011). Figure 17 provides an overview of the home energy system components of PowerMatching City and Table 3 summarizes the configurations of the home energy systems that are present in the various households. The underlying premises for the operation of the home energy system were that (1) operation would be automated as much as possible and (2) the participating households would not experience loss in comfort concerning the use of their electric appliances nor the available heat for hot water and space heating.

Table 3: Configuration of technologies in the households

Total number of households 22							
HHP 12				**μCHP** 10			
Own PV 2		**Virtual PV** 10		**Own PV** 2		**Virtual PV** 8	
Smart appliances		**Smart appliances**		**Smart appliances**		**Smart appliances**	
Yes	No	Yes	No	Yes	No	Yes	No
1	1	5	5	1	1	4	4

4.2.1 Automatic coordination mechanism PowerMatcher

Central to the operation of PowerMatching City as a smart energy system is its coordination mechanism that monitors and controls energy supply and demand balance in the cluster. This coordination mechanism makes use of the demand response possibilities of the devices connected to the cluster. The energy supply and demand in the network of PowerMatching City is automatically balanced with an agent-based algorithm called 'PowerMatcher' developed by TNO. A comprehensive description of PowerMatcher- technology is given by Kok et al. (2012). In general terms, PowerMatcher uses different types of agents that together coordinate the matching of supply and demand of electricity in the network based on market mechanisms. An ICT interface layer between the devices and the PowerMatcher allows a device agent to trade the consumed or produced

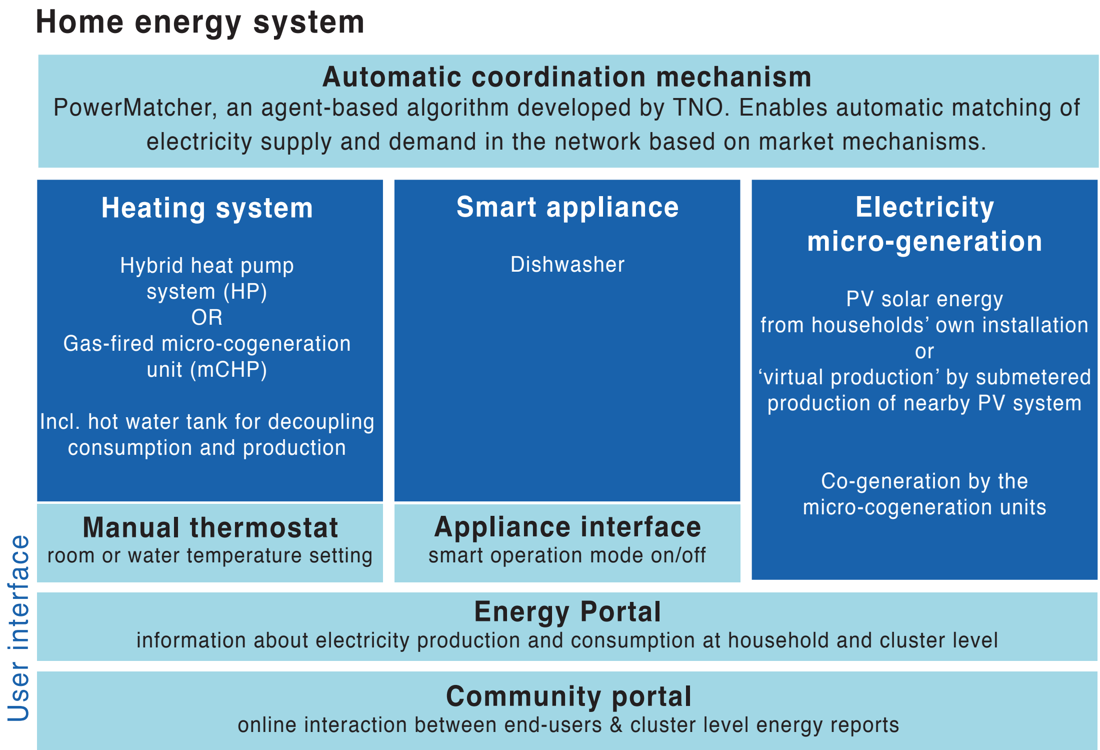


Figure 17 Overview of home energy system

electricity on a local market. The PowerMatcher for example aims to sell a households' self-produced electricity when it is most valuable and to buy electricity when it is cheapest on the grid. The agent operates within boundary conditions set by the end users. So for example, when the dishwasher is set to finish a cycle at four o'clock in the afternoon, its agent will try to find a time slot to operate at the lowest cost, while making sure it finishes on time.

The coordination mechanism can be adjusted to suit different goals and needs of the participants in the smart grid. To this end, the agent's objectives and trading conditions are modified. For example, PowerMatcher could instead of optimizing for lowest costs for the end users independent of the sources of production, be set to maximize consumption of self-produced electricity.

In the households a 'home energy computer' is installed which functions as a gateway for the coordination activities of PowerMatcher as well as local storage of data that were used for the monitoring and operation of the smart energy system.

4.2.2 Demand response for heating systems

Two types of heating systems were implemented that can be used for demand response. Twelve households were equipped with a hybrid heat pump system (HHP) while ten households were equipped with gas fired micro-cogeneration systems (µCHP).

The hybrid heat pump system consists of an air-source heat pump (Samsung, 4,5 kW thermal power output), a condensing boiler (Intergas, 20 kW thermal power output) and a 210-liter hot water tank. The heat pump is used for the basic heating demand throughout the year. The condensing

boiler is used for peak loads, i.e. hot tap water and during the cold winters when the efficiency of the heat pump drops. The hot water tank serves as a buffer and thereby enables decoupling of electricity and heat consumption. As a result demand response is possible: the heat pump can generate heat at optimal times according to electricity tariffs or renewable electricity availability, while the household can use the heat when it is needed.
The micro-cogeneration systems make use of a micro-cogeneration unit (Whispergen, 6kW thermal and 1 kW electrical power output) and a 210-liter hot water tank. The micro-cogeneration unit produces heat and electricity simultaneously. The minimum run time for efficient production of electricity is 30 minutes. An auxiliary gas heater, built into the micro-cogeneration unit, can boost the thermal power output with another 6 kW. Similar to the households with a heat pump, the hot water tank stores produced heat, and thus enables decoupling of heat production from heat consumption.

4.2.3 Demand response with appliances

Twelve households were equipped with two smart appliances: a dishwasher and a washing machine. Both were equipped with Miele@Home technology. These appliances can be used in 'normal' and in 'smart mode'. In 'smart mode' PowerMatcher, the smart energy system's coordination mechanism, can control the appliances remotely. The coordination is based on the supply-demand balance in the smart grid in combination with end user settings, such as the time by which an appliance should finish the wash cycle.
During the period in which the studies described in this thesis took place, between June 2010 and January 2013, demand response with the smart appliances had not been fully possible due to communication problems between the smart appliances and the PowerMatcher. The communication problems with the washing machine remained unsolved throughout this period. Demand response with the dishwasher was possible beginning in February 2012.

Table 4: Overview of smart grid technologies in the households

	Energy system components	Power Output (per household)	Number of Households
Micro – cogeneration units (µCHP)	µCHP	1 kW electric 6 kW thermal 6kW thermal (auxiliary burner)	10
Hybrid Heat Pump units (HHP)	HHP	4.5 kW thermal	12
	Gas fired boiler	14 kW thermal	
Photovoltaic systems	Virtual	1590 Wp electric (on average)	18
	Real on roofs of participating households	Households with µCHP: 2300 W_p 300 W_p Households with HHP: 750 W_p 550 W_p	4

4.2.4 Renewable energy sources

Renewable energy production in the PowerMatching City cluster consists of photovoltaic (PV) solar energy for each household and wind energy. Four households produced electricity with their own PV solar installation. The other households had 'virtual PV production', via sub-metering of a PV system on a building of one of the project partners in the city of Groningen. In this way the effect of the PV production on the cluster could be taken into account at the household level. In addition to PV solar energy, a wind turbine was connected to the cluster. The production of this wind turbine (2,5 MW) was scaled down virtually to match the consumption levels of the households.

4.2.5 User interface

Interactions between end users and the technical system take place via the user interface. In the first phase of PowerMatching City, the interface of the home energy system consisted of the following elements (see also Figure 18):

1. *The end users could use a thermostat to set the desired room temperature (Figure 19). The thermostat had to be set to the desired temperature by turning a knob. Additionally, the thermostat could be set to 'stand-by' via a button, which lowered the temperature setting to a pre-defined level for 7 hours.*
2. *The interfaces of the smart appliances let the end user choose the appliance's operation mode, i.e., automated via PowerMatcher or direct operation. For the washing machine in automated mode the end user could state when the washing machine has to be ready. It then allowed the dishwasher an 8-hour time window to finish a program in automated mode.*
3. *An Energy Portal was available after login via the Internet (Figure 20). This website provided information about electricity production and consumption in kWh at the household level and for the cluster of houses as a whole. The information was presented in the form of bar and line graphs representing the last month and last two days.*
4. *A community portal enabled online interaction between end users. Strictly speaking, this portal was not about interaction between the end user and the technical system, but rather about communication between end users and with the project team. The community website was implemented later than the previous elements, in April 2012.*

4.3 The participating households

The sample for the research presented in this thesis consisted of 22 households. They participated in the project on a voluntary basis and were recruited through the network contacts of DNV KEMA (e.g. former employees and contacts of those employees in e.g. local sustainability initiatives), as well as via a call for participation in a local newspaper. Two of the participants were also employees of DNV KEMA and members of the project team. They took part in the design, installation and maintenance of the home energy systems.

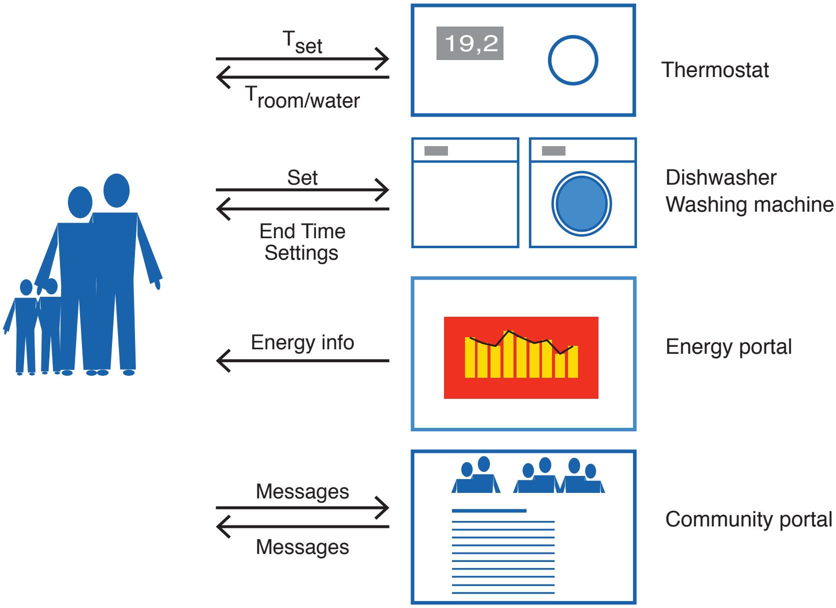


Figure 18: Schematic of user interface of the home energy system

Figure 19: Manual thermostat (source: DNV KEMA, information leaflet about PowerMatching City)

The following sections describe the group of participating households and compare the sample with statistical data from the Netherlands. Most Information about the households became available via research activity A, B, N and P (see appendix A), including information about the household characteristics collected via questionnaires. The amount of respondents to the questionnaires ranged from 12 to 16. Combined, they provided information about 18 of the 22 households. Additionally, basic information, such as addresses, was available for all households. Whenever used, data from 2009 were complemented with information from later research activities to reflect the 2012 context.

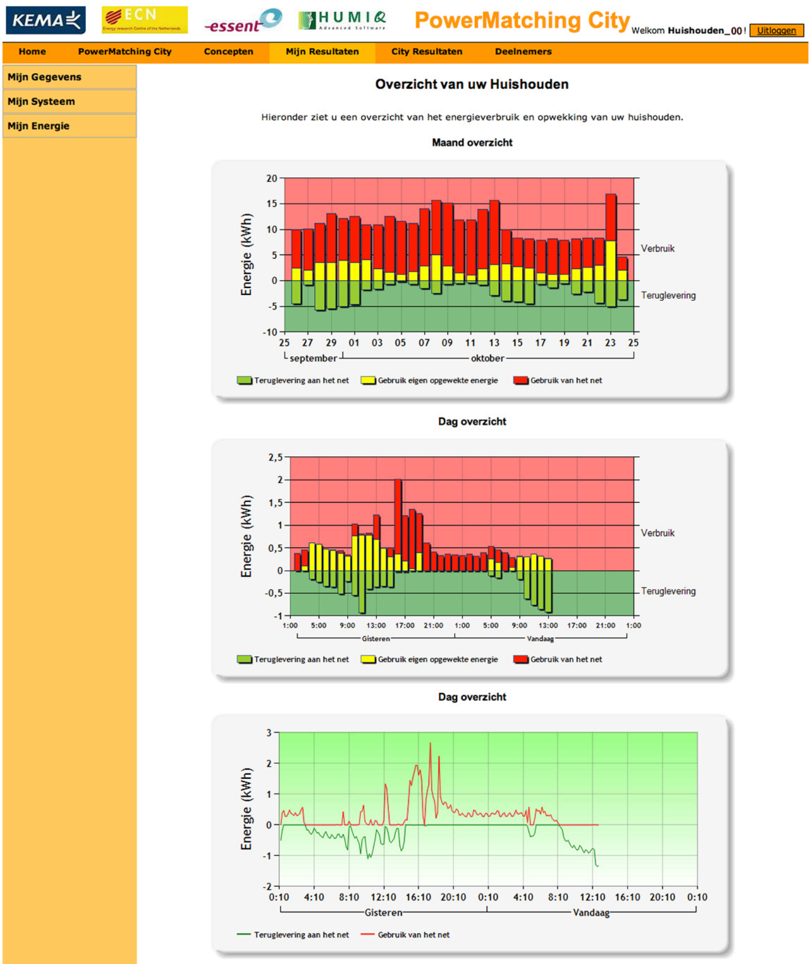


Figure 20: Screenshot of Energy Portal showing the energy consumption and production of a household with PV system for the current and past month (top, October & November 2011) and current day and day before in bar and line chart (bottom two).

4.3.1 Location

Most of the households, 17 of 22, are located west of the city of Groningen, in or in the vicinity of the village of Hoogkerk. One household is located southeast of Groningen. Four households are outside the Groningen/ Hoogkerk area. In Figure 21 and 22 the approximate locations of the households are indicated.
The location of most houses in the Hoogkerk area was intentional and one of the selection criteria.

4.3.2 Types of dwellings and floor surface

Self-reported information about the type of house and floor surface was available for 13 households. The participating households live in detached houses (7 of 13) or semi-detached houses (5 of 13), except for one household consisting of one person living in an apartment. This distribution differs from the overall situation in The Netherlands, where the majority of the population (61%) lives in terraced houses (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013).

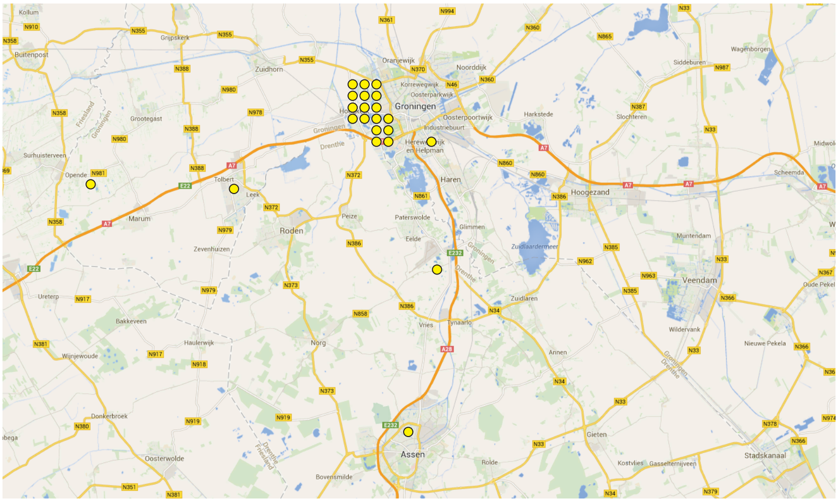


Figure 21: Approximate location of the participating households in and around the area of Hoogkerk.

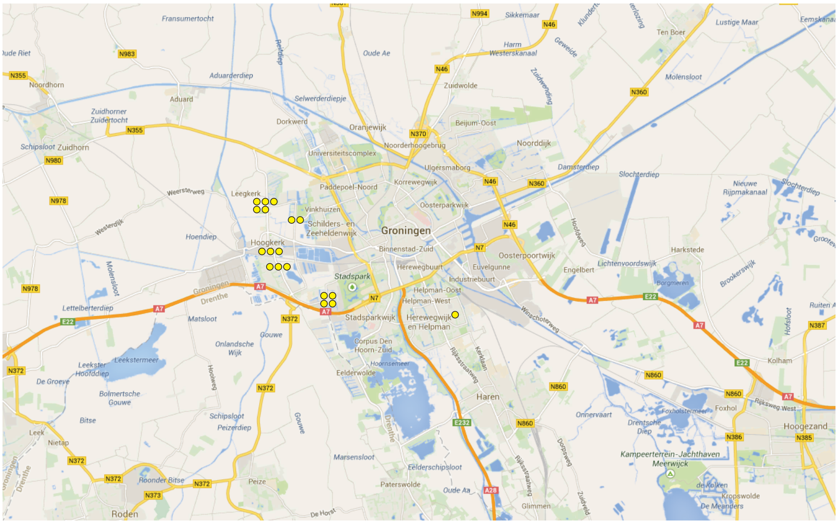


Figure 22: Approximate location of the participating households in Groningen and Hoogkerk

The floor surface of all dwellings in PowerMatching City is over 100 m2, with 3 houses of less than 150 m2, 7 between 150 and 200 m2 and 3 houses above 200 m2. The average floor surface of Dutch dwellings is 136 m2 (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013), which is less than what the majority of households in PowerMatching City have available.

Table 5: Cross table of type of dwelling and floor surface (N=13)

		Floor area				
	Number of households per category ↘	< 100 m^2	100 - 149 m^2	150-199 m^2	>= 200 m^2	**Total**
Type of dwelling	Terraced house	0	0	0	0	**0**
	Corner house	0	0	0	0	**0**
	Semi-detached house	0	1	3	1	**5**
	Detached house	0	1	4	2	**7**
	Apartment	0	1	0	0	**1**
	Total	**0**	**3**	**7**	**3**	**13**

	Number of households per category ➘	Construction year <1919	1919-1945	1946-1970	1971-1980	1981-1990	1990-2000	>2000	Total
Type of dwelling	Terraced house	0	0	0	0	0	0	0	**0**
	Corner house	0	0	0	0	0	0	0	**0**
	Semi-detached house	0	0	1	0	0	7	2	**10**
	Detached house	2	1	2	1	0	4	1	**11**
	Apartment	0	0	0	0	0	0	1	**1**
	Total	**2**	**1**	**3**	**1**	**0**	**11**	**4**	**22**
	Distribution PMC sample (%)	**9,1%**	**4,5%**	**14%**	**4,5%**	**0,0%**	**50%**	**18%**	
	Distribution The Netherlands (%)[a]	6,9 %	13,9%	27%	17%	15,4%	12%	7,9%	

[a] Source: Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013. Cijfers over Wonen en Bouwen 2013. Den Haag.

Table 6: Cross table dwelling type and construction year (N=22)

4.3.3 Construction year and year of occupation

The year of construction of the houses in the sample ranges from 1900 to 2005. The majority of the houses were built after 1990, eleven between 1990 and 2000 and four between 2000 and 2009. In comparison with the Netherlands, many more of the families participating in PowerMatching City live in houses built after 1990, 78% compared to 20% for The Netherlands (Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013). Most households have lived in their house for 10 years or less. Recent comparative data for The Netherlands were not found in respect to this number.

4.3.4 Household composition

In terms of household composition, the majority of households was composed of two persons without children (6 out of 18) or four persons, two adults and two children (7 out of 18), as shown in Table 8. Furthermore two households consisted of one-person, two households of two adults and one child and one household including three children. Note that the term 'child' is used here to indicate the family relation. For some households, the children were over 18 years old, as discussed below and in Table 9. In comparison to the overall numbers for The Netherlands, the average amount of household members in PowerMatching City was 3,1 persons, which is slightly higher than the average of 2,2 persons for the Netherlands (Centraal Bureau voor de Statistiek, 2013). The percentage of 2- and 3-person households in the PowerMatching City sample was close to the percentage for the Netherlands (Table 8). There was a higher amount of 4- and 5-person households and a lower percentage of 1-person households in the PowerMatching City sample compared to the national figures.

		Year of moving in 1980 - 1989	1990-1999	2000-2009	Total
Type of house	Terraced house	0	0	0	**0**
	Corner house	0	0	0	**0**
	Semi-detached house	0	2	3	5
	Detached house	2	1	4	7
	Apartment	0	0	1	1
	Total	2	3	8	13

Table 7: Cross table type of dwelling with year of moving in (N=13)

	PMC Sample		The Netherlands (1-1-2012)[a]	
Household size	Number of households	Distribution (%)	Number of households	Distribution (%)
1 person	2	11%	2 761 764	37%
2 persons	5	28%	2 455 421	33%
3 persons	2	11%	909 274	12%
4 persons	7	39%	971 486	13%
5 persons	2	11%	414 879	6%
Total	**18**	**100 %**	**7 512 824**	**100 %**

[a] Source: Centraal Bureau voor de Statistiek, www.cbs.nl, retrieved via StatLine on 25 July 2013

Table 8: Household size and distribution in PowerMatching City and Netherlands (N=18)

Age of household members

The ages of the household members divided over household sizes are shown in Table 9. Most participants were in the 50 to 64 age range. In the majority of two-person households their members were aged between 50 and 64. Children having left the house to live on their own may explain this situation.
The average age[2] of the persons in the participating households including children is 29, 2 (-0,4) years and 51,7(-0,4) years old excluding children. The average age of the children was 14,1 (-0,4). One 'adult' was under 40 years old, the rest (33 persons) were 40 or older, with the eldest person aged 79 years old. With respect to the children, 4 were 20 years or older. This concerns 4 households, of which 2 households with 1 and 2 households with 2 children living at home.
For a comparison between the age distribution in the sample and in The Netherlands overall, see the last rows in Table 9. There were relatively more persons between 40 and 65 years old in the sample. The sample also had more children between the ages of 10 and 14.

Education levels

Education levels of the adults in the households are MBO and higher[3]. The majority finished education at HBO level (11 of 22, N=12 households), followed by University level (7 of 22) and MBO level (4 of 22). The education levels of the participants in PowerMatching City were high compared to the population of The Netherlands, with 82% versus 29% respectively of persons with HBO and University degrees (Centraal Bureau voor de Statistiek, n.d.).

Income

The households' disposable income levels[4], as reported by the respondents (N=13), showed a wide spread, as illustrated in Figure 21. The average income was between €3000 and €4000 per month. The disposable income was

---

2 For some respondents age was reported only in June 2013. Their age as of December 31st 2012 may therefore need adjustment accordingly, depending on the birth date. Between brackets is the possible difference in age.

3 These education levels are specific to the Dutch educational system. Indicative translations would be: LBO = Lower vocational education; MBO= intermediate vocational education, HBO=higher vocational education. HAVO = higher secondary education (preparatory for HBO), VWO = Secondary education preparing for university.

4 In Dutch the term 'netto-inkomen' is used

higher than the average disposable income of €2900 per month (€ 34400 per year) for The Netherlands (Centraal Bureau voor de Statistiek, n.d.).

Household size (persons)	Number of households per age category									
	0-9	10-14	15-19	20-29	30-39	40-49	50-64	65-79	80 +	Total per household size
1 person	0	0	0	0	0	0	1	1	0	**2**
2 persons	0	0	0	0	1	1	7	1	0	**10**
3 persons	0	0	0	1	1	2	2	0	0	**6**
4 persons	2	6	3	3	0	7	7	0	0	**28**
5 persons	0	4	2	0	0	1	3	0	0	**10**
Total per age category	**2**	**10**	**5**	**4**	**2**	**11**	**20**	**2**	**0**	**56**
Distribution PMC sample (%)	4%	18%	9%	7%	4%	20%	36%	4%	0%	100%
Distribution The Netherlands (%)[a]	11%	6%	6%	12%	12%	15%	20%	12%	4%	100%

[a] Source: Centraal Bureau voor de Statistiek, www.cbs.nl, retrieved via StatLine on 25 July 2013

Table 9: Age of household members compared to household size and to age distribution in the Netherlands overall (N=18)

Education level	PMC Sample	The Netherlands[a]
LBO	**0%**	22%
MBO	**18%**	30%
HAVO, VWO	**0%**	11%
HBO	**50%**	19%
WO (university)	**32%**	10%

[a] Source: Centraal Bureau voor de Statistiek, www.cbs.nl, retrieved via StatLine on 25 July 2013

Table 10: Comparison education levels PowerMatching City and The Netherlands (2012)

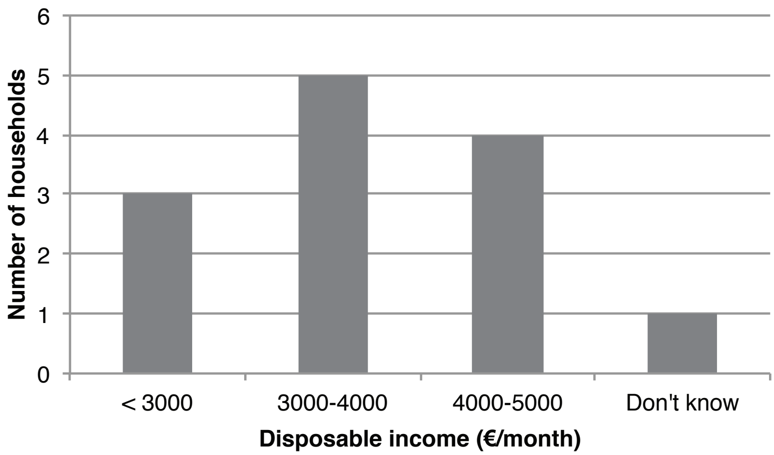


Figure 23: Distribution of income in the PowerMatching City sample (N=13)

4.3.5 Energy consumption and production

Historical information about the households' energy consumption and production was available from research activity A. Because the project started as a technical feasibility study for demand response in 2007 and changes in the amounts of energy consumption were initially not to be measured, the households' historical energy consumption was unfortunately neither recorded nor stored. The inventory made in research activity A, did however provide some insight into the energy use of the participating households.
Electricity consumption in the households was 3896 kWh per year, based on 20 households[5]. This was slightly higher than the average for the Netherlands, which was 3430 kWh in 2009 (Centraal Bureau voor de Statistiek, n.d.). Figure 24 provides an overview of the responses, indicating a wide spread in the consumption levels of the households, with households using half or a third of the Dutch average as well as a household that consumed more than twice the Dutch average.

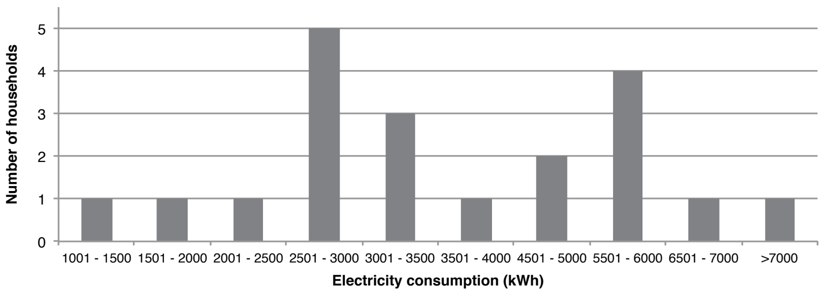


Figure 24: Responses to amount of electricity consumed in kWh (N=20).

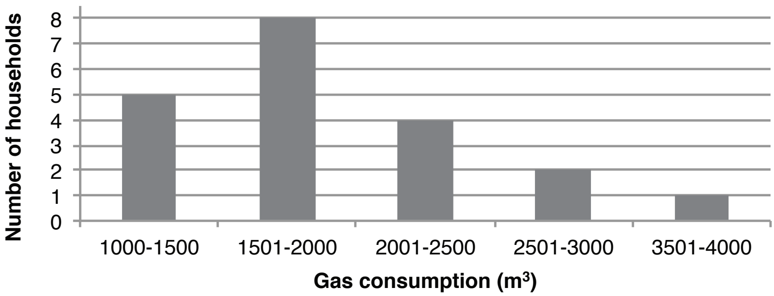


Figure 25: Responses to amount of gas consumed in m3 (N=20).

With regard to the households' gas consumption, the average of the sample was at 1952 m3 for the year 2009, which was is calculated based on the consumption reported by the respondents (N=20). Figure 25 shows the responses for the amounts of gas consumed. Most of the households consumed less than 2000 m3, which is below the average of the reported data. The average was thus strongly influenced by the higher gas-consuming households. The average gas consumption for Dutch households in 2009 was 1621 m3 (Centraal Bureau voor de Statistiek, n.d.). Most households

5 Data were available from 21 households. One of these households is however a farm and the reported electricity and gas consumption include business consumption. This household is excluded from energy calculations that concern the whole cluster as it distorts the data. E.g. the electricity consumption was about 35000 kWh and gas consumption 3817 m3.

reported consumption near this average as can be seen in Figure 25. Seven of the 20 households consumed less than the average for the Netherlands. When differentiating among housing types, it appears that, based on the reported energy consumption levels, most households consumed below or near the Dutch average per housing type. This is particularly true for gas consumption. For electricity consumption several households reported consumption above average; 2 households for terraced houses, 4 for detached houses and the one household in an apartment. Cross-tables with an overview of the consumption per housing type are provided in Appendix B.

All homes in the sample had insulation and double-glazing. In most cases it was already implemented when they first moved into the house, as part of the original construction features (7 of 13) or as installed by previous owners (3 of 13). Others had added them when they moved in the house or shortly thereafter (3 of 13).

4.4 Conclusion

This chapter introduced PowerMatching City as a case of a smart energy system implemented in real households. The set-up of the system design was described, indicating the technical challenges in the realization of the system. Furthermore the sample of participating households was described. With 22 participating households the sample was rather small and statistical analysis was limited. The characteristics of the sample did not coincide with distribution of characteristics throughout The Netherlands as a whole and is thus not representative for the Dutch population. The types of houses and household composition in the sample are diverse and range from an apartment for one person, to a terraced house with two persons and a detached house with a family of four. Compared to the Dutch population, the sample was characterized by higher education levels, higher than average income, more detached houses and relatively new houses. In terms of gas and electricity consumption levels, there were many lower than average consumers but also some very high consuming households.

The value of the research into this case can be found in the newness of the topic. There were no full concept smart energy systems that were up and running in households in The Netherlands at the time of the research, nor is it common to date. The insights from the study into PowerMatching City can serve as a starting point for future research concerning implementation and testing of smart energy systems up to the household level, as well as for product and service development.

5

Energy balance analysis in PowerMatching City

This chapter is based on and adapted from the analysis conducted by Faidra Filippidou for her Master thesis for Sustainable Energy Technology at Delft University of Technology.

5.1 Introduction

In the previous chapter the PowerMatching City project has been described as a pilot study of a smart energy system with real households. In this smart energy system multiple goals are optimized via the coordination mechanism called PowerMatcher. The overall set-up of the smart energy system was described and the group of 22 participating households was characterized in terms of, among others, household composition, housing type and energy consumption before installation of the smart home energy systems. In this chapter electricity consumption and production in the cluster of households are analyzed in order to gain insight into the energy balance in the cluster. The expression 'energy balance' in this chapter refers to the relation between the levels of electricity production and consumption of the households in PowerMatching City. Insight into the energy balance is not only relevant from the perspective of technical performance, but it may also indicate whether there is potential for end users to contribute to optimization of the smart energy system performance through their energy related behavior. As argued in Chapter 2, end user behavior may complement the technical operation of the system in optimizing its performance. Additionally, more active involvement of end users in household energy management would be in line with the proposed empowerment of end users to become co-providers in accordance with the currently provided technical and financial opportunities for co-provision.

Furthermore, insight into the energy balance is relevant for the design of smart energy systems, in which, as described in Chapter 4, multiple goals are to be achieved, ranging from goals for the network operator and energy provider to the goals of individual households. The goals can be conflicting. For example, the local (virtual) network of PowerMatching City, may be optimized by the PowerMatcher to balance local electricity production with electricity consumption within the cluster and minimize electricity flows to and from the overall grid, or based on achieving financial benefits for the households in the cluster independently of the electricity flows into and out of the microgrid. These two strategies pursue different goals, may lead to differences in the energy balance of the cluster and as a result affect the way in which stakeholders in the system achieve their goals. Insights from the case of PowerMatching City could provide a basis for discussion in the design process of similar smart energy systems in order to develop smart energy systems and related products and services that fulfill the goals of all stakeholders in the electric power system, from households and communities on the demand side to network operators and energy providers on the provision side of the electric power system.

To characterize the relations between the energy consumption and production in the cluster of households, the amounts of consumption, self-production and consumption of self-produced electricity were compared in several ways. The analysis spans from April 2012 to January 2013. In addition to insights based on the analysis presented in this chapter, the authors used monitoring data to support communication with end users. Weekly 'energy reports' about energy consumption and production in the cluster were published on the community website (see Chapter 7). These reports contained information about the energy consumption and production of the cluster of households over the course of the preceding week.

In the following section, 5.2, the research approach is explained, describing the main research questions as well as the methods used for data collection and analysis. The analysis results are addressed in Section 5.3, based on daily, weekly and monthly overviews. Also comparisons between seasonal performance and differences between the households with µCHP and households with HHP systems are presented. The chapter concludes in section 5.4 with a general discussion of the results and inferences on the observed energy balance in PowerMatching City and how this information can be leveraged in product and service development for smart grid households.

5.2 Research approach

The main goal of this study was to quantify the energy balance in the cluster of households, in order to understand to what extent self-production (i.e. electricity produced by the households) and electricity consumption are being matched. This study focused on the households' overall electricity consumption and production, because the smart energy system of the PowerMatching City demonstration project is built to manage electricity supply and demand in the virtual microgrid. This study is explorative in nature, as a first step in quantification of the balance between electricity consumption and production in the cluster, which can lead to research questions to address in further research.
The overall research question addressed in this chapter is:
What was the balance between energy consumption and production at household and cluster levels?
This question is divided in the following sub questions relating to differences that can be observed in energy balance for different seasons and for the two types of home energy systems, the HHP system and the µCHP system:

- a) *What were differences in the energy balance for summer versus winter?*
- b) *What were differences in the energy balance for the households with hybrid heat pump (HHP) system versus those with micro-cogeneration system (µCHP)?*
- c) *What differences can be observed in the energy balance at the household level in the relations between self-production and consumption?*

Before a description of how the analysis took place, it is necessary to describe how energy balance is defined for this study. Energy balance refers to the relations between electricity consumption, self-production and electricity delivery to, or consumption from, the grid by the cluster or individual households. When a household produces electricity (self-production), this electricity can be used directly in the household or delivered to the grid. How much of the self-production is used in the household depends on its electricity demand at that moment. If at any given moment self-production is lower than the electricity demand, electricity will be drawn from the grid (electricity produced from sources outside the household). When self-production is higher than household demand, the surplus electricity will be delivered to the grid (for consumption elsewhere). Figure 26 depicts the relation between self-production and consumption as well as delivery-to-grid and consumption-from-grid. Note that delivery-to-grid and consumption-from-grid are depicted in the same figure. In this study the energy balance characterization will span a certain time (5 minutes, a day, a month). Therefore it is possible for delivery-to-grid to occur at one moment and consumption-from-grid to take place the next. In PowerMatching City the electricity production and consumption is recorded in five-minute intervals, so both can occur within this time span and will be presented as such.

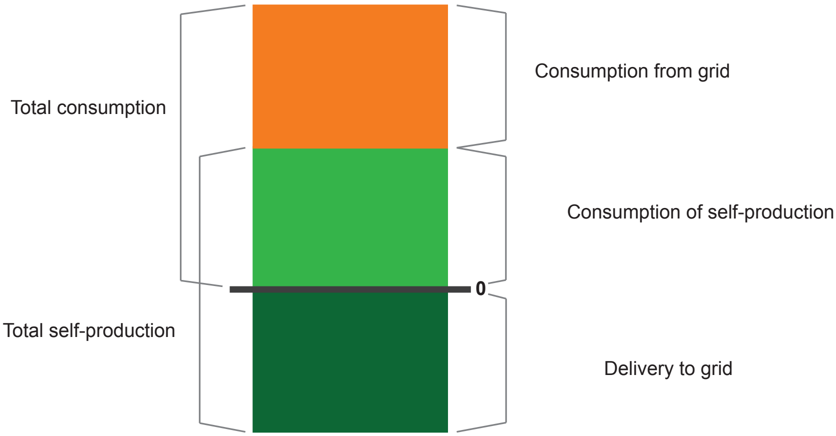


Figure 26: Relations between sorts of electricity consumption and production described for the energy balance in this study

For this study, the energy balance was evaluated with respect to self-sufficiency, based on the perspective that the cluster can be considered a (virtual) microgrid. This approach allows for an estimation of how independent the cluster can be from the grid as well as how much room there is to consume electricity from, and deliver to, the surrounding electricity grid. The analysis took place based on the available monitoring data per each household. Unfortunately these data do not allow for specification of the energy balance for the whole cluster as one system nor for specification of hypothetical flows of electricity between households.

This study is based on the analysis of electricity consumption and production that was measured in 21 of the 22 participating households over a period of 10 months, from April 2012 to January 2013. One of the households with

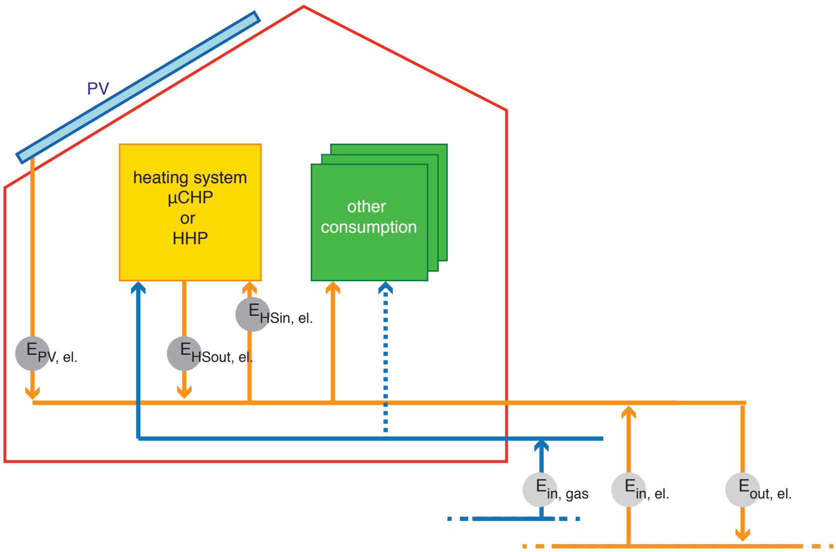


Figure 27: Schematic overview of the home energy system and the meters collecting consumption and production data.

µCHP was excluded because it runs a farm and the the related business activities were included in the data measurements. In order to examine the differences in performance between the two types of heating system implemented in PowerMatching City, two subgroups were distinguished: A 'µCHP group' of 9 households and a 'HHP group' of 12 households.

5.2.1 Data collection

The data collected for the purpose of this study are the overall electricity consumption from the grid, electricity delivery to the grid per household, the electricity consumption and production of the heating system and the PV solar electricity production. The data set contains monitoring data that were recorded each five minutes. For the energy production only production by the µCHP and PV solar panels could be taken into account. The production of the wind turbine was not available for the cluster and could thus not be included in the analysis.
The measurements took place via kWh meters in the households. These meters were installed as part of the initial system design of PowerMatching City. The measurement data from the kWh meter per household were registered in a 'home energy computer' each 5 minutes and periodically sent to the central database. Figure 27 provides a schematic overview of the measured variables that were included in the data set. An overview of the measured variables is given in Table 11.
The data could be retrieved from the database with specific queries by persons from DNV KEMA authorized to access the database[1]. The data were exported to MS Excel format to facilitate the production of the Energy Reports for the end users in the households. The monitoring data were registered as cumulatives for 5 minutes for the whole 24 hours of every day. As a result, there are 288 measurements per day for each of the categories for each household.
The data were screened and corrected in order to make it usable for analysis. Each household was evaluated to assess wether it could be included in the analysis over a certain period (day, month or week). The screening procedure is described in Appendix C.

5.2.2 Data analysis

In order to characterize the energy balance, the following information was to be extracted from the data:

- *Amount of electricity consumption per household*
- *Amount of self-produced electricity per household*
- *Amount of self-produced electricity that is consumed in the household*
- *Amount of self-produced electricity that is delivered to the grid by the households*

Not all of the information that is needed for the analysis is directly

1 The information was retrieved on a weekly basis from May to September 2012 for the production of the Energy Reports for the end users. The remaining data, before and after the production of the Energy Reports, were retrieved on a monthly basis.

Table 11 Energy data that were used in the analysis

Symbol	Variable	Unit
Total system		
$E_{in,\ el}$	Electricity consumed in the households	kWh
$E_{out,\ el}$	Electricity delivered by the households (either to other households or sold to the grid)	kWh
Heating system		
$E_{HSin,\ el}$	Electricity consumed by the heating system	kWh
$E_{HSout,el}$	Electricity produced by the heating system [a]	kWh
PV solar system		
$E_{PV,el}$	Electricity produced by the photovoltaic panels per household	kWh

[a] only applicable for the μCHP systems

provided by the measurement data. Household electricity consumption is a combination of the electricity drawn from the grid and self-produced electricity. Similarly the amount of self-produced electricity that is consumed by the household has to be derived from the measured electricity production and the electricity that is delivered to the grid. To calculate the different amounts of electricity consumption and production the following equations, with the variables presented in Table 11, were used:

- *Total household electricity production (TP):*
  $TP = E_{PV,el} + E_{HSout,el}$ *(in kWh)*
- *Consumption of self-produced electricity (CSP):*
  $CSP = TP - E_{out,\ el} = E_{PV,el} + E_{HSout,el} - E_{out,\ el}$ *(in kWh)*
- *Total household electricity consumption (TC):*
  $TC = E_{in,\ el} + CSP = E_{in,\ el} + E_{PV,el} + E_{HSout,el} - E_{out,\ el}$ *(in kWh)*

The aggregated housholds' amounts were used to calculate the cluster level of consumption and production.

Three indicators were defined for evaluating self-sufficiency in the PowerMatching City cluster, namely Production Utilization (PU), Energy Demand Satisfaction (ES) and Overall Self-Sufficiency (OSS).

1. $PU = CSP / TP * 100\%$ *(in %)*
   This indicator specifies the share of self-produced electricity that was used in the household. When its value is 100%, all the self-production could be used at the moment in which it was generated.
2. $ES = CSP / TC * 100\%$ *(in %)*
   This indicator specifies how much of the consumption is covered by self-production. A value of 100% indicates that the self-production could fully satisfy electricity demand at the moment in which it was generated.
3. $OSS = TP / TC * 100\%$ *(in %)*
   This indicator denotes self-sufficiency over a period of time. Contrary to the previous indicators that are based on simultaneous production and consumption, this indicator provides a value for how much of the self-produced electricity theoretically could have been consumed.

The indicators can be used to characterize energy balance for different time spans. For this study indicator values were defined for days, weeks and months.

5.3 Energy balance at cluster level

In this section the results for energy balance at the cluster level are discussed. For cluster level results, the energy balance is presented as an aggregate of the measured electricity consumption and production per household in the analyzed group, i.e. whole cluster, µCHP households and HHP households. Energy balance at the cluster level is discussed here based on three different time scales. First it is examined for a day, showing fluctuations in consumption and production over the day. It is discussed for the time span of a month and a week, based on the cumulative amounts per day. For insight into the difference between summer and winter performance, data from July 2012 and January 2013 were compared. Furthermore performances between the whole cluster, µCHP group and HHP group were compared. The values for the indicators –PU, ES and OSS – are determined for each time scale as well as for all months included in the data set.

5.3.1 Daily energy balance at cluster level

Based on the 5-minute interval measurements it is possible to show the fluctuations of electricity consumption and production over a day. Figure 28 to 30 represent the energy flows for the cluster, the µCHPs and HHP group over twenty-four hours on Sunday July 22th 2012. This was a sunny summer day with a minimum temperature of 6°C, a maximum temperature of 20°C and almost 11 hours of sunshine[2] (KNMI, 2013a). An overview of the daily amounts averaged per household and of the indicator values is provided in Table 12.

In the daily energy balance overview, depicted in Figure 28, a difference can be observed between night and day level consumption. The spikes in consumption between 0.00 and 2.00 a.m. can be explained by the electricity consumption of HHP systems. Also it can be observed that the lowest electricity consumption, marked by the orange area, was between approximately 2 and 4.30 p.m. Consumption quickly rises from 07.00 - 09.30 a.m. accounting for the morning activities of the household members. Furthermore there are several spikes during the day. After 4 p.m. energy consumption drops to approximately 1 kWh per 5 minutes. In the evening, from about 8.00 to 11.30 p.m. there are some spikes, which are best visible in Figur 29 and 30. These are not caused by electricity consumption of the heat pumps and may be due to appliances use, such as dishwashers and tumble dryers.

With respect to electricity production it can be observed that self-production was dominated by PV solar energy generation and that most of the electricity production was consumed in the households. During the hours of PV production, from roughly 6 a.m. to 6.30 p.m., depicted with the yellow line, the electricity taken from the grid (dashed red line) was lower. The households then used their self-produced electricity, visualized by the light green area. Still some of the electricity production is delivered to the grid (the dark green area). This indicates that some of the households were not directly using all of the electricity that is produced by the PV panels. From 12.30 to 14.30 hours there is electricity production by the µCHPs.

2 The monthly average temperature of July 2012 was 16,5 °C (KNMI, 2013b).

	22/7/2012		
	Cluster	µCHP group	HHP group
	(n=20)	(n=8)	(n=12)
Electricity, per household per day (in kWh)			
Total electricity consumption (TC)	15,5	15,7	15,4
Electricity delivered from the grid ($E_{out, el}$)	11,2	11,6	10,9
Consumption of self-produced electricity (CSP)	4,4	4,1	4,5
Total electricity production (TP)	5,1	5,3	5,0
PV ($E_{PV,el}$)	5,0	4,9	5,0
Own PV	1,3	1,5	1,2
Virtual PV	3,7	3,4	3,9
µCHP ($E_{HSout,el}$)	0,1	0,4	-
Electricity delivery to the grid ($E_{out,el}$)	0,8	1,2	0,5
Indicators (in %)			
Production utilization (PU)	85%	77%	90%
Energy demand sufficiency (ES)	28%	26%	29%
Overall self-sufficiency (OSS)	33%	34%	33%

Table 12: Electricity consumption and production per household for July 22nd, 2012.

Figure 29 and 30 show the same day for the µCHP group and HHP group respectively. The average electricity consumption and production per household were similar, with about 15 kWh consumption and 5 kWh production per household. The PU value is however higher for the HHP group. This can also be seen in the daily pattern of the HHP group (Figure 30), where most of the PV production appears to be consumed in the households. The µCHP group delivers more electricity back to the grid, resulting in a lower PU. Particularly the shape of the µCHP electricity production in Figure 29 suggests that its production is delivered back to the grid. A closer look at the development of the prices[3] on this day (Figure 31) shows that the PowerMatcher was functioning. At 12 p.m. the virtual electricity price rose to 50. As a result the µCHP systems started to operate in order to sell surplus electricity to the grid. At the same time the HHP systems stopped consuming electricity from the grid.

The value for PU was 85% for the whole cluster, indicating that most of the self-produced electricity was consumed in the households. This indicator's value is lower for the µCHP group (77%) and higher for the HHP group (90%). This difference may be explained by the price-based control of the PowerMatcher, which caused the µCHPs to produce electricity in order to sell it to the grid.

The ES values are 28% for the whole cluster, 26% for the µCHP group and 29% for the HHP group. Electricity consumption by the households is thus for about a quarter provided by self-production. The higher indicator value for the HHP group indicates that the households in this group could satisfy more of their own demand with self-production. The HHP group had higher self-production per household as well as lower consumption levels on average per household on this day.

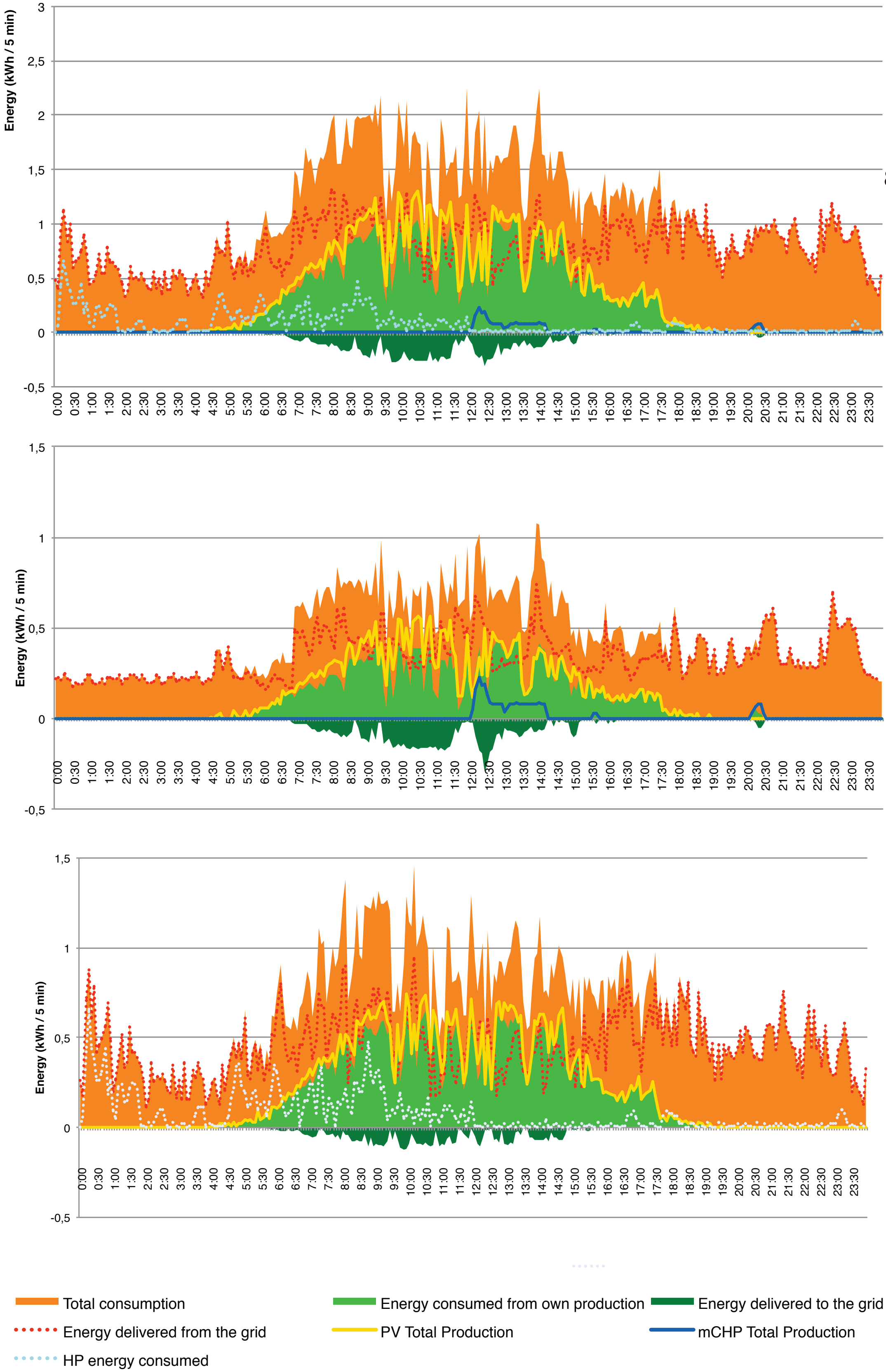
The values for OSS indicate that a third of the consumption can theoretically

Figure 28 (right page): Daily energy balance overview for the whole cluster – Week 30 (22/7/2012), based on 20 households

Figure 29 (right page): Daily energy balance overview for the µCHP group – Week 30 (22/7/2012), based on 8 households

Figure 30 (right page): Daily energy balance overview for the HHP group – Week 30 (22/7/2012), based on 12 households

3 Price development for the PowerMatcher was set based on the tests that were executed by project partners.



Energy (kWh / 5 min)
Energy (kWh / 5 min)
Energy (kWh / 5 min)
Total consumption
Energy consumed from own production
Energy delivered to the grid
Energy delivered from the grid
PV Total Production
mCHP Total Production
HP energy consumed

be covered by self-production. Comparison with the ES values shows that the achieved match between supply and demand was close to its potential (OSS). The mismatch, i.e. difference between ES and OSS, is 5%, 8% and 4% for the three groups respectively.
For comparison, 32 to 34 and Table 13 provide an overview of the energy balance on January 20th, 2013. This was a day with a minimum temperature of minus 7,4 °C, a maximum temperature of minus 1,5°C and 1,8 hours of

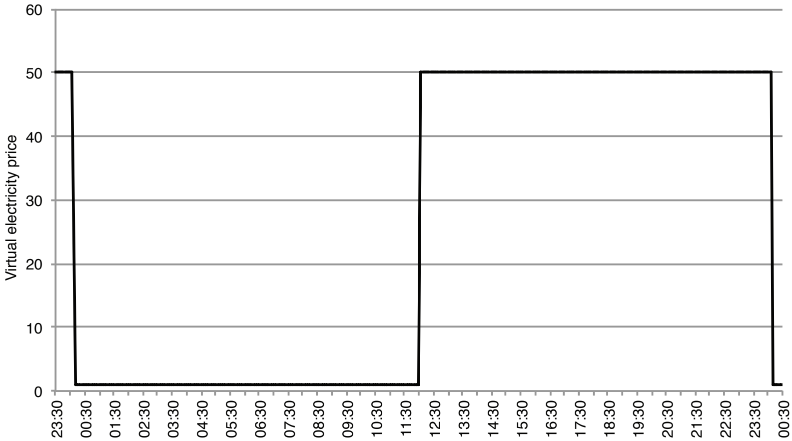


Figure 31 : Price development in the PowerMatching City cluster on July 22nd 2012.

sunshine[4] (KNMI, 2013a). The first thing to notice is that the overall electricity consumption (TC) is higher than in July. The electricity consumption over the 5 minutes intervals does not drop below 1 kWh and peaks to about 5,5 kWh. The electricity produced by the PV panels is about a sixth of the production in July. Again most of the PV production appears to be consumed in the cluster. Electricity production of the µCHPs is higher than in July and is spread over the whole day. This can be explained by higher heat demand in winter. The virtual electricity price in the cluster was constant. The operation of the heating systems was therefore not triggered by changes in price, but only based on household heat demand. Still, based on the shape of the graph in Figure 33, µCHP electricity production appears to result in electricity delivery to the grid, as was the case on July 22nd.
The PU for the whole cluster is 55%. This is much lower than the value in July (85%). For the µCHP and HHP groups the indicator values are 38% and 100% respectively, which indicates that the µCHP households deliver most of their produced electricity to the grid and that the HHP households consume all of their self-produced electricity. A closer look at the graphs for both groups (Figure 33 and 34) indicates that the electricity production by the µCHPs during the day is high in comparison to the total consumption. It may well be that at several moments during the day (e.g. between 2 p.m. and 4 p.m.) the produced electricity was higher than the electricity demand. The HHP households depend on only PV solar panels, for which production is low in winter. At the time of PV electricity production, the demand was 2 to 3 times higher than what was produced. A 100% value for PU is therefore plausible.
The ES values are 9% for the whole cluster, 12% for the µCHP group and 7%

4 The monthly average temperature for January 2014 was 1,4°C (KNMI, 2013b)

	20/1/2013		
	Cluster	μCHP group	HHP group
	(n=19)	(n=8)	(n=11)
Electricity, per household per day (in kWh)			
Total electricity consumption (TC)	13,0	11,4	14,2
Electricity delivered from the grid ($E_{out, el}$)	11,9	10,0	13,3
Consumption of self-produced electricity (CSP)	1,1	1,4	1,0
Total electricity production (TP)	2,1	3,6	1,0
PV ($E_{PV,el}$)	0,8	0,5	1,0
Own PV	0,1	0,2	0,0
Virtual PV	0,6	0,3	0,9
μCHP ($E_{HSout,el}$)	1,3	3,1	-
Electricity delivery to the grid ($E_{out,el}$)	0,9	2,2	0,0
Indicators (in %)			
Production utilization (PU)	55%	38%	100%
Energy demand sufficiency (ES)	9%	12%	7%
Overall self-sufficiency (OSS)	16%	31%	7%

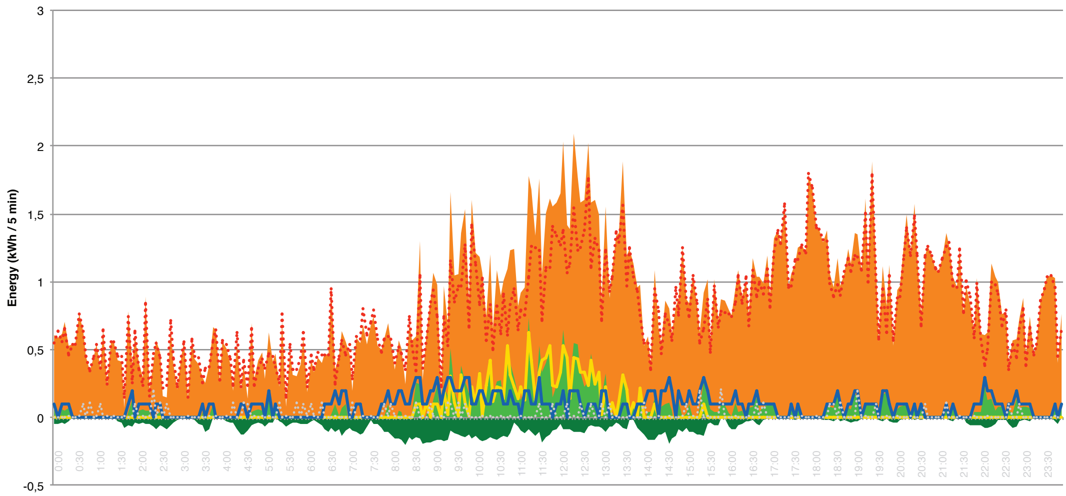
Table 13: Electricity consumption and production per household per day for January 20th, 2013.

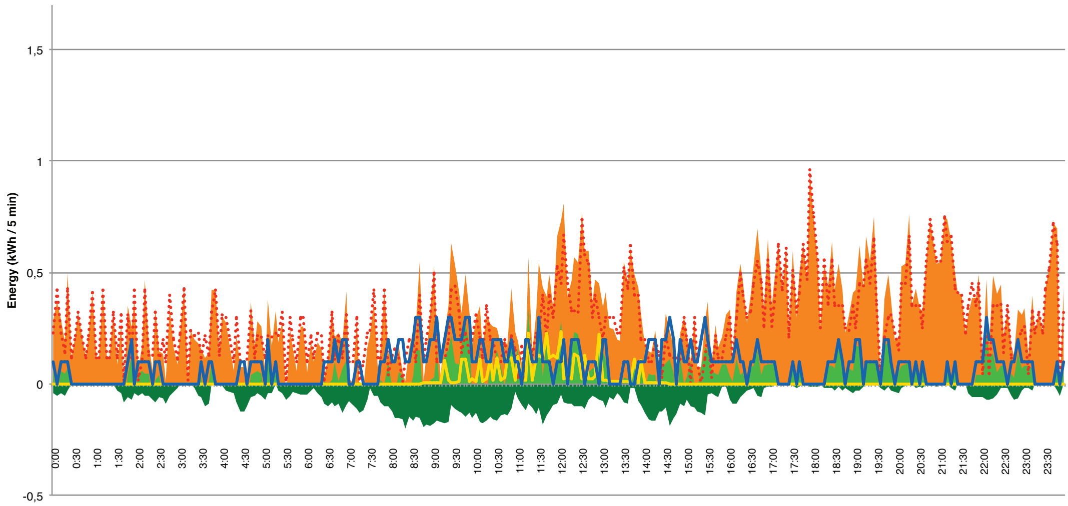
for the HHP group. These values are much lower than the values attained on July 22nd, which could be expected since PV solar power production was much lower on January 20th. The self-production of electricity on January 20th is dominated by production of the μCHP systems. The ES for the μCHP households is higher than for the HHP households, because of the higher quantities of self-produced electricity as well as lower electricity consumption per household.

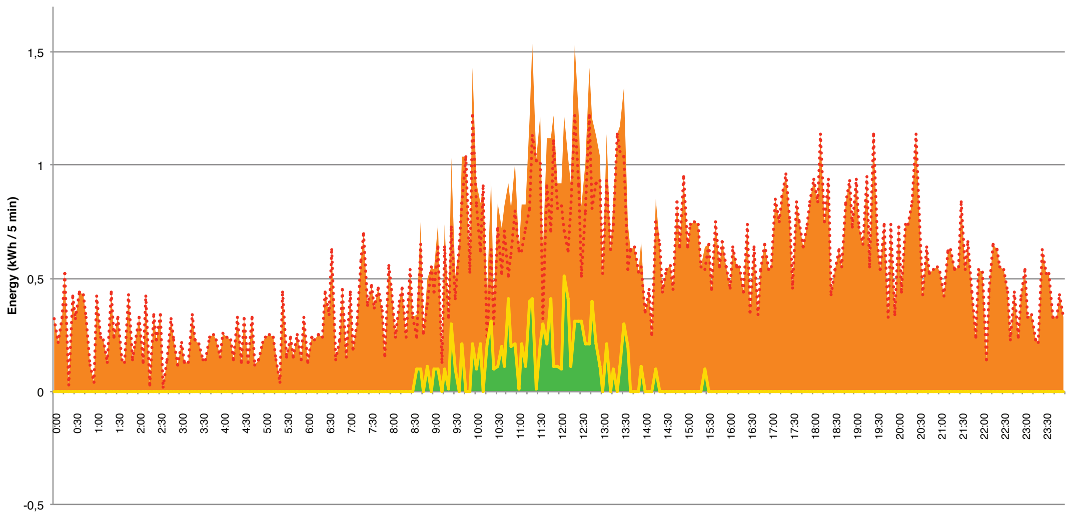
	July 2012	January 2013
Electricity, per household per day (in kWh)	(n=20)	(n=19)
Total electricity consumption (TC)	12,7	11,8
Electricity delivered from the grid ($E_{out, el}$)	10,7	10,7
Consumption of self-produced electricity (CSP)	2,0	1,1
Total electricity production (TP)	2,8	1,9
PV ($E_{PV,el}$)	2,6	0,5
Own PV	0,9	0,1
Virtual PV	1,6	0,4
μCHP ($E_{HSout,el}$)	0,2	1,4
Electricity delivery to the grid ($E_{out,el}$)	0,7	0,8
Indicators (in %)		
Production utilization (PU)	74%	59%
Energy demand sufficiency (ES)	16%	9%
Overall self-sufficiency (OSS)	22%	15%

Table 14: Electricity consumption and production data for July 2012 and January 2013.

Upon examination of the values for OSS it can be observed that the indicator value for the HHP group is the same as for ES. The HHP group thus attains the theoretically possible utilization of its self-production. For the μCHP group, the ES is less than half of the OSS (12% vs. 31%). There







Total electricity consumption (TC) Consumption of self-produced electricity (CSP) Electricity delivered to the grid (Eout, el)
Electricity delivered from the grid (Ein, el) PV production µCHP production
HP electricity consumption

appears to be a mismatch here between self-production and consumption in the µCHP group.

In summary, comparing the two days and between the two types of households show that the match between self-production and consumption is better for the HHP households, both in July and in January. This is reflected in higher PU values and smaller differences between the values that were realized for ES and OSS (the realized and theoretical consumption of self-produced electricity). In July he OSS was similar for the µCHP group and HHP group. In January however, OSS for the µCHP group is at nearly the same level as on July 22nd, but below 10% for the HHP group.

5.3.2 Month and week overviews of energy balance

In the following section, the period between July 2012 and January 2013 is discussed to provide insight into seasonal differences in The Netherlands. Figures 35 and 38 and present the energy balance for July 2012 and January 2013. Table 14 provides an overview of the electricity consumption and production data, normalized per household and per day. For each month one week is examined further for the differences between the µCHP and HHP households, presented in Table 15.

Comparison between cluster data for July 2012 and that for January 2013 indicates that electricity consumption was higher in July than in January. The average consumption per household per day is 12,7 kWh in July vs. 11,8 kWh in January, a difference of 0,9 kWh. The average production per household per day is higher for July 2012, 2,8 kWh, than for January 2013 1,9 kWh. This difference is due to a higher PV production in July 2012. In line with the higher self-production, the consumption of self-produced electricity (CSP) is also higher in July than in January. The graph also shows influence from solar irradiation according to the day of the month. The amount of production as well as the consumption of self-produced electricity increased with the increase of solar radiation. See for example July 22nd to 29th. For January this relation is not visible, since most of the TP comes from the µCHPs, whose electricity production is related to the households' heat demands.

With respect to the indicators, PU is above 50% for both months, so more than half of the self-produced electricity is consumed in the households. For July this amount is 74%, whereas for January it is 59%. The higher self-production in July results in the higher values for PU and ES. The value of ES is 16% and 9% respectively for July and January. Despite the several days of missing monitoring data for the virtual PV production, the consumption was covered better in July than in January. This indicates a high influence of PV solar production on the cluster's self-sufficiency. Based on higher installed PV production capacity compared to the µCHP production capacity, namely approximately 31 kWp vs. 9 kW, this result could be expected. The OSS values are 22% and 15% respectively for July and January.

Figure 32 (left page): Daily energy balance overview for the whole cluster – Week 4 (20/1/2013)

Figure 33 (left page): Daily energy balance overview for the µCHP group – Week 4 (20/1/2013)

Figure 34 (left page): Daily energy balance overview for the HHP group – Week 4 (20/1/2013)

5.3.3 Comparison HHP and µCHP groups

The previous section provided an overview of production and consumption for the total cluster. To compare the role of the different heating systems in the energy balance, two weeks are examined for the differences between

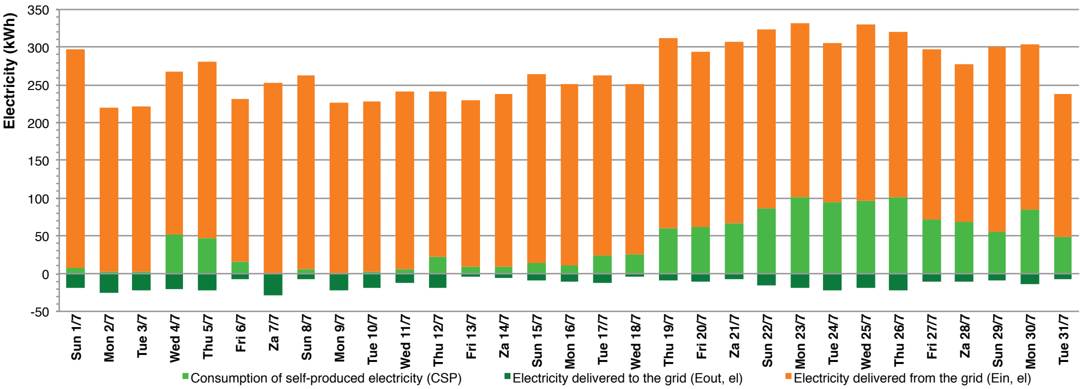


Figure 35: Energy balance overview July 2012. The registration of the virtual PV production was missing for several days: from 1 to 3, 7 to 11 and 13 to 16 July.

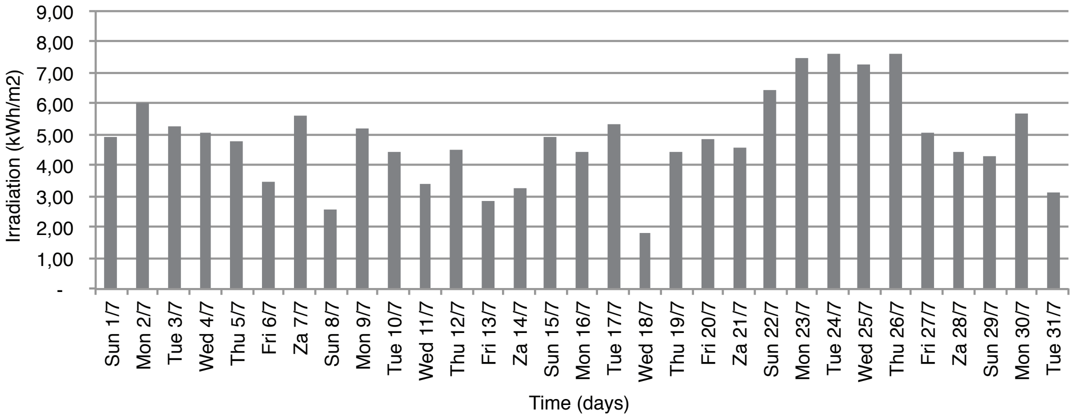


Figure 36: Global irradiation in July 2012 (KNMI, 2013a)

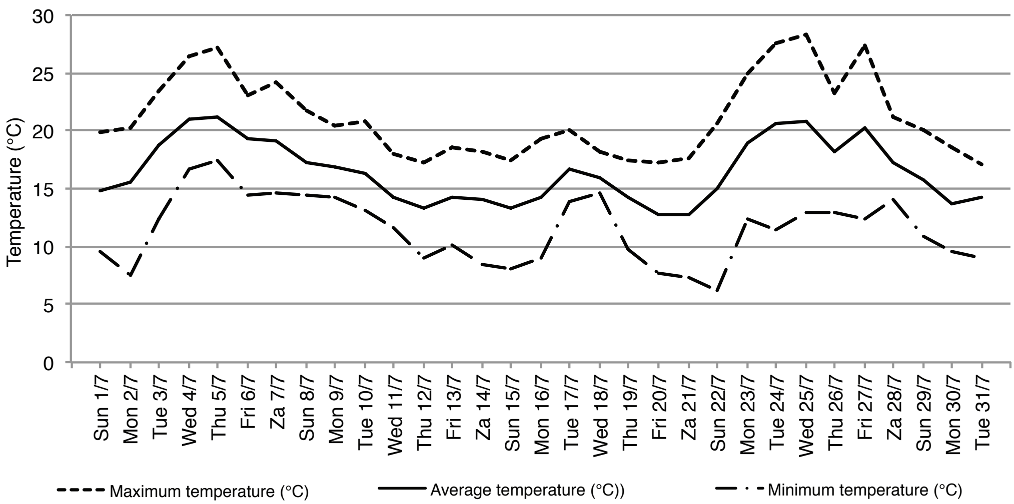


Figure 37: Temperature in July 2012 (KNMI, 2013a)

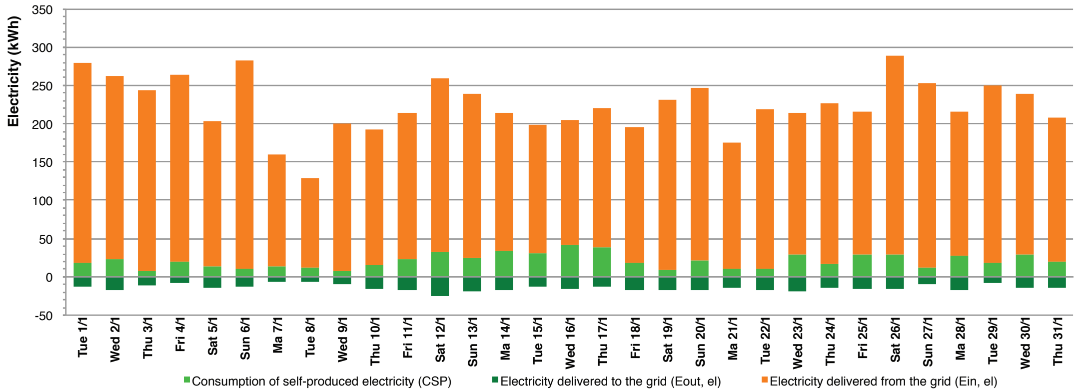


Figure 38: Energy balance overview January 2013

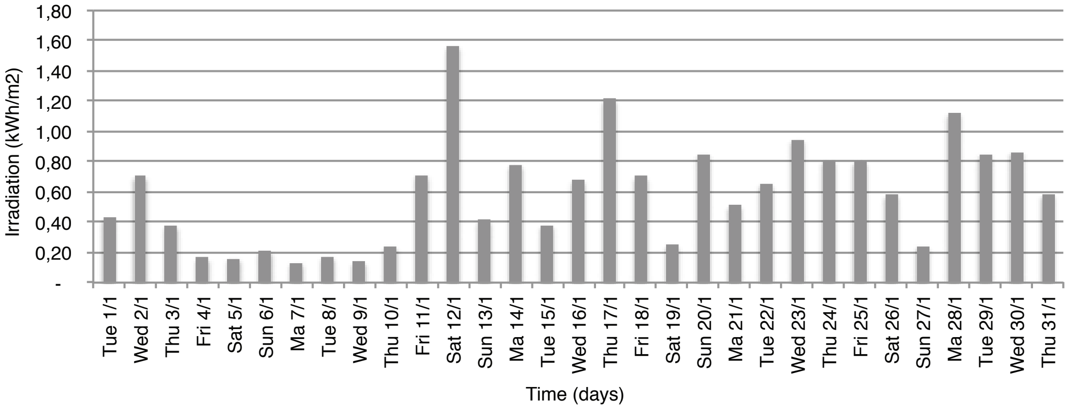


Figure 39: Global irradiation in January 2013 (KNMI, 2013a)

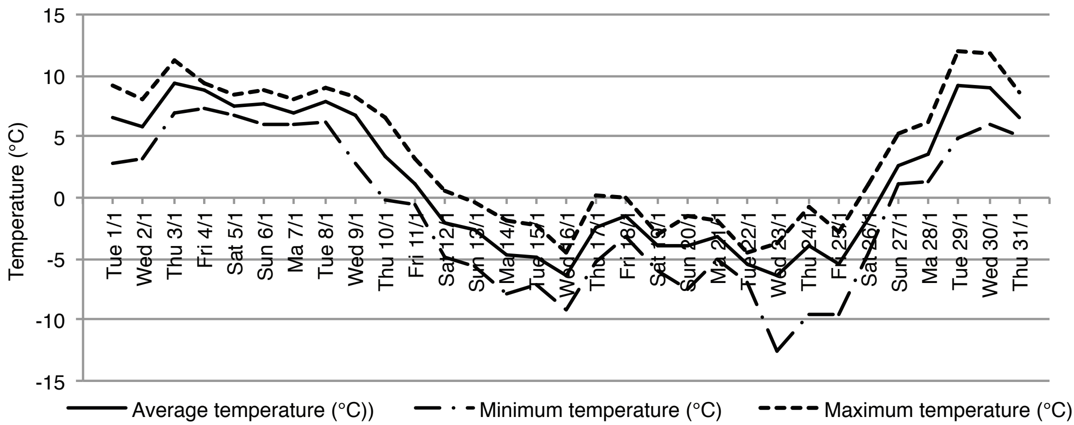


Figure 40: Temperature in January 2013 (KNMI, 2013a)

Table 15: Electricity consumption and production averaged per household per day for Week 30 and Week 4.

	Week 30, 22/7/2012 – 28/7/2012			Week 4, 20/1/2013 – 26/1/2013		
	Cluster	µCHP group	HHP group	Cluster	µCHP group	HHP group
	(n=20)	(n=8)	(n=12)	(n=19)	(n=8)	(n=11)
Electricity, per household per day (in kWh)						
Total electricity consumption (TC)	15,2	15,6	15,0	11,9	12,6	11,6
Electricity delivered from the grid ($E_{out, el}$)	10,8	11,3	10,4	10,8	10,8	11,0
Consumption of self-produced electricity (CSP)	4,4	4,3	4,5	1,1	1,8	0,6
Total electricity production (TP)	5,3	5,6	5,0	2,0	3,8	0,6
PV ($E_{PV,el}$)	5,2	5,3	5,0	0,5	0,3	0,6
Own PV	1,3	1,7	1,1	0,1	0,1	0,0
Virtual PV	3,8	3,7	4,0	0,4	0,1	0,6
µCHP ($E_{HSout,el}$)	0,1	0,3	-	1,5	3,6	-
Electricity delivery to the grid ($E_{out,el}$)	0,8	1,3	0,5	0,8	2,0	0,0
Indicators (in %)						
Production utilization (PU)	84%	76%	90%	57%	47%	100%
Energy demand sufficiency (ES)	29%	28%	30%	9%	14%	5%
Overall self-sufficiency (OSS)	35%	36%	34%	16%	30%	5%

µCHP and HHP groups, week 30 in July 2012 and week 4 in January 2013. Electricity consumption per household per day is higher for the µCHP group in week 30 and week 4, respectively 0,6 and 1 kWh. The differences are bigger for self-production. Whereas in week 30 the average self-production per day per household is not far apart (µCHP: 5,6 kWh, HHP: 5,0 kWh), self-production in week 4 is much higher in the µCHP group (3,8 kWh), than in the HHP group (0,6 kWh). The amount of µCHP production constitutes a higher share of total production in January than in July, thus explaining the difference.

With regard to the indicators, the PU value is higher for the HHP group in both week 30 and week 4. Remarkable is that the indicator value in week 4 is lower for the µCHP group and higher for the HHP group compared to week 30. This suggests that, like for the daily energy balance overviews, there is an apparent mismatch between moments of electricity production by the µCHPs and moments of consumption in the households. µCHP production took place at times when demand levels were lower than the production level, while PV production was mostly consumed directly by the households.

The ES in July is similar for the two groups, with 29% and 30%. In week 4, January, however the 14% indicator value for the µCHP group is more than double the value of 5% for the HHP group. This can be explained by the higher levels of self-production by the µCHP households in winter. Self-production by HHP households fully depends on PV production, which is very low in January compared to July, lower by about a factor of 10.

The values for OSS are 35% and 16% for week 30 and week 4 respectively. But whereas, the differences in OSS between the µCHP and HHP groups are small in week 30 (36% vs. 34%), the values differ a lot in week 4 (30% vs. 5%). Again the variation can be attributed to the differences in self-production between the two types of households. Interesting is the difference between ES and OSS. In week 30 the difference for cluster, between µCHP and HHP groups is small, suggesting that most of the potential consumption of self-produced electricity is achieved, i.e. consumption and self-production are matched. In week 4 however, the OSS is almost double the value of ES for the whole cluster. This difference occurs in the µCHP group, since the HHP group uses all of its self-produced electricity. It appears that the mismatch concerns about half of the production of the µCHPs (14% vs. 30%).

5.3.4 Self-sufficiency indicators development over the months

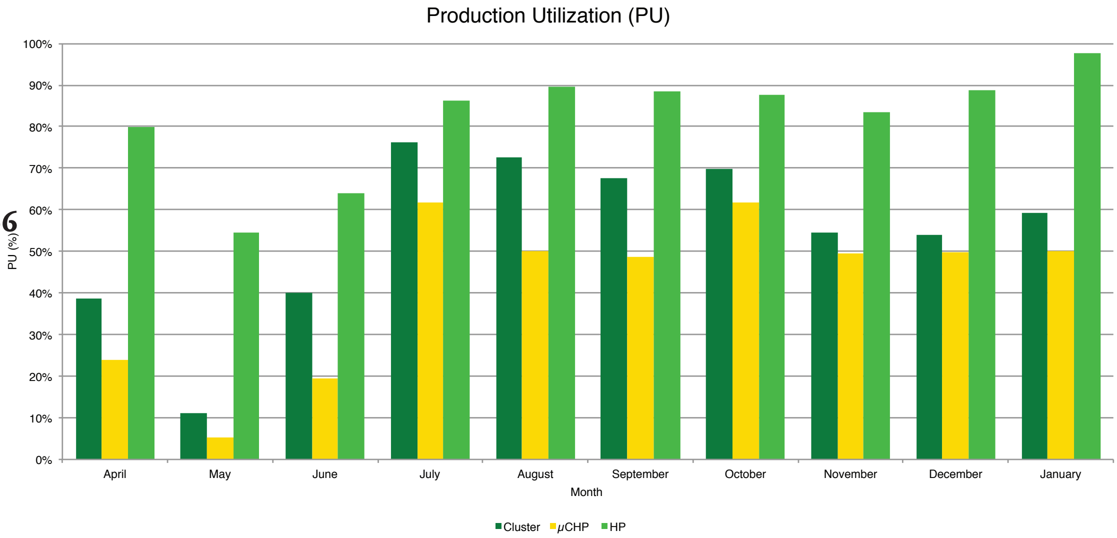
In the previous sections, particular periods of total measured time were addressed. The indicators for the energy balance were already discussed for those specific time spans. In this section, an overview is given of the variations in the indicator values for the ten months that were analyzed. This was done for the total cluster, the μCHP group and the HHP group in order to see not only changes over time, but also between the two heating systems that were implemented. Do note that virtual PV production measurements were not available from 10/4/2012 to 27/6/2012 and for several days in the weeks after until 16/7/2012 due to maintenance. For reference, Figure 44 provides an overview of the temperature, hours of sunshine and global irradiation during the analyzed months.

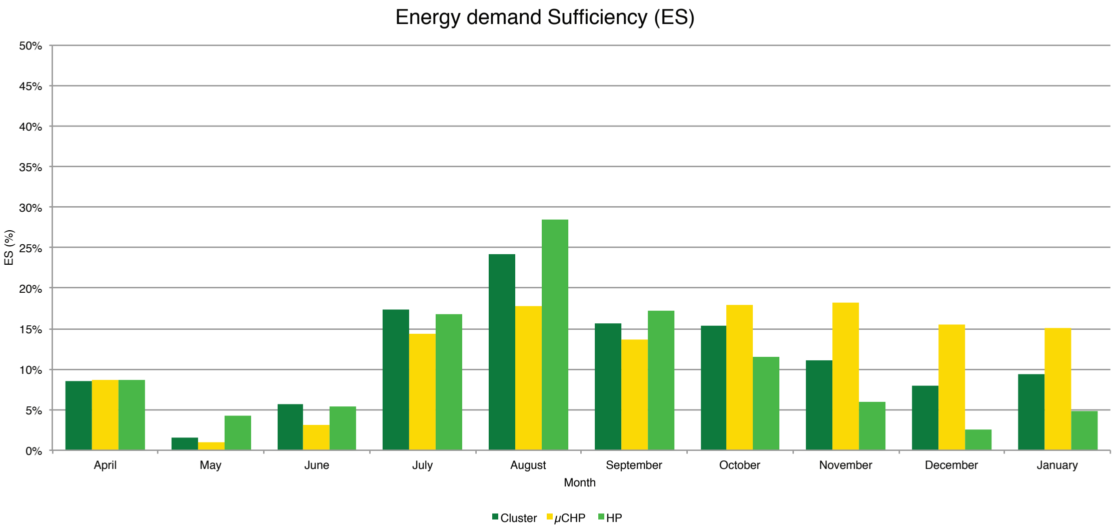
Production utilization

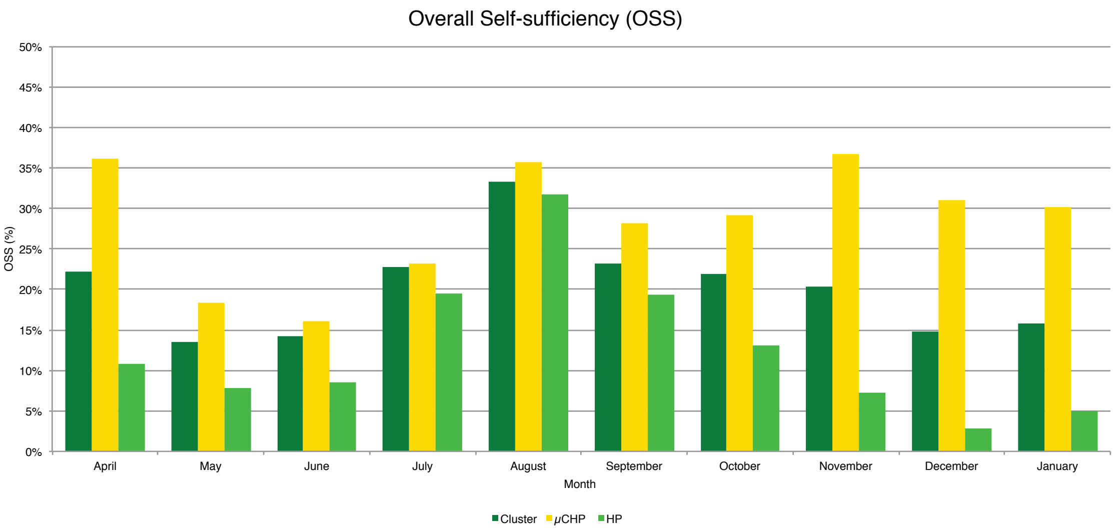
In Figure 41 the PU is presented over the months and for the total cluster, the μCHP group and the HHP group. The indicator scores range from 11% to 76%. Had electricity production from the virtual PV panels been taken into account, the values for May to July could have been higher. Based on the global irradiation values for the respective months, the PV solar production would be in the range of the production recorded in September for April and August for May to July. The highest PU values correspond to the months July and August, when the production of PV solar energy was highest. Based on this overview and with the potential values for May to July, it can be observed that the percentage of consumption from self-produced electricity is above 50% for the cluster. This value indicates that the majority of the energy produced in the cluster is actually consumed within the cluster throughout the year.
For the μCHP households, the indicator values are lower than for the whole cluster, but still around 50% for August to January, with a minimum of 49% and maximum of 62%. The indicator values for the HHP households are higher than for the μCHP group, between 58% in May and 98% in January. For August to January, the months with virtual PV production measurements, the percentages are around 90%, with 83% in November as the lowest and 98% in January as the highest percentage.
The difference in indicator values between the μCHP and HHP groups may be related to (1) the very low self-production of the HHP households and (2) the coordination of the PowerMatcher by which the μCHPs tend to be switched on when electricity prices are high and the μCHP housholds can sell electricity to the grid. The operation of the coordination mechanism was observed for July 22nd. Because the tariff structure of PowerMatcher varied during the analyzed period for this study, additional analysis for daily patterns in relation to pricing would be required to explain effects on differences in indicator value.

Energy demand satisfaction

The values for ES are depicted in Figure 42, for the whole cluster, the μCHP group and the HHP group. The ES reaches a maximum value of 28% with the HHP group in August. The monthly values for ES indicate that the majority of the electricity consumption in the households comes from


Production Utilization (PU)
PU (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
April
May
June
July
August
September
October
November
December
January
Month
Cluster
μCHP
HP


Energy demand Sufficiency (ES)
ES (%)
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
April
May
June
July
August
September
October
November
December
January
Month
Cluster
μCHP
HP


Overall Self-sufficiency (OSS)
OSS (%)
50%
45%
40%
35%
30%
25%
20%
15%
10%
5%
0%
April
May
June
July
August
September
October
November
December
January
Month
Cluster
μCHP
HP

the grid, rather than from self-produced electricity. This can be explained by the energy system design, which was not devised to cover the entire electricity demand with production capacity in the cluster. The April and May-July values would have been in the same range as those for September and August respectively had data from virtual PV production been available. For the whole cluster ES is highest for July and August, related to higher levels of PV solar production during the summer. The decline of ES after August for the HHP group, who only has PV solar panels as a source of self-production, confirms this relation. While ES in July to September is higher in the HHP group, it is higher for the μCHP group in November to January. For the μCHP group the values for July to January are close to each other, between 14% and 18%. The electricity production by the μCHPs 'takes over' from PV production as the outside temperatures and solar irradiation decrease in autumn and winter. It appears that, based on the indicator's values, the lower PV production in winter is compensated by higher μCHP production, resulting in similar performance on the ES.

Figure 41(left page): Values per month for production utilization (PU), the consumption self-produced electricity and the electricity delivered to the grid as part of the total production, for the total cluster, the μCHP group and HHP group.

Figure 42 (left page): Values per month for Energy demand sufficiency (ES), the consumption self-produced electricity and the electricity delivered to the grid as part of the total consumption, for the total cluster, the μCHP group and HHP group.

Figure 43 (left page): Values per month for overall self-sufficiency (OSS), for the μCHP group and HHP group.

Overall self-sufficiency

The cluster OSS is depicted In Figure 43, the μCHP households and the HHP households. The indicator's values for the cluster range between 14% and 33% from April to January. Like for PU and ES, the values for April and May-July should have been in the same range as the values recorded for September and August respectively had data from virtual PV production been available. Considering the months with full virtual PV monitoring data, the highest value for OSS is 33% in July and the lowest 15% in December.
For all months OSS is higher for the μCHP group. Based on the months with full virtual PV monitoring data, OSS ranges from 28% in September to 37% in November. The electricity production by the macho systems again plays a role here. In the HHP group the highest values are observed in summer (July to September), due to the PV production as their only source of self-production. OSS is around 30% in summer, which is similar to the OSS for the μCHP group. In November, December and January OSS drops to respectively 6%, 2% and 5%. So while the μCHP group appears to have a more or less constant potential for consumption of their self-produced electricity, the HHP group suffers a seasonal effect, with very low amounts of consumption that can be offset by self-production.

5.4 Energy balance at household level

To gain further insight into the differences between the households, these were analyzed on the basis of the three indicators for self-sufficiency. Like in the previous section, comparisons were made between January and July as well as between the performance of the whole cluster, the μCHP group and the HHP group. Since the analysis yielded similar results for the day and month, the discussion here will be limited to the month values of the indicators. The values for PU, ES and OSS per household for July and January are presented in Figures 46 and 47.
The overviews show differences in performance per household based on the heating system (μCHP or HHP) and PV system (Own PV or Virtual PV).

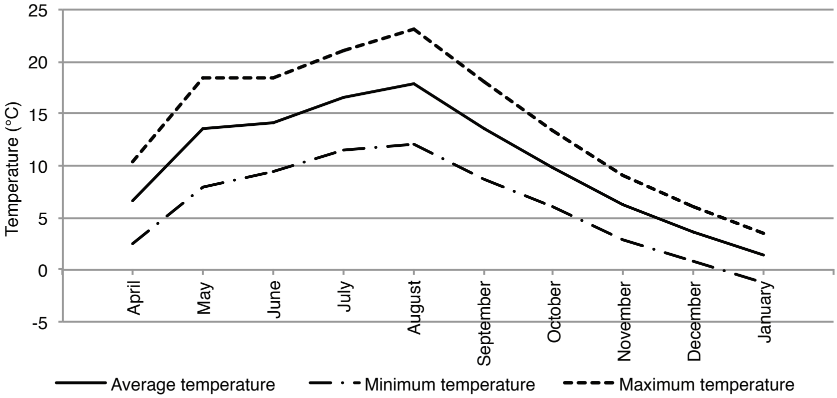


Figure 44: Temperature per month from July 2012 to January 2013 (KNMI, 2013a)

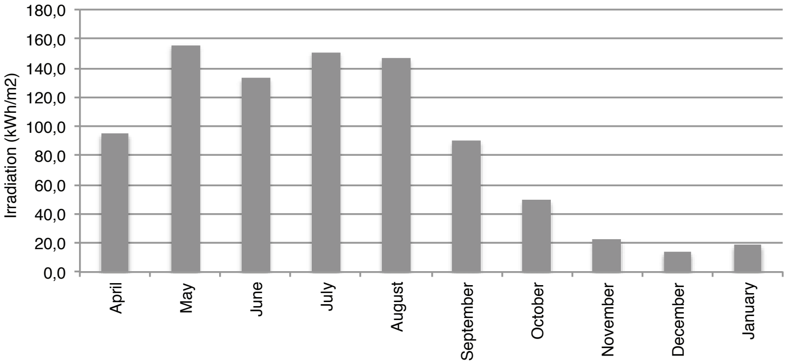


Figure 45: Global irradiation per month from July 2012 to January 2013 (KNMI, 2013a)

The values for ES in July are between 10% and 20% for most households (13 of 18). One household has a lower ES, 5%. And four households have an ES higher than 20%, with the highest ES at 37%. A relation between CSP and TC cannot directly be observed here. The spread in TC of the households appears to be the reason for this.

For January, ES values are below 10% for all HHP households. For the µCHP households, ES ranges between 13 and 65%. As observed in previous sections, low ES values can be attributable to low self-production of the households, as is the case for the HHP households in winter. There appears to be a positive correlation between CSP and TC for the HHP households (see Figure 52). For the µCHP households such a relation is not apparent.

The OSS values for July range between 6% and 71%. Two households with own PV, those with highest installed capacity, achieved the highest OSS, namely 46% and 71% respectively. For these households the difference between OSS and ES, i.e. the difference between potential and realized consumption of self-produced electricity, is also highest. Remarkable is that there is no difference between OSS and ES for the HHP households with virtual PV, while Households with their own PV, µCHP or both have a higher OSS than ES. More detailed analysis could produce the underlying reason.

In January, OSS values range from 3% to 65%. The highest values are found for the µCHP households, which achieved an OSS of 19% to 65%. The OSS for the HHP households is between 3% and 6%, except for one household

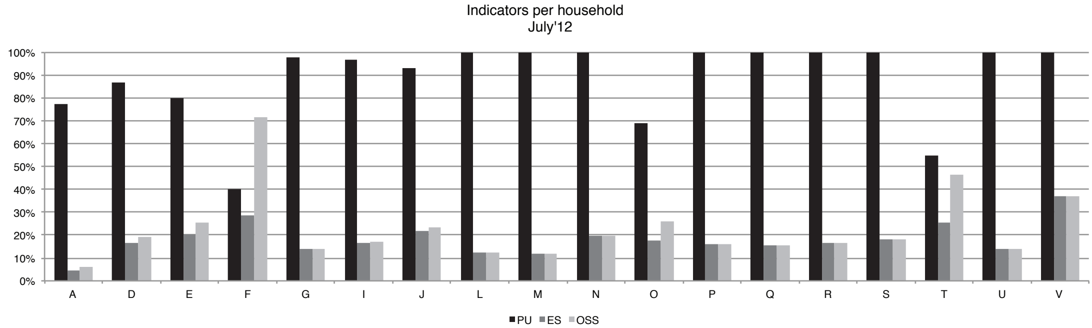


Figure 46: Indicator values per household for the month July. Three households were excluded due to negative or zero values for one or more indicator. Households A to J have a μCHP and Households L to V a HHP system.

[hh8] with 13% OSS. This household has its own PV system and yielded the second highest OSS in July. Also for January, the difference between OSS and ES is zero or near to zero for HHP households with virtual PV production. The difference between OSS and ES for the μCHP households is bigger in January than in July, except for one household. This may be due to the major share of μCHP electricity production during January's self-production. As we observed in the daily energy balance, the CSP appears to be lower with electricity production from the μCHPs than from the PV solar systems.

With respect to the comparison between household performances in the scatter diagrams, Figures 50 and 53, there does not seem to be a correlation between TP and TC in July. In January, like for ES, a correlation is apparent between TP and TC for the HHP households.

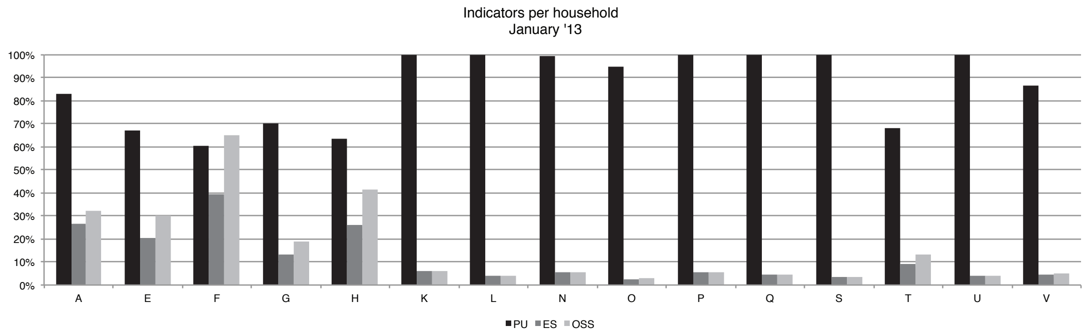
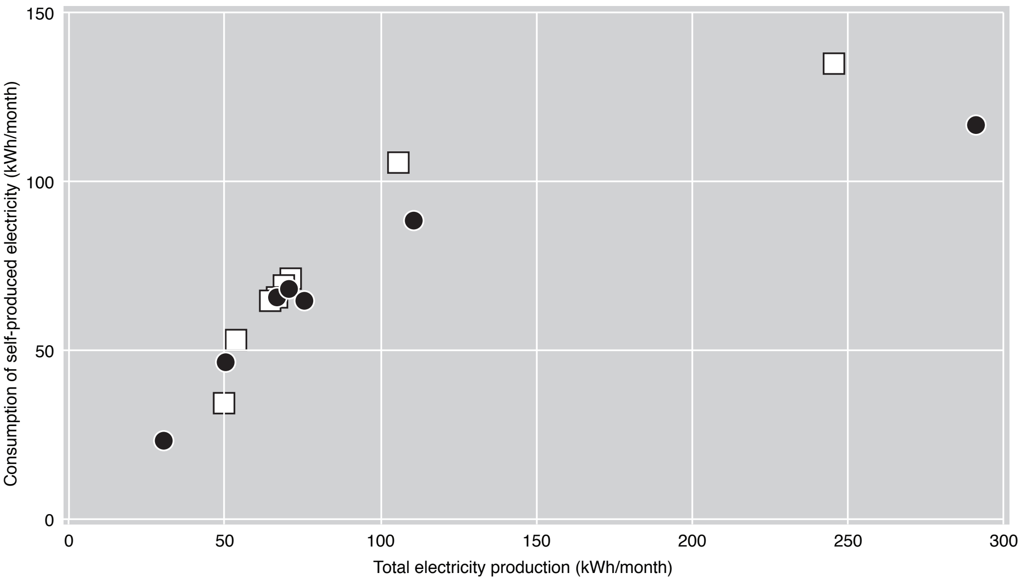
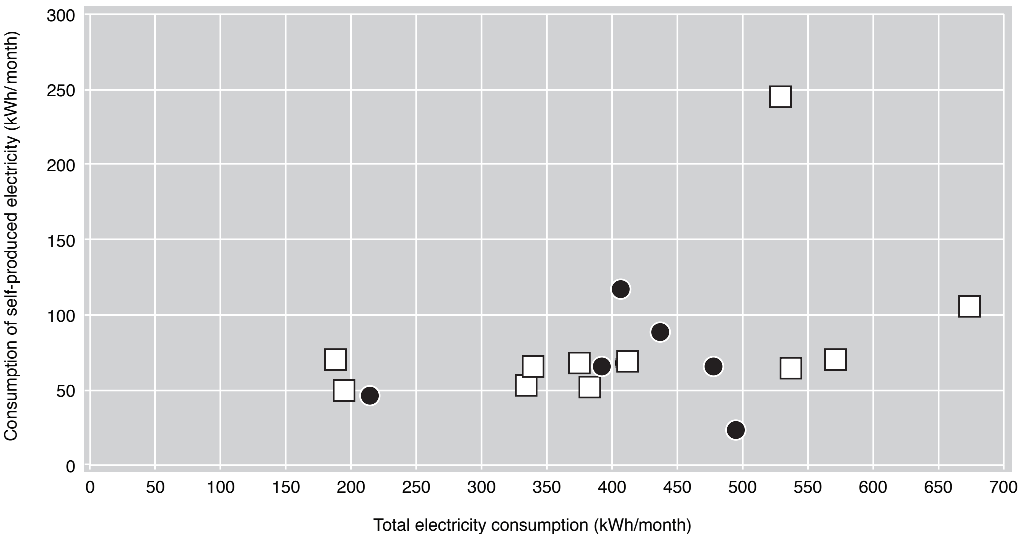


Figure 47: Indicator values per household for the month January. Six households were excluded due to negative or zero values for one or more indicator. Households A to H have a μCHP and Households K to V a HHP system.


Consumption of self-produced electricity (kWh/month)
Total electricity production (kWh/month)


Consumption of self-produced electricity (kWh/month)
Total electricity consumption (kWh/month)

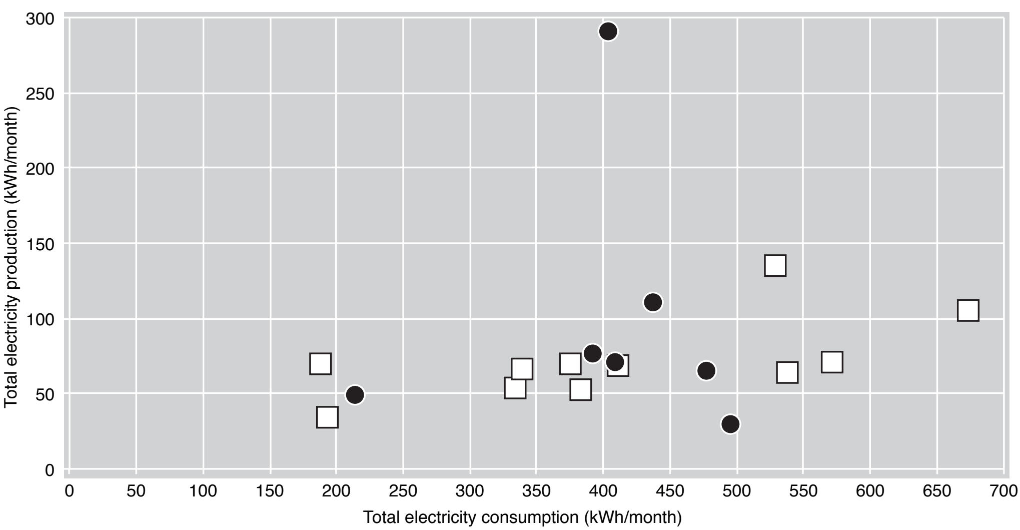

Total electricity production (kWh/month)
Total electricity consumption (kWh/month)

Figure 48 (left page): Total electricity production (TP) versus consumption of self-produced electricity (CSP) for July 2012

Figure 49 (left page): Total electricity consumption (TC) versus consumption of self-produced electricity (CSP) for July 2012

HP households

mCHP housholds

Figure 50 (left page): Total electricity consumption (TC) versus total electricity production (TP) per household for July 2012

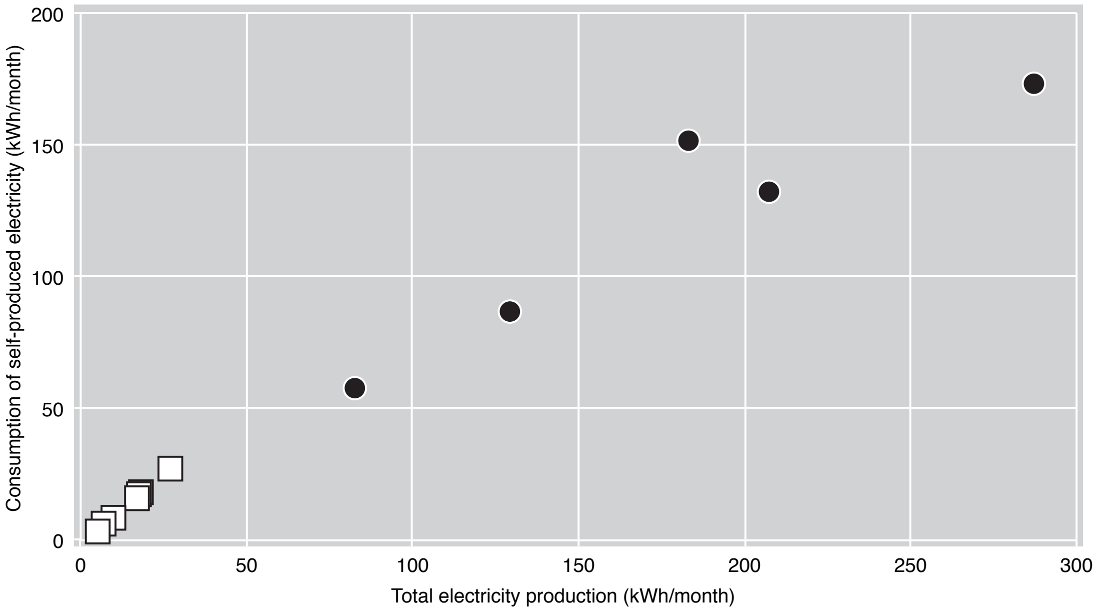
Figure 51 (right page): Total electricity production (TP) versus consumption of self-produced electricity (CSP) for January 2012

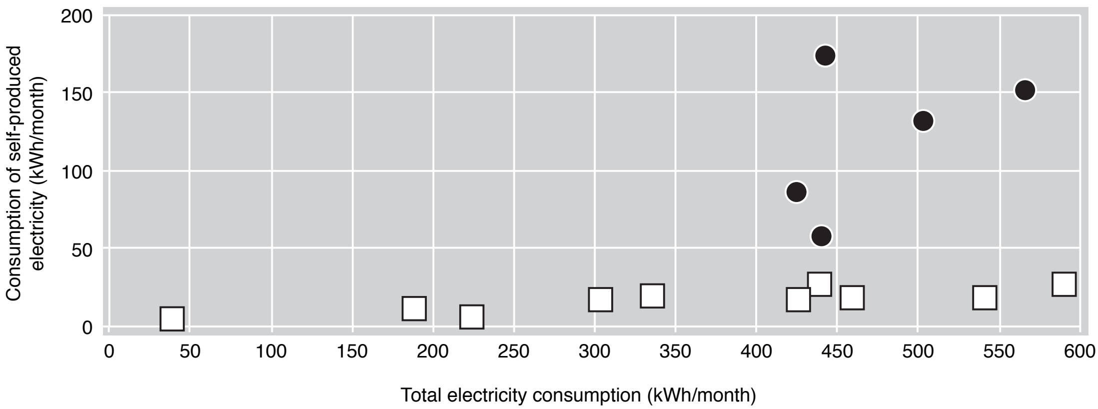
Figure 52 (right page): Total electricity consumption (TC) versus consumption of self-produced electricity (CSP) for January 2012

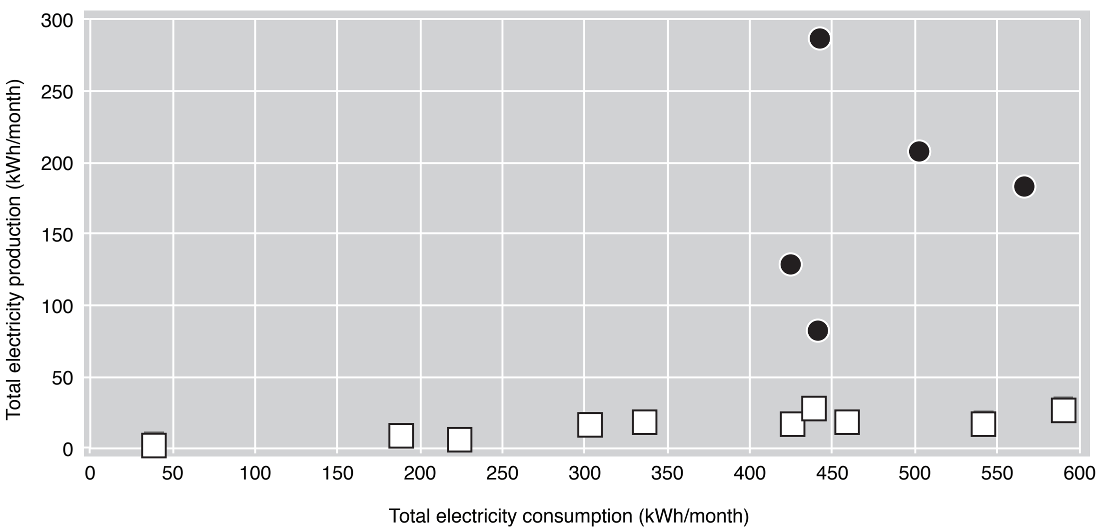
Figure 53 (right page): Total electricity consumption (TC) versus total electricity production (TP) per household for January 2012

□ HP households

● mCHP housholds


Consumption of self-produced electricity (kWh/month)
200
150
100
50
0
0
50
100
150
200
250
300
Total electricity production (kWh/month)


Consumption of self-produced electricity (kWh/month)
200
150
100
50
0
0
50
100
150
200
250
300
350
400
450
500
550
600
Total electricity consumption (kWh/month)


Total electricity production (kWh/month)
300
250
200
150
100
50
0
0
50
100
150
200
250
300
350
400
450
500
550
600
Total electricity consumption (kWh/month)

5.5 Discussion and conclusion

The goals of this study were to quantify the energy balance for the cluster households in PowerMatching City, to compare summer to winter and the two types of heating systems that were installed in the households to each other. To this end the measured data for self-production, consumption and delivery to the grid were analyzed, visualized and expressed in indicators.

In this study we quantified the dependency of PowerMatching City households on the overall grid to meet their electricity demand and to deliver surplus electricity to the grid. The system design of PowerMatching City , i.e. the installed production capacity, 'limited' the attainable overall self-sufficiency (OSS) to 30 to 35%. This is the case in summer for both the μCHP and HHP groups. In winter, OSS was still about 30% for the μCHP group, since the μCHP production compensates the decrease in PV production in winter. For the HHP group, on the other hand, OSS drops below 10% because of low PV production in January. To increase OSS the self-production capacity of the cluster could be increased. In addition to PV as a renewable source, a wind turbine[5] or several micro-wind turbines could be included so as to differentiate the generation pattern of the intermittent resources. Furthermore, household energy consumption could be lowered through energy efficiency measures and end user behavior. To what extent OSS can be increased based on increased self-production and lower electricity consumption cannot be indicated based on this study and would require additional research. The potential for matching production and demand, discussed below, would have to be included here as well.

With respect to the simultaneous matching of self-production and consumption, described by PU and ES indicators, a mismatch could be observed in both July and January, particularly for the μCHP households. A mismatch was observed between the realized CSP and the potential CSP (i.e. a difference between indicators ES and OSS) up to 53% for the μCHP households in week 4, meaning that less than half of the produced electricity was consumed at the same moment in the households (PU indicator: 47%). This mismatch may be attributed to the PowerMatcher coordination mechanism, as observed for July 22nd when a μCHP system was prompted to generate electricity. But, as noted for January 20th, a relation with the coordination mechanism is not always apparent. On this day, electricity production by μCHP systems probably followed the heating demand for space heating and hot water, hence leading to surplus production vis a vis the household's demand at the time. A mismatch between self-production and consumption could also be observed with respect to PV production, particularly for the households with their own PV panels with high installed capacity.

A better match between self-production and consumption could be achieved by shifting electricity demand to moments of electricity production and vice versa in the case of μCHPs. This could be achieved by behavioral changes in

5 Note that the PowerMatching City cluster included a wind turbine in first instance. The analysis in this study did not include wind energy due to practical considerations in the project organization. Based on the analysis, additional renewable sources would increase the potential self-sufficiency of the cluster, hence a recommendation for a wind turbine.

the household that affect the consumption pattern. At the same time, the operation settings of the µCHP heating system could be adjusted to better match consumption patterns in the households. In anticipation of the next chapter, end users in PowerMatching City have actually expressed interest in contributing to supply-demand matching. Further investigation of the daily consumption patterns per household could provide additional insight into when behavioral actions can be beneficial for supply and demand balancing and how operation settings of µCHP systems can be adjusted. Inquiry with the end users in relation to the observed patterns should furthermore indicate their willingness and possibilities to shift electricity consumption.

The results are discussed here from the perspective of self-sufficiency at the household level. Self-sufficiency is important when the main goal of the smart energy system is to limit the amount of electricity flowing in and out of a microgrid and energy services to households are tuned to this goal. However, as described in the introduction of this chapter there are several goals to achieve in the smart energy system. The achievement of these goals would be evaluated differently with respect to the indicators formulated in this study. For example, when PowerMatching City is used as a Virtual Power Plant low PU indicator values should be achieved. Follow-up research that includes evaluation of the coordination mechanism and home energy system settings (e.g. when to start generating heat to store in the hot water tank) could further address the performance on different goals of the smart energy system.

This study could not evaluate to what extent electricity production and consumption were matched (virtually) within the cluster. It may well be possible that surplus electricity of µCHP households could be delivered to HHP households. While mismatch would then occur at the household level, at cluster level other households in the cluster could use the households' self-production. Further research that takes the flows within the cluster into account could address this issue.

The relevance for practice of this study is that insight into energy balance can be used for optimizing the design of the smart energy system, not just for the technical performance of the system, based on its installations and installed capacity of self-production, but also for the way in which the system works and the goals of stakeholders are met. While energy providers and network operators may need more detailed analysis to assess their optimization goals, the analysis presented in this chapter can provide a relatively simple overview that can be used as a starting point to communicate with end users about (a) the performance of one's home energy system in terms of energy flows within, out of and into the household, related to remote control as well as household behavior, (b) the relation between individual household performance and the performance of the cluster or overall grid, (c) the goals of different stakeholders and how they affect energy management in the smart energy system.

Firstly, communication based on energy balance insight can be used to include end users in the development process of a smart energy system. For PowerMatching City particularly, it is recommended that such discussions are based on more recent data, since the project has changed over time and more households are involved. For new-to-design smart energy systems, for instance for energy cooperatives or neighborhoods with interest in local self-production, the example of PowerMatching City could be a starting point to discuss the design of the smart energy system design and more specifically the products and services for households. An end user centered approach would require that overall smart energy system design aligns the goals of energy companies, such as grid stability and cost-effectiveness, with end user goals and needs, so that also end user behavior may be supportive of optimal system operation.

Secondly, the results of this study can be considered for interface design of PowerMatching City and similar smart energy systems. The visualization was based on the visualization of the Energy Portal (See section 4.2.5), i.e. a combined graph of total consumption, self-production, delivery to grid and consumption of self-produced electricity. The difference was the graphic layout and the production of daily graphs, which also include appliance specific information. These daily graphs allowed the researchers to evaluate in more detail how the system was operating. To provide insight into daily energy patterns, this type of graph may be useful to end users as well in order to gain insight in daily patterns of consumption and production, for aggregate amounts as well as for appliance specific information. This graphical representation should not be considered as the main information provided to end-users, as it may be rather technical for the majority of end-users. The graphics can be used to complement information on the household performance on a more abstract level. On this abstract level, the indicators that have been developed in this study may be useful, to provide a quick overview of the potential levels of household self-sufficiency (OSS) and the actual achieved levels of self-sufficiency (ES and PU). It is recommended that these indicators are combined with contextual information, such as comparative information from other households (Ehrhardt-Martinez et al., 2010), overall smart energy system performance and actions of the automated coordination mechanism that influence performance on the indicators (Chapter 2, section 2.5.1). It is beyond the scope of this thesis to address design of energy information for households in further detail. The recommendations here are only complementary to recommendations formulated in other research concerning energy saving (e.g. Fischer, 2008; Van Dam, 2013) and further user research into ways to shape the interface between end users and smart energy systems for co-provision is highly recommended.

The study discussed in this chapter approached energy system performance from a technical perspective and suggested ways to use energy balance information in communication to end-users. In the next chapter, the performance of the smart energy system will be addressed based on the experiences of the end users with the smart energy system. Differences in goals between stakeholders in the energy system and the user interaction with the energy system will be addressed in more detail based on end user's reflections on the use of the technologies implemented in their homes.

Main results and design implications of this chapter

Main results

- *The energy balance analysis led to visualization of the energy balance over a given time and to characterization of this balance with self-sufficiency indicators.*
- *OSS of the households was 30 to 35% for µCHP and HHP households in summer. In winter, OSS of the HHP households dropped below 10%, due to low self-production. Increase of OSS could be achieved by a combination of energy saving in the households (energy efficiency measures and behavioral changes) and an increased amount of self-production capacity per household or at cluster level.*
- *A mismatch between momentous self-production and consumption is highest among households with a µCHP heating system. The mismatch could not be fully ascribed to coordination via the PowerMatcher coordination mechanism. Operational settings as well as end user behavior could be geared to one another to increase PU and ES.*
- *While self-sufficiency is one of the goals for smart energy system operation, full evaluation of the performance would have to include additional criteria and indicators that enable assessment of the various goals involved in a smart energy system optimization for all stakeholders, from end user to network operator.*

Implications for product- and service design

- **Involvement of end users in the development process of smart energy systems:** *Energy balance analysis with simple graphical information and indicator values can be used to involve end users as stakeholders in the development of smart grids. The results from this study, or studies based on data from other smart energy systems, can be used as a starting point to discuss current and desired performance of the system in light of the multiple goals that were set for its operation.*

- **Feedback information to end-users:** *The graphical representation and indicators could be useful in feedback to end users concerning their performance in terms of co-provision. The results would however have to be considered part of a larger overall design, with more intuitive and contextualized information.*

6

Empowering end users as co-providers in PowerMatching City

6.1 Introduction

In Chapters 1 and 2 the changing role of end users from passive consumers to co-providers in the electricity system was discussed. This transition implies that household energy management, in addition to efficient energy use, also includes scheduling consumption to match favorable times for the energy system, production of electricity and trading of electricity that is surplus to the household's need. In Chapter 2 these points were referred to as four aspects of co-provision[1] and it was argued that products and services implemented at household level can enable end users to incorporate these four aspects in their home energy management. The development of these products and services would furthermore be led by different end users' preferences, for example concerning the amount of effort one wants to put into the household's energy management.

In this chapter the second research goal for the PowerMatching City study is addressed: To evaluate to what extent did the smart grid products and services in PowerMatching City empower the end users to become co-providers in the smart energy system. The study concerns the end users who were part of PowerMatching City in phase 1, up to the end of the year 2012.

Section 6.2 will address the research approach to this part of the study. Then the results are discussed in section 6.3 with regard to the experiences of the end users with the home energy system and the overall smart energy system (Section 6.3.1) and with regard to the theoretical framework presented in Chapter 3 (section 6.3.2). The chapter ends with a discussion and conclusion that combines the findings in section 6.4 and 6.5.

6.2 Research approach

The PowerMatching City project provides a good opportunity to evaluate smart grid technology in a situation where households actually make use of the technology in their households. People can be asked to imagine a given situation, but it is more powerful to let people experience such a situation and to learn from those experiences (Bakker et al., 2010). In order to find out to what extent the end users in PowerMatching City have been enabled to become co-providers in the smart energy system, this study takes two perspectives: firstly the experiences of the end users with the smart energy system and secondly the way in which the implemented smart energy technology facilitates co-provision behavior for household energy management. These two perspectives can be found back in the research framework (see Figure 55), which illustrates the interactions between social and technical elements in the smart energy system. The first perspective is that of the end users and the way they perceive and use the implemented technologies. The second perspective builds on the possibilities the system offers and that enable co-provision. These two perspectives are translated for this study in the following research questions:

1 These were formulated as: 1. Using electricity efficiently. 2. Planning or shifting electricity consumption to times that are favourable for the energy system, for example when renewable energy is locally available or when overall demand in the system is low. This also includes avoiding consumption of electricity at times of peak demand in the system. 3. Producing electricity when it is favourable for the local grid, for example via a micro-cogeneration unit. 4. Trading self-produced electricity that is surplus to household needs.

a. *What were the experiences of the end users with the use of the smart energy system, i.e. the interaction with the home energy system and the participation in a smart energy system with automated coordination mechanism?*

b. *To what extent can the implemented products and services enable household energy management concerning the four aspects of co-provision?*

The first research question was answered based on several research activities that took place during the project. The research activities that were included in the analysis are described in appendix A. Each research activity addressed specific research questions with respect to the information needs for the project progress at that moment. At the same time, the research activities have in common that they addressed the interaction of the participants with the smart energy system. Therefore they could be used to evaluate the experiences of the end users in PowerMatching City. The majority of the information that was relevant for answering question a) came from evaluative interviews that were held in 2011 (research activity H, N=16), a questionnaire in 2012 (research activity N, N=16) and interviews in 2012 (research activity O, N=5). The questions and structure used for these activities is included in appendix D.

The data that were gathered in the research activities underwent qualitative analysis . The results from the research activities were coded based on the questions that were to be answered for this study. Wherever possible, the

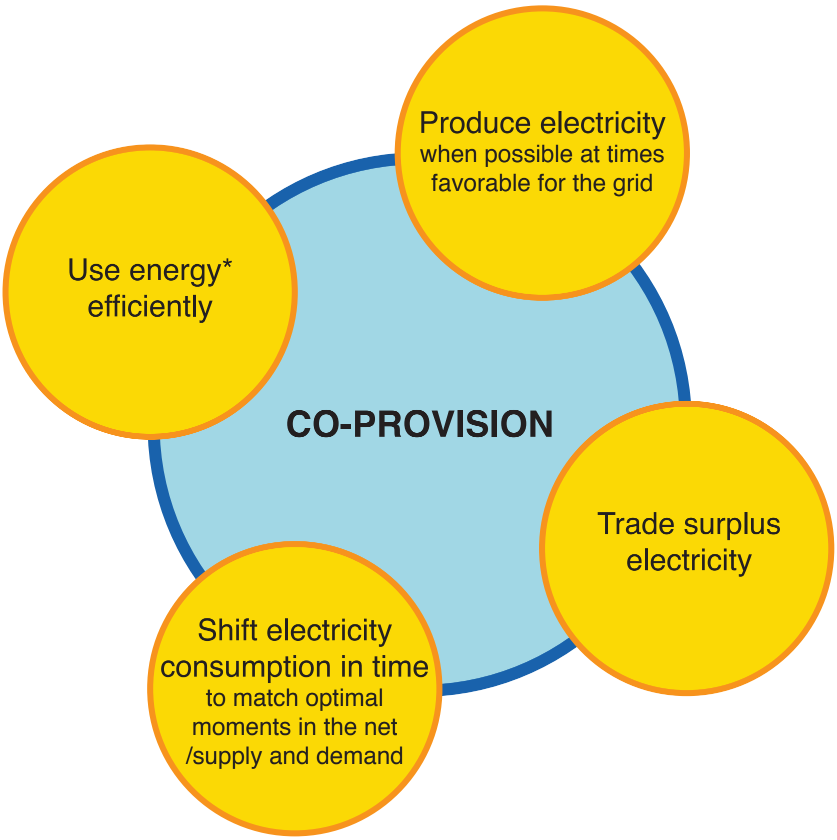


Figure 54: The aspects of co-provision in home energy management for households connected in a smart energy system

results were quantified to indicate the spread of different answers among the respondents. In the data analysis the use of the home energy system was addressed first, followed by analysis of information concerning the households in relation to the smart energy system.

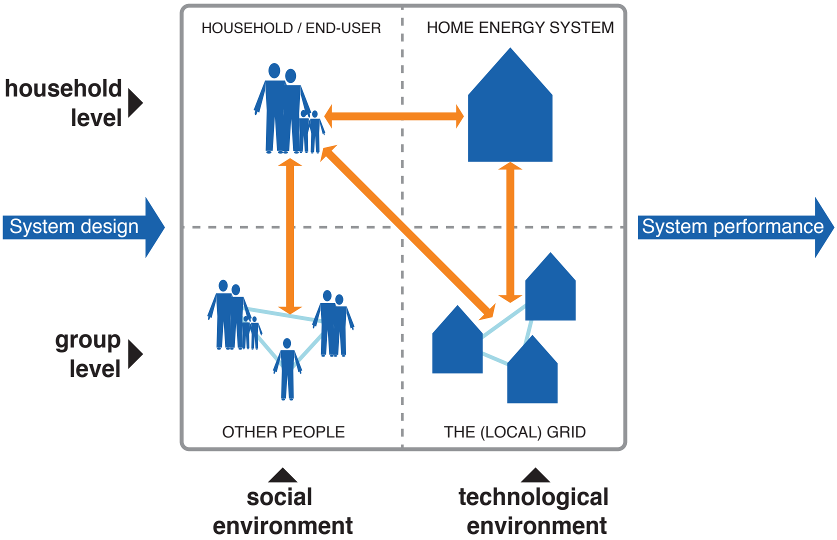


Figure 55: Research framework for this thesis

The second research question about the extent to which the implemented products and services enable the four aspects of co-provision in household energy management was answered by means of the framework and layer model that were presented in Chapter 2, Table 1 and Figure 2/3 respectively. The framework was filled in based on the description of the system design (see Chapter 4) and the elements of the layer model that are present in PowerMatching City are indicated. The analysis includes a reflection on how the system interacts with the end users and to what extent the end users are able, and required, to take action for co-provision.

6.3 Results

6.3.1 End user perspective on the implemented system

Over the course of the project information was collected concerning the experiences and opinions of the participants. In the following, the results concerning the perspective of the end users on the smart energy system are discussed along the lines of:

- *The use of the home energy system in terms of the heating system, smart appliances and energy portal.*
- *The goals of the end users with regard to household energy management*
- *End user involvement with the matching of supply and demand in the smart energy system.*

The majority of the findings discussed in this section are based on semi-structured interviews. To illustrate findings, quotes of end users were selected that can provide richer insight into the findings. These quotes are included in Appendix E and indicated between brackets, for example [Quote 6].

Use of the home energy system

The description of the system design in Chapter 4, defined the functions the home energy system fulfills: space heating and hot tap water supply, production of electricity and control of appliances to enable matching of supply and demand in the cluster (by shifting energy consumption and production). In the following, the experiences of the end users with the home energy system are discussed based on the components of the home energy system the end users could interact with: (a) the heating system, (b) the smart appliances, and (c) Energy portal. The PV solar panels are not discussed here because the households are not interacting with them, other than via the Energy Portal. The Community website is excluded from this discussion because it is not directly coupled to the home energy system and its main purpose was social interaction rather than interaction with the technology. The community website will be discussed in more detail in Chapter 7.

The main sources of data are interviews with 16 households that were held two years after implementation of the home energy system (research activity H) and in which the satisfaction with the home energy system was the central topic.

Heating system

The degree of comfort provided in terms of space heating and the provision of hot tap water by the home energy system appears to be satisfactory for most households. All households are aware that they are taking part in an experiment. Initial problems with the heating systems therefore appear not to influence the households' satisfaction with the heating system at the time of the interview. To give some insight into the technical problems that have occurred: Out of the 16 households participating in the interviews 6 of the 7 respondents with µCHP reported that their µCHP had been replaced at least once. All respondents with HHP (9 of 16) indicated to have encountered problems with the HHP, such as high electricity consumption by the heat pump due to long operation periods in the beginning of the pilot and failures. Two years later, at the time of the interviews, most problems had been solved and the heating systems were operational. [Quote 1]

With respect to the space heating, only two of the respondents (2 of 16) stated that the heating system was not providing sufficient comfort compared to their previous system. For one household with a low-temperature heating system, it had not yet been possible to set the heating system to deliver the desired comfort levels for space heating. The household suggested that the capacity of the heating system was insufficient for their house. [Quote 2 & 3]

Two respondents (2 of 16) explicitly expressed that the new system was an improvement in comparison with their previous out-of-date heating system. One respondent indicated that the expected increase in heat comfort was fully achieved. For the other household the financial benefit was positive. The hot water provision had also improved as two respondents (2 of 16) explicitly mentioned. [Quote 4 to 7]

While the provision of heat was overall satisfactory, the majority of respondents to the interviews indicated dissatisfaction with the way in which to set the room temperature (14 out of 16). Their main complaints concerned the fact that the thermostat could not be programmed (11 of 16) and the accuracy of setting the room temperature (3 of 16). Several of the households had been using a programmable thermostat (7 of 16) or had been planning to buy one (1 of 16) before taking part in PowerMatching City. They saw the change as having to downgrade to a manual thermostat. [Quote 8]

The stand-by mode on the thermostat made it possible to set the heating to a 'sleep/away' mode at lower temperature. This function had a standard duration of seven hours and had to be set manually. Considering the statements of the respondents, this was not found to be practical. The timing was not adjustable, so one had to calculate the best time to start the 7 hours of stand-by or accept that the heating was not adjusted to the household members' schedules. [Quote 9 & 10]

The households accustomed to a programmable thermostat sometimes forgot to adjust the settings, because it was not part of their routine behavior. Also the households suggested that their heating would be on longer, potentially resulting in higher energy consumption. They would turn down the thermostat when going to bed, while the programmed thermostat would automatically turn it down earlier. [Quote 8, 11 & 12]

One of the households installed a different thermostat, a 'web thermostat' remotely programmed and activated via Internet. Another end user, who had heard about this, had considered to follow this example, but in the end abandoned the idea. [Quote 13]

The thermostat that was provided by the project could be used to set either the room temperature or the temperature of the water circulating in the heating system. Most households used the room temperature setting. Two households, who did not manage to reach a comfortable indoor climate based on the room temperature setting, used the water temperature setting. Furthermore, two other households indicated having tried to use the heating system based on water temperature. Both households noticed higher gas consumption and switched back to setting the heating based on the room temperature. One of these households also noticed that the water temperature-based heating resulted in the whole house heating up faster. They would sometimes still use the heating system based on water temperature, because it enabled them to close radiators in the room where the thermostat is located (and thus the room temperature sensor) and focus the heating on another room where they would be present, the study for example.

Demand response with the heating systems

As described in Chapter 4, the heating systems in PowerMatching City were designed to enable demand response. For the HHP systems demand response in PowerMatching City is based on the timing of electricity consumption. For the μCHP systems, it is based on their function as micro-generators and they are thus controlled for the timing of electricity production. The demand response was controlled automatically via PowerMatcher. The boundary condition for demand response was the temperature setting on the thermostat, meaning that provision of sufficient

heat for the household was to be guaranteed at all times.
A sound alerted end users in PowerMatching City when their HHP or µCHP system started operating. The users could also track the activity afterwards in the graphs on the Energy Portal. In this respect a number of respondents commented that they did not find the timing of the HHP or µCHP operation logical in relation to their own electricity production and consumption (4 of 16). Comments were made by eleven (out of 16) respondents about a lack of understanding of operation of the heating systems and inability to influence the operation of the system. A question raised, for example, was why does the µCHP sometimes switch on in the middle of the night, when the household doesn't have heating demand? [Quote 14 to 20]

The findings with respect to the use of the heating system illustrate a lack of end users' insight into how the system operates. This is related to not having enough information to understand what the system does or why and a need for more control over the heating system's timing of consumption and production (in the case of a µCHP). Remarkable is that participants stated that they wanted to 'steer' the system or to 'play the game', but failed to specify what they would like to do concretely. The 'steering' and 'playing the game' can be interpreted as having control over the system by influencing system settings according to the households' wishes, to, for example, fine-tune the system to use self-produced solar power, and to be able to play a more active role in the matching of consumption and production by adjusting behaviors, such as switching on the washing machine when the µCHP is producing electricity or when there is excess electricity production in the cluster of households.

Smart dishwasher and washing machine

By mid 2011 twelve households had received a smart dishwasher and washing machine. Due to technical difficulties in the communication between PowerMatcher and the appliances, only the dishwasher could be operated in 'smart mode' from February 2012 onwards. Both appliances could however be used manually.
In the interviews held in mid 2011 (research activity H) the use of a smart dishwasher and washing machine were addressed (in 13 of the 16 interviews). At that time the appliances were not usable in smart mode yet. Several of these households (6 of 16) expressed their interest in using smart appliances because they expected that it would enable them to be more involved in the operation of the smart energy system. This was expressed by households who had received a smart appliance as well as by those who did not. [Quote 20 to 23]
Two of the households interviewed in November 2012 (Research activity O, N=5) had a smart dishwasher. Their comments indicated that the smart dishwasher operation had not changed their normal way of using the appliance. They would turn on the dishwasher at night in smart operation mode and the dishes would be done in the morning, i.e. within the 8-hour timeslot for smart operation. This differed from their normal usage in that the PowerMatcher coordinates the exact time the appliance starts operating, rather than it starting directly. The households just switch on the appliance and accept that it will switch on within the next few hours. They appeared not to have adjusted their routines and seemed to not have

experimented with what would happen at other times of the day. The two participants reported satisfaction with the way it works. [Quote 24 & 25]

The observed practice of these end users demonstrates that although they adapted their behavior to use the smart dishwasher, i.e. using the smart operation mode, their routines did not have to change and they were not consciously "playing a smart energy game". The action of another household may relate more to playing a game. The respondent indicated that, since the smart operation was not working yet, the family used the time switch on their smart dishwasher and washing machine. Another household that did not receive the smart appliances invested in a washing machine and tumble dryer with a time switch and used the time switch to do the laundry. [Quote 26 & 27]

For the cases discussed here, the planning of energy use was still based on a day- and night tariff structure. Further research with a different tariff structure should point out how use of appliances by the households is affected when the timing is less straightforward.

In addition to matching the energy demand of smart appliances to a low tariff, the households expressed a desire to use appliances to consume the electricity they were self-producing. One household for example preferred to adjust the end-time of the appliance to the predicted production of the µCHP, to delivering that production to the grid. Another household indicated willingness to set a long time span to enable optimal control via PowerMatcher, as well as interest to react to surplus electricity production to switch on an appliance. The remarks from these households indicate that in order to plan appliance usage (i.e. the co-provision aspect of shifting consumption) they need information about the current and future situation in the smart energy system. [Quote 20 & 28]

Energy Portal

The Energy Portal offered information about consumption and production for the households. The Portal was visited regularly immediately following installation of the smart home system. Over a period of a year, from February 2010 to January 2011, the 'my energy' page of the portal received approximately 1200 visits. On average this corresponds to about 23 views per week in total and 1 visit per household per week[2].

In September 2010, responses to a written questionnaire (research activity E, N=16) indicated that four respondents (out of 16) visited the website in the previous 7 days, three did so throughout the previous 7-14 days, four during the previous 15-30 days, three more than 30 days ago and one respondent never. This response indicates a big spread in how often households viewed the website. The median of the responses coincides with a last viewing of the website 15-30 days preceding the questionnaire. The main reasons for visiting the website were: to gain insight into energy consumption and production (6 of 16), to check whether the installation was working properly (3 of 16) and to see if the website's content and design had changed "to be more significant" (2 of 16). The last response suggests that the information

2 The estimate is based on web statistics for 'unique views' of the 'My Energy' section of the website over the period of February 2009 to January 2010. As the use of the website was not a priority for the research in phase 1 of the project, the access to the statistics of website visits were not made accessible at the time of writing. This information was derived from a print screen of the website that has been used in presentations. (See appendix F)

had not yet been found useful or interesting at the time.

Approximately a year later, during interviews in mid 2011 (research activity H) 7 out of 16 interviewed households indicated that they either hardly ever viewed, or had not at all viewed, the Energy Portal. The reasons given were that it did not (a) offer interesting information, (b) offer information that could support actions to achieve their energy related goals, such as energy saving or matching supply and demand, or (c) lead to new ways of interacting with the system. [Quote 30 & 31]

The end users who did visit the website on a regular basis, ranging from several times a week (3 of 16) to sometimes or once a month (6 of 16), were interested in the amounts of energy used and produced, comparing the figures to those of their own meter readings, or would access to check if the system was working. None of the participants appeared to use the Energy Portal to implement changes in their energy-related behavior. As some of the results mentioned above illustrate,, the portal did not provide an interface with actionable information.

When asked for suggestions concerning the Energy Portal, the 12 respondents (12 of 16) came up with suggestions concerning provision of information and possibilities for control and behavior. A list of 30 suggestions was extracted from the interviews and were grouped as shown in Table 16 in three main clusters:

a. **Provision of information on the portal:** *Most suggestions were given for this first cluster, i.e. the information provided on the portal. Interest was expressed in receiving more detailed energy feedback information, for example at the appliance level, and adding missing information such as gas consumption. Also suggestions were given for receiving 'feed forward' information that could steer the behavior of the end users, for example with tips and the prediction of PV production. Lastly, a desire for information that related household production and consumption to that of the overall smart energy system was indicated.*
b. **Control possibilities via the portal:** *A desire was expressed to control the home energy system via the portal, particularly the heating system. Also influence over the settings for operation of appliances based on PowerMatcher.*
c. **Communication and presentation of information:** *The thoughts on communication and presentation of information included, 'pushing' energy information to the household via e.g. weekly or monthly e-mails and a forum for exchange of information among participants. Furthermore it was suggested that the information on the portal was to be made understandable for 'non-technical persons' and the information should support them in taking action. This suggestion indicates that the Energy Portal required a background or at least interest in energy technology to be understood.*

Participants' energy-related goals

Giving the finding that end users wanted to use the Energy Portal to reach personal energy-related goals (see previous section), further discussion about the participants' energy-related goals is in place.

Before the home energy system was implemented in the households,

A. Provision of information on the portal	
Feedback	
Household level	
• Detailed information (appliance specific / per room / per square meter)	4
• Show virtual PV production	1
• Show gas consumption	3
• Provide insight in own consumption, production and delivery to grid	1
• Historical insight	2
• Comparison with other households	3
Relation to cluster/grid	
• Insight in demand and supply of the electricity grid	1
• Insight in one's contribution to the overall functioning of the smart energy system	2
Feed forward	
• Insight in and prediction of available energy	2
• 'Feed forward' on results of one's activities	1
PowerMatching information	
• Insight in the PowerMatching process in order to be able to act in line with this process (insight at cluster/grid and household level)	2
B. Control possibilities via the portal	
• Use portal to control the heating system	1
• Ability to influence the matching process (the software agents)	2
C. Communication and presentation of information	
• Receive 'pushed' information, e.g. via e-mail with information about the past week or month	1
• A discussion forum or something similar to exchange information with other participants	1
• Tips to take action, for example what are good moments to switch on the washing machine	1
• Visualization that is understandable for less technical persons	1
• Information should provide actionable information	1

Table 16: Portal suggestions by the respondents (12 of 16). The number in the last column indicates the amount of times it was mentioned.

the end users were asked about their goals concerning the energy management in their home (Research activity B). Of the 11 responses, 5 related to maintaining comfort (3x maintain comfort, 1x healthy indoor climate, 1x ease of using multimedia devices) and 6 related to energy saving and sustainable energy production (3x lower energy consumption, 1x lower resource consumption, 1x use energy consciously, 1x produce sustainable energy).

In 2011 the households were asked about their goals again in an interview (research activity H), this time more specifically about their goals in the context of PowerMatching City and whether they felt their goals had been reached. The question resulted in ambivalent answers. Over time they had gained more insight into the set-up of the smart energy system and had experienced it in practice. Their answers with respect to goals often included a personal goal and a complementary goal related to the way the smart energy system works or is intended to work. Each of the 16 respondents mentioned energy saving as a main goal, though with variations in their formulation, such as saving energy and lowering the energy bill. Other goals that were mentioned were:

- *Contribute to the matching of supply and demand in the smart energy system (6 of 16)*
- *Maintain or increase comfort levels in the home (5 of 16). Two of these respondents explicitly mentioned that their goal was to strike a balance between comfort (as high as possible) and consumption (as low as possible).*
- *Become energy neutral, i.e. overall yearly consumption and production are equal (2 of 16). One of these respondents indicated that it was not feasible within this project.*
- *Lower the energy demand from the grid (1 of 16). This respondent considered doing so via PV solar energy self-production.*
- *Contribute to decentralized electricity production as a solution for an improved power system (1 of 16).*
- *Be part of a smart energy network beyond household level (1 of 16).*
- *Continuation of the project with satisfied end users, particularly for the heat pump households (1 of 16). This respondent indicated that dissatisfaction with system operation leads to doubts about further use of the system.*

Here we should note that the mentioned goals concern the reality of the project, to what is feasible, and to what the 'ideal' situation for the end user would be. It is striking that several households indicated that the goals they intended or expected to reach were not reached. They could for example not verify whether energy saving was achieved in their household or whether it could not be achieved because of trouble with the installation. To a question about whether households had changed their energy consumption behavior (research activity N). Nine of the sixteen respondents indicated having become more conscious of their energy consumption. This response does not indicate behavioral change, though it suggests that they may have continued or intensified their existent energy saving activities. The other seven respondents indicated that no changes took place. Reasons given for not making changes included that they found no guiding information to help them adjust their behavior, that is was difficult to control the home energy system, and that the dishwasher and washing machine could not be programmed for smart operation via PowerMatcher.

Apparently, the end users' goals evolved over time as they realized what kind of goals they could and could not realize while participating in the project. As a result, goals for energy saving were pushed to the background and goals which were more specific and more closely related to the project's goals were formulated, namely to contribute to the matching of supply and demand through the installations and when possible through their own behavior. On the one hand this illustrates that these respondents have a better understanding of the possibilities of the project. On the other hand the inability of the respondents to reach their personal goals can be considered a weakness of the implemented smart energy system.

The apparent discrepancy between household goals and the smart energy system design became explicit during a simulation game session (Research Activity G, N=12). This game, which is described in appendix G, stressed the economic incentives underlying operation of PowerMatcher and did not stimulate energy saving. One team decided to prioritize energy saving over gaining victory points, because they found it unthinkable that energy saving would not be part of energy use in a smart energy system. A major part of the debriefing discussion focused on saving energy and the households' interest to contribute to a sustainable energy system, rather than the potential economic benefits of smart energy management. While economic benefits were considered important, the sustainability aspects of a smart energy system appeared to be more important for most respondents.

<u>Households' involvement in management of the energy system</u>

When the households were introduced to the home energy system in PowerMatching City, they were instructed that they would be connected in a smart energy system in which supply and demand are matched. This section addresses the extent to which the end users experienced their participation in the smart energy system.

In the interviews in 2011 (research activity H) this topic was discussed with nine of the respondents. Three of them indicated they felt as part of a smart grid because they were aware that they are connected in a smart grid, even though they could not really notice it or actively participate. Six of them stated they did not feel as part of the system. They did not experience the matching of supply and demand and mentioned that there was no information on the website about the matching or possibility to influence the system. [Quote 31 to 33]

A questionnaire in October 2012 (research activity N) yielded similar results. The majority of the households indicated that they either hardly noticed, or did not notice at all, their contribution to the matching of supply and demand in the local smart grid (14 of 16). Most respondents (11 of 16) stated they would have liked to perceive more of the matching, as it would have enabled them to be more conscious about their participation in a smart energy system and adjust their behavior to optimize the matching process. Also a desire for increased control over the matching process was indicated, as it was also expressed in the suggestions for the Energy Portal. [Quote 34 & 35]

The simulation game session (Research Activity G, N=12) addressed the interaction between households as part of energy management at the cluster level. The game showed that the electricity tariffs were influenced by the energy consumption patterns of the participants. The better the coordination between the households, the more equal the tariff distribution became over the day (see also the description in appendix G). In the debriefing after the game, the participants suggested that insight into the electricity flows at the cluster level could help them to shift their consumption timely in order to avoid peaks in tariff.

Visualization of energy flows at the cluster level and between households was already mentioned as a possible improvement of the Energy Portal (research activity H). In October 2012 this topic was discussed in more detail with five households (Research activity O). All five respondents indicated they found such insights interesting. One person would use it as background information for how the system works, while the others considered it useful as real-time information about the operation of the smart energy system at cluster level. The cluster level information was furthermore found useful when information that allowed for comparison between households was included.

Some respondents indicated they were satisfied with the current level of activity required of them as end users (2 of 16, Research activity N), stating for example that after setting the boundary conditions the home energy system should operate automatically [Quote 36 & 37]. Similar comments were made in the simulation game session (Research Activity G), where there was consensus among the group of players that automation of the matching of supply and demand was indispensible and would have to take care of the energy management at the cluster level. Insight into cluster level's energy flows and the relations between the households and the energy flows could support them in making an extra contribution to energy management in the smart energy system.

6.3.2 Co-provision in PowerMatching City from a technology perspective

In the previous section the experiences of the end users with the implemented technology in PowerMatching City were discussed. These experiences suggested that the design of the system could be improved with respect to the interaction between technology and end users. This section explores the extent to which co-provision was enabled from a technology point-of-view, thereby addressing the second research question of this study.

The system that was implemented in the households participating in PowerMatching City was described in Chapter 6. In order to analyze how this system can enable co-provision from the technology point of view, the categories of products and services presented in Chapter 2 (Table 1) were set out against the four aspects of co-provision in Table 9. These four aspects were discussed in Chapter 2 and are (1) using energy efficiently, (2) Planning or shifting electricity consumption in time, (3) Producing electricity when it is favorable for the local grid and (4) Trading self-produced surplus electricity. Which aspect of co-provision behavior is enabled for the household, automatically or through end user's behavior is indicated according to category.

Categories	Layer of the model in Figure 9	Specific technology in PowerMatching City households	Aspect of co-provision activity enabled	
			1. Using electricity efficiently	*2. Planning consumptic*
Micro-generators	Core technology	• Micro-cogeneration units (μCHP) • PV solar panels	Y – considering that the electricity generation is a by-product of gas consumption.	NA
Energy storage systems	Core technology	*Heat storage:* - Hot water storage tanks in home	(Y) - When the technology is efficient (or more efficient than a previous system)	Y - Decoup consumptic when desir energy (ele favorable (e available er PowerMatc
Smart appliances	Core technology	*Heating system* • Micro-cogeneration units • Hybrid heat pumps system (HHP) *Smart household appliance* • Dishwashers	Y - Under the assumption that these appliances are more efficient than the previous	Y - Automa
Smart/digital meters	Core technology	- Electricity meters - Gas meters In PowerMatching City the meters are only used to read out measurement data. Metering data was available for overall consumption and production as well as appliance specific (μCHP, HHP, PV)	(Y) – Indirectly, given that these devices provide information to end users in which they can take action.	(Y) – Indire devices prc PowerMatc and (2) to e consumptic
Time varying pricing	Service for energy management	None - Real time pricing (RTP) is used for operation of the PowerMatcher, but real prices were not reflected yet, nor communicated to end users.	N	N
Energy monitoring and control systems *For end user involvement*	Intermediary products and services	• Thermostat (control of temperature) • Energy portal (information on electricity consumption and production)	Y – By control over thermostat settings (Y) – When the provided information enables the end users to take action to lower electricity consumption **End user involvement with smart energy system**	N - Not pos system shi thermostat (Y) - When enables the **End user i energy sy**
Energy monitoring and control systems *Automated*	Service for energy management *	• PowerMatcher (via PowerMatching City energy services gateway)	N	Y - PowerM
Additional services	Service for facilitation an motivation of changes	• Community website	(Y) - When information / interaction on the website enables the end users to take action to lower electricity consumption **End user involvement with smart energy system**	(Y) - When on the web users to tal electricity c **End user i energy sys**

Table 17: Overview of the ways in which the Smart energy system in PowerMatching City enabled co-providing behavior. 'Y' means: supported, '(Y)': conditionally supported, 'N': Not supported, 'NA': not applicable. End user involvement with the smart energy system occurs in the shaded cells.

ıctivity enabled			
ntly	*2. Planning or shifting electricity consumption*	*3. Producing electricity when it is favorable for the local grid*	*4. Trading self-produced surplus electricity*
electricity ct of gas	NA	Y - For the μCHP only, automated via PowerMatcher	Y - For μCHP and PV, automatically via PowerMatcher
/ is than a	Y - Decouples production from consumption, so one can use heat when desired, while consuming energy (electricity or gas) when its favorable (e.g. low tariff or locally available energy), automated via PowerMatcher	Y - For the μCHP, due to the decoupling of production and consumption, automated via PowerMatcher	(Y) - When the household makes use of the feed-in premium
that these ent than	Y - Automatically via PowerMatcher	Y – only by the μCHP, automated via PowerMatcher	(Y) - When the household makes use of the feed-in premium, automatically
these on to end ake action.	(Y) – Indirectly, given that these devices provide information to (1) PowerMatcher for automatic shifting and (2) to end users to shift consumption themselves.	NA – the meters could be used to give control signals but in the system design of PowerMatching City control signals are given by the PowerMatcher via the ‘home energy computer’	(Y) – Indirectly, by providing data to PowerMatcher and/or energy supplier
	N	N	N
ıostat nformation take action nption **ith smart**	N - Not possible to set heating system shifting behavior via the thermostat (Y) - When the provided information enables the end users to take action **End user involvement with smart energy system**	N - No information is made available to enable this. Furthermore, end users cannot influence their μCHP production	N - No information available in this respect. Surplus is automatically delivered to the grid
	Y - PowerMatcher	Y - PowerMatcher	Y - Based on the automatic delivery of surplus electricity to the grid.
ıteraction e end ıer **ith smart**	(Y) - When information / interaction on the website enables the end users to take action to lower electricity consumption **End user involvement with smart energy system**	N – Only automated operation	N – Automatically

* In the definition whether the provided energy monitoring and control system is an intermediary product/service or a service for energy management, the distinction is made between whether it is an in-home product or a service provided from ‘outside’ the household respectively. For PowerMatching City it is considered a service for energy management.

When regarding the entire system by means of the 'layer model' (Figure 56 and discussed in Chapter 2), it can be observed that all layers were represented in the smart energy system design for PowerMatching City. The layer model describes the relation between products and services in a smart energy system in four layers. At the center are core technologies, which are combined with the layers of intermediary products and services, services for energy management and services for facilitation and motivation to change. In PowerMatching City the core technologies were the micro-generators, hot water storage, smart appliances and smart meters. The Energy portal was an intermediary product that provided information to end-users. The PowerMatcher with its coordination mechanism enabled the automatic control of appliances (incl. heating systems) as a service for household's energy management. The outer layer, i.e. services for facilitation and motivation to change, were not part of the initial system design for PowerMatching City. The community website could however be regarded as a product/service aimed at facilitating changes. This observation resulted in the addition of an extra row to Table 17, concerning additional services, which represent the outer layer of the layer model.

With respect to enabling the four aspects of co-provision, it can be observed from the overview in Table 9 that all aspects were in some way enabled by the implemented smart energy system. The co-provision activities in the smart energy system were mostly automated via PowerMatcher or were 'inherently automatic' to the electricity system, such as delivery of surplus electricity production to the grid. This automation concerns three aspects of co-provision: shifting, producing and trading. The enabling of efficient energy use by the energy system was dependent on efficient operation of the appliances and on end users' behavior being geared towards achieving or maintaining low energy consumption levels. The latter could be supported by the information on energy consumption and production on the Energy Portal. As discussed in the previous section, the Energy Portal did not adequately support the end users in reaching energy saving goals.
The implemented technology (product-service) enabled households to act as co-providers based on the automation of co-provision activities. The home energy system was:

- *Supposed to be) efficient,*
- *Shifting of consumption took place by control of the heating system and the dishwasher via PowerMatcher,*
- *Electricity production was made possible via PV system and μCHP,*
- *Controlled automatically via the PowerMatcher and*
- *The delivery of surplus electricity was sold to the electricity supplier via a feed-in premium.*

As the automation took care of the co-provision activities, the end user's behavior in co-provision was limited to setting the thermostat and operating the dishwasher in smart operation mode.
This confirms the initial goal of the PowerMatching City design to maintain the comfort levels of the end users. In a way, the system did not require the end users to change the way they manage their household energy consumption. Only minor changes were required in the interaction with the thermostat (manual setting for those who had a programmable thermostat)

and dishwasher (a possibly longer time before dishes are clean).
Thus from a technology point-of-view the system enabled a co-providing role of the households. End users hardly had to adjust their behavior and did not have to be involved in the matching of supply and demand. Based on information from the Energy Portal the end users could access and use information about their energy consumption and production– as long as they knew how – in order to influence the operation of the system, to, for example, lower energy consumption of the heating system by changing thermostat settings or change timing when using electrical appliances to match electricity production. End users who wanted to use the information to adjust their energy related behavior had to do so based on evaluation of past performance results provided by the feedback information on the portal.

As described in the previous section, research into the experiences of the end users showed that the technical potential the smart energy system of PowerMatching City offered as well as the feedback on the Energy portal, was not sufficient to satisfy the end users that were interested in optimizing their home energy management for a smart grid context.

6.4 Discussion and conclusion

The main question for this study was to what extent the smart grid products and services in PowerMatching City empowered the end users to become co-providers in the smart energy system. Two sub questions have been formulated concerning (a) the experiences of the end users with the use of the smart energy system and (b) the extent to which the implemented products and services enabled the four aspects of co-provision in household energy management. The findings suggest that while their house is technically equipped to contribute to the balancing of supply and demand in the smart energy system, the end users were not sufficiently enabled to take up a more active role as co-providers.

6.4.1 Main findings

The experiences that were reported by the end users indicate that the main function of the home energy system, i.e. providing space heating and hot water, was fulfilled satisfactorily, but that the interaction with the home energy system was not to the satisfaction of most end users. The available information via the Energy Portal, the thermostat and the appliances, was not sufficient for the end users to understand what was happening in the energy system. In addition to a lack of information, the end users missed a sense of control over the system to make sure that the coordination mechanism operated in line with the end user's interests. This highlights a need for trust in the provided products and services for energy management. The Energy Portal, thermostat and smart appliances did not enable such control. Also was the information on the Energy Portal insufficient as a means to evaluate a households' performance of its energy-related goals and to take actions in order to pursue them. For most households the primary goal was to save energy. During the project, several households also indicated an interest to contribute to the matching supply and demand and willingness to adjust their behavior to some extent for this goal. The desired level of involvement differs per respondent, ranging from as much automation as possible to a high level of self-control over the system's operational decisions. With respect to co-provision, the findings thus suggest that , based on the current home energy system design, although willing, the end users were not able to become involved in household energy management as co-providers.

6.4.2 Discussion of the findings

The findings of this study illustrate how the design of a system can shape the interaction between end user and technology. As discussed by Verbeek and Slob (2006), the way the interaction is shaped determines the performance of the overall system. In this study, we see that rather than facilitating certain behavior, the technology limits the end users in their ability to contribute to the system performance. In the case of this study, we see that the initial idea on how to shape the interaction between end user and system was not satisfactory to the end users. The original idea that the system should work as automated as possible was not fully supported from the end user point-of-view. Some actually tried to become involved in the management of the energy system, for instance by using the timers for the washing machine, or by switching on the washing machine when the sun shines. This process of adapting to the technology in ways that suit the end user is called domestication and can yield unexpected results as (e.g. Frissen and Van Lieshout, 2006). Frissen and Van Lieshout suggested that such a finding is an essential part in product development and promoted a Living Lab approach focusing on everyday practices to foster insights from, and by, end users for product development. With respect to PowerMatching City, we could observe such insights being used in the development towards the project's second phase.

The results of this study indicate differences between end users, both between as within the households, in interests and involvement in household energy management. It is argued that that design of home energy management systems (HEMS) are required to facilitate the needs and wishes of differences between types of end users for energy saving. This means addressing differences between households as well as taking into account differences between members of the same household (Hargreaves et al., 2010; Van Dam, 2013). Similarly, for co-provision behavior in a smart grid context, several types of HEMS will be shaped differently for end users to be facilitated in a role as co-provider.

This study builds on the assumption that end users can take up an active role in the management of supply and demand that is complementary to automated coordination. An alternative standpoint is that the system should be as much automated as possible and should avoid interference of unpredictable end user's behavior. From that perspective, the observation that co-provision was technically enabled and that the end users were satisfied with the heat provision could be a sufficient answer to state that the households are taking part in a smart grid as co-providers. The question remains how to deal with dissatisfaction concerning the insight into, and control over, the system. Even when end users prefer full automation, apparently some form of information has to be available that can provide the end users with sufficient insight and control over set boundary conditions that the system is acting in their best possible interest. Future research could provide insight into minimum required levels of insight and

control.
The relevance for practice of the findings of this study is that a design-driven (socio-technical) approach to product and development for households is important to develop successful products that are not only technically functional but also socially acceptable for those who have to use them in daily life. Furthermore, the findings provide insight for further product- and service development, for a next phase of the PowerMatching City project, but potentially also for other smart grid projects involving real households. Complementary research, both quantitative and qualitative, is required to continue building up knowledge on how to shape the interaction between end users and the technology in smart energy systems and for product and service design. Based on this study, further research is recommended with respect to:

- *Design parameters for a HEMS in a smart grid context, where home energy management includes the 4 aspects of demand response*
- *Different types of incentives in addition to economic incentives to motivate demand response by households, including social, environmental and financial incentives.*
- *How to achieve optimal smart energy system performance and end user satisfaction though a combination of automation and demand response, i.e. behavioral change, by end users.*

6.4.3 First insights from continued research in PowerMatching City

In the second phase of PowerMatching City, some of the lessons from this study have already been taken up in the further development toward services for energy management. An in-home display was developed

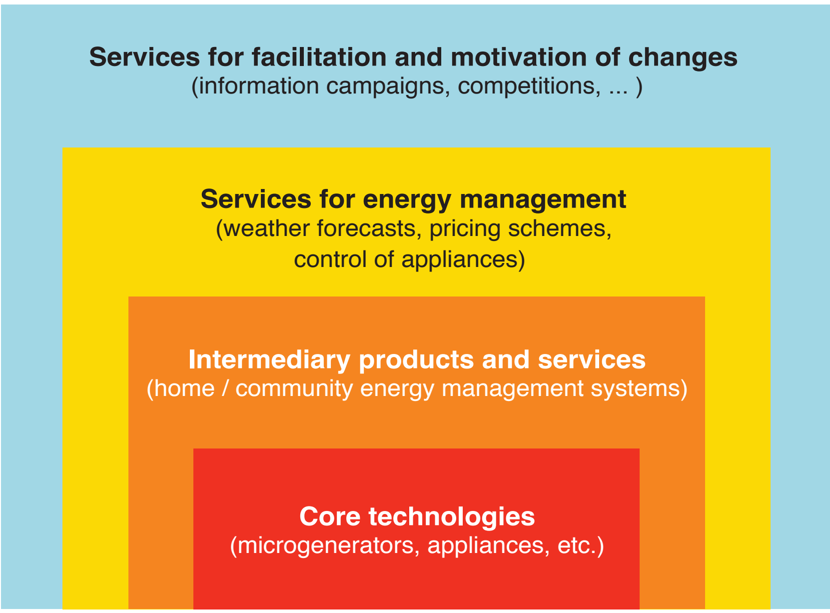


Figure 56: Layer model describing the relation between products and services making co-provision possible

and two ‘business propositions’ were implemented. The in-home display (Figure 57), was installed as an app on a tablet-pc, The propositions, or energy services as the term is used towards the end users, are (a) Together sustainable – The PowerMatcher optimizes for use of locally produced electricity and (b) Smart cost saving – The PowerMatcher optimizes for lowest costs.

The design of the in-home display was based on the metaphor of a house in a natural environment. The rooms in the house represent information about energy consumption and production in the household and show when time slots are favorable for the active proposition (low energy tariffs or locally available energy respectively). The surroundings of the house change appearance according to favorable times to consume electricity. A bright atmosphere with green pasture represents an auspicious time and a dry desert-like background indicates an inauspicious one. Energy flows moving in and out of the house indicate the energy delivery to and from the grid and the community. For example, in Figure 57 the background and indicator in the upper left room indicate a favorable time for electricity consumption. The self-production of the household at this given time is higher than the household’s needs and the surplus is delivered to the community and ‘outside’ grid. This is visualized in the color of the solar panels, the energy flows and the middle display on the right of the screen. By touching the elements of the house and the menu items on the side of the screen, users can access more detailed information. Also, they can access the community website via one of the menu items.

Research into the experiences with, and performance of, the energy display and propositions is ongoing. Informal inquiry with the involved researchers suggests that the first reactions to the energy display were positive .The new display provides for improved insight into system operation at household level. Energy consumption information appears to be used by households to save energy and predictions about tariffs while availability of locally

Figure 57: Main screen of the Energy Monitor developed for the second phase of PowerMatching City.

produced electricity help end users to plan the operation of appliances. However, end users have to take time (use a manual) to get a grip on all the available information and several end users have not (yet) expanded the effort.

The implementation of the propositions has provided insight into a need for transparency about smart energy system operation beyond household level as well as communication about how and to what extent household goals are facilitated. While end users receive feedback and predictions at the household level, PowerMatcher optimizes the smart energy system at the cluster level. This has resulted in surprising situations for end users. For example, a washing machine in a given household would switch on during 'red' high tariff times instead of 'green' low tariff times, because PowerMatcher was programmed to operate according to the overall cluster's best interest. Although for the cluster overall this may have been optimal, the end users feel disadvantaged. These first insights suggest that, the design of the interface as well as the propositions and the communication related to it, would benefit from an intuitive user interaction, transparency in system operation up to cluster level and fine-tuning of the coordination mechanism as to result in relative benefit for individual end users as well as the overall cluster of the smart energy system. The challenge here is to bring the interface and service-related feedback and feed-forward down to the essentials, while at the same time accommodating a conceptually and technically complex process of supply and demand matching to provide energy services that end users trust, can use and supports them in their personal goals.

Main results and design implications of this chapter

Main results

- *Although implemented products and services in PowerMatching City technically enabled the households for co-provision, the end users themselves lacked an ideal level of information and control to take up a more active role.*
- *Energy related goals of end users appear not to have been supported by the current home energy system, such as energy saving or shifting of consumption to contribute to smart energy system operation.*
- *End users were interested in taking up a more active role as co-providers.*
- *In order to take up a more active role as co-providers, end users need actionable energy information that allows them to evaluate and trust the performance of the system in terms of saving and shifting of consumption as well as to plan appliance operation. Information for comparison with other households and insight into cluster level energy flows is required to put one's individual household performance in context.*

Implications for product- and service design

- **Interaction design:** *The interface between end user and energy system should provide sufficient and useful insight into, and control over, the operation of the smart energy system. Different end users will require different levels of control, so tailoring of information is important.*
- **Accommodation of goals:** *End user goals may differ from the goals of a smart energy system. In order for end users to adopt and use smart energy technology, the achievement of end user goals has to be accommodated in the overall product and service design.*
- **Experiential learning by end users:** *By using a product- or service end users learn about its possibilities and limitations, which can lead to changes in how products and services are valued. Smart energy product-service combinations can use this phenomenon to gradually introduce end users to involvement as co-provider.*
- **Experiential learning by product and service providers:** *For the development of smart energy systems at the household level, 'real-life testing' with end-users in their normal living environment is recommended to learn how new products and services affects end-users in their day-to-day lives. Furthermore, involving end-users as co-designers is recommended. Product and service providers can, via the interaction with the end-users, learn about their needs, preferences and concerns. Living Lab approaches could provide useful guidelines for such a process (Bakker et al., 2010; Keyson et al., 2013; Niitamo et al., 2006).*
- **Design-driven approach:** *Lessons from this study indicate that technology development had to be complemented with a user-centered and integral design approach. Product and service development with a design-driven approach is recommended in order to devise design solutions that are successfully adopted by end users.*

7

Social interactions within the community of smart grid households

7.1 Introduction

In PowerMatching City, 22 households were connected in a smart grid. They thereby formed a distinct community, which could be considered a social network of people who interact with each other based on the common ground that connects them, in this case the use of smart energy technology in their home. This chapter addresses the third research goal posed in Chapter 4 concerning the interest in, and potential for, social interaction between the participants in the smart energy system.

Past research suggests that social influence is a powerful means to stimulate behavioral change. Throughout the innovation adoption process, which can also be considered as behavioral change, interpersonal communication with peers and experts plays an important role (Rogers, 2003). Social interaction is considered as one of several external conditions to influence behavior and as such included in an integrative model by Wilson and Dowlatabadi (2007). In light of the MOA model (Ölander and Thøgersen, 1995) discussed in Chapter 3, social interaction could provide an opportunity for behavior to occur, as we also found for the Energy Battle (Chapter 3). Additionally, it has been argued that community-based approaches can be supportive for the acceptance of behavioral changes towards pro-environmental behavior, and are recommended as part of intervention strategies (Gardner and Stern, 1996; Heiskanen et al., 2010); and for successful adoption of smart grids (Wolsink, 2011).

Based on this past research end users' interest in social interaction in PowerMatching and the way in which social interaction could be facilitated as part of the products and services for end users were explored. The underlying idea is that facilitation of social interaction could support end users in becoming more involved with energy management at the household and cluster levels. As part of this study an inventory was made of the on-going social interactions and end users' interest in social interaction. Following the inventory, a 'community website' was introduced as a means to facilitate social interaction. Section 7.2 discusses the research approach. The results for the inventory and the intervention with the community website are addressed in section 7.3. Finally section 7.4 provides a discussion of the findings and conclusion.

7.2 Research approach

The overall research goal for this chapter was introduced in the previous section: To explore the interest in, and potential for, social interactions among the participants in the smart energy system for engagement with home energy management This study is structured along the following questions to gain insight into the occurring social interactions and the interest for social interaction:

a. *What social interaction occurs within the group of participating households?*
b. *Is there an interest in more or other interaction and if so, in what form?*

To answer questions a and b, an inventory was made of the social interaction that occurred between the participating households in PowerMatching City, by means of a 'social network map' workshop (Research activity E) and semi-structured interviews (part of research activity F). Based on this inventory a complementary website for the Energy Portal with energy information was set-up and evaluated, which was structured along the following questions. Findings concerning these questions could provide insight in the challenges for implementation of a community website as a means to facilitate social interaction in a smart energy system context.

a. What are the requirements of the participants for an online interaction in addition to energy information?
b. To what extent was the implemented community website used?
c. How did the participants evaluate the community website?

For question c, a design session (research activity J) was organized in which the participants were asked to reflect on possible functionality of a complementary part to the Energy Portal that would address social interaction. Subsequently they were asked to sketch their design of this part of the website. Based on the insights from the design session and within the constraints of the project a 'community website' was built, for which research questions d and e were formulated. The resulting community website was evaluated by observing the activities on the community website (research activity K), such as the amount of views, the amount and content of posts and comments (question d). Furthermore evaluation with the end users took place (question e) in a focus group session (research activity L) about 3 months after implementation of the 'community website', and as part of semi-structured interviews at the end of the intervention in November 2012 (research activity O). In the next section the research methods are addressed in more detail as part of the presentation of results.

7.3 Results

7.3.1 Inventory of social interactions

To get a picture the social interactions between the participants in PowerMatching City, a map was drawn during a participant meeting. Each attending participant indicated his or her contacts with other households in the cluster. The results of this social network map workshop indicated little contact between the participants in PowerMatching City outside the general project meetings. Figure 58 depicts these contacts with the solid lines. Most of the participants indicated to have had contact with one participant who also was a technician at DNV KEMA and who worked on the design, installation and maintenance of the systems (6 of 9 participants in the workshop). Other connections related to knowing each other from work, the street they lived in, a local volunteer project, meeting on the street or attending the meetings of a PowerMatching City 'co-design group' of PowerMatching City.

The interviews complemented the findings of the social network map discussion and included response of more participants (N=16). These responses are presented with dotted lines in Figure 58. Fourteen households indicated that contact occurred outside the general PowerMatching City project meetings. Five participants reported to have regular contact with neighbors, four have a relationship through their work, four met by coincidence in a shop, for example, and one household was acquainted with another participating household. The contacts were about experiences with the installations, concerning (a) general exchange of experiences, (b) the discussion of problems and (c) comparison of energy consumption levels. The reasons for getting into contact were mostly failure of the installations or doubts about its proper functioning. The households contacted the people they knew, a neighbor or colleague, with the same installation. [Quote 1 to 4]

The interviews also addressed the respondents' interest in more social interaction between participants. Out of the 16 respondents, six showed interest in more interactions and 4 were ambivalent in their answer. The households that were ambivalent in their answer indicated that some interaction could be useful, but at the same time doubted it could be facilitated in a useful way. Three of these households were interested in comparative information on energy consumption, as a means to benchmark one's own consumption. The fourth was interested in other households' experiences with the operation of the installations rather than in specific household energy consumption because of its difficulty to compare different living conditions.

Seven respondents (7 of 16) made a suggestion on how they wanted social interaction to take shape. Three of them indicated a preference for online interactions, for instance connected to the existing Energy Portal, three wanted their online interactions to be combined with periodic meetings, three to four times a year, and two respondents had a preference for just meetings. In summary, there appeared to be an interest for online social interactions in addition to the website of the Energy Portal and the meetings that had been organized. The exchanges were to consist of sharing experiences, questions and answers or tips on household energy management and the use or settings of the installations in order to improve their performance in, for example, energy saving. Comparison to other households' energy consumption was indicated as useful in starting discussion, while at the same time the households recognized that each household's situation is unique. Connecting with households with the same installation, HHP or μCHP, was considered relevant for useful exchange of information.

Some of the respondents (4 of 16) had been part of a 'design group' that had met in workshops to discuss the user interface of the home energy system (research activity B). These meetings were highly appreciated because they provided an opportunity to share experiences as well as contribute to the project's evaluation and development.

When asked whether the respondents discussed their energy consumption with others, 12 respondents (12 of 16) stated that they talked about their energy consumption levels or the appliances and installations with other people. This could be neighbors, family, friends and colleagues. They exchanged information about energy consumption levels and household energy management, such as thermostat settings and insulation to save energy. Also they told others about the installations that were implemented for PowerMatching City, anytime the subject of energy use came up. The interactions could be general (small) talk or detailed discussions. Two respondents indicated not having discussed this topic with others and two respondents did not answer this question. [Quote 5 to 10]

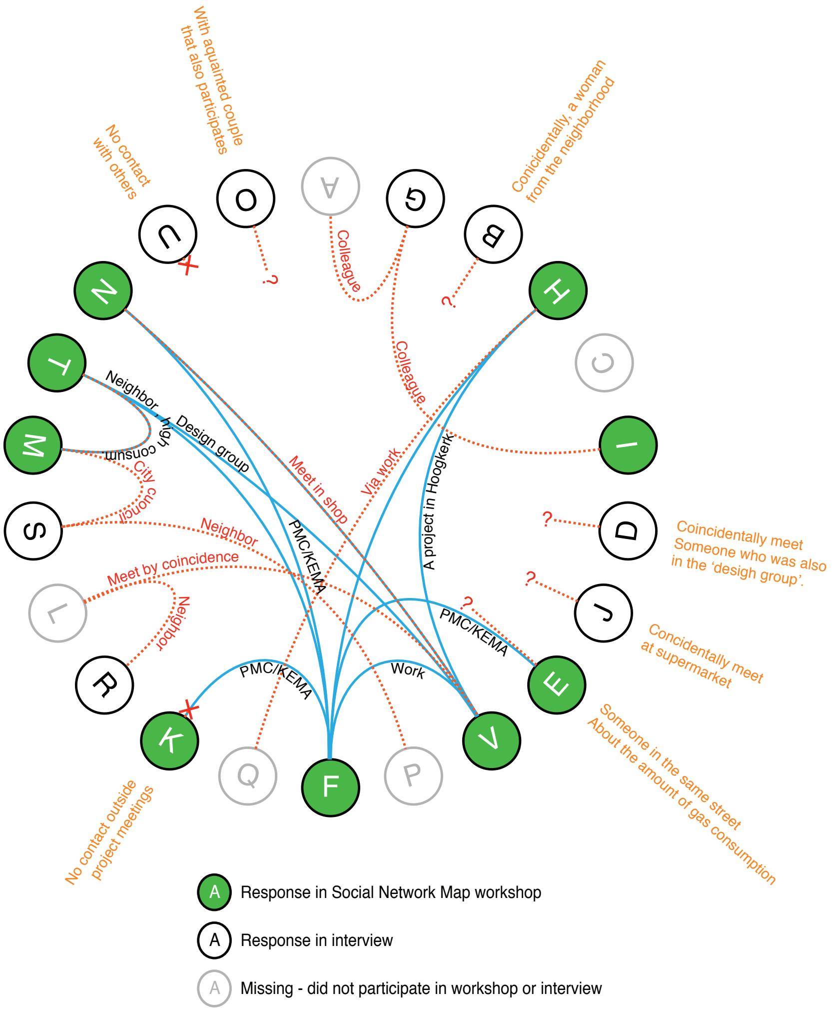


Figure 58: Schematic of social interactions in the PowerMatching City community based on results from a social network discussion (solid lines) and semi-structured interviews (dotted lines).

7.3.2 Community website development & implementation

Based on the responses from the exploratory inventory, discussed in the previous section, a community website was designed and implemented to complement the Energy Portal. Considering the interest in social interaction in PowerMatching City and expressions of interest from households to use a website for communication, it was decided to explore how an online platform for social interaction would be valued. The set-up and results of a co-design session are discussed hereafter, as well as the considerations for the subsequent development and implementation of the community website.

Design suggestions by the end users

In the development process of the community website the end users were consulted in a co-design session (research activity J). This design session specifically focused on the social interaction that could become part of the user portal. Approximately 15 persons participated, who worked together in three groups.
The starting point for the session was a mindmap with a first proposal for the content of the website by the author (Figure 59). Participants

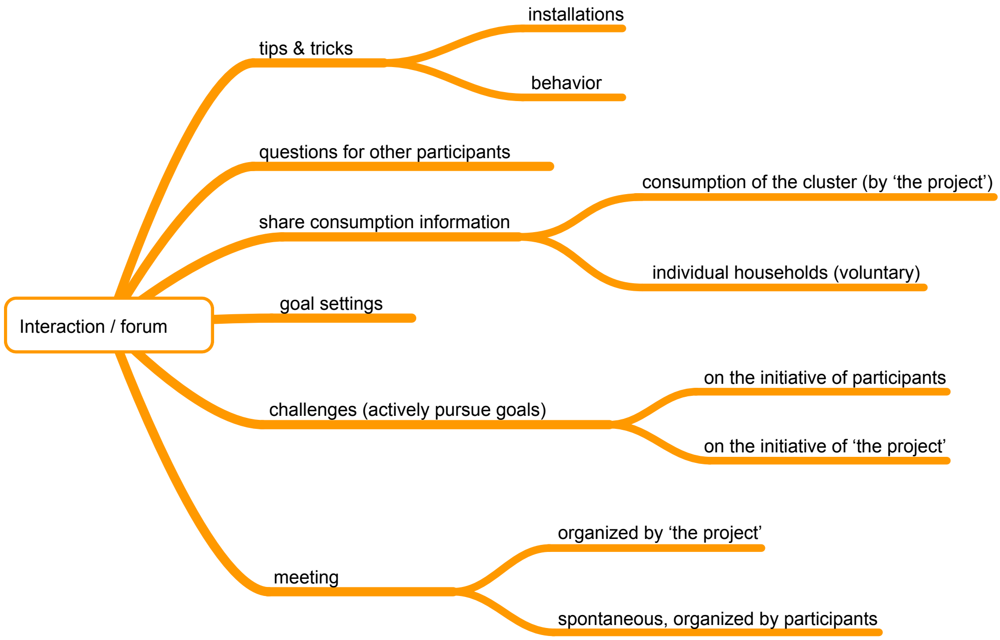


Figure 59: Mindmap that formed the starting point for the co-design session about the community website (translated from Dutch).

were asked to discuss the mindmap and indicate what they considered a ‘must have’, a ‘wish’ or ‘not wanted’ for the community website. They were also invited to add their ideas and suggestions to the overview. The mindmaps with comments are included in Appendix H. The comments on the mindmaps indicated what the groups found important and also provided specification of website elements based on the groups’ ideas. For example, group 1 suggested that the sharing of individual households’ energy consumption was to be presented relative to the other households. The responses differed too widely according to the group to summarize them all in a single vision. It was however clear that sharing and comparing energy consumption data were considered a ‘must’ and the possibility to ask questions to other participants was described as ‘desirable’. There also appears to have been consensus about meeting invites sent via an online platform in combination with e-mail notification.

Based on the discussion about the mindmap, the groups made designs for the community website and finally presented them to each other. In total four designs were created, as one group split up in subgroups to work out their ideas. Figure 60 depicts two of the resulting designs. In Appendix H all four designs are presented. The drawings represent ideas for both content and format of the community website hosted by the user portal.
In the design drawings the participants have not limited themselves to a ‘community section’ of the website, but have placed community interaction in the broader context of the existing project website and Energy Portal. The participants were thus also making suggestions for the then available Energy Portal. The main ideas of the participants were to include social interaction in an online website based on (a) comparison of energy consumption and (b) exchange of questions, tips & tricks. Furthermore, suggestions were given for the visualization of energy consumption and project communication. For the visualization of energy consumption they suggested for example to add costs and gas consumption to the currently available electricity in kWh

(E.g. in the left side drawing in Figure 60), as well as to provide historical information. With respect to project communication, information about the project and implemented technologies was suggested as well as updates and news concerning project progress and maintenance.

Based on the results from this design session, the main elements for a PowerMatching City website including social interaction could be extracted and clustered into four areas:

- *General project information about: the project, the installations and maintenance*
- *Active communication by the project organization to and with the participants*
- *Communication between the participants*
- *Information for insight into energy consumption and production*

Figure 61 provides an overview of the areas. The grey areas indicate how the online platform that was available at the time of the design session was related to these areas. The community interaction is most directly related to communication between participants and between the project organization and the participants.

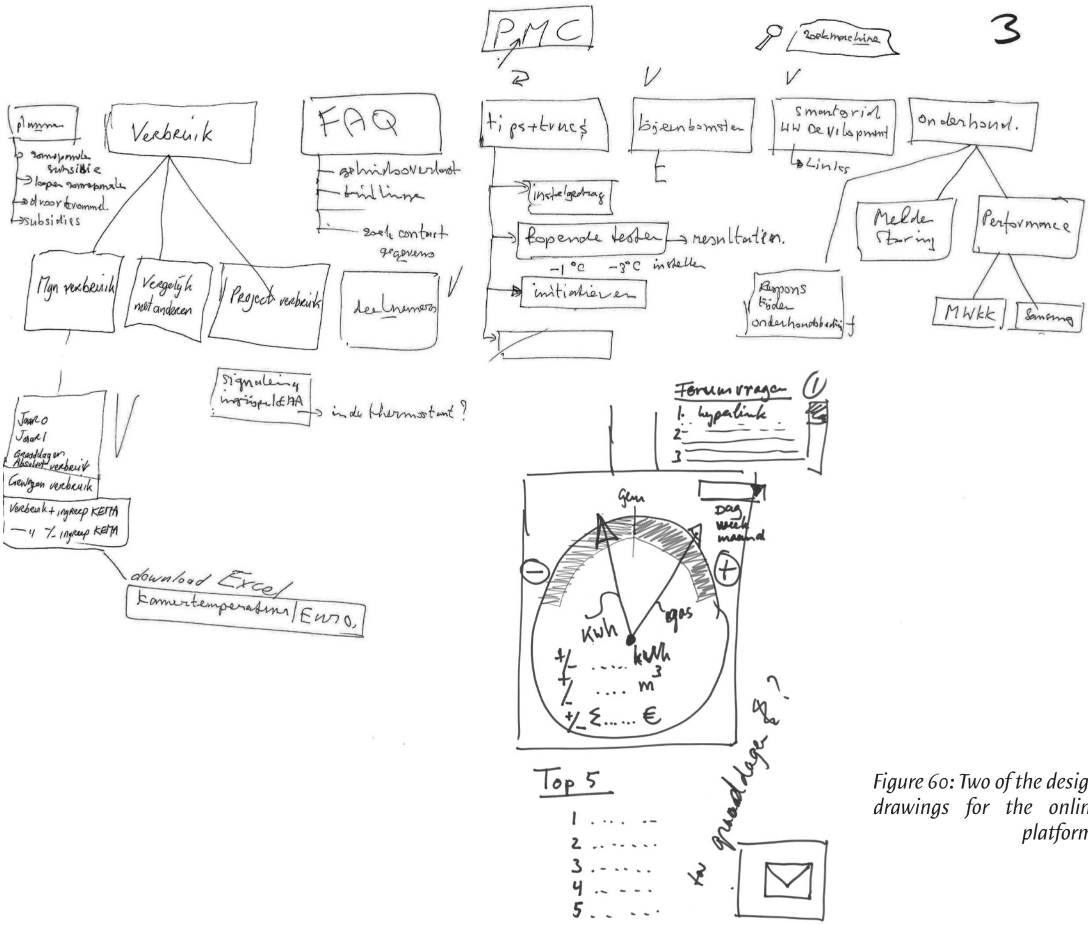


Figure 60: Two of the design drawings for the online platform.

In addition to the suggestions for content, practical issues were mentioned such as a direct e-mail hyperlink to facilitate contact with the project organization and a requirement to log-on to safeguard personal information on the website. With respect to the energy consumption and production information, an option to download information was suggested.

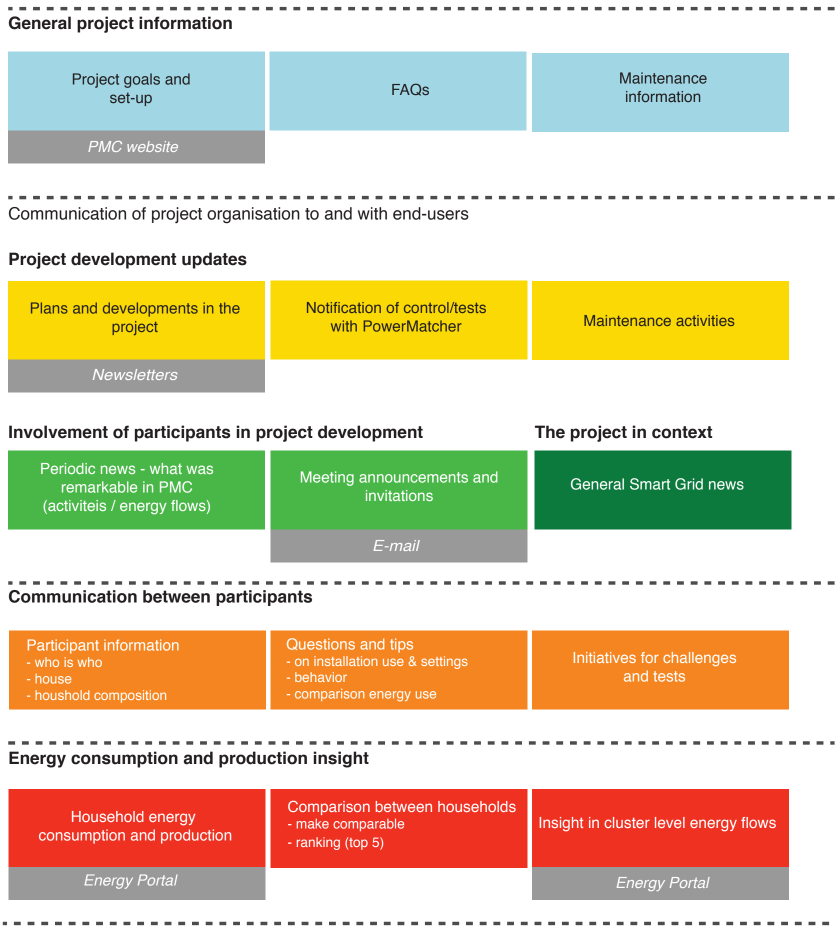


Figure 61: Common aspects for design of the interaction & information on the community website.

Design of the community website

The ideas were translated into the actual website within constraints of both time and resources[1]. It was decided that the facilitation of social interaction would focus on reciprocal questions among participants and access to participant's profiles. Because of its basic function as a weblog where people can start discussions, an existing platform was chosen for the website, namely Wordpress[2]. It was possible to make the website private by restricting access to only the participants and selected project members. Additionally, this platform provided the possibility to make a

1 Initially the design was intended to become part of an improved user portal. The development of this portal was however delayed. Due to time constraints for the execution of this study, the community interaction was set-up as a separate website that could be used complementarily to the existing user portal.

2 www.wordpress.com

customized website design and its user interface is relatively user-friendly and transparent. Possible limitations to the utilization of this community website based on an existing platform were:

- *Lack of integration with the energy portal. The community website was set-up as a separate website, since a renewed design of the Energy Portal was delayed.*
- *The participants had to register themselves for the website and for an e-mail service to receive a notice when new posts were published.*
- *Despite a relatively user friendly interface, those not very familiar with internet and particularly interactive media, may encounter difficulty when using the website. Guidelines were to be provided.*
- *The website was launched in a project meeting in April 2013. About twelve households attended this meeting.*
- *Community website*

The community website was designed as a main page with four tabs represented in the top menu, as depicted in Figure 62. The tabs connected to the following pages:

- *A home page with recent posts. This page updated whenever new posts were published.*
- *Project news page. This page displayed the entries posted within the category 'project news'. Whenever new posts were published this page updated. The purpose of this page was to display posts relating to developments in the project. Participants page. This page displays posts categorized as 'about participants'. The idea behind this page was that the participants could introduce themselves. Because made up of posts, the page was updated as new posts were published.*

Figure 62: Screenshot of Community Portal, with the welcome message (first post.

- *A page 'about this website'. This was a static page providing a general description of the website's goals, general rules for website usage and a list of the project team members who could access the website.*

Figure 63: Screenshot of Community portal, with an 'Energy report' as last post. The post includes a hyperlink to access the detailed Energy Report. The graph represents the fluctuations in electricity consumption and production during a day.

On the right side of the screen, see Figure 62 and Figure 63, the website provided hyperlinks to the Energy Portal and to the general PowerMatching City website, so that these could be reached relatively easy. Below the hyperlinks there is a categories menu. A click on one of the menu items, for example Tips & Tricks, would result in a selection of posts in that category.

Posts could be written by any end user who has access to the website. When they wrote a post, one or more categories related to the post could be selected. End users who wanted to react to a post could add a 'comment', which would be displayed on the website along with the post, see Figure 64. In this way discussion was enabled.

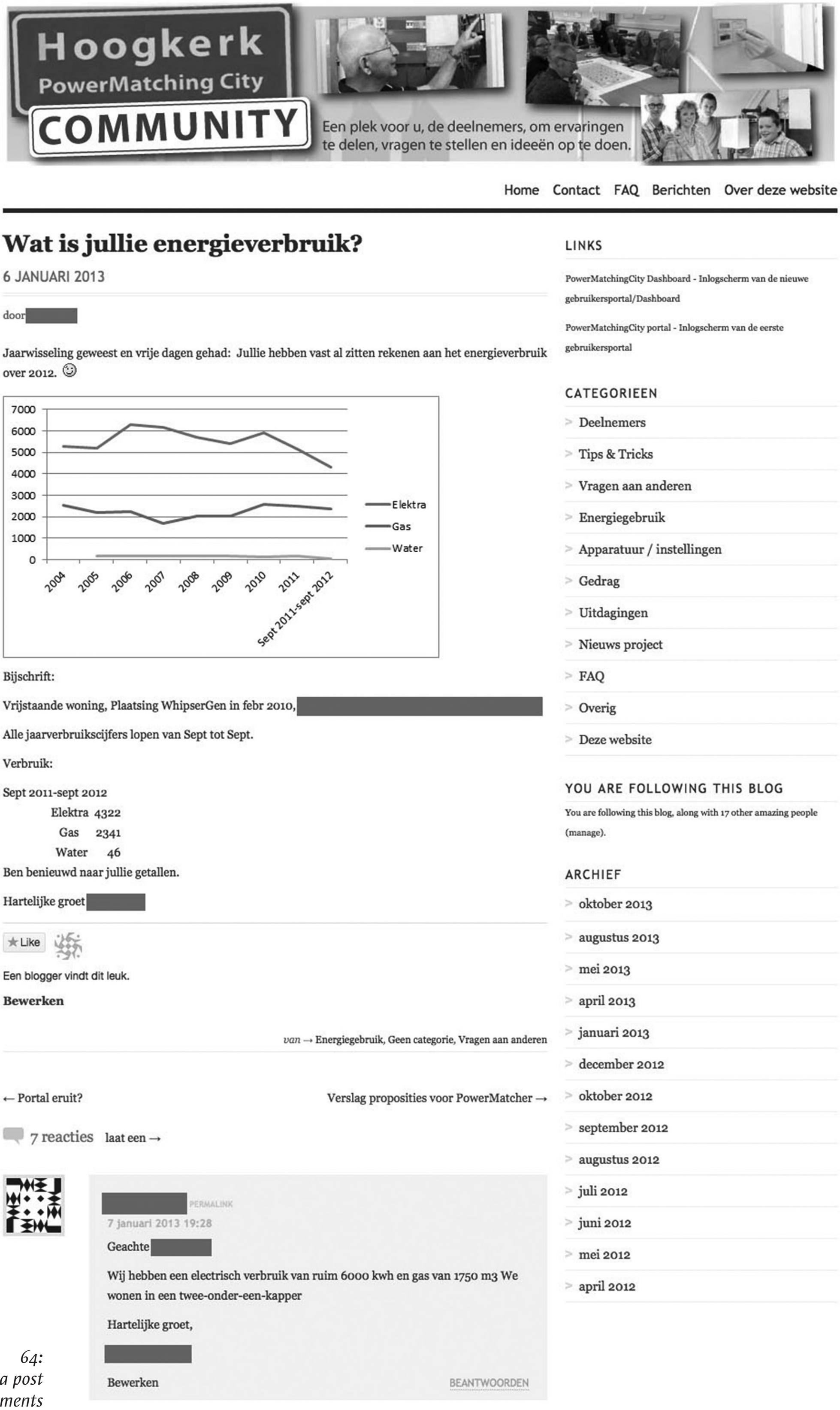
Energy reports

In order to provide community level energy information as well as an incentive to visit the community website, weekly reports were generated about the community's energy balance, i.e. the cluster of households, and published on the community website. The reports were compiled based on an analysis of weekly consumption and production data from PowerMatching City (see also Chapter 5). The reports evolved over time, from a text based short report directly in the post, to a more graphical layout with information specified for the two groups of households, HHP and μCHP respectively. The graphic representation of the data remained similar to the way the information was presented on the Energy Portal, with bar graphs and similar use of colors, so that end users could compare household level information with cluster level information. Figure 63 and Figure 65 provide examples. The Energy Reports are described in more detail in Appendix K.

7.3.3 The community website in practice

Activities by end users

During a period of 9 months, from the website introduction on April 11th 2012 to January 31st 2013, there were 54 posts and 41 comments in total. Seventeen of these posts were written by eight of the end users. Those end users also commented on posts. Furthermore, three end-users with access to the website did not write posts, but did enter comments. In total, sixteen of the participants were able to log into the website. Most of the messages that were posted related to (a) requests for information or a manual (3 posts), (b) sharing of experiences, mostly related to a technical problem and how it was solved (3 posts) and (c) sharing of energy consumption and production information (3 posts), including an offer to help others make an overview of past years with degree days for making yearly consumption levels comparable. Furthermore the households introduced themselves, two of them via a post and three others via a comment to a post in which households were asked to introduce themselves. Other posts included news about PowerMatching City in the media, information about a new product to follow one's own PV production, a general remark on smart grids and a spontaneous report of a project meeting. In appendix I an overview is given of the posts by the end users and the amount of comments to the posts. An overview of all posts and page views is provided in appendix J.



Hoogkerk PowerMatching City COMMUNITY

Een plek voor u, de deelnemers, om ervaringen te delen, vragen te stellen en ideeën op te doen.

Home Contact FAQ Berichten Over deze website

Wat is jullie energieverbruik?

6 JANUARI 2013

door [redacted]

Jaarwisseling geweest en vrije dagen gehad: Jullie hebben vast al zitten rekenen aan het energieverbruik over 2012. ☺

Bijschrift:

Vrijstaande woning, Plaatsing WhipserGen in febr 2010, [redacted]

Alle jaarverbruikscijfers lopen van Sept tot Sept.

Verbruik:

Sept 2011-sept 2012

Elektra	4322
Gas	2341
Water	46

Ben benieuwd naar jullie getallen.

Hartelijke groet [redacted]

★Like

Een blogger vindt dit leuk.

Bewerken

van → Energiegebruik, Geen categorie, Vragen aan anderen

← Portal eruit? Verslag proposities voor PowerMatcher →

7 reacties laat een →

[redacted] PERMALINK

7 januari 2013 19:28

Geachte [redacted]

Wij hebben een electrisch verbruik van ruim 6000 kwh en gas van 1750 m3 We wonen in een twee-onder-een-kapper

Hartelijke groet,

[redacted]

Bewerken BEANTWOORDEN

LINKS

PowerMatchingCity Dashboard - Inlogscherm van de nieuwe gebruikersportal/Dashboard

PowerMatchingCity portal - Inlogscherm van de eerste gebruikersportal

CATEGORIEEN

- Deelnemers
- Tips & Tricks
- Vragen aan anderen
- Energiegebruik
- Apparatuur / instellingen
- Gedrag
- Uitdagingen
- Nieuws project
- FAQ
- Overig
- Deze website

YOU ARE FOLLOWING THIS BLOG

You are following this blog, along with 17 other amazing people (manage).

ARCHIEF

- oktober 2013
- augustus 2013
- mei 2013
- april 2013
- januari 2013
- december 2012
- oktober 2012
- september 2012
- augustus 2012
- juli 2012
- juni 2012
- mei 2012
- april 2012

Figure 64: Example of a post with comments

Energiebericht week 34

Publicatie 31/08/2012

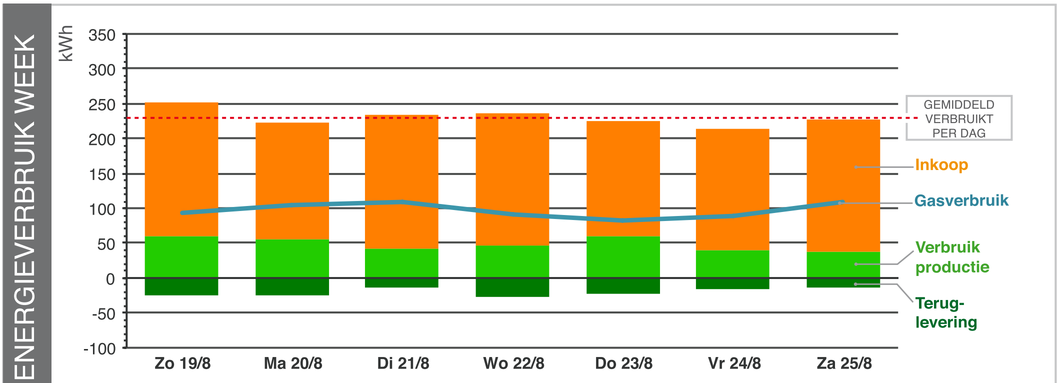
19 t/m 25 augustus 2012

Deze week was vergelijkbaar met de week ervoor. U verbruikte voor een groot deel uw eigen opgewekte zonne-energie. Uw wekte iets minder op en verbruikte juist iets meer. Voor de zondag, waarvoor we een overzicht van de dag maakten is goed te zien dat u overdag ook grotendeels die opgewekte energie benut.

In dit bericht vind u een overzicht van de PMC community als geheel, incl. dagverloop (pag. 1 - 3), een specificatie voor de huizen met micro-WKK (pag. 4 - 6) en een specificatie voor de huizen met warmtepomp (pag. 7 - 9).

Hebt u vragen, opmerkingen, suggesties?
We horen ze graag via de community website: powermatchingcity.wordpress.com,
of een e-mail naar Powermatchingcity.GCS@dnvkema.com.

COMMUNITY OVERZICHT

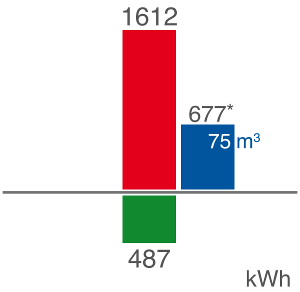


[o.b.v. meetgegevens elektriciteit van 19 huizen en meetgegevens gasverbruik van 10 huizen geëxtrapoleerd]

Verbruik vs productie

De verhouding tussen energieverbruik en productie in de huizen in PMC.

TOTAAL VERBRUIK



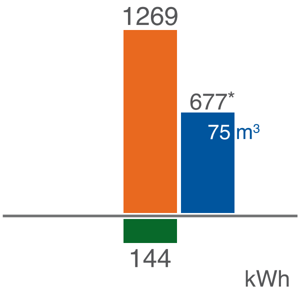
PRODUCTIE

De productie was 30% van het totale elektriciteitsverbruik. Vorige week was dat 43%. Het gasverbruik, 677 kWh, was ook ongeveer 30% van het totaalverbruik, net als vorige week.

Inkoop vs teruglevering

De verhouding tussen wat u in PMC hebt ingekocht en wat u hebt teruggeleverd.

INKOOP



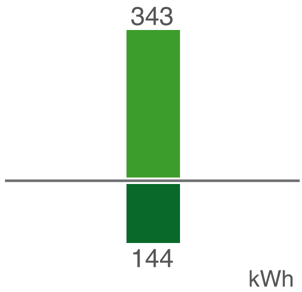
TERUGLEVERING

De hoeveelheid teruggeleverde energie was 144 kWh, 11%.van wat was ingekocht. Dat is de helft van vorige week (20%).

Verbruik eigen productie

De hoeveelheden van de in PMC geproduceerde energie die u zelf verbruikt en teruggeleverd hebt.

VERBRUIK EIGEN PRODUCTIE



TERUGLEVERING

Het grootste gedeelte van de geproduceerde energie hebt u deze week zelf verbruikt, 70 %. Dat is vergelijkbaar met vorige week (68%).

* Het gasverbruik is omgerekend naar kilowatturen. 1 m3 gas komt overeen met 8,972 kWh. Dit gasverbruik is alleen het gasverbruik van het verwarmingssysteem, dus verbruikt door micro-WKK en/of aanvullende CV ketel. Het gasverbruik is gemeten voor 10 huizen en geëxtrapoleerd voor een schatting van de gehele groep. Specificatie naar de groepen met micro-WKK en warmtepomp is (nog) niet mogelijk.

TOTAAL 70 kWh 10 — Hoeveelheid per week / Hoeveelheid per dag

VERBRUIK
Elektriciteit

COMMUNITY

TOTAAL ELEKTRICITEIT
1612 kWh 230
[o.b.v. 19 huizen, waarvan gegevens beschikbaar zijn]

TOTAAL GAS
677 kWh 97
[o.b.v. meetgegevens 10 huizen, geëxtrapoleerd naar 19 huizen]

WARMTEPOMP
85 kWh 12
[o.b.v. 12 huizen met warmtepomp]

PER HUIS

TOTAAL ELEKTRICITEIT

HOOGSTE VERBRUIK: 130 kWh 19

GEMIDDELD VERBRUIK: 85 kWh 12

LAAGSTE VERBRUIK: 13 kWh 1,9

WARMTEPOMP
7,1 kWh 1,0

TOTAAL GAS
36 kWh 5,1

Kijkend naar het gemiddelde verbruik per huishouden zijn zowel elektriciteit als gasverbruik zo goed als gelijk ten opzichte van vorige week. Dat geldt ook voor het verbruik van de warmtepompen.
Deze week waren er weer 19 in plaats van 21 huishoudens waarvan er voldoende meetgegevens waren voor dit energiebericht.

PRODUCTIE

COMMUNITY - TOTALEN

TOTAAL
487 kWh 70
[o.b.v. 19 huizen, waarvan gegevens beschikbaar zijn]

micro-WKK
25 kWh 3,6
[o.b.v. 7 huizen met mWKK]

EIGEN ZONNEPANELEN
135 kWh 19
[o.b.v. 4 huizen met eigen panelen]

VIRTUELE ZONNEPANELEN
327 kWh 47
[o.b.v. 19 huizen]

PER HUIS - GEMIDDELDEN

micro-WKK
3,2 kWh 0,5
[o.b.v. 7 huizen met mWKK]

EIGEN ZONNEPANELEN
34 kWh 4,8
[o.b.v. 4 huizen met eigen panelen]

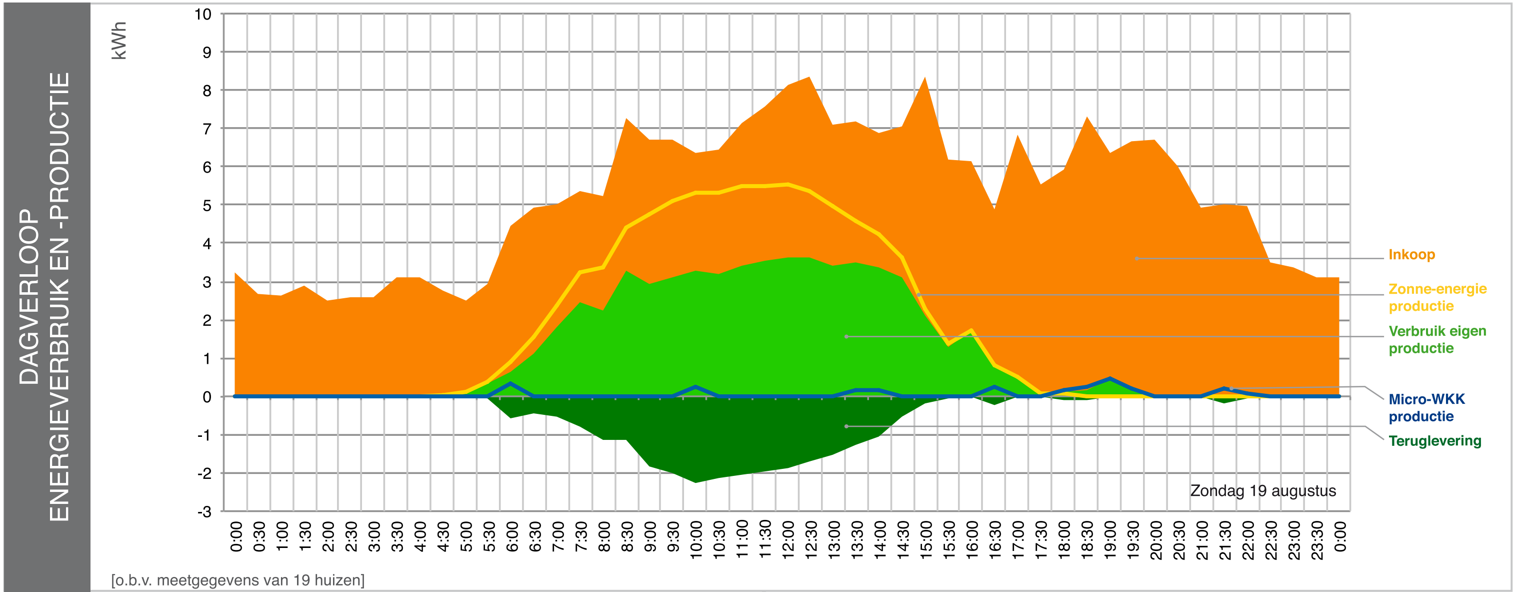
VIRTUELE ZONNEPANELEN
17 kWh 2,5
[o.b.v. 19 huizen]

Kijkend naar de gemiddelden per huis, is te zien dat er minder zonnige dagen zijn. Er werd namelijk weer minder zonne-energie geproduceerd. De productie door de micro-WKKs was iets lager dan vorige week.

POWER MATCHING CITY

DAGVERLOOP TOTAAL COMMUNITY

Zondag 19 augustus



Deze grafiek geeft het verloop over de dag aan van energieverbruik en opwekking.
De waarden zijn op basis van het energieverbruik van een half uur, in kilowatturen.

Deze zondag waarvan het energiegebruik in de grafiek hierboven staat was weer een prachtige dag. Dat is te zien in de zonne-enegieproductie. De productie bleef wel een stuk onder het verbruik. Een van de huizen met eigen zonnepanelen is niet meegenomen in de grafiek. Daarom is de totaalproductie wat lager dan vorige week.
Qua energieverbruik is te zien dat het meeste van de opgewekte energie door uzelf is verbruikt. Verder was het verbruik overdag het hoogst wanneer ook de zonnepanelen het meest opleveren.
Het patron is vergelijkbaar met vorige week. Het energieverbruik neemt vanaf ca. 6 uur ‘s ochtends toe. Tegen het eind van de middag zit er een lichte ‘dip’ in het verbruik en om 23.30 uur lijkt iedereen weer te slapen. Zullen er mensen zijn geweest die omdat de zon scheen ook hun (af)wasmachine of andere grote energieverbruiker aangezet hebben? Gezien het aanhoudende zomerweer gebruikt u weinig warmte en produceerden de micro-WKKs niet veel. De energie die ze produceerden werd terugeleverd aan het net. Waarschijnlijk kregen ze daar een goede prijs voor en besloot de energiecomputer de mWKK in te schakelen.

Over deze grafiek:
In deze grafiek staat energieverbruik en -productie van één dag weergegeven, de zondag van de week. Het gaat om totalen van de Power Matching City community in kilowatturen (kWh) per half uur. Naast de bekende elementen van de weekoverzichten (in oranje, lichtgroen en donkergroen), zijn er twee extra lijnen. De gele lijn geeft aan wat de productie van de zonnepanelen (virtuele + eigen panelen) was, de blauwe lijn de productie van de micro-WKKs. Opgeteld geven ‘Verbruik eigen productie’ en ‘Inkoop’ het totaalverbruik op een bepaalde tijd aan.

Energiebericht - Power Matching City community

pag. 3 van 9

Figure 65: The first thee pages of an energy report, which describe the performance of the cluster as a whole.

Evaluation with end users

Evaluation in a focus group in June 2013 (research activity L, 7 respondents) and interviews in October 2013 (research activity O, 5 respondents), indicated that although the idea of a community website for sharing and comparing information was found interesting, the respondents lacked incentives to use the community website to post messages.

At the time of the focus group, the website had been online for almost three months. During the focus group it was suggested that e-mail would be sent when new messages are posted. Apparently, the option to 'follow' the website updates through e-mail notices had not been seen by the participants, despite a prominent location on the website and earlier suggestions in a manual about the website. Also two participants suggested they themselves put some effort in the community website to make it more interesting for them. After the meeting, more activity on the website followed by these attendees.

With respect to the Energy Reports, it was indicated that differentiation between the μCHP and the HHP group would be useful to compare their performance to that of other households with the same system. Also a differentiation between the sources of electricity production was suggested, i.e. production by the PV solar system and the μCHP. After the focus group, the Energy Reports were adjusted to include a differentiation between HHP and μCHP households and for different sources of electricity production.

Four interviews in October, seven months after introduction of the community website, allowed for a more detailed discussion of the Community Website. All of the households had access to the website and had written a post or comment. One of the interviews was with a couple, of which one person was interested in online interaction, while the other person indicated a preference for in person meetings.

Two respondents indicated that they were very interested in using the website and intended to actively contribute to it. In practice however this did not happen. They indicated that they eventually forgot. One of them thought about sharing information and news, the other wondered about what to write about since he did not really feel as being part of a network and he would have had to be actively involved in the operation of the smart energy system. [Quote 11 &12] The two other participants did not express particular interest or disinterest in using the website. Both had viewed the website regularly in the beginning. One of them had taken initiative by posting, and responding to, messages, especially following the focus group during which he suggested the participants be more active.

The interviews confirmed what was suggested during the focus group, that despite the participants' interest, there was insufficient incentive to be active on the community website. Reasons given for the lack of incentive were:

- *There was little activity on the website and in the project (4 of the respondents),*
- *The website was separate from the Energy Portal and project e-mails with newsletters and meeting invitations (3 respondents),*
- *The posts or other available information were not relevant for the participants (2 respondents),*

* *The group of participants was not considered a community (2 respondents), with a clear common goal (1 respondent); neither did they all live close together or know each other well (1 respondent),*
* *When the system was operating well, you did not notice it and you were not urged to actively think about the project (1 respondent).*
* *Suggestions given for how the community website could be more useful included:*
* *Integrating energy consumption and production feedback, project communication (incl. tips and background information) and community interaction into one platform.*
* *Enabling comparison with other households or average consumption and production*

7.4 Discussion and conclusion

The goal of the study discussed in this chapter was twofold. Firstly to explore the occurrence of, and interest in, social interaction among the households in the smart energy system and secondly to evaluate how online social interaction could take shape in the community of households.

With respect to the first goal, the findings of this study indicate that most of the households had contact with other participants within PowerMatching City. About half of the households were also interested in more social interaction within the context of the project. This interaction could take place online as well as in meetings. They were interested in exchanging experiences and exchanging information concerning energy consumption and production. The latter could support them in improving their performance, for example in energy saving.

With respect to the second goal, the evaluation of how online social interaction could take shape; the findings suggest that indeed there was an interest in online social interaction. In practice however the available community website was not used a lot. Evaluations carried out with the households suggest that usefulness of the website was compromised by the way in which it was integrated in the project. For example, the Energy Portal and the community site were separate websites, which inhibited a direct reaction to lets say an observed peak in energy consumption on the Energy Portal. Furthermore, end users did not use the Energy Portal a lot (see Chapter 6), so they were not involved in household management via the Energy Portal.

Not only the design, but also the project's overall set-up may have played a role in the success of the community website. As mentioned by some end users, the households neither lived closely to each other nor were they a community with shared goals. Initially, the project did not actively facilitate introductions or experiences and goals sharing between households. To start community building based on this status quo would require more effort than the implementation of the community website together with some minor changes in communication.

In the second phase of PowerMatching City the community website was maintained and furthermore used as a means for project communication. A project team member in charge of communication with the end users took over moderation of the website. Furthermore the community website was integrated in the new version of the Energy Portal as one of the menu items. Full integration was not possible due to software incompatibility, so the user was redirected to the existent community website via a hyperlink. Project information was added to the website in the form of FAQs, regular news updates were posted and a software update allowed for automatic e-mail notifications about website activities (rather than end users having to opt-in to 'follow' the website).

Based on informal inquiry with the involved researchers and project team members, it appears that interest in communication via a community website was still active, but the use remained limited to a core group that looked at the website and writes posts or comments. About half of the participants appear not to have actively accessed the website. The format of the website and the separate sign-in appear to remain a barrier as possibly does the lack of triggers observed in the first phase. Participants who joined the project in phase 2 and live in the same street also indicated that it's just as easy for them to walk to one of the neighbors.

The practical relevance of the findings is that insight was gained into the possibilities as well as difficulties for implementation of a platform for social interaction in a smart grid community. As mentioned in section 6.4.2, by having people try out and experience a new idea, they are able to respond with ideas for its usefulness and suggestions for further development. This study is a case in which such first exploration took place. Although it concerns a specific group of participants (see also Chapter 4), the study illustrated that besides the characteristics of a community, the overall organization for implementation of a smart energy system plays a role in its possibilities and success.

The challenge in facilitating social interaction in the PowerMatching City community was that the community was geographically dispersed and that there was not an explicit common goal for the households to achieve, other than to participate in the pilot project. Initially the project had not been geared towards end users getting to know and interact with each other. Based on this study, we suggest that for a community website to be effective, the participants first have to get to know each other and each others' goals concerning participation in the project and/or home energy management so as to establish common goals. Once in place, the means of interaction have to be sufficiently accessible and easy to use. Also presence (prompts/triggers) of the website is important, for example via e-mails for new posts or integration of the community platform in the energy monitor. Most of all there have to be incentives to join in a conversation, such as project developments that trigger comments or community members or moderators that start discussions. Another basis for interaction could be information on the joint performance of the community, for example with insights into the community energy flows and balance and with comparative feedback information so that households can relate their own household's energy consumption and production with that of other community members.

A second lesson for practice is that an online platform such as the community website can be a useful and interactive means for communication to, with and between project participants. This can enable a project team to be close to what happens at the user side, as well as to be involved in a process of co-design. Care should be taken to how it is set up, as illustrated in this study. Moderation of the interactions is also very important. In the fields of product design and service development this approach may have become

already common. In the area of electrical engineering it still is new.
To complement insights from the PowerMatching City context, further research and development is required in smart energy systems with a different set-up and which include social context from the start, to understand under what circumstances and in what form social interaction can provide a context for end users in a smart energy system that can support end users in a positive contribution to energy management in smart grid communities.

Main results and design implications of this chapter

Main results

- *Several participants interacted with each other about the performance of their home energy systems and problems that arose. They shared experiences and compared performance. These contacts were mostly with people they already knew such as a neighbor or a colleague and not based on acquaintance through the project.*
- *Although there was expressed interest in increased communication and facilitation of communication through an online platform, activities on the community website remained low. Lack of incentives and usability issues appeared to have played a role.*
- *The challenge in facilitating social interaction in the PowerMatching City community was that the community was geographically dispersed and there was not an explicit common goal for the households to achieve, other than participate in the pilot project.*

Implications for product- and service design

- **Integrated design:** *A community platform for a smart grid community would benefit from integrated design, where information for home energy management (such as feedback & predictions) is linked to possibilities for interaction with peers and service providers (the project team in the case of PowerMatching City).*
- **Incentives for interaction:** *To incentivize interactions, moderation is important, for example by posing questions that can engage end users in aspects of home energy management, to find out the best time to switch on the washing machine or to identify times of highest consumption peak and come up with solutions to lower the peak. Similarly, game elements, such as competitions or cooperative challenges could be introduced as temporary interventions.*
- **Characteristics of community:** *The characteristics of the community define to what extent online interaction is found interesting and useful. Products and services need to be tailored to different kinds of target groups Furthermore community formation tends to be based on the existence or development of common goals, which would need to be accommodated by the offered product-service combination.*
- **Time & flexibility:** *While technologies may be implemented and made functional from one day to the other, the development of a community takes time and cannot be fully controlled. It may be supported by design (means for interaction, organization). In development of products and services that use social interaction as a factor to facilitate co-provision, the product or service provider has to take this into account and be flexible to make adjustments over time.*

8

Conclusions and discussion

8.1 Introduction

This thesis started with the observation that residential end users of electricity can take up a more active role in balancing supply and demand in the electric power system. The deployment of ICT in the electricity grid makes it possible to include household energy consumption and production as a resource for grid management. Moreover, with products and services at the household level end users could be enabled to take up a more active role as co-providers in smart grids. Energy management for a household in a co-providing role could involve several aspects, namely efficient energy use, shifting of consumption in time, self-production of electricity and trading of excess electricity. Currently household energy management is mostly geared and stimulated toward efficient energy use. A shift to co-provision would therefore also require a shift in the mindset and behavior of end users. Rather than simply consuming electricity when it is convenient, households would have to react and anticipate to the situation in the electricity grid. There is still little knowledge of how products and services can empower end users to take up such a role.

The main questions that were explored in this research are:

1. *In what ways can products and services support end users in taking up a co-provider role in a smart grid context?*
2. *What are implications for the design of smart grid related products and services for supporting end users in a co-provider role?*

These questions were addressed through a literature review (Chapter 2) and field studies involving two pilot projects (Chapters 3 to 7). In both pilot projects end users used a product-service combination aimed at changing their household energy use in terms of behavior and/or automation. The implemented product-service combinations were evaluated with respect to their potential to empower end users in a role as co-providers. A research framework (Figure 66) was used to describe the performance of a smart energy system as a result of the interactions between users and technology and between users and other people (See Chapter 1).

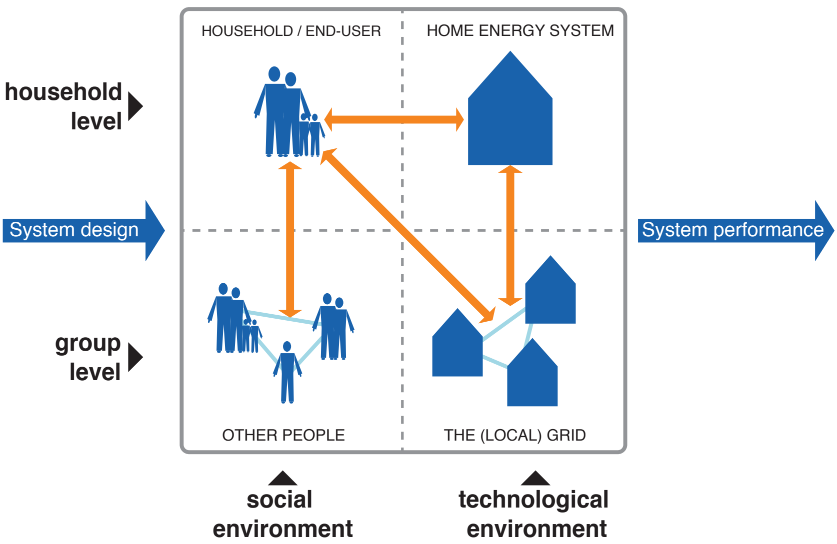


Figure 66: Research framework

The first case, Energy Battle, provided insights into how an energy saving game might enable and motivate end users to change their energy consumption behaviors. The game focused on the current role of end-users as mere consumers of energy (Chapter 3). The second case, PowerMatching City allowed for the evaluation of several aspects of co-providing households connected in a smart energy system, ranging from energy balance, use of the home energy system and the potential role for social interactions to support end-users' transition to a co-providing role (Chapter 4 to 7). In each of the chapters, the findings were discussed and recommendations for further research suggested. This chapter brings these findings together, leading to a general conclusion based on the combined findings of each study.
Answers to the main research questions are discussed in section 8.2. In Section 8.3 limitations of the research and the relevance of the research are discussed as well as a reflection on the research framework. Recommendations for further research and for practice are offered in Section 8.4.

8.2 Conclusions

8.2.1 How can products and services support end users

With respect to the question about how products and services can support end users transition to a co-provider role in a smart grid context, the two cases studied in this research have addressed end user involvement in different ways. In this section the conclusions are first discussed according to each study, followed by a conclusion combining the findings of the studies.

Energy Battle

The Energy Battle study (Chapter 3) showed that a temporary intervention in the form of a voluntary competition as a motivator for behavioral change could result in high energy savings during the intervention. The 17 participating student houses achieved savings of up to 45%, with an average of 24% over a four-week period. The levels of savings were, as expected from previous research, not maintained when the intervention stopped. The main lessons from this study were that the intervention provided a context for energy saving activities, both for households motivated by winning and for households merely interested in becoming aware of energy saving possibilities. Cooperative actions between household members furthermore appeared to be supportive in achieving the households' (temporary) goal for energy saving. The challenge for the design of a product-service combination such as the Energy Battle is to facilitate energy savings that are maintained in the long term. Guidance of behavioral change to reshape habitual behavior or make investment decisions would be important here. . Integration of a game in a larger program to motivate behavioral changes should also be considered to achieve impact on the longer term.

PowerMatching City

In the PowerMatching City pilot project the energy balance of the smart energy system, the extent to which end users were empowered as co-providers and the supportive role of the social context were examined.

Energy Balance

With respect to the energy balance, the analysis (Chapter 5) indicated a potential for changes in end user behavior to contribute to matching of supply and demand in the smart grid. There appear to be mismatches between momentous self-production and consumption in the households, which cannot be ascribed to the PowerMatcher coordination mechanism steering surplus electricity delivery to the grid. From the perspective that supply and demand matching should be optimal within the cluster, 'manual demand response' by end users could be supportive of the smart energy system performance, in addition to the optimization of settings for automated matching of supply and demand via PowerMatcher.

Experiences with the implemented technology

The implemented smart energy technology in the households had limited effect on the ability of end users to become more active in their home energy management. The system was technically functioning and the households expressed satisfaction with the heating systems. The end users however also exhibited lack of useful insight in, and control over, the operation of the system to ascertain the achievement of their households' energy related goals, such as energy saving or time-shifting appliance use to match local production. As a result, a few end users reported increased awareness of their energy use and hardly any behavioral changes were mentioned. This was particularly the case for the first phase of the project. The improved interface in the second phase provided end-users with information about system operation and for shifting appliance use in time. First inferences are that several end users became more actively involved in energy management in order to decrease consumption and shift the times of appliance use. But the issues of trust and control over the underlying mechanisms of smart energy system remain unsolved. The challenge is building a smart energy system that is transparent and user friendly for residential end users and to which they can, and want to, contribute. The user interface plays a key role in providing end users with sufficient insight and control to achieve their own goals as well as to contribute to the goals of other stakeholders, such as local matching of supply and demand, avoidance of peak loads and consumption of renewable energy. In PowerMatching City end users have demonstrated to be interested and able to take up a more active role as a co-providers in the electric power system when they have the opportunity to do so and when they perceive it as meaningful.

Potential for social interaction

Contacts between participating households in PowerMatching City occurred spontaneously as a means to increase understanding of how the system worked, solving problems or comparing system performance between households. Half of the participating households expressed interest in social interaction. Web-based exchanges were rated useful to facilitate communication related to energy practices at the community level. The introduction of the online platform sparked high initial interest. However, in practice, this did not match actual usage because there were not many incentives to use the website. During the second phase, the community website could be reached directly via the energy monitor and the project team of PowerMatching City started to use it more actively as a means to communicate with end users, in turn drawing more attention to the website. Based on this study, it is suggested that for a community website to be effective, the participants first have to be acquainted with each other to establish a common ground and shared goals. Once in place, the means of interaction have to be sufficiently accessible, easy to use and preferably integrated with a home energy management system. Additionally, active presence of the website is important, for example by push notifications about new posts. Most of all there have to be incentives to join in a conversation, such as project developments that trigger comments or questions and information shared by fellow community members or a moderator. Another basis for interaction could be information on the joint performance of the community, such as the community energy balance and comparisons between households so that households can relate their own household's energy consumption and production to the overall energy system and to the performance of community members. In a case such as PowerMatching City a combination of meetings and online interaction could be organized, where participant meetings could support interest and incentives for online sharing and discussion.

Conclusions from both cases

The studies in this thesis have addressed different aspects of end user involvement as co-providers in the energy system. The product-service combinations have in both cases facilitated co-provision to some extent, but in very different ways. Whereas Energy Battle's strongpoint was the motivation for behavioral change, this was the weaker point in PowerMatching City. On the other hand, an Energy Battle alone does not guarantee long-term changes, whereas PowerMatching City has a strong structural base to enable co-provision on the long run due to its focus on the implementation of core technology for co-provision. Additional facilitation of end user involvement in energy management could improve system performance. Taking a user-centered perspective, products and services should enable end users to reach their households' goals with respect to electricity consumption and production. With respect to smart grids, this means that products and services can be used to enable co-provision aspects of household energy management automatically through their functionality, but end users have to be empowered to become involved in order to complement the performance of the system. This involvement can be enabled in different ways. Intermediary products and information services will have to enable end users to interact with the energy system at the individual household level as well as at the community or local grid level. Information in relation to the community's or local grid's supply-demand balance may provide the ability as well as the motivation for end-users to engage in co-provision. Services for demand response then define the way in which co-provision becomes valuable for end-users. They have to be based on the end users' interests, such as maximizing the use of locally produced renewable energy or minimizing energy costs. Additionally, services can be offered that temporarily spur involvement with the system and motivate households to take measures. They can be interventions at the household level, such as reminders to review system settings, tips for behavioral change and investment in technology, as well as interventions involving interaction between households, such as cooperative action or competitive games to reach a common goal. The extent to which co-provision of the household is achieved through technical solutions, such as fully automated demand response, or behavioral changes can differ and defines the level of active end-user involvement in home energy management, as illustrated in Figure 67.

8.2.2 Implications for designing products and services

Based on the insights from the studies implications were formulated for designing products and services that enable co-provision by residential end users. In Chapter 2 design recommendations were formulated as a result of literature study. In Chapters 3, 5, 6 and 7 design implications were presented for the specific studies of Energy Battle and PowerMatching City. In this section implications are discussed that were inferred from the findings of the studies and combined in four themes.

- *Design of user interface is key for empowering end-users in a role as co-providers*
- *Use leverage from social interactions in product and service design*
- *Smart energy system design is part of an experiential learning process*
- *Using an integral design approach with end-users needs as a starting point*

<u>Design of user interface is key for empowering end-users in a role as co-providers</u>

The user interface determines the information and control available to end-users and as a result the extent to which, and the ways in which, they can become involved in management of the electric power system as co-providers. Both Energy Battle and PowerMatching City demonstrated that the implemented intermediary products and services played a key role in enabling the end users to adjust their behavior. In both cases end users had a positive attitude towards behavioral change to improve their household's energy performance. The energy feedback information in combination with controls, such as a button for smart operation mode and timers on washing machines, provided them with ability and motivation to make changes to their consumption levels, for PowerMatching City also their consumption pattern. The research indicated however that the design of the interface could be improved. For example, PowerMatching City's interface initially lacked transparency about system performance and could not engage end users to optimize their household energy consumption, such as through 'manual demand response'.

The implication for designers of smart grid products and services is that they have to carefully consider what the user interface has to enable and motivate the end users for. The complexity of smart grid operation has to be boiled down to intuitive information and control, that places an end user's actions for household level energy management in the context of the supply-demand management at grid level and in which the end user participates in a co-provider role. As different end users have different needs and abilities with respect to their co-provider role, user interfaces have to be differentiated for different types of end users. On one side of the spectrum could be a 'set-and-forget-system' with high level of automated demand response and on the other side a 'do-it-yourself system' for which a household relies heavily on their own 'manual' demand response to make use of locally produced, cheap electricity. 'Set-and-forget' would require a different type of interface, with focus on settings, than 'Do-it-yourself' for which information to guide behavior would be key and that should maintain or regularly renew end user involvement with home energy management.

Use leverage from social interactions in product and service design

PowerMatching City and Energy Battle were both projects in which social interaction was part of the implemented products and services. While social interaction occurred in different ways throughout these studies, end users described it as supportive in motivating and enabling behavior change. On the one hand household level interactions played a role in achieving energy savings, particularly for Energy Battle. On the other hand, the relations between households influenced performance. In Energy Battle the competition context motivated energy saving activities. In PowerMatching City, sharing of experiences and comparisons of heating system performance and energy consumption kept participants involved in the project, knowledgeable about, and motivated to, take up a co-provider role.

These observations lead to the conclusion that when designing products and services, the potential role of social interaction has to be taken into account as a means to positively contribute to motivation and ability of end users to act as co-providers in the electric power system. Particularly for smart grids where electricity production and consumption are balanced locally, fostering a social bond between the actors in the smart grid may be beneficial for a system in which the energy consumption and production of each individual household contributes to the overall management of the (local) smart grid. Social interaction could consist of different levels of involvement, to give some examples:

- *Comparisons of energy performance between households in the smart grid.*
- *Visualization of the opportunities for local balancing of supply and demand in one's neighborhood based on the combined production capacity of the neighborhood.*
- *Trading or sharing of production capacity and self-produced electricity*

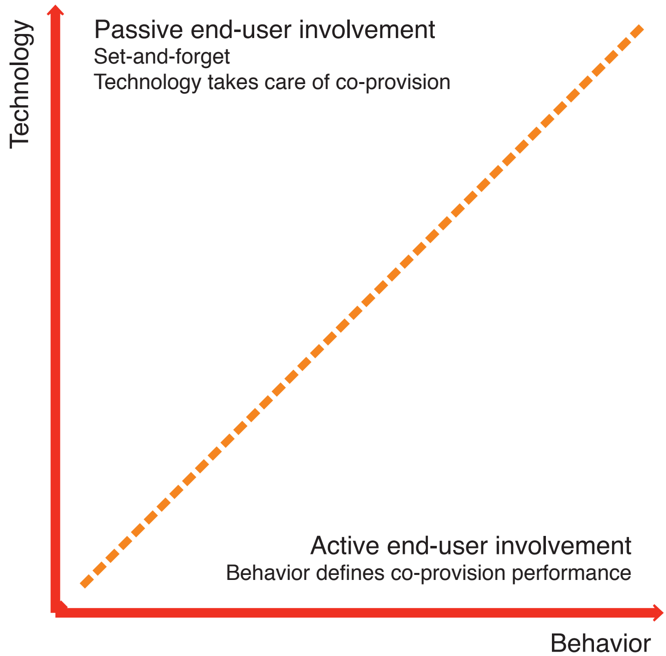


Figure 67: Co-provision by households as a balance between a technological and behavioral dimension.

within a local energy cooperative.

- *Online communication for the organization of a cooperative to create an enabling and motivating context for (shared) co-provision*

Smart energy system design is part of an experiential learning process

Energy Battle and PowerMatching City were both pilot projects, intended to test a concept in practice. Lessons from practice, with real users were used for further developments of the products and services[1]. In PowerMatching City the development process, with the implementation of the technology, the end user research and co-design for the energy monitor and business propositions consisted of an experiential learning process of for both project team and end users. As the project progressed the project team learned about the needs and wishes of end users through the end user research. The project team decided to place more effort to the user interface in order to satisfy needs of end users and, at the same time, enable the energy providers to test energy services. On the other hand, the end users learned about the possibilities and limitations of the implemented technology by using the products and services over a couple of years. Whereas most households started with energy saving as their goal for their participation in the project, two years later the end users formulated goals that were more focused on smart grid operation, such as time-shifting their electricity consumption and contributing to the overall matching of supply and demand within the cluster.
The energy balance analysis (Chapter 5) indicated furthermore, that a simple representation of the energy balance over time could be used as

1 The Energy Battle experiences, in combination with bigger and further elaborated product-service combinations, led the company to develop an online platform for insight and cooperation on energy saving and demand response. (Personal communication with S.Versluis, 2014).

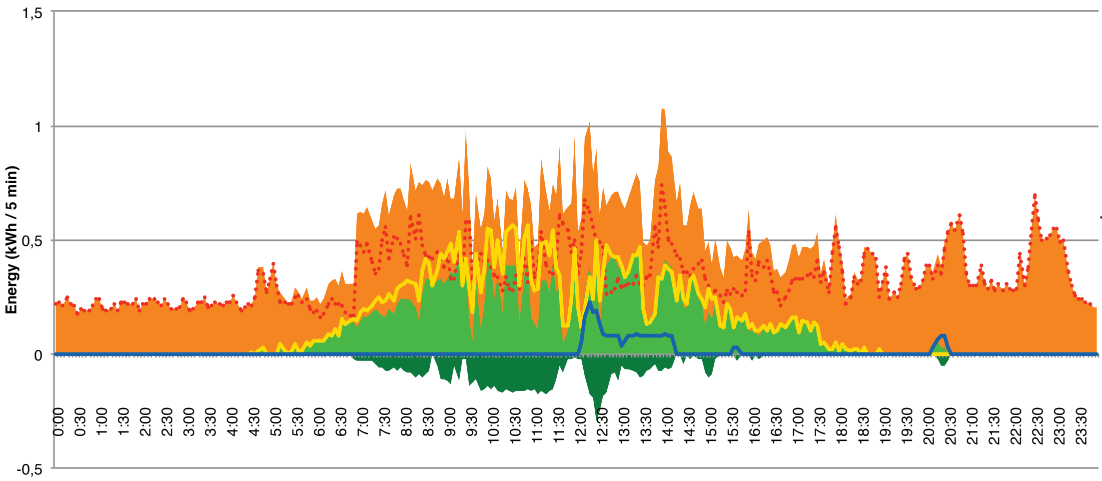
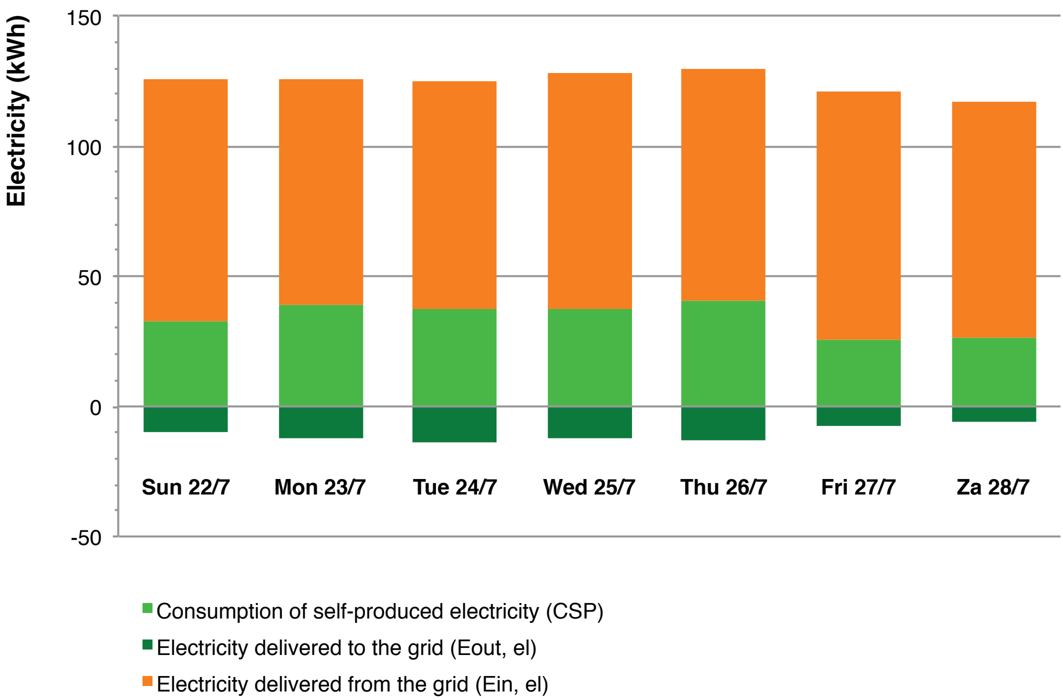


Figure 68: Daily energy balance overview for the μCHP group – Week 30 (22/7/2012), based on 8 households

a basis for stakeholders in the smart grid to understand system operation and to discuss how each other's goals can be achieved. Figure 68 and Figure 69 show the balance on a 5-minute and day basis respectively. This information can be used to discuss how the self-production and appliances use such as μCHPs affect the energy balance of the households and the cluster. In a co-creation process the goals of end-users and energy companies can be negotiated, and lead to the definition of products and services that meet needs of diverse end-users as well as energy companies' needs for management of the electric power system. For example, with a home energy management system (HEMS) households can choose a minimum level for consumption of their self-produced electricity compared to delivery to the grid. This setting determines the extent to which they

Figure 69: Energy balance overview on a day timescale – Week 30 (22/7/2012), based on 8 households.



share their electricity with the local community or to which a (contracted) energy company may use their μCHP as part of a virtual power plant.

The findings in this thesis lead to the design implication that for complex and new systems such as smart grids, involving different types of end-users, early in the process and involving them as a partner rather than a passive end-user is required to (1) come up with products and services that will provide value for end-users as well as other stakeholders in smart grids and (2) can facilitate the adoption process of smart grid products and services. Communication about each other's goals, supported by visualization of actual or desired energy flows, business models and user-technology interaction is key to this process. The facilitation of co-creation processes, for example for cooperatives together with energy companies, would in itself be a service that can be supportive in a transition to smart grids.

Using an integral design approach with end-users needs as a starting point

In section 8.2.1 it was concluded that combinations of products and services that address both technological and behavioral aspects of co-provision are required to empower end users as co-providers in smart grids. Energy Battle had a strong focus on behavioral change by increasing the motivation and ability to save energy. We observed that the followed approach could engage people in home energy management in a fun way. However, without the achievement of structural changes in habitual behavior or the technologies and services used in the homes, significant long-term effects are not very likely.

In the case of PowerMatching City the focus initially was on technology implementation and thereby provided a structural change to enable co-provision by the households. For adoption of the technology and to involve the end users as co-providers in the smart grid, the behavioral aspects required further attention to the system design. Improved insight and control as well a possibility to contribute to supply-demand management on one's own terms were found to be necessary for products and services that are meaningful for the end users.

An integral approach, such as introduced in Chapter 2, with the layer model (see Figure 70) would help to strike a balance between technological functionality and end user practices and their development over time. For successful adoption of a co-provider role, end-user needs and capabilities have to be the starting points for the design of products and services that are intended to enable co-provision.

8.3 Discussion

The empirical research in this thesis took place in practice, in two pilot projects with design concepts that were first tested with real households. The advantage of this approach was that the research could actually contribute to developments in practice. The disadvantage was that as a researcher one had little control over timing and developments in the overall project and thereby a myriad of factors (technology, planning, communication, etc.) that may – or may not – influence end user experience and behavior. For example a second field study for Energy Battle was planned for households

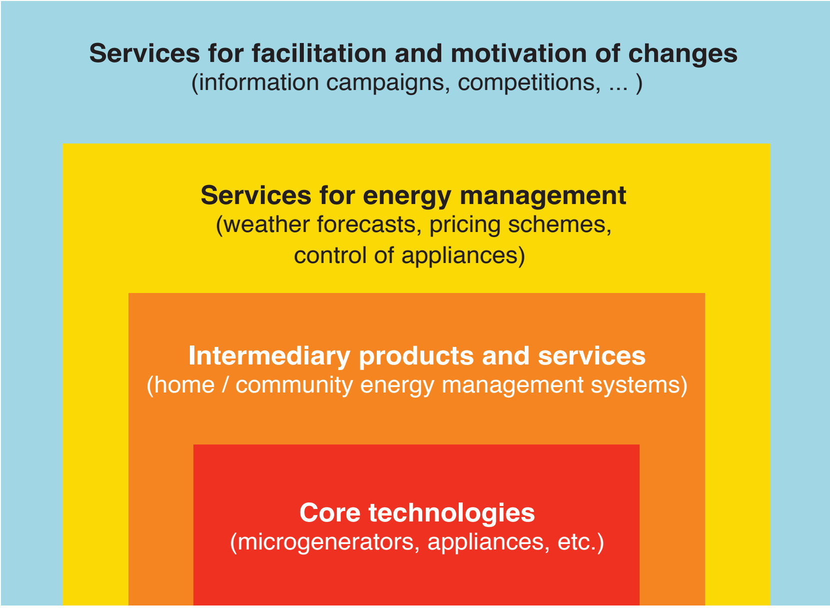


Figure 70: Layer model, depicting the relation between products and services making co-provision possible

with children, but was cancelled due to lack of participants. And the implementation of the 'community portal' in PowerMatching City was built as a separate website because time constraints related to the PhD research did not allow for the time necessary to receive and operate the new Energy Monitor for the project's second phase.
Limitations for the research results have been discussed in their specific chapters. The sample sizes in the empirical studies were small and not representative for the Dutch population. These limitations can, together with the limited control over the experimental context in which end-users were studied, be considered as a weakness of the research presented in this thesis. The strength of the research lies in the explorative approach, which despite its limitations, provided understanding of motivations, needs and capabilities of end-users in smart energy systems. The quantitative methods for measurement of the energy savings (Energy Battle) and the energy balance (PowerMatching City), provided insight in the potential for energy saving and supply-demand matching respectively. The qualitative methods produced rich insights into how the implemented products and services enabled, or restrained, end users in becoming more engaged with their home energy management. Of these methods, the co-creation activities also contributed to ongoing development processes by formulation of criteria and solutions for design.

The contribution to knowledge of this research lies in the insights into the end user side of smart grids with respect to products and services for smart grid deployment at the household level and the user needs for such products and services. While reports on smart grid deployment emphasize the importance of end user involvement, research on end user engagement in the smart grid is in its infancy, and most research efforts have focused on economic incentives to stimulate time-shifting of electricity consumption in combination with technical automation (Darby and McKenna, 2012). Insight from such research is relevant when considering the economic implications of smart grid deployment and the market mechanisms

underlying the operation of the electric power system. The research in this thesis took a step beyond economic and technical approaches, by exploring the social aspects of smart grid technology.
With respect to the theoretical stance of this thesis, the research framework was based on theory about user-technology interaction and behavioral change from a social-psychological perspective. The research therefore produced results focusing on the relations between end-users and the implemented products and services, in combination with factors such as motivation, ability and opportunity that influence behavior. Given the interdisciplinary nature of the research, there are several fields of literature to which this thesis can contribute. Its contributions lie in the area of user-technology interaction, pro-environmental behavior, design for sustainable behavior, smart energy systems and user interface design. Though it must be noted that the results are specifically related to household energy consumption.

The research in this thesis has focused on the micro-level and the use of products and services. For further study, the research framework, as presented in the Introduction (see Figure 66), could be revised in two directions. Firstly, to include more detail on how products and services can be designed based on the needs and capabilities of the end users. A combination with the layer model may be useful, as would a Product-Service-System approach (Joore, 2010; Tisschner et al., 2009), which includes the way in which products and services are built up and 'delivered' to customers. Information flows, value creation but also money flows and long-term use of products and services can get a place in such a model. Secondly, extension of the current research framework at micro level to a framework that includes models at the macro-level of socio-technical systems can be considered. Since the transition to smart grids takes place at a societal level (van Vliet et al., 2005; Verbong and Geels, 2007), design solutions will have to be considered in their broader context of social and technical development at higher system levels. A social practices approach (Spaargaren et al., 2006) may provide a useful linking pin between micro- and macro level processes.

The relevance for practice of this thesis can be found in the placement of this research as part of a development process towards deployment of smart grid products and services. The empirical research took place as part of the development process. Activities and insights related to the end user research in both cases have directly contributed to ongoing and new product- and service development. The studies furthermore demonstrated that the performance of a smart energy system is a combined effort by end-users and technology as described in the research framework. This stressed the relevance of an interdisciplinary, design-driven approach to smart grid deployment.
The difficulty in designing for smart grids with actively participating end users is that the development process is open-ended. There are no clearly defined design goals or expected end-results yet. To move on in the development we have to keep our options open to avoid technological lock-in and at the same time formulate delimited design goals to be able to conceive and test potential smart grid solutions. As proposed by Klopfert and Wallenborn (2011) trials of new products and services are a crucial part

of the domestication process of smart energy technologies. With respect to the cases in this thesis, the design process for a smart energy system such as PowerMatching City is complex as it concerns a combination of design solutions whose impact can only be defined as the products and services are being implemented. The design process thus has to be flexible in order to adapt to changing circumstances with respect to technological challenges as well as end user needs and capabilities that develop over time. Design for a temporary intervention such as Energy Batlle is less comprehensive. The design goals can be defined on a clearly defined end-result for the intervention, such as a certain amount of energy saving or time-shifting of appliances use.

8.4 Recommendations for future research and product-service development

This final section of the thesis provides general recommendations for research and development with respect to empowering end users as co-providers in our electric power system. They are formulated as two paradoxes concerning (1) high-tech versus low-tech solutions and (2) community-based versus individual approaches.

Low versus high-tech solutions

While engineers and designers often tend to look for advanced technical solutions, the low- or no-tech solutions are not to be forgotten. There are already several products and services on the market that can engage end users for aspects of co-provision which do not necessarily require an advanced smart infrastructure in households and can still result in satisfactory supply-demand balancing. For example PeakSaver is a service to switch appliances, typically air conditioners, on and off remotely ("Peak Saver," 2014). This service uses ICT, but does not require a Smart Meter in a household. The conditions under which shifting takes place are straightforward and therefore easily communicated to end-users[2]. For manual demand response specific devices exist that inform an end user about the net stability or price levels, allowing them to decide whether to shift the use of an electric appliance to a different time (e.g. "Energy Orb," 2014). A 'no-tech' example that illustrates how social practices may change is CoolBiz. Excessive demand for air-conditioning in Japan was lowered by a campaign to change cultural norms and stimulate people to wear less formal, cooler, clothing (Sanchanta, 2011).
The key point here is that developers of products and services have to be aware that complex technology, such as fully automated demand response, may not always be necessary to improve the performance of the electric power system. Given the intention to involve end users in the management of the electric power system, the challenge for future research and development is to figure out how end user's contribution to supply and

2 The PeakSaver plus program: "During peak electricity demand times, typically on hot summer days, a signal will be sent to reduce the electricity demand of your central air conditioning system, which in turn helps to reduce the amount of electricity needed by the Province. You won't even notice a difference, and you're doing your part to conserve without incurring time, effort or cost!" (www.peaksaver.com, last accessed May 4th, 2014)

demand balancing can be enabled with simple, transparent and user-friendly approaches. Herein technology should play a supportive rather than leading role in involving end users in the management of the smart grid to the extent they are willing and able.

Community-based development and implementation for individual households

A recurring theme in this thesis is the use of community-based approaches to involve end users in becoming co-providers. A community-based approach to smart grid development could be a viable way to come up with smart grid solutions that can provide value to end users as well as energy providers and network operators. In a smart grid supply and demand would be matched locally as much as possible (i.e. at a community or neighborhood level). This provides opportunities for cooperative forms of local energy management, for example based on the principles of community-based resource management (Ostrom, 1990; Wolsink, 2011) with a high level of end user involvement. Also community-based programs can be supportive to the adoption process of new behaviors and technologies given an enabling and motivating influence of social interaction (Gardner and Stern, 1996; McKenzie-Mohr, 2010).
This use of community-based approaches appears contradictory to the liberalized energy market in Europe where energy providers generally focus on, and compete for, individual consumers. This liberalized market however also brings opportunities for change, with new market players, different business models and increased consumer power. Consumers actually appear to increasingly organize themselves for collective action. In the Netherlands, for example, collective purchasing of energy contracts is becoming common practice for consumers to enforce lower priced energy contracts. Also there is strong growth in the number of local sustainable energy initiatives. In the Netherlands there are about 110 registered cooperatives of which 95 came into existence beginning in 2007. These cooperatives generally focus on local energy production from wind, solar or other sources, but they often also collectively organize energy efficiency measures or electricity contracting via 'conventional' energy providers. The interests of the local community, such as employment and social cohesion, play an important role in the cooperative's activities and national and local governments are looking for ways to facilitate cooperatives, as their 'citizen power' is considered a vital part of the energy transition at local governance level (Planbureau voor de Leefomgeving, 2014).
At the intersection of policymaking and local citizen-led initiatives, top-down and bottom-up initiatives to energy transition can meet and create synergies. Also for energy companies - network operators, energy providers, ESCOs[3] - cooperation with bottom-up initiatives can provide opportunities for supply and demand management in the grid as well as for business propositions. It can be expected that there will be many different configurations of smart grids, tailored to local circumstances with respect to social environment and technical possibilities, implemented at different

3 The term ESCO stands for 'Energy Service Company' and relates to companies that offer energy-related services and are not directly linked to an energy provider or network operator (the organizations that primary take care of energy provision). An energy provider or network operator can however also set up its own ESCO.

paces and with approaches ranging from individual to collective adoption of smart grid products and services.

Further research should create a better understanding of: (1) to what extent community-based approaches can facilitate energy transition to smart grids with co-providing end users, (2) what role can the current and potential new energy companies play in community-based smart grid deployment and (3) given a liberalized energy market focusing on individual consumers and assuming that community-based approaches will not be effective everywhere, classify approaches with various levels of community involvement to establish an electric power system in which end users are empowered to play a co-providing role. The development of product-service combinations can be based on the defined approaches and will thereby more concretely shape the interaction between end users and energy system.

References

Abrahamse, W., Steg, L., Vlek, C., Rothengatter, T., 2005. A review of intervention studies aimed at household energy conservation. J. Environ. Psychol. 25, 273–291.

Ackermann, T., Andersson, G., Söder, L., 2001. Distributed generation: a definition. Electr. Power Syst. Res. 57, 195–204.

Ajzen, I., Fishbein, M., 1980. Understanding Attitudes and Predicting Social Behaviour. Prentice Hall Inc., Englewood Cliffs, NY.

Alanne, K., Saari, A., 2006. Distributed energy generation and sustainable development. Renew. Sustain. Energy Rev. 10, 539–558.

Allcott, H., 2011. Social norms and energy conservation. J. Public Econ. 95, 1082–1095.

Bakker, C.A., Van Eijk, D.J., Silvester, S., Reitenbach, M.E.F.R., de Jong, A.M., Keyson, D.V., Scott, K., 2010. Understanding and modelling user behaviour in relation to
sustainable innovations: the living lab method, in: Horvath, I., Mandorli, F., Rusak, Z. (Eds.), Proceedings of TMCE 2010 Symposium.

Bång, M., Svahn, M., Gustafsson, A., 2009. Persuasive design of a mobile energy conservation game with direct feedback and social cues. 3rd Int. Conf. Digit. Games Res. Assoc. (DiGRA 2009).

Bergman, N., Eyre, N., 2011. What role for microgeneration in a shift to a low carbon domestic energy sector in the UK? Energy Effic. 1–19.

Bhamra, T., Lilley, D., Tang, T., 2011. Design for Sustainable Behaviour: Using Products to Change Consumer Behaviour. Des. J. 14, 427–445.

Biel, A., Thögersen, J., 2007. Activation of social norms in social dilemmas: A review of the evidence and reflections on the implications for environmental behaviour. J. Econ. Psychol. 28, 93–112.

Blessing, L., Chakrabarti, A., 2009. DRM, a Design Research Methodology. Springer.

Bliek, F., van den Noort, A., Roossien, B., Kamphuis, R., de Wit, J., van der Velde, J., Eijgelaar, M., 2010. PowerMatching City, a living lab smart grid demonstration, in: Innovative Smart Grid Technologies Conference Europe (ISGT Europe), 2010 IEEE PES. pp. 1–8.

Bliek, F., van den Noort, A., Roossien, B., Kamphuis, R., de Wit, J., van der Velde, J., Eijgelaar, M., 2011. The role of natural gas in smart grids. J. Nat. Gas Sci. Eng. 3, 608–616.

Breukers, S.C., Heiskanen, E., Brohmann, B., Mourik, R.M., Feenstra, C.F.J., 2011. Connecting research to practice to improve energy demand-side management (DSM). Energy 36, 2176–2185.

Breukers, S.C., Van Mourik, R.M., 2013. The end-users as starting point for designing dynamic pricing approaches to change household energy consumption behaviours. Report for Netbeheer Nederland, Projectgroep Smart Grids (Pg SG). Arnhem.

Caillois, R., Barash, M., 1962. Man, play and games. Thames and Hudson, London.

Centraal Bureau voor de Statistiek, 2013. Demografische kerncijfers per gemeente 2012. Den Haag.

Centraal Bureau voor de Statistiek, n.d. Statline [WWW Document]. URL www.cbs.nl (accessed 7.25.13).

CER, 2011. Electricity Smart Metering Customer Behaviour Trials (CBT) Findings Report - CER11080a. Dublin.

Costa, E., 2011. SASÉR - educative serious game about Smart Grids and renewable resources, Master thesis. Delft University of Technology, Faculty Industrial Design Engineering, Delft.

Dahlstrand, U., Biel, A., 1997. Pro-environmental habits: propensity levels in behavioural change J. Appl. Soc. Psychol. 27, 588–601.

Darby, S., 2010. Smart metering: what potential for householder engagement? Build. Res. Inf. 38, 442–457.

Darby, S.J., McKenna, E., 2012. Social implications of residential demand response in cool temperate climates. Energy Policy 49, 759–769.

Dietz, T., Gardner, G.T., Gilligan, J., Stern, P.C., Vandenbergh, M.P., 2009. Household actions can provide a behavioral wedge to rapidly reduce US carbon emissions. Proc. Natl. Acad. Sci. U. S. A. 106, 18452–18456.

DIY Kyoto, 2010. Wattson [WWW Document]. URL www.diykyoto.com
Dobbyn, J., Thomas, G., 2005. Seeing the Light: the Impact of Microgeneration on Our Use of Energy. Sustain. Consum. Roundtable.

EcoGrid [WWW Document], 2013. URL www.eu-ecogrid.net/ecogrid-eu/the-bornholm-test-site (accessed 3.19.14).

Ehrhardt-Martinez, K., Donnelly, K.A., Laitner, J.A., 2010. Advanced metering Initiatives and residential feedback programs: A meta-review for household electricity-saving opportunities. Washington.

Eichhammer, W., Fleiter, T., Schlomann, B., Faberi, S., Fioretto, M., Piccioni, N., Lechtenböhmer, S., Schüring, A., Resch, G., 2009. Study on the Energy Savings Potentials in EU Member States, Candidate Countries and EEA Countries.

Ellis, M., Jolland, N., 2009. Gadgets and Gigawatts, Policies for Energy Efficient Electronics. Paris.

Energy Orb [WWW Document], 2014. URL www.ambientdevices.com (accessed 4.30.14).

European Commission, 2010. Energy 2020 - A strategy for competitive, sustainable and secure energy.

Faruqui, A., Sergici, S., Sharif, A., 2010. The impact of informational feedback on energy consumption-A survey of the experimental evidence. Energy 35, 1598–1608.

Fischer, C., 2008. Feedback on household electricity consumption: a tool for saving energy? Energy Effic. 1, 79–104.

Fogg, B.J., 2003. Persuasive Technology: Using Computers to Change What We Think and Do. Morgan Kaufmann Publishers.
Fogg, B.J., 2009. A Behavior Model for Persuasive Design. Persuasive'09.

Foster, D., Lawson, S., Blythe, M., Cairns, P., 2010. Wattsup?: Motivating reductions in domestic energy consumption using social networks. Nord. 2010.

Fox-Penner, P., 2010. Smart Power - Climate Change, the Smart Grid, and the Future of Electric Utilities. Island Press, Washington.

Frissen, V., Van Lieshout, M., 2006. ICT IN EVERYDAY LIFE: The Role of the User, in: Slob, A., Verbeek, P.-P. (Eds.), User Behavior and Technology Development: Shaping Sustainable Relations Between Consumers and Technologies. Springer, pp. 253–262.

Gardner, G.T., Stern, P.C., 1996. Environmental problems and Human Behavior Pearson Custom Publishing, Boston, MA.

Geelen, D., Keyson, D., 2012. USING ENERGY: Beyond individual approaches to influence energy behavior, in: Reinders, A., Diehl, J.C., Brezet, H. (Eds.), The Power of Design: Product Innovation in Sustainable Energy Technologies. Wiley.

Geelen, D., Keyson, D., Boess, S., Brezet, H., 2012. Exploring the use of a game to stimulate energy saving in households. J. Des. Res. 10, 102–120.

Geelen, D., Scheepens, A., Kobus, C.B.A., Obinna, U., Mugge, R., Schoormans, J.P.L., Reinders, A., 2013. Smart energy households' field tests in The Netherlands with a design-driven approach, in: 4th European Innovative Smart Grid Technologies (ISGT) Conference. Copenhagen, Denmark.

Giordano, V., Gangale, F., Fulli, G., Sánchez Jiménez, M., 2011. Smart Grid projects in Europe: lessons learned and current developments. Joint Research Centre of the European Comission, Petten.

Groot-Marcus, J., Terpstra, P., Steenbekkers, L., Butijn, C., 2006. Technology and household activities, in: Verbeek, P., Slob, A. (Eds.), User Behavior and Technology Development: Shaping Sustainable Relations Between Consumers and Technologies. pp. 33–42.

Grunneger Power [WWW Document], 2013. URL www.grunnegerpower.nl (accessed 3.19.14).

Guerra-Santin, O., Itard, L., 2010. Occupants' behaviour: determinants and effects on residential heating consumption. Build. Res. Inf. 38, 318–338.

Gustafsson, A., Katzeff, C., Bang, M., 2009. Evaluation of a pervasive game for domestic energy engagement among teenagers. Comput. Entertain. Vol. 7.

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, 6111–6119.

Heiskanen, E., Johnson, M., Robinson, S., Vadovics, E., Saastamoinen, M., 2010. Low-carbon communities as a context for individual behavioural change. Energy Policy 38, 7586–7595.

Herrmann, N., Gölz, S., Buchholz, B., 2008. Washing with the sun: Results of a field test for the use of locally generated renewable electricity and load shifting in households. Int. J. Distrib. Energy Resour. 4, 253–263.

Huizinga, J., 1949. Homo Ludens, A Study of the Play-Element in Culture. Routledge and Kegan Paul Ltd., London.

Jackson, T., 2005. Motivating sustainable consumption - A review of models of consumer behaviours and behavioural change. A report to the Sustainable Development Research Network. London.

Jégou, F., Manzini, E., 2008. Collaborative Services - Social innovation and design for sustainability.

Joore, P., 2010. New to Improve, The Mutual Influence between New Products and Societal Change Processes. Delft University of Technology.

Keirstead, J., 2007. Behavioural responses to photovoltaic systems in the UK domestic sector. Energy Policy 35, 4128–4141.

Keyson, D. V., Al Mahmud, A., Romero, N., 2013. Living Lab and Research on Sustainability: Practical Approaches on Sustainable Interaction Design, in: Augusto, J.C., Wichert, R., Collier, R., Keyson, D., Salah, A.A., Tan, A.-H. (Eds.), Ambient Intelligence 4th International Joint Conference, AmI 2013, Dublin, Ireland, December 3-5, 2013. Proceedings. Springer International Publishing, pp. 229–234.

Klopfert, F., Wallenborn, G., 2011. Empowering consumers through smart metering. Brussels.

KNMI, 2013a. Daggegevens van het weer in Nederland - weerstation Eelde [WWW Document]. URL http://www.knmi.nl/klimatologie/daggegevens/download.html (accessed 11.26.13).

KNMI, 2013b. Maandgegevens van het weer in Nederland - weerstation Eelde [WWW Document]. URL http://knmi.nl/klimatologie/maandgegevens/datafiles/mndgeg_280_tg.txt (accessed 11.26.13).

Kobus, C.B.A., Mugge, R., Schoormans, J.P.L., 2012. Washing when the sun is shining! How users interact with a household energy management system. Ergonomics 1–12.

Kok, K., Roossien, B., MacDougall, P., van Pruissen, O., Venekamp, G., Kamphuis, R., Laarakkers, J., Warmer, C., 2012. Dynamic pricing by scalable energy management systems — Field experiences and simulation results using PowerMatcher, in: 2012 IEEE Power and Energy Society General Meeting. IEEE, pp. 1–8.

Kuijer, L., 2014. Implications of Social Practice Theory for Sustainable Design. Delft University of Technology.

Lewin, K., 1951. Field theory in social science; selected theoretical papers. Harper & Row, New York.

Lockton, D., Harrison, D., Stanton, N.A., 2010. The Design with Intent Method: A design tool for influencing user behaviour. Appl. Ergon. 41, 382–392.

Lopes, M.A.R., Antunes, C.H., Martins, N., 2012. Energy behaviours as promoters of energy efficiency: A 21st century review. Renew. Sustain. Energy Rev. 16, 4095–4104.

Lutzenhiser, L., 1993. Social and Behavioral Aspects of Energy use. Annu. Rev. Energy Environ. 18, 247–289.

Malone, T.W., Lepper, M.R., 1987. Making learning fun: A taxonomy of intrinsic motivations for learning, in: Snow, R.E., Farr, M.J. (Eds.), Aptitude, Learning and Instruction III: Conative and Affective Process Analyses. Erlbaum, Hillsdale, N.J., pp. 223–253.

Marris, E., 2008. Upgrading the Grid. Nature 454, 570–573.

McCalley, L.T., Midden, C.J.H., 2002. Energy conservation through product-integrated feedback: The roles of goal-setting and social orientation. J. Econ. Psychol. 23, 589–603.

McKenzie-Mohr, D., 2010. Quick Reference: Community-Based Social Marketing.

McKenzie-Mohr, D., 2011. Fostering Sustainable Behavior: An Introduction to Community Based Social Marketing. New Society Publishers.

Mert, W., Tritthart, W., 2009. Get smart! Consumer acceptance and restrictions of Smart Domestic Appliances in Sustainable Energy Systems. TRANSPOSE Midterm Conf.

Ministerie van Binnenlandse Zaken en Koninkrijksrelaties, 2013. Cijfers over Wonen en Bouwen 2013. Den Haag.

Mullan, J., Harries, D., Bräunl, T., Whitely, S., 2012. The technical, economic and commercial viability of the vehicle-to-grid concept. Energy Policy 48, 394–406.

Nemtzow, D., Delurey, D., King, C., 2007. The green effect. How demand response programs contribute to energy efficiency and environmental quality. Public Util. Fortn.

Niitamo, V.-P., Kulkki, S., Eriksson, M., Hribernik, K.A., 2006. State-of-the-art and good practice in the field of living labs, in: Proceedings of the 12th International Conference on Concurrent Enterprising: Innovative Products and Services through Collaborative Networks. Milan, Italy, pp. 349–357.

Obinna, U., Joore, P., Wauben, L., Reinders, A., 2013. Water related sustainable innovations and the smart grid, in: Proceedings of the 16th European Roundtable on Sustainable Consumption and Production (ERSCP).

Odom, W., Pierce, J., Roedl, D., 2008. Social Incentive & Eco-Visualization Displays: Toward Persuading Greater Change in Dormitory Communities. "Public Situated Displays to Support Communities" Work. OZCHI 2008.

Ölander, F., Thøgersen, J., 1995. Understanding of consumer behaviour as a prerequisite for environmental protection. J. Consum. Policy 18, 345–385.

Ostrom, E., 1990. Governing the commons: The evolution of institutions for collective action. Cambridge University Press , Cambridge, England.

Paetz, A.-G., Dütschke, E., Fichtner, W., 2012. Smart Homes as a Means to Sustainable Energy Consumption: A Study of Consumer Perceptions. J. Consum. Policy 35, 23–41.

Peak Saver [WWW Document], 2014. URL www.peaksaver.com (accessed 4.9.14).

Petersen, J.E., Shunturov, V., Janda, K., Platt, G., Weinberger, K., 2007. Dormitory residents reduce electricity consumption when exposed to real-time visual feedback and incentives. Int. J. Sustain. High. Educ. 8, 16–33.

Planbureau voor de Leefomgeving, 2014. Energiecoöperaties: ambities, handelingsperspectief en interactie met gemeenten.
Rogers, E.M., 2003. Diffusion of innovations, 5th editio. ed. Free Press, New York.

Sanchanta, M., 2011. Japanese Energy Strategy: Hawaiian Shirts [WWW Document]. URL http://online.wsj.com/news/articles/SB10001424052702304563104576357073463476358 (accessed 4.9.14).

Sanquist, T.F., Orr, H., Shui, B., Bittner, A.C., 2012. Lifestyle factors in U.S. residential electricity consumption. Energy Policy 42, 354–364.

Sorrell, S., 2007. The Rebound Effect: an assessment of the evidence for economy-wide energy savings from improved energy efficiency. UK Energy Research Centre.

Spaargaren, G., Martens, S., Beckers, T.A.M., 2006. Sustainable technologies and everyday life, in: Verbeek, P.-P., Slob, A. (Eds.), User Behavior and Technology Development: Shaping Sustainable Relations Between Consumers and Technologies. Springer, Dordrecht, pp. 107–118.

Spaargaren, G., van Vliet, B., 2000. Lifestyle, Consumption and the Environment: the ecological modernisation of domestic consumption. Soc. Nat. Resour. 9, 50–76.

Spagnolli, A., Corradi, N., Gamberini, L., Hoggan, E., Jacucci, G., Katzeff, C., Broms, L., Jönsson, L., 2011. Eco-Feedback on the Go: Motivating Energy Awareness. Computer (Long. Beach. Calif). 44, 38–45.

Stern, P., 2000. Psychology and the science of human-environment interactions. Am. Psychol. 55, 523–530.

Stromback, J., Dromacque, C., Yassin, M.H., 2011. Empower Demand. The potential of smart meter enabled programs to increase energy and systems efficiency: a mass pilot comparison. Helsinki.

Texel Energy [WWW Document], 2013. URL www.texelenergie.nl (accessed 3.19.14).

Tisschner, U., Ryan, C., Vezzoli, C., 2009. Product-service-systems, in: Crul, M.R.M., Diehl, J.C., Ryan, C. (Eds.), Design for Sustainability - A Step by Step Approach. United Nations Environment Programme, pp. 95–101.

Van Dam, S., 2013. Smart energy management for households. Delft University of Technology.

Van Dam, S.S., Bakker, C.A., Van Hal, J.D.M., 2010. Home energy monitors: Impact over the medium-term. Build. Res. Inf. 38, 458–469.

Van Vliet, B., Chappells, H., Shove, E., 2005. Infrastructures of Consumption: Environmental Innovation In The Utility Industries. Earthscan, London.

Verbeek, P.-P., Slob, A., 2006. Analyzing the relations between technologies and user behavior: towards a conceptual framework, in: Verbeek, P.-P., Slob, A. (Eds.), User Behavior and Technology Development: Shaping Sustainable Relations Between Consumers and Technologies. Springer, Dordrecht, pp. 385–399.

Verbong, G., Geels, F., 2007. The ongoing energy transition: Lessons from a socio-technical, multi-level analysis of the Dutch electricity system (1960–2004). Energy Policy 35, 1025–1037.

Verplanken, B., Wood, W., 2006. Interventions to Break and Create Consumer Habits. Am. Mark. Assoc. 25, 90–103.

Versluis, S., 2008. Strategic design of an energy saving game. Graduation thesis. Ind. Des. Eng. Delft University of Technology, Delft.

Wilson, C., Dowlatabadi, H., 2007. Models of Decision Making and Residential Energy Use. Annu. Rev. Environ. Resour. 169–203.

Wolsink, M., 2011. The research agenda on social acceptance of distributed generation in smart grids: Renewable as common pool resources. Renew. Sustain. Energy Rev. 16, 822–835.

Wood, G., Newborough, M., 2007. Energy-use information transfer for intelligent homes: Enabling energy conservation with central and local displays. Energy Build. 39, 495–503.

Zachrisson, J., Boks, C., 2012. Exploring Behavioural Psychology to Support Design for Sustainable Behaviour Research. J. Des. Res. 10, 50–66.

Appendices

A. Overview of research activities during the PowerMatching City project

The tablve below lists the research activities in PowerMatching City related to the experiences of the end-users participating in the pilot project.

ID number	Date(s)	Name/Description	Type of method #	Total respondents / participants	Goal / main topic of activity	Relation to other method (e.g. follow-up questionnaire)
A	2009	Inventory of households	Questionnaire 2	1	Gather basic information about the households, heating system, and energy consumption	
B	2009, Oct	Questionnaire before system implementation	Questionnaire in two parts: 1. Via telephone, 2. Via Internet	Part 1: 13 Part 2: 12	Gather basic information about households, as well as baseline concerning attitudes and values	
C	2009, Nov	Questionnaire functioning installations & energy portal	Written questionnaire	22 (Total 23, but one resp. is excluded because the household stopped their participation)	Gather information whether the installations were working properly and accessibility and visiting of the website	
D	2010, June	Design group meeting	Group discussion 6		Understanding the user-perspective (What happened in the homes?)	
E	2010, Sept	Satisfaction	Questionnaire 1	6	Measuring the end-user satisfaction	
F	2011, June 30th	Reaching goals questionnaire	Questionnaire (completing sentences)	12	Gain insight in whether and how households are able to reach their goals	
G	2011, June 30th	Social network map	Exercise + discussion	9	Gain insight in social interaction in the group of households	
H	2011, July-Sept	Evaluation of end-users' 1. use of the installations and energy portal, and 2. occurrence and interest in social interaction in the community	Interviews (semi structured)	16	Analysis of current interaction with home energy system, satisfaction with the system	
I	2011, Oct 6th	Gridshift - Simulation game	Game 1	2	Test game and discussion about the smart grid operation of PMC	

J	2011, Nov 9th	Co-design session community website	Co-design session 1	12 (to check), divided in four groups	Insight for design of community website	
K	2012, April 1th – January 2013	Community website	Design intervention	16 registered as user, of which 9 have posted	Enable social interaction among households	
L	2012, June 28th	Reflection on community website	Focus group	7	Feedback on community website. Also provided general info on experiences in PMC	Related to community website (K)
M	2012, October	Inventory household appliances	Inventory/questionnaire with table to fill in	16	Gain insight in household energy consumption	Combined with questionnaire (N)
N	2012, October	Questionnaire	Questionnaire (qualitative with open and multiple choice questions)	16	Gain insight in attitude, behavibra changes, experience and interests with active contribution to smart energy system	Combined with inventory (M)
O	2012, 14-15 Nov	Interviews PMC past and future	Interviews (semi-structured)	5 Low amount of respondents due to division of participants over several research activities in this month	1) Evaluation community website, (2) Evaluation of involvement participants in project. (3) Vision on future of smart grid in households	Related to community website (K)
P	2013, June	Questionnaire PMC2 baseline	Questionnaire	14 households, of which 11 filled in by both partners (or single when a single person household)	Baseline measurement for interventions in PMC phase 2. The information was used to complement and check information available from the inventory before system implementation in 2011 (research activity B).	

B. Crosstabs energy consumption – house type

Gas consumption (m^3)									
	1000-1500	1501-2000	2001-2500	2501-3000	3001-3500	3501-4000	**Total**	***Average per housing type for The Netherlands***	
Type of dwelling									
Semi-detached house	3	6	0	0	0	0	9	***2400***	*all households have below average consumption*
Detached house	1	2	4	2	0	1	10	***3100***	*most households have below average consumption*
Apartment	1	0	0	0	0	0	1	***1200***	*household has average consumption*
Total	5	8	4	2	0	1	20		

Electricity consumptoin (kWh)															
	1001 - 1500	1501 - 2000	2001-2500	2501 - 3000	3001 - 3500	3501-4000	4001-4500	4501 - 5000	5001-5500	5501 - 6000	6001-6500	6501 - 7000	Total	Average per housing type for The Netherlands	
Type of dwelling															
Semi-detached house	0	1	0	3	3	0	0	0	0	1	1	0	9	3950	most (7) households have consumption below average, 2 above
Detached house	1	0	1	1	0	1	0	2	0	3	0	1	10	4600	6 households have below and near average consumption , 4 above
Apartment	0	0	0	1	0	0	0	0	0	0	0	0	1	2250	Household has above average consumption
Total	1	1	1	5	3	1	0	2	0	4	1	1	20		

Source: Centraal Bureau voor de Statistiek, www.cbs.nl, retrieved via StatLine on 25 July 2013

C. Data screening procedure

In order to perform the energy balance analysis the collected data was first screened for missing data and errors. Additionally, data were corrected in order to make it usable for analysis. Missing data occured because of maintenance of meters or interruptions in the data communication process. For example, measurement data could be missing for a whole week or some days. The missing data could relate to one specific meter in a household or all the measurements in the household. In the latter case, the problem most likely occurred in the 'home energy computer'. Households for which data were missing for the whole data set (week or month) or a part of the data set were excluded from analysls. For a dataset of a week, three or more days with data were required for inclusion. For a data set of a month at least 25 days with measurments had to be available.
Measured values that were inconsistent within the range of data, were considered as errors. The data was screened and corrected semi-automatically for those errors in the process of calculating the values of energy consumption or production over a the 5 minute period between measurements, here referred to as 'absolute values'. In the data analysis the absolute values are used to determine the total consumption or production over a time slot of interest. In the resulting range of absolute values, deficiencies could be spotted as negative values that are not realistic because the kWh meters should always add up, or very large values connected to faults at the meters or failures in data transmission from the meters to the 'home energy computer'. An if code was used to fiiter the data set and applied to each cell of the data set. The if code is described as follows:

if cell value < 0 , then cell value = 0
cell value > a , then cell value = 0
else cell value = cell value

In this code a takes the value of 1 when the modification was performed for individual households and the value of 5 when performed for the whole cluster, µCHP group or heat pump group. Which means that when in the time slot of 5 minutes between the measurements, the consumption was higher than 1, respectively 5 kWh the measurement was excluded, because it was not likely that these values would be higher.
The result of the screening and correction of the data sets was that missing data points for households were identified, based on which during the analysis a household could be excluded from analysis when there was too much data missing for the analyzed period. Furthermore erroric data in the measurements were modified to minimize their impact on the data set and make the data ready for analysis.

D. Interview guides & questionnaires for research activities

Interview guide for research activity H

Semi-structured interview for evaluation of end-users' use of the implemented technology and occurrence and interest in social interactions in the community.

Gebruik van de installaties en de portal
1. Kunt u omschrijven hoe u de installaties en de portal gebruikt?
2. Ervaart u problemen in het gebruik van de installaties en de portal?
3. Wat zou u willen dat er verbeterd wordt aan de installaties en de portal?

Energiegedrag
1. Is uw energiegedrag de afgelopen 1, 5 jaar veranderd? Kunt u een toelichting geven? (Onder energiegedrag versta ik alle handelingen die u (on)bewust onderneemt om uw energieverbruik te volgen of te regelen)
2. Destijds heeft u aangegeven dat u wekelijks de gas, electriciteitsmeter en watermeter bijhoudt in een tabel. Is dat nu veranderd? Zo ja, hoe?

Doelen
1. In het telefonisch interview dat we met u afgenomen hebben in November 2009 heeft u aangegeven dat uw belangrijkste doelen waren: [In vullen o.b.v. eerdere antwoorden]
2. Welk doel zou u op dit moment willen bereiken met uw nieuwe installaties en portal?
3. Is dat voor u veranderd in de afgelopen 1,5 jaar? Kunt u dit toelichten?
4. Wat is op dit moment uw belangrijkste doel?
5. Bent u in staat dit doel te bereiken?
6. Wat heeft u daarvoor nodig?
7. In welke mate ondersteunt de techniek u in het behalen van uw doel?
8. Wat zou er aan de installaties en portal verbeterd moeten worden om u wel in staat te stellen uw doel te bereiken?
9. Is dat in de afgelopen 1,5 jaar veranderd? Kunt u toelichten hoe?

Learning loop
1. Wat heeft u in Powermatching City geleerd van uw energiesysteem?
2. Hoe denkt u dat de apparatuur werkt?
3. Hoe zou u willen dat de installaties werken?
4. Wat zou u willen leren van het systeem?
5. Zijn er volgens u ongewenste effecten van het gebruik van de installaties en de portal?

Sociale interactie en vergelijking mbt energieverbruik in PMC
1. Hebt u contact (gehad) met andere deelnemers buiten de deelnemersbijeenkomsten om?
Zo ja,
a. Wat was de aanleiding? (misschien kenden ze elkaar al?)
b. Hoe vaak en op wat voor gelegenheden?
c. Welke onderwerpen worden besproken? (PMC technologie/ energieverbruik algemeen / niet energie of PMC gerelateerd)
d. Is het contact er nog steeds?
Zo nee,

e. Kunt u een reden geven waarom niet?
2. Hebt u behoefte aan meer interactie met andere deelnemers over energieverbruik van uw huis en/of de installaties?
Zo ja,
a. Specificeer s.v.p. (energieverbruik en/of installaties).
b. In welke vorm? (bijv. via internet of persoonlijk > forum, facebook, bijeenkomsten, inloopspreekuur)
Zo nee,
c. Waarom niet?
3. Spreekt u met anderen over uw energieverbruik? Binnen ‘t gezin of ook daarbuiten (bijv. met deelnemers in PMC of anderen)?
4. Vergelijkt u uw energieverbruik met dat van anderen? Of zou u daar interesse in hebben? Op welke manier?

Questionnaire for research activity N
Questionnaire to gain insight in attitude, behavioral changes, experience and interests with active contribution to smart energy system

De volgende vragen gaan over hoe u momenteel thuis met energie omgaat en welke rol PowerMatching City daarin speelt.

1. In hoeverre wordt er nu bij u thuis gelet op het energieverbruik?
O Niet
O Weinig
O Neutraal
O Veel
O Heel veel

2. Bent u degene die het meest met energieverbruik bezig is?
O Ja
O Nee, ik doe dat samen met (één van) mijn huisgenoten
O Nee, iemand anders namelijk .... (bijv. partner, dochter, zoon)

Kunt u toelichten hoe zich dat uit in uw dagelijks leven? Wat doen u en/of uw huisgenoten? Hoe worden/zijn de eventuele huisgenoten daarbij betrokken?
....
....

3. Houdt u er rekening mee op welke tijdstippen u stroom verbruikt? Bijvoorbeeld voor dag- en nachttarieven, of wanneer er zonne-energie voorhanden is?
O Ja, ik/wij ....
O Nee, ik/wij ....

4. Gebruikt u momenteel een product of dienst om inzicht te kunnen hebben in uw energieverbruik, zoals bijvoorbeeld Plugwise, Toon of Wattcher?
O Nee
O Ja, namelijk ....

5. Lijkt het u nuttig om uw energieverbruik te kunnen vergelijken met andere mensen?
O Heel nuttig
O Nuttig
O Neutraal
O Niet nuttig
O Helemaal niet nuttig

Kunt u uw antwoord toelichten?
....
....

6. Zou u willen weten hoe uw energieverbruik en opwekking zich verhouden tot dat van andere PowerMatching City deelnemers?
O Nee, want ....
O Ja, wel anoniem, want ....
O Ja, hoeft niet anoniem, want ....

7. Door uw deelname aan het project kreeg u allerlei nieuwe apparatuur in huis zoals de warmtepomp of micro-WKK, en voor sommigen ook de slimme wasmachine en vaatwasser.
Nogmaals terugkijkend, heeft die nieuwe apparatuur van het PowerMatching City project uw gedrag in huis beinvloed?
O Ja, veel. Toelichting: ....
O Ja, enigszins. Toelichting: ....
O Nee. Toelichting: ....

8. Hebt u zelf nog aanpassingen gedaan in huis op het gebied van energieverbruik en opwekking sinds uw deelname aan het project? Bijvoorbeeld door energiezuinige apparaten aan te schaffen of te investeren in isolatie of zonnepanelen?
O Nee, want ....
O Ja, ik/wij hebben ....
Wanneer was dat ongeveer? ....

De huizen in PowerMatching City vormen samen een netwerk, waarbinnen kan worden afgestemd wat goede momenten zijn om energie te verbruiken en energie te produceren. Zo worden via de “PowerMatcher” uw slimme apparaten aangestuurd (de wamtepomp of micro-WKK, vaatwassers en wasmachines). Ook kan geregeld worden waar de opgewekte energie naar toe gaat (of eigenlijk wie het koopt), bijvoorbeeld naar andere deelnemers in PowerMatching City.

9. Hebt u het gevoel dat u met uw huishouden onderdeel bent van een lokaal energie netwerk?
O Nee, want ....
O Ja, want ....

10. Zoals hierboen staat geschreven draagt u bij aan het afstemmen van vraag en aanbod van energie in PowerMatching City. Hoeveel merkt u daarvan?

O Niet
O Weinig
O Neutraal
O Veel
O Heel veel

Licht s.v.p. uw antwoord toe:
....
....

11. Zou u hier meer of minder van willen merken?
O Minder, want ....
O Meer, want ....

12. In hoeverre zou u minder of meer actief willen deelnemen aan het slimme energiesysteem?
O Veel minder actief
O Minder actief
O Neutraal
O Actiever
O Veel actiever

13. In vervolg op het antwoord op vraag 13:
Wat verstaat u onder actiever of minder actief deelnemen?
Probeert u het s.v.p. zo concreet mogelijk te omschrijven.
....
....

Tot slot:
Zijn er nog andere zaken waarover u iets wil melden met betrekking tot deze inventarisatie en vragenlijst?
....
....

Hartelijk dank voor het invullen!

Sensitizer, Interview guide and images for research activity O

Semi-structured interview about the experiences in PowerMatching City with the project meetings, community website and about a future visions of the participants for local smart grids like PowerMatching City. A sensitizing assignment was sent by e-mail one week before the interview.

Interview guide

Sensitizer - voorbereiding interview

Het interview gaat over uw ervaringen in PowerMatching City, over de bijeenkomsten, de community website en uw aanbevelingen en ideeën voor de toekomst. Om u vast een beetje te prikkelen voor volgende week, vraag ik u om kort na te denken over het volgende:

BIJEENKOMSTEN & ACTIVITEITEN

> Bij wat voor bijeenkomsten bent u geweest de afgelopen tijd?
> Wat vond u de meest interessante of leuke bijeenkomst?

COMMUNITY WEBSITE

> Neem weer een kijkje bij de PowerMatching City Community online (powermatchingcity.wordpress.com). Wat komt u er tegen en wat spreekt u aan, dan wel niet aan?

TOEKOMST

> Denk terug aan al uw ervaringen in de PowerMatching City test. Wat is **de** aanbeveling die u zou willen meegeven aan het project?
> Stelt u zich PowerMatching City over 10 jaar eens voor. Veel meer huizen en buurten zijn dan uitgerust met technieken die vergelijkbaar zijn met wat u nu in huis hebt. Wat merkt u ervan u thuis en in de buurt?

Introductie
Interview over:
- hoe u nu in het project staat
- hoe u in het project betrokken bent
- de PMC community website
- en meer toekomst gericht: hoe u aankijkt tegen ‘community’ in een toekomstig slim energiesysteem
- Als er tijd over is aan het einde evt. uw installatie te bekijken.
- Onderdeel van promotie-onderzoek
- Gebruikers ervaringen in smart grid en manieren om gedragsverandering

te ondersteunen
- En daarnaast om aanbevelingen te kunnen doen voor dit project en vervolgpilots met slimme energietechnologie.
- Open gesprek. Het gaat om uw mening, dus zeg vooral wat u denkt.
- Duur: 1, max 1,5 uur

A – U & het energiesysteem van PMC Hoogkerk
U doet nu een paar jaar mee met dit pilotproject.
1. Kunt u aangeven hoe u nu in de test/het project staat?
Bent u tevreden?
Waarover wel, waarover minder/niet?
Prompt: Met betrekking tot de installaties/apparatuur...
Prompt: Met betrekking tot de communicatie rondom het project...
2. Geldt dat ook voor uw partner/gezinsleden? Hoe kijken zij er tegen aan?

B – Bijeenkomsten / activiteiten met deelnemers
U bent de afgelopen jaren op verschillende manieren betrokken bij het project. Informatiebijeenkomsten, ontwerpsessies, groepsdiscussies, de community website. Ik wil ingaan op die activiteiten en uw ervaringen daarmee.
Eerst over de bijeenkomsten.
3. Bij hoeveel bijeenkomsten bent u ongeveer geweest?
4. Wat voor/welke bijeenkomsten waren dat? [lijst bijeenkomsten]
5. Welke bijeenkomsten spraken u het meeste aan?
[informatie/uitleg | informatie verzamelen/onderzoek | discussie | mee-ontwerpen | game/spel]
Prompt: Welke vond u het leukst? Het interessantst?
Prompt: Wat had u eraan?
Prompt: Hoe ervoer u het contact met andere deelnemers?
Prompt: Welke informatie was voor u nuttig?
Prompt: Wat vond u van de bijeenkomsten waarin u over ontwikkelingen in het project werd gevraagd mee te denken?

6. Wat zou u aanbevelen voor bijeenkomsten in het vervolg van het project?
Prompt: Wat soort voor bijeenkomsten? Hoe zouden ze opgezet moeten/kunnen worden? Prompt: Wat voor programma? Welke onderdelen in het programma?
Prompt: Suggesties voor locatie?
Prompt: Suggesties voor planning? En organisatie?

C – Community website
In april is de “PowerMatching Community website” geïntroduceerd.
[afbeeldingen laten zien]
(Was u bij de introductie avond?)
7. Kijkt u er wel eens naar?
8. Wat betekent de site nu voor u? Wat vind u er nu van?
9. Wanneer zou deze website nuttig/waardevol voor u zijn?
Ik heb hier een paar prints, en een afbeelding met de elementen van de website. Zodat we wat meer in detail over de website kunnen praten.

10. Kunt u per menuonderdeel aangeven of u het nuttig vindt? Waarom wel/niet?

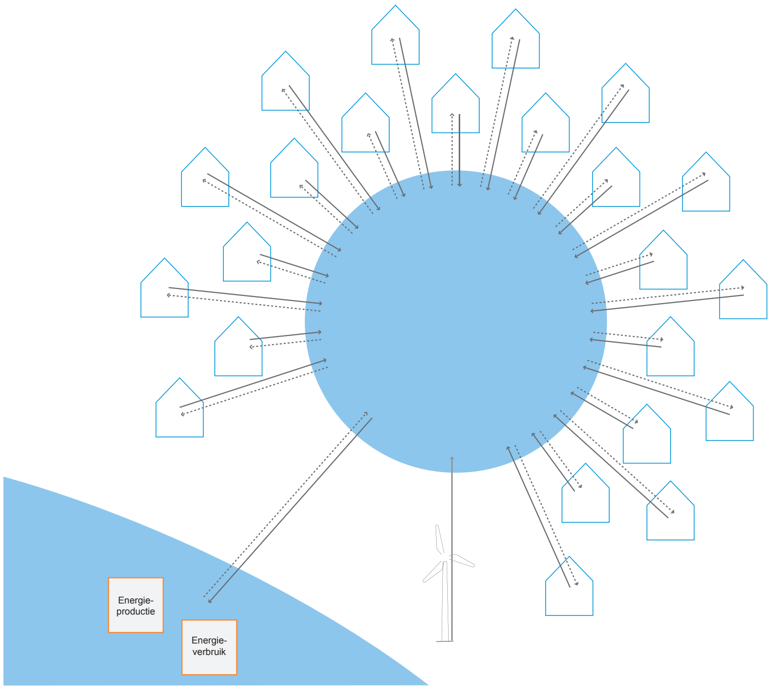
11. Wat zou u veranderen om het wel (of meer) nuttig/interessant te maken?
Prompt: Weglaten mag ook.
Prompt: Iets toevoegen? Of combineren met iets anders?
12. Om zelf berichten te plaatsen. Wat zou u motiveren (een aanleiding vormen) voor het schrijven van een bericht?
Prompt: Of een discussie starten / uitdagen andere deelnemers (als info voorhanden)?
13. Hebt u eigenlijk behoefte aan zo'n platform? Waarom wel / niet?
Prompt als positief: En wat voor vorm, of wat zou u daarmee willen doen/ of daarop willen vinden?
Prompt: Vergelijking met anderen?
Prompt: Ervaringen uitwisselen
Prompt: Tips delen
Prompt: Doelen stellen (bijv. doelen stellen, zoveel mogelijk PV benutten)
Prompt: Anderen uitdagen, samen doelen stellen

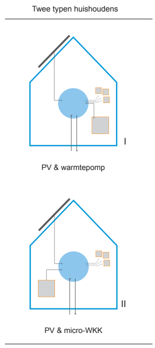
Uw suggesties kunnen mee in het vervolg. Het idee is om voorlopig deze website nog te houden en hem op den duur te vervangen voor een wat gemakkelijker te gebruiken systeem.
Voor communicatie project <-> deelnemer en deelnemer <-> deelnemer

D – Community (& energieberichten)
Ik wil iets meer ingaan op PMC als lokaal energiesysteem.
(uit vragenlijst:) De huizen in PowerMatching City vormen samen een netwerk, waarbinnen kan worden afgestemd wat goede momenten zijn om energie te verbruiken en energie te produceren. Zo worden via de "PowerMatcher" uw slimme apparaten aangestuurd. Ook kan geregeld worden waar de opgewekte energie naar toe gaat (of eigenlijk wie het koopt), bijvoorbeeld naar andere deelnemers in PowerMatching City.
Ik heb hier schematisch het cluster van huizen in PMC weergegeven.
In de vragenlijst hebt u aangegeven dat u niet echt merkt dat u onderdeel bent van een lokaal energiesysteem waarin vraag en aanbod wordt afgestemd.
14. Als we dat voor u inzichtelijk zouden kunnen maken. Hoe staat u tegenover het krijgen van informatie over de energiestromen in PMC, dus in het cluster?
15. Wanneer zou dat voor u relevant zijn?
16. Wat voor informatie zou u voor PMC verwachten?

Met de energieberichten op de community website heb ik een eerste poging gewaagd. In de zomer heb ik elke week, als het lukte, een overzicht van verbruik en opwekking in PowerMatching City als geheel geplaatst.
17. Wat vindt u van die overzichten?
Prompt: Begrijpt u ze?
Prompt: Wat hebt u aan deze informatie?
18. Wat zou er moeten veranderen aan de berichten? Wat zou u aanraden om ze te verbeteren?
Prompt: Zou een weergave die meer in deze richting gaat (zoals in deze afbeelding energiestromen) beter kunnen werken?

E – De toekomst
Er staat veel te gebeuren in PMC. De energiemonitor waar stap voor stap





aan wordt doorontwikkeld, een nieuwe groep deelnemers.
In mijn laatste e-mail heb ik het al gevraagd:
19. Als u terugkijkt: wat zou de aanbeveling zijn die u aan het team van PMC wil meegeven? (evt. top 3).

En een sprong naar de wat verdere toekomst, ook gevraagd in de e-mail:
20. Stelt u zich PowerMatching City over 10 jaar eens voor. Veel meer huizen en buurten zijn dan uitgerust met technieken die vergelijkbaar zijn met wat u nu in huis hebt. Wat merkt u ervan thuis en in de buurt?
Prompt: kunt u zich daar iets bij voorstellen?
21. U bent door deelname aan PMC ervaren met het 'smart grid' / slimme energietechnologie. Ik heb drie aspecten van energiesysteem voorleggen beschreven in extremen. Kunt u aangeven welke u het meest aanspreekt voor uw eigen situatie in de toekomst? En het toelichten? [markeren in 5-punts schaal]
a. gecentraliseerd systeem met grootschalige opwekking <--> decentraal systeem met kleinschalige opwekking
b. individueel <--> collectief/community (management van energiestromen)
c. geautomatiseerd <--> zelf doen (vgl. huidige situatie)

F - Afsluiting
22. Hebben we nog iets gemist in dit gesprek? Is er nog iets dat u kwijt wil?
23. Als er nog tijd is: mag ik uw installatie zien? Ik benieuwd hoe het eruitziet.

Hartelijk bedankt. Mocht u nog een vraag hebben later of nog wat willen aanvullen na dit gesprek, dan kunt u gerust contact opnemen.

E. Original quotes from interviews
In the main text quotes from respondents are used. These quotes are

translated from Dutch and in some cases adjusted to improve the flow of the text. Still, the author maintained the meaning of the text as close as possible to the original statements. The pieces of transcripts in Dutch that the quotes are based on are provided in this appendix.

Chapter 6 – End-users' empowerment as co-providers in PowerMatching City

Original text / Translation

1
De laatste ketel die draait nu een halfjaartje. Naar uiterste tevredenheid. Moet zeggen er mankeert niks aan, ik vind het vreemd maar hij doet het gewoon.
The last installation has been running for about half a year. I have to say, there's nothing wrong. It feels weird, but it's just working fine.

2
Ketel zit aan vloerverwarming vast, het heeft heel erg lang geduurd voordat het een beetje goed regelbaar was. We hadden in het verleden nooit een probleem. We zetten hem op 20 graden en het werd 20 graden, grotendeels in [via] de vloer[verwarming] en de rest werd vanaf de ketel [via de radiatoren] zeg maar uh [verwarmd]. Dat vind zij [partner] gewoon vervelend, logisch. Als de vloer niet warm wordt en de cv moet het warm zien te krijgen dat is gewoon een hele andere warmte.
The installation is connected with the floor heating and it took a long time before it was possible to control it well. In the past we have had a problem. We would set it to 20 degrees and it [the room temperature] would be 20 degrees, mostly via the floor heating. The rest would be heated by the radiators. She [partner] simply doesn't not like it, obviously. When the floor does not heat up and the radiators have to heat the space the heat is different.

3
... dit apparaat voor ons een te lage capaciteit is voor ons huis, omdat we het hier niet warm genoeg krijgen, met dit apparaat. De vorige ketel die ik had, had ik mijn kachel altijd rond de nou 19, 20 graden. Maar ik heb hem ehmm nu wel eens op 22 gehad. ...dat is niet wat ik gewend was.
...the installation has too low capacity for our home. It's not heating sufficiently. With the last installation I had, I would set the temperature to 19-20 degrees. But how, I've had it at 22 degrees. ... it's not what I was used to before.

4
[We verwachtten] dat we qua warmte comfort er een stuk op voorruit zouden gaan, zowel voor warm water als voor ruimteverwarming.
Die verwachtingen zijn voor de volle 100% uitgekomen. Ja, alle kamers worden nu warm, en we hebben een prima warm water voorziening.
Dit systeem warmt het huis sneller op. En dat is eigenlijk op de kamers waar we ook werken, dus bij de studeerkamer en de logeerkamer nog beter merkbaar dan beneden.
We expected that our comfort levels, in terms of heat, would improve a lot.

The expectation was “fulfilled for the full 100%.
Yes, all rooms are heated now and we have excellent hot water provision. This system heats up the house faster and we can feel that even better in the study and the guest room than downstairs [in the living room].

5
Vorig jaar hebben we iets van 400 euro terug gekregen op de energierekening, dus dat was geweldig. Of dat nu puur die Powermatching is of dat het gewoon is omdat het een hogere rendementsketel is die we anders waarschijnlijk ook zouden hebben gehad.
Last year we received a refund of about €400 on our energy bill. That was great. Whether it was purely because of the Powermatching or because it’s simply a more efficient heating system... Something we would also have invested in otherwise.

6
We hebben heel goed warm water, zowel voor douchen als gewoon gebruik in de keuken. Er is altijd water en goed van temperatuur. Dat was bij de vorige ketel niet, het kostte veel meer tijd voordat het er was, moest opgewarmd worden, terwijl het nu klaar staat.
The hot water is excellent, for taking a shower as well as for use in the kitchen. There’s always water and at a good temperature. We did not have that with the previous heating system, where it took more time for hot water to arrive. It had to be heated first. Now it’s directly available.

7
Het is sneller warm, dat kwam waarschijnlijk ook omdat onze vorige cv ketel boven was en deze zit echt naast de douche en naast de keuken. Dus de afstand is veel korter. Het is veel sneller warm en ik heb het idee dat het heter is.
It [the water] heats up faster. That may also be because our previous heating installation was upstairs. This one is next to the shower and next to the kitchen so the distance is much shorter. It heats up faster and it seems to be hotter as well.

8
Wat ik nog altijd zeer storend vind is dat er geen klokthermosstaat bij zit. Dat vind ik eigenlijk het grootste manco. Dat kan weer leiden tot inefficiënt gebruik want je kunt niet zorgen dat op ieder gewenst moment van de dag de temperatuur is die je zou wensen.
I still find it annoying that there’s no programmable thermostat. That’s the biggest problem [of the heating system]. It may lead to inefficient use, because you cannot make sure that the temperature is at the desired level every moment of the day.

9
Je kunt 1 vaste termijn verlaging instellen. Zeg 6, 7 of 8 uur, dat is nog wel eenmalig aan te geven en daar moet je het mee doen. Daar moet je dan rekening mee houden . Dus als ik ’s ochtends wegga om 8 uur, dan kan ik de ketel wel in zijn verlaging zetten, maar dan wordt het 8 uur later pas weer warm. Als er nou om 12 uur iemand thuiskomt, wat dan? Dus dan zet je de verlaging niet in. Hetgeen weer een hoger verbruik tot gevolg heeft,

dus dat vind ik niet echt fraai.
You can set [the thermostat to] a lower temperature for a fixed period. Say for 6,7, or 8 hours, you can that setting once [the duration] and then you'll have to work with it. So you have to take it into account. When I leave the house at 8 a.m., I can lower the temperature, but it will only heat up again 8 hours later. What if someone arrives at 12 a.m.? The result is that you won't lower the temperature, which thus results in higher consumption. So I don't really like that.

10
Dat is gewoon een rare waarde. Het is eigenlijk niet voldoende, want inderdaad als je morgens de deur uitgaat, ben je meer dan 6,9 uur van huis als je een normale werkdag hebt. Ook als normale nacht , er van uit gaande dat je hem dan ook bijtijds weer lager zet. Je moet hem niet lager zetten op het moment dat je in je bed ligt. Dat is ook een uur of 8 of zo. Dus je zou richting, 8, 9 a 10 uur moeten kunnen instellen, hoeveel uur je nou eigenlijk wil dat hij verlaagd is. Dus die 6,9 uur is een beetje gek. Het is dan inderdaad wel lekker, dat je morgens de deur uit gaat en dan die 6,9 uur. Dat betekent dat de verwarming middags om 3 uur zo onderhand aanspringt. Dan is het heerlijk warm als je tegen 5 uur, half 6 thuis komt. [maar eigenlijk al te vroeg warm]
It's simply a weird number [the duration of the stand-by function on the thermostat]. It's not sufficient, because when you leave in the morning and you're more than 6,9 hours away on a normal working day. And for a normal night, assuming that you turn it down again on time. You shouldn't use the stand-by function when you're going to bed because that's also about 8 hours. So the time period should be set to 8, 9 or 10 hours. So 6,9 hours is strange. It would be nice [warm] in the morning. When you set the stand-by function when you leave the house in the morning, it would switch back to higher temperature at about 3 p.m. At 5, 5.30 p.m. when you arrive back home it would be warm. [But it would actually be too early.]

11
Maar ehmm ja, hoe vaak wij wel niet in de winter, dat is nu nog niet het geval want hij is stookt ook niet zo, maar hoe vaak we 's avonds ook niet vergeten om ook om op dat knopje te drukken. Dus zodat hij 7 uur een wat lagere temperatuur heeft. Dat is legio. Omdat dat gewoon niet in de routine zit en ik weet dat die er nooit zal komen.
Well, how often in the winter, not now as the heating system is not being used for space heating, but how often we forget to press the button of the stand-by function in the evenings, so that the room temperature is lower for 7 hours. It's very often. It's not part of our routine and I know it will never be.

12
's Avonds ging hij [de vorige thermostaat] ook aan om vijf uur en ja om elf uur of half elf ongeveer ging ie automatisch uit tenzij wij nog visite hadden of nog in de kamer waren. Met deze is dat dus niet zo. Deze blijft gewoon langer aan. En die ander ging dus helemaal automatisch. En ik moet ook eerlijk zeggen ik vergeet deze ook vaak 's avonds uit te zetten. Maar dan moet ik hem dus op die nachtstand zetten en dan is het dat ie zeven uur verder pas aan gaat.

In the evening the [previous thermostat] would automatically switch on [to higher temperature] at five o'clock and back off [to a lower temperature] at about eleven o'clock, unless we had visitors or would still be in the room. With this one it does not work like that. This one simply stays on longer. The other one would function automatically. And I have to admit that I often forget to switch it off at night. Then I'm supposed to put it on night mode ['stand-by' function] and it would last seven hours before it switches on again.

13
Klopt, [hij heeft een webthermostaat] Dat heb ik [hem] gevraagd en die wilde ik ook. Die was helemaal niet zo duur en die kon hij dan via zijn Iphone bedienen. Maar dan heb ik thermosstaten in de kamer, want het maakt de bestaande niet overbodig. Dat vond ik nou weer niet zo'n goed idee
That's right. I asked him [about a programmable thermostat] and I wanted it as well. It's not too expensive. He could control it via his Iphone. But I have thermostats in the [living] room, and the programmable thermostat would make them redundant, which I didn't think was a good idea.

14
Er zit wat, doordat je deelneemt aan die proef, een wat afwijkend stookgedrag wat in die grafieken zichtbaar wordt, laat ik eens wat noemen, als ik inderdaad 's avonds, om een uur of 11 [naar bed ga] en om half 11 de verwarming een paar graden lager zet. Dan vraagt ie dat laatste half uur , dan vraagt de kamerthermosstaat niks meer. Dan ga ik naar bed en om half 12 hoor ik de ketel aan springen. Dat vind ik nou vreemd, er is geen warmtevraag in het huis en ik kan me niet voorstellen dat de energieprijs midden in de nacht zo hoog wordt dat men denkt: laten we eens alle turbines [μCHPs] aanzetten. Dus ik weet niet waarop het gestuurd wordt, maar zo werkt het dus blijkbaar. Het is niet helemaal inherent aan mijn eigen warmte vraag en mijn stookpatroon. ... De warmte die kan hij niet kwijt dus slaat hij op. De elektriciteit kan hij niet opslaan, dus moet hij leveren [aan het net]. In mijn huis er niemand die 's nachts nog erg veel stroom gebruikt. Dus de logica ontgaat mij.
Because of our participation in the pilot test, there's some abnormal heating behavior [of the heating system], which is visible in the graphs. Let me give an example, in the evening at 10.30 p.m. I turn down the thermostat a few degrees, so the thermostat would not ask for heat for the last half hour [before going to sleep]. Then I go to bed and at about 11.30 p.m. I hear the heating system switch on. I find it strange, there's no heat demand in the house and I cannot imagine that the energy tariff in the middle of the night is suddenly so high that they think [PowerMatcher]: let's switch on the μCHPs. So I don't know on what basis the control of the heating system takes place but it apparently works like this.
It's not very coherent with my own heat demand and heating pattern however...It cannot use the heat [to heat the house] so it will be stored. [..] The electricity cannot be stored, so it has to be delivered. In my house there's no one using a lot of power at night. So I do not understand the logic of it.

15
Je ziet dat de warmtepomp op de gekste momenten van de dag aan schiet. Ik weet niet of hij dat dan doet omdat er vraag vanuit huis is of dat de software dan zegt van ... Qua tijd zou het niet helemaal kloppen namelijk. Er is veel elektriciteit beschikbaar dus je kan nu zorgen dat vat vol raakt. Interviewer: Je wilt gewoon beter begrijpen wat er gebeurt en waarom het gebeurt? Respondent: Ja. Vanuit de klant gezien dan zou het gewoon prettig zijn als je de agents een beetje kan beïnvloeden in combinatie met leveranciers.
The heat pump switches on at the weirdest moments of the day. I don't know if it's because there's [heat] demand in the house or because the software says eh. With respect to timing it wouldn't be correct. [When] There's a lot of electricity available, you can arrange for the hot water tank to fill up.
Interviewer: You want to understand better what happens and why?
Respondent: yes, From a customer perspective it would be nice if you could influence the agents a bit in combination with the providers.

16
Wanneer ik een piek in het stroomverbruik zie kan ik niet goed zien waar het vandaan komt.
When I see a peak in electricity consumption I don't know where it comes from [what caused it].

17
In theorie weet ik hoe het werkt, maar ik zie de logische momenten waarop die gaat draaien niet. Het lijkt vrij willekeurig te zijn. Ik zie wel wanneer die aanslaat [in de grafiek]. Ik zie drie momenten vandaag. [...] Het zou wel mooi zijn als je tips krijgt, bijvoorbeeld dat als je het zo doet dan gebruik je het slimmer. Ik kan er niet mee spelen. [...] Het gebruik van installaties is onprettiger omdat als we hier aan draaien [een instelling wijzigen] weten we niet wat er gebeurt.
In theory I know how it works, but I do not see the logic moments [I do not see logic in the moments] that it [heat pump] switches on. It appears to be at random, I don't get it. I do see when it switches on. There are three moments today. [...] It would be nice to receive tips, for example that 'when you do this' your [electricity] use is smarter. I cannot play with it [...] The use of the heating system installations is less comfortable because when we turn this knob [adjusts a setting] we do not know what will happen.

18
Ik zou meer inzicht willen hebben in het functioneren van dat ding. Dus bijvoorbeeld een display of zo iets had ik eigenlijk op die warmtepomp willen zien. Bijvoorbeeld of hij aanstaat, wat hij doet en wat hij verbruikt. Wat meer actuele informatie hierover, wat de installatie verbruikt en wat ie levert. Daar is nu nauwelijks op te sturen door mij. Ik kan vanaf de website wel een maand terug kijken, maar dat is puur grafisch he. En altijd kijk je terug in de tijd. Als ik wil weten hoe mijn warmtepomp het doet, dan moet ik eigenlijk inloggen en naar het grafiekje kijken of hij elektriciteit heeft verbruikt. Op basis daarvan kan ik dan inschatten of hij het wel of niet heeft gedaan. Dat vind ik een beetje merkwaardig.
I'd like to have some more insight in how this thing works. So, let's say I

would have liked a display or so on the heat pump [to see] whether it's on, what it does, what it consumes. Some more real-time information about what the installation consumes and what it delivers. It's hardly possible for me to adjust to it / use the information. On the website [Energy portal] I can look back a month but there are just graphics. And you always look back in time. If I want to know how my heat pump is working I should actually log in and look at the graph to see if it consumed electricity, based on which I can estimate whether it was operating or not. I think that's a bit peculiar.

19
[naam van project teamlid] zei "Wij weten een paar uur van te voren wt er beschikbaar komt" Dat is is heel kort van te voren eigenlijk. Ja dat zou ik zelf ook leuk vinden [om te weten]. Nu weet ik helemaal niks. Het is echt een black box en dat vind ik heel erg jammer. Dat zou mij nog meer inzicht geven of de overtuiging. Mijn man wil bijvoorbeeld heel graag zonnepanelen. Ik vind dat helemaal niet mooi op het dak. Het past niet bij het huis, want daar gaat het om. Op zich sta ik er best wel achter, alleen... Als je via je portal kunt zien wat werkelijk de bijdrage is van zonnecellen en dat het een grote fundamentele bijdrage is...
Well, [name of project team member] said that they know a few hours in advance what will be available [energy]. That's quite short ahead. I would like to know that too. Now I don't know anything. It's a black box and I think that's a pity. It would provide me with more insight or conviction. My husband, for example, wants to have solar panels for a long time already. I do not like the way it looks on the roof. It does not match the house, and that's the point. I do support it, but... When you could see in the portal what the contribution of the solar panels is, and when its a substantial contribution...

20
Zodra die wasmachine en die vaatwasser bijvoorbeeld aangestuurd kunnen worden kan ik mijn bijdrage leveren door ze op een bepaalde tijd te vullen, de wasmachine en de vaatwasser en een tijd in te stellen waarop ik vind dat het klaar moet zijn. Die tijd kan natuurlijk heel ruim zijn. We werken hier allemaal, dus het hoeft niet op een bepaalde tijd klaar te zijn. ... Als ik bijvoorbeeld op de portal zou kunnen zien wanneer er een overschot is aan stroom dan zou ik kunnen besluiten dat ik nu beter even mijn wasdroger aan kan zetten dan dat ik een paar uur wacht.
As soon as the washing machine and dishwasher can be controlled [by PowerMatcher]. Then I can make my contribution by filling them at a certain time and set a time at which I think they should be ready. The time span [between filling and finishing] can be long off course. We all go to work here, so it does not have to be ready at a specific time.
For example when I could see on the portal when there's a surplus of electricity I could decide to use my tumble dryer now rather than wait a few hours.
[This household had the smart DW & WM]

21
Het leek ons leuk om mee te doen met het smart grid verhaal met apparaten erbij. Dat je op een bepaald moment gaat nadenken wat een gunstig moment is om ze te gebruiken. Het gaat ons niet om de kosten,

maar om we intelligent met stroom kunnen omgaan. In Nederland zijn er veel piekmomenten, het is ’s morgens druk en ’s middags van 4 tot 6. Het leek ons wel aardig.
We liked the idea to participate in a smart grid wit [smart] appliances, so that you’d think at some point what are favorable moments to use an appliance. The costs are not our priority, but how to use electricity intelligently. In the Netherlands there are many peak moments, in the morning and in the afternoon from 4 to 6. We liked the idea.
[This household signed up for the smart DW & WM, but was not selected]

22
Het zou een soort spel worden, waarbij ik door mijn gedrag het restitutiebedrag per maand zou kunnen beïnvloeden. Het gaat dan om heel weinig geld. Maar dan is het leuk, dan is daar een spel, waarbij je zodanig kunt sturen dat het effect heeft op de geldstroom. Maar gaat dat nog komen?
It was to become a sort of game, whereby I could influence the restituted amount [money] each month based on my behavior. It would be very little money. But it is fun; it’s a game in which your actions can affect your money flow. But will that still be realized?
[This household had the smart DW & WM]

23
Daar kon je je voor intekenen [voor de wasmachine en vaatwasser]. Wij hadden net een paar jaar daarvoor een nieuwe wasmachine gekocht. Dan doe je dat toch niet. Maar op zich was dat wel leuk geweest. Interviewer: En waarom? Respondent: Vanwege het spelletje, om te zien of het inderdaad bezuinigt en hoe zeg ik dat ... in het kader van energiebesparing en het milieu. Wat zou ik daar alleen aan kunnen doen. Interviewer: Ja, want hoe denkt u een bijdrage te kunnen leveren met de wasmachine? Respondent: Als dat ding op een gegeven moment draait wanneer het ergens heel hard gewaaid heeft. Er staan natuurlijk ergens windmolens en die zonnepanelen doen ook mee [...] Op het moment dat je dan het goedkoopste stroom en meeste stroom hebt om dan die dingen te gebruiken die je toch gebruikt.
You could sign up for it [smart dishwasher and washing machine]. We happen to have bought a new washing machine a few years before, so we wouldn’t do that. It would have been nice though [to have the smart dishwasher and washing machine]. Interviewer: Why? Respondent: From the perspective of the game, to if savings actually occur and, how do I say it... With respect to energy savings and the environment. What can I myself do about it? Interviewer: And how do you think you can contribute via the washing machine?
Respondent: Well, if it operates at a certain time when there’s a lot of wind ... there are wind turbines somewhere, and solar panels as well. [...] To use the appliances you would use anyhow at the times that you have the cheapest electricity and the most electricity [supply].
[This household did not opt for the smart DW & WM because they recently bought a new WM]

24
Zonder dat ik op de startknop druk doe ik hem dicht. Dan is ie, zeg maar, stand-by. Er is een kastje van Miele in de meterkast dat alle

elektriciteitsdraden in mijn huis af gaat en ziet: “daar staat een Miele en die staat op stand-by”. Die geeft dan weer een signaal af van [wanneer hij moet starten]. Hij zou binnen iets van zes uur moeten gaan lopen. ... 4 van de 5 keer loopt ie ook. Maar dan binnen het halve uur. Als ie dan niet loopt dan is ie gewoon uitgevallen. En dan loopt ie dus helemaal niet. Dus als je ‘m voor de nacht aanzet bijvoorbeeld, dan kan het zomaar zijn dat ie niet aan gegaan is. Dus heel vaak zetten we ‘m dan toch gewoon, met die knop, weer aan.
Without pushing the start-button I close it [the dishwasher]. It’s on stand-by then. A Miele box in the meter cupboard checks all the electricity wires in my house and notices: “ah, there’s a Miele appliance on stand-by”. The box then sends a signal [when it should start]. [...] It should switch on within about 6 hours. ... 4 out of 5 times it switches on within half an hour. And when it doesn’t, it usually fails and does not start washing at all. So when you turn it on it for the night for example, it might be that the dishes aren’t done in the morning. Thus, often we start the dishwasher in the morning.

25
Eigenlijk iedere avond als ik ‘m gebruik zet ik ‘m op de @Miele stand zodat je ‘m alleen maar op stand-by zet. Dan begint ‘ie zelf. De vaatwasser. De wasmachine heb ik nog nooit geprobeerd, want volgens mij werkte dat nog niet. Maar, ik heb het ook nog nooit geprobeerd eerlijk gezegd. De vaatwasser doet het goed. Alhoewel, de routine was eigenlijk al, ‘s avonds na 11 uur. Voor het naar bed gaan richt ik ‘m in en zet ik ‘m aan. Dan zit je eigenlijk al in het lage tarief. Dus in die zin merk ik ook dat hij binnen 5 minuten start als ik ‘m op de stand-by zet. Dat is eigenlijk bijna altijd zo. Een enkele keer heeft ‘ie het niet gedaan. Dat zag je’s ochtends. Dan is er iets misgegaan blijkbaar. Interviewer: En hij start bijna altijd binnen 5 minuten? Respondent: Ja. Als je ‘m na 11 uur aanzet start ‘ie eigenlijk altijd binnen 5 minuten.
Every night, when I use it, I use the @Miele setting [smart operation mode] with which you set the dishwasher to stand-by. Then the dishwasher starts automatically. I have not tried the washing machine, because I don’t think it already works. But, to be honest, I haven’t tried. The dishwasher works well, although, our routine already was to use the dishwasher at night after 11 p.m. So before going to bed, I would fill it and turn it on. Then you use electricity at the low night tariff. I also noticed that when I set it to stand-by, it usually starts within 5 minutes. A few times it did not work and something apparently failed. Interviewer: Does the dishwasher always start within 5 minutes? Respondent: Yes, when you turn it on after 11 p.m. it generally starts within 5 minutes.

26
Dat is op zich wel grappig want [...] de vaatwasser en de afwasmachine die konden we vroeger niet met de klok regelen zodat ie op het goede moment aanging. Met de kennis van PowerMatching City en wetende dat er ergens rond drie, vier uur ’s nachts [een goed moment is]. Dan laten we door de klok in te stellen de wasmachine en afwasmachine rond die tijd aanslaan. ... Dus we spelen eigenlijk de PowerMatcher na, door het zelf in te stellen.
It’s funny because we could not use a timer with the washing machine and the dishwasher before to run them at the right moment. With the knowledge of Power Matching City and knowing that around 3 or 4 a.m. [is

a favorable time] we use the timers to switch on the washing machine and dishwasher around that time. ... So we are actually acting as a PowerMatcher by planning the machine operation ourselves.

27
De wasmachine moest toch vervangen worden, dus ik heb zowel een droger als een wasmachine gekocht waar een timer opzit. Dus als er gewassen wordt, probeer ik dat ook zoveel mogelijk in de nachturen te doen.
The washing machine had to be replaced, so I bought a tumble dryer and a washing machine with a timer. So when we're doing the laundry, I try to do it at night.

28
Het gaat erom dat het nu wordt gevuld [vaatwasser/wasmachine] en we hebben het niet [meteen] nodig. Zeg maar morgen vroeg moet ie klaar zijn, dus dan zou het kunnen dat ie vannacht om 3 uur aangaat. Maar dan brandt mijn kachel dus niet. Dan gebruikt hij normale stroom terwijl tot 11 uur zelf stroom produceer en misschien niet alles opmaak. Het zou ideaal zijn om dan [terwijld] de kachel aan [is]... Dan zou je al de eindtijd om elf uur gaan zetten. Maar dat is voor het hele project misschien wel weer een te korte periode.
The point is that it [dishwasher / washing machine] will be filled now and we do not need it before tomorrow morning. Then it could switch on at 3 a.m. But my heating is not on [thermostat not set to high temperature], and the appliance would use normal electricity, while I have produced electricity myself until 11 p.m. and maybe did not use it all. It would be ideal to set the end-time therefore to 11 p.m. But that may be too short a time span for the project.

29
Ik kan alleen maar achteraf vaststellen wat ik verbruikt heb. Dan zou ik aan de hand daarvan moeten zien wat ik in mijn verbruik zou kunnen aanpassen. Dat is de vraag. Ik vind het moeilijk om aan te geven wat dat is [wat ik kan doen].
I can only see afterwards what I have consumed and based on that I should be able to see what adjustments I can make in my usage. That's the question. I find it difficult to know what to do.

30
De portal, er valt nog niks te tweaken of zo. ... Er zitten geen knopjes op de portal waardoor ik kan proberen hier in huis iets te optimaliseren of zo. Ik kan alleen achteraf kijken hoe laat ie [een apparaat] aansloeg of zo. Ik heb nog wel even naar het totaalverbruik gekeken. Maar verder heb ik er niet zo heel veel te zoeken.
The portal. It is not possible to tweak,...there are no buttons on the portal that allow me to optimize something in my home or so. I can only afterwards see at what time it [appliance] switched on. I have looked at the total consumption, but for the rest there's not much of interest for me.

31
Wanneer ik de plaatjes van smart grids zie, door publicaties of in de krant of iets van de KEMA. Dat is mooi, [weten dat] ik daar deel van uit maak. Of

als ik hoor dat anderen daar belangstelling voor hebben in de wereld. ... er is een televisieploeg geweest uit Korea
When I see images of a smart grid, by publications or in the newspaper, or [information] from KEMA. That is nice and I'm part of it. Or when I hear that others around the world are interested. ... There has been a visit by a camera crew from Korea

32
[Ik heb niet het gevoel dat ik onderdeel uitmaak van PowerMatching City]. Ik zie inderdaad helemaal niks. Want mensen met de micro-wkk, dat zouden mijn tegenpolen moeten zijn. Omdat ik natuurlijk verbruik [met de warmtepomp] en zij elektriciteit produceren. Dat is de basis van het smart grid, maar daar zie ik maar weinig van terug, behalve de theorie.
[I do not feel like I'm part of PowerMatching City] I don't see anything indeed. Because people with a µCHP, they should be my opposite. Because I'm consuming [with the HHP] and they are producing electricity. That's the basis of the smart grid, but I do not see it, except the theory.

33
Ik ben daar niet echt mee bezig. Ik weet wel hoe het werkt. Interviewer: Als het gaat om het matchen van vraag en aanbod heeft u het gevoel dat u daar een bijdrage aan levert? Respondent: Ja, maar ik doe daar niks in. Het is niet zo dat ik zie dat er aanbod is en dan dat ding ga aanzetten of zo. Of dat de prijs beneden een bepaald niveau komt. Dat gebeurt voor mij. Dat is prima en dat is ook logisch. Je moet dat automatiseren natuurlijk. Interviewer: Eigenlijk hebt u nu niet alle informatie die gaat over het smart grid? Respondent: Nee. Ik kan nog wel wat op de portal zien. Hoeveel er in totaal is opgewkt. Dan is het aardig om zien of we meer gebruikt hebben dan we hebben opgewekt of andersom. Daar kun je nog wel een link leggen. Interviewer: Wat denkt u dat als u het totaal ziet? Respondent: Nou dan zie ik dat een substantieel deel van wat we gebruiken in ieder geval ook wordt opgewekt. Dus dat is leuk.
I'm not very engaged with it, I mean, I know how it works. Interviewer: What I mean is that with regard to the matching of supply and demand, do you feel your contribute? Respondent: Yes, but I do not do anything for it. Not like I switch on the installation or the price drops below a certain level. It's arranged for me. That's fine and logical; it has to be automated off course. Interviewer: Actually you do not have all the information about the smart grid? Respondent: No. There's some information on the portal. The total production. So it's nice to see whether we've consumed more than we used or the other way around. So that links [to the smart grid]. Interviewer: What do you think when you see the total? Respondent: I see that a substantial part of what we consume is also being produced. So that is nice.

34
Bewust kiezen voor momenten waarop energie wordt gevraagd, inspelen op de mogelijkheid om gewenste energie aan het netwerk te leveren.
Consciously choose moments of energy demand, take advantage of the possibility to deliver the desired energy to the grid.

35
Zelf bepalen wanneer de micro-WKK draait (productie van elektriciteit).

Actiever ingrijpen op het energiesysteem, ook in relatie tot de stroomprijs (op the spotmarkt)
Decide myself when the µCHP is running (electricity production). More active participation in the energy system, also in relation to the electricity price (at spot market)

36
Prima zo. Het moet niet teveel tijd kosten.
It's fine like this. It should not take up too much time.

37
Ik vind het mooi als ik een slim energie systeem één keer moet instellen en dat het daarna zelf zijn werk doet.
I'd appreciate it when I have to set the system once and from then on the energy system operates by itself.
Chapter 7 Social interaction in PowerMatching City

1
We zien elkaar nog wel eens een keer op kantoor. Als je narigheid hebt met dat ding, dan heb je allemaal spannende dingen aan elkaar te vertellen. En lekker met elkaar klagen natuurlijk en ehh, janken dat het gefrustreerde gevoel van wat heb ik het toch zwaar. Dat is zeker het afgelopen halfjaar veel minder geworden. Als ie draait dan valt er ook niks over te vertellen. Dat is net zo als je auto wanneer die het iedere dag doet. Dan sta je helemaal niet verbaasd te kijken dat het zo fijn is dat mijn auto het iedere dag doet.
We happen to see each other at work. Especially when you've got trouble with the unit, there are all kinds of exciting issues to discuss. And complaining of course, crying about how hard it is. Last year that has definitely been much less. When it's all functioning properly there's not much to talk about. It's like your car, when it's working well, you're not surprised at all that your car is working well every day.

2
Omdat die van ons stuk was. Op een gegeven moment dan vraag je van "hoe is het bij jullie, bij ons is het niet positief". Toen bleek dat zij ook haar tweede [installatie] had. Dus daar praat je dan over.[Contact met iemand die in de buurt woont]
Because our installation was broken we asked someone else how it worked out for them and explained our system was not working well. We then heard that she [a person living nearby] also had a second installation. So that's what we talk about. [Contact with a person living nearby]

3
Dat ging met name over het gasverbruik van de ketel. Interviewer: Ok. Want zij hebben de zelfde ketel? Respondent: Ja. Interviewer: En toen kwam u er ook achter dat jullie veel meer gebruikten dan … Respondent: Ja.
The contact was about the gas consumption of the installation. They have the same installation. And that's how we found out that we used much more gas than them.

4
Je hebt de temperatuursinstelling van de kamertemperatuur, maar je kan dat ook regelen op basis van watertemperatuur. [We hebben dat geprobeerd, om te zien:] wat gebeurt er dan met je gasverbruik. Dat ging hartstikke hard! Dus zijn toch maar weer naar die andere [deelnemers] toegegaan. Dan wisselde je ervaringen uit over het systeem. Dat was met name de 1e maanden dat het zaakje draaide.
The temperature can be controlled for the room temperature, but also for the water temperature in the system. We tried if that would work and looked at how it affected gas consumption. Well, that turned out to be much higher! So we contacted other participants and well, exchanged experiences with the heating system. That happened particularly in the first months after installation of the system.

5
[We hadden contact] met de buren. Bijvoorbeeld over dat verwarmingen gedoe. Op het werk ook wel. Ik weet ook dat er huishoudens zijn die zogenaamde elektriciteitsdagen hebben. Maar dat is ook een beetje om te voorkomen dat kinderen teveel achter een beeldscherm zitten. [Ik praat er ook wel over met] mijn vriendin en mijn ouders. Hoe hoog je de verwarming zet en hoeveel je verbruikt, hoe is je huis geïsoleerd is of over wat bijvoorbeeld een houtkachel kan schelen [in energieverbruik / kosten].
[We talked] with the neighbors. For example about the problems with the heating systems. Also at work I talk about it. ... And with my friend and my parents. About how high to set the temperature, their consumption levels, whether their house is insulated or even if using a wood stove could help save energy.

6
[Met de overbuurman] bijvoorbeeld. Ik noteer de meterstanden en soms is er iets geks te zien. Bijvoorbeeld, er veel of weinig verbruik. En met de jaarrekening natuurlijk over hoe het afgelopen jaar is gegaan. Of je moet bijbetalen of geld terug krijgt. Dat soort dingen.
With my neighbor for example. I record the meter readings and sometimes discuss it when something strange occurred, like very high or low consumption levels. And with the yearly bill of course, to discuss how it went last year. Whether you have to pay extra or receive money back. That kind of topics.

7
Met collega's. [Bijvoorbeeld,] een collega die een veel oudere woning heeft vraag ik naar zijn energieverbruik. [...] met de buurman heb ik het er weleens over gehad, wat zijn verbruik is. [...] tot nu toe kom ik met de conclusie dat wij een vrij laag energie verbruik hebben. Wat het gevolg is

van dat we hier in een vrij moderne woning zitten, zwaar geïsoleerd. Een heel comfortabele woning.
With colleagues. I asked a colleague with much a much older house what their energy consumption is. [...] Or with the neighbor I've discussed his level of energy consumption. In comparison we have relatively low energy consumption, which is due to our rather modern and well-insulated house. A comfortable house.

8
Als het zo uitkomt ja. Ik vind verwarmingsinstallaties leuk dus als het zo uitkomt dan heb ik het erover. En als iemand langskomt. Ik heb het ook aan de buren laten zien.
When the theme happens to come up I talk about it. I like heating systems so when the topic comes up I talk about it. Also when someone is visiting. I've also showed it to the neighbors.

9
Ja, regelmatig. Het is niet echt dagelijks, maar we praten ook over installaties [Dit is gerelateerd aan ons werk]. We vinden het gewoon leuk om er over te praten.
[Met anderen delen we informatie over] de werking van het systeem. Voor heel veel mensen is het vreemd. Bijna niemand kent het. [...] De meeste mensen zijn wel geïnteresseerd. We vertellen hoe het werkt dat je je eigen energie opwekt [met dit systeem].
Yes, regularly. Not every day, but we do talk about installations. [It's related to our work]. We like talking about it. We discuss how the system works. For many people it is a new system. Hardly anyone knows about it. [...] Most people are interested and we explain them how it can be that you produce your own electricity.

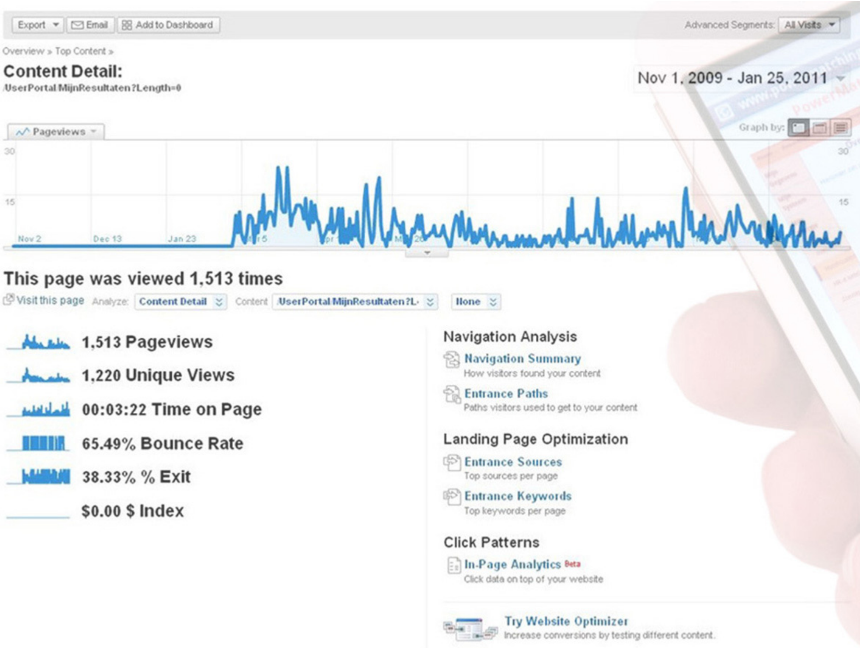
10
We maken regelmatig gewag van het feit dat we zo'n apparaat hebben. Dan vragen ze altijd: "waarom heb je zo'n apparaat?" Dan leggen we dat uit. En "scheelt dat ook nog wat?" "Ja. het scheelt ook nog wat". Dus wij verkopen hem redelijk naar anderen toe. Vooral als je zegt dat je 400 euro hebt terug gekregen [op de energierekening].
We regularly tell others about the installation we have. Then people always ask why and whether you can save energy. We explain them and tell them that we've received back €400 on our energy bill the first year. So, we're promoting it to others.

11
Ik vind het idee goed. Het komt tegemoet aan de behoefte die er in ieder geval bij mij wel is om dingen met elkaar te delen. Alleen ik merk wel dat ik in de praktijk niet of nauwelijks er naar kijk. Het ontsnapt aan mijn aandacht. Op een of andere manier zit er een behoefte bij mij om daar gebruik van te maken, maar in de praktijk gebeurt het niet.
I like they idea. It addresses a need I have to share with things with others. But I notice that, in practice, I do not or hardly look at it. It escapes my attention. Somehow I feel the need to use it, but in practice it does not happen.

12
Ik had daar hele ideeën om daar [de community website] actief wat mee te gaan doen. Na jouw vraag van "wie doen er eigenlijk allemaal mee [in PowerMatching City]" heb ik toen een antwoord geschreven. Eerlijk gezegd heb ik daarna een keer naar zo'n energiebericht gekeken, van "hoe zit dat eruit?". Of een keer naar een vraagje dat iemand stelde. Maar daarbuiten heb ik er weinig aan gedaan. dat heeft waarschijnlijk ook te maken met dat, ik maak onderdeel uit van een netwerk, maar ik merk er niet zoveel van en ik hoef er niet zoveel voor te doen. Dus wat ik zou niet weten wat ik daar verder nog over zou moeten schrijven.
I had big ideas about becoming actively involved [in the community website]. After on your question "who are the people participating [in PowerMatching City]?" I wrote a response. To be honest, after that I may have looked at an energy report once, out of curiosity what it would look like. Or at a question someone had asked. But besides that, I haven't done much. Probably it has to do with that we're all part of a network but I don't notice it much and I do not have to do anything for it. So I wouldn't know what to write about.

F. Visits to 'My Energy' section of Energy Portal

The data that was available, taken from a PowerPoint presentation:



The website views started end February 2010 (based on the graph), so there is approx imately 1 year (12 months) of website views

12	months						
1513	page views	126,1	views per month	4,2	per day		
1220	unique views*	101,7	views per month	3,4	per day	23,5	per week
22 households		4,6	views per month per household	0,2	views per day per household	1,1	views per week per household

*Uni ue views: one visit which can include viewin of several a es calculated with Goo le Toolin

G. GridShift simulation game

Gridshift is a game about smart grid technology at the household level. The goal of the game is twofold. Firstly, the aim is to let people experience demand response in a smart grid context based on time-varying pricing. The second goal of the game is to start a discussion about the perceptions, demands and wishes of end-users for 1) the involved technologies and related products and services and 2) the potential roles of households connected in a local smart grid.

Starting point for development of the game was the observation that participants in PowerMatching City appeared not to understand very well how the smart energy system of PowerMatching City functions and that they were eager to experience more of the smart energy system. A game could provide a means for the participants to experience the smart grid in operation with dynamic tariffs.

The game is set-up as a board game for six players (or six teams of two to three players) and supported by computer for simulation of dynamic tariffs and score-keeping (in MS Excell). In a number of rounds the players can invest in their appliances to become 'smart' and more efficient and they can invest in wind and solar power. The use of appliances results in victory points, but their energy consumption has to be paid for. To win the game, a player has to gain most victory points, while staying within budget.

The presentation on the next page introduces the rules, as they are presented to the players at the start of the game session. The final slides are used after the game for the debriefing of the game and discussion.

The game was initially developed and tested as part of a Game Design course at Delft University of Technology and elaborated afterwards for a game session with participants of PowerMatching City and students participating in an energy conference. The first experiences with the game provided sufficient insight for the research in this thesis. Further development of the game concept is recommended for larger scale application.

The initial game concept for GridShift was designed by S.Oruç, S. Meijer, D.Geelen and N. Pahlavan in 2011 as part of a Game Design course at the facutly of Technology, Policy and Management, Delft University of Technology, and was further elaborated S.Oruç, S. Meijer, D.Geelen.

Gridshift game instructions and debriefing (presentation):

Welcome to

GridShift

A game about changes in our energy use at home

Programme:
- Introduction
- Play
- Discussion

Gridshift EDC 2011/KEMA - November 23, 2011 TUDelft

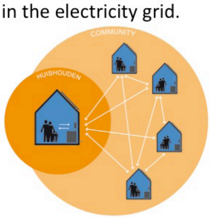
A changing energy system

Production and distribution to be improved:
- Efficiency
- Resilience
- Integration of renewable energy sources
- Decentralized generation (and consumption)

Gridshift EDC 2011/KEMA - November 23, 2011 TUDelft

You will be 'prosumers'

Production and consumption in your home contributes to balancing demand and supply in the electricity grid.
- Demand reacts on supply
- Variable tariffs
- Up to community level



Gridshift EDC 2011/KEMA - November 23, 2011 TUDelft

Gridshift

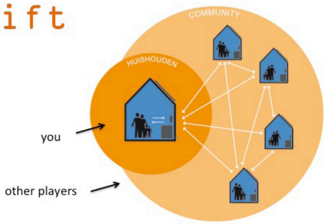
Imagine:
Power Matching City becomes Power Matching Europe

Variable tariffs have been implemented
Based on:
- Available energy mix
- Energy demand in the local network

What does it mean for your household?

Gridshift EDC 2011/KEMA - November 23, 2011 TUDelft

Gridshift

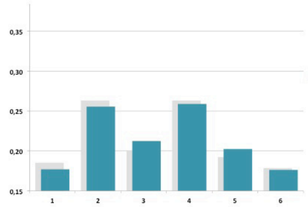


Goal:
Manage your energy consumption with variable tariffs.
Win by gaining most points.
But: stay within your budget

Gridshift EDC 2011/KEMA - November 23, 2011 TUDelft

Gridshift

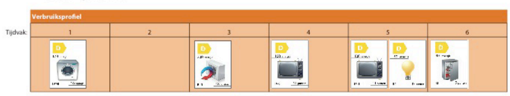
Tariffs per time slot



Gridshift EDC 2011/KEMA - November 23, 2011 TUDelft

Gridshift

Your household
- User profile

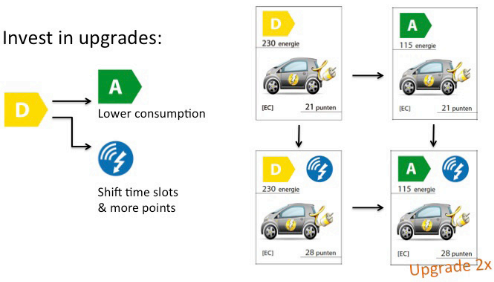


- Initial capital (2500) to spend on:
  - Energy bill
  - Investment

Gridshift EDC 2011/KEMA - November 23, 2011 TUDelft

Gridshift

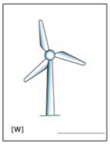
Invest in upgrades:



Gridshift EDC 2011/KEMA - November 23, 2011 TUDelft

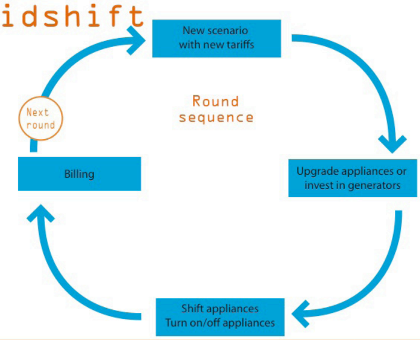
Gridshift

Invest in energy generators



Your production: discount on energy bill

Gridshift



Gridshift

On screen:

- Scenario
- Tariffs
- Costs

Gridshift - Ronde 1

Nieuws van de dag

Met name fossiele brandstoffen

Beschikbaarheid / Energiemix

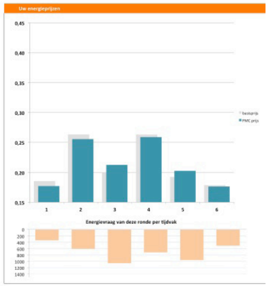
100 % Beschikbaarheid
0 % Wind
0 % Zon
100 % Olie & gas
0 % Kernenergie

Cijfers deze ronde

	Familie Eco	Familie Kantoor-aan-huis	Meneer de Student	Mevr. en Mnr. Pensionado	Fam. Hightech	Mevr. Single
Kosten						
Energierekening	143	156	148	158	150	157
Korting eigen opwekking	0	0	0	0	0	0
Investering	0	0	0	0	0	0
Totaal uitgaven	143	156	148	158	150	157
Verbruik en puntenscore						
Energieverbruik	700	700	700	700	700	700
Score	71	71	71	71	71	71

Tussenstand

Totaalscore	0	0	0	0	0	0
Vermogen (balans)	3500	3500	3500	3500	3500	3500



Gridshift

Let's play…

Gridshift Discussion

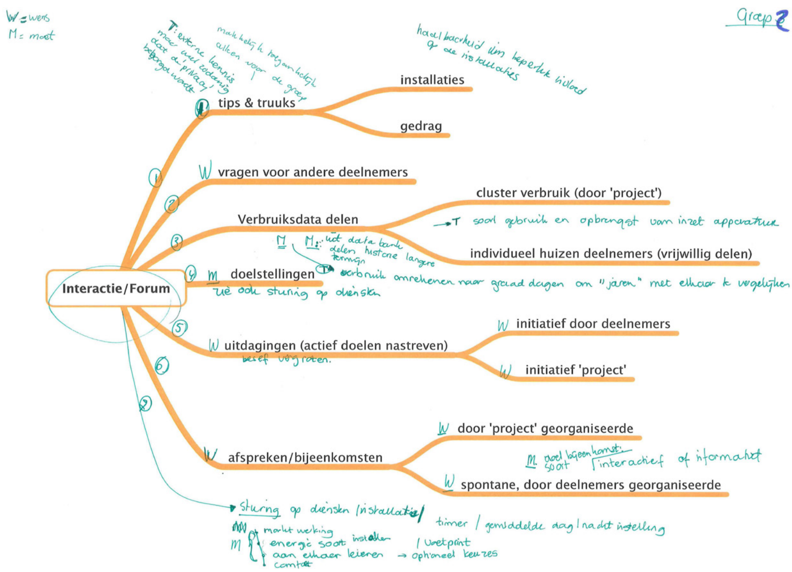
a. Experiences
   - What struck you most?
   - What did you learn?

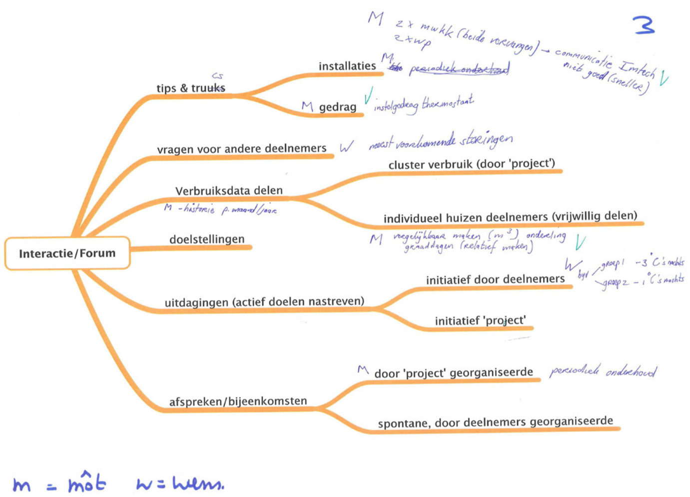
b. How do you see your role (activities) as a household in a smart energy system

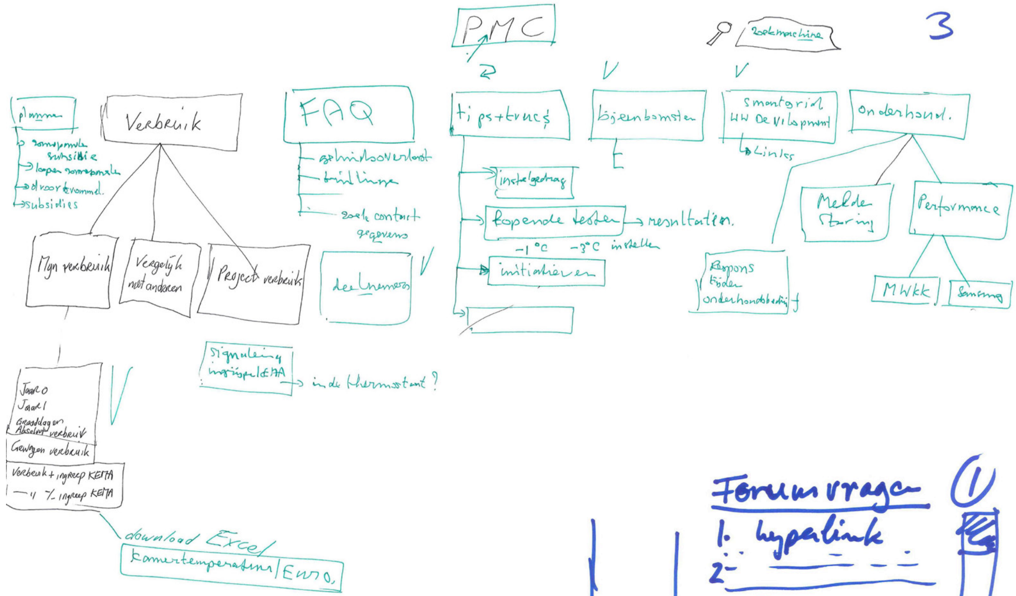
c. Suggestions for the game itself

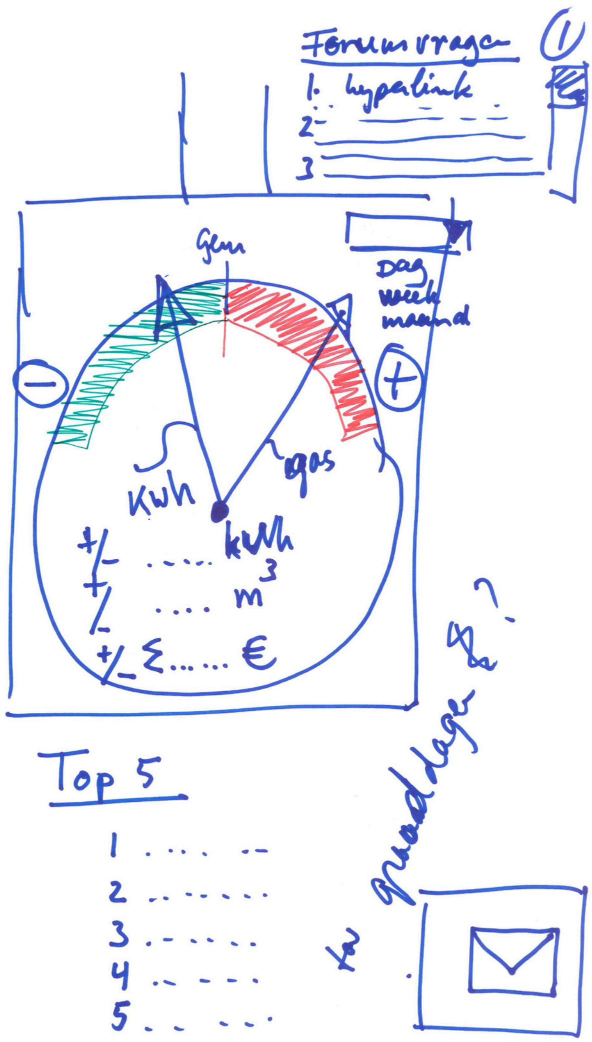
H. Results of design session community website

Commented mindmaps and concept designs for online platform









groep 2

extra smoelboek
groeps + huis
opstssamenstelling

inloggen eenvoudig
voorwaarde
voor gebruik

Interactie / forum

• toegang door apps

Algemeen
project informatie

(1) discussie voor verschillende topics (warmtepomp / MWKK)
→ inzetten verschillende kennis groepen
↖ kema
kennis groepen
+ andere deelnemers

(2) onderdeel opnemen in forum

(3) elkaar voor elkaar beschikbaar, resultaten kunnen in de
tips / trucks discussie gevoerd worden

(4) geprognotiseerde gebruik tov.

(5) effect willen zien van wat je onderneemt (bij punt 7) bijv. gebruik
zonne panelen
• jaarbasis % inzetten van soorten stroom | doelstelling kosten / comfort /

6

(7) zie plaat. → dient op wijk niveau

Knoppen

groep 2

vraag +
antwoord
gebruikers

high-light
van de week:
wat viel op deze week
in het project.
input KEMA.

tips + trucs voor
"uitgaand"
uitwisselen.

Draait KEMA
aan de knoppe ??
wat merk ik daarvan.

achtergrond info over
het systeem in huis.
Hoe leg ik het aan de familie uit
Tip + Jannelien (?) laat

comfort-slide:
- opwarmsnelheid / bijspringen 2e
- klokthermostaat / functies

invloed APX prijzen
en fluctuaties in beeld
brengen
relatie met Grid zichtbaar maken.

Effecten laten zien van
verschillende systemen.

I. Overview of activity on community website and page views

(continued on next pages)

Month	Week nr (Sunday as first day of the week)	Date	Activity (Between brackets is indicated who wrote a post. [DG]: author of this thesis, [PM#]: Project team member, [hh#]: household number)	Amount of comments to a post	Amount of posts in a week	Amount of comments to the posts in total	Page views per week
April	15	10-04-2012 10-04-2012 11-04-2012 11-04-2012 11-04-2012 11-04-2012 11-04-2012 11-04-2012 12-04-2012 13-04-2012 13-04-2012	Post "Welkom" [DG] Post "Wie doet er eigenlijk allemaal mee?" [DG] **Introduction of community website (meeting)** Post '(no title)" [PM1] Post "Smart Grid = Sim net" [hh L-HHP] Post "Een leerzame avond" [hh M-HHP] Post "Voorbeeld" [DG] Post "IMG-20120411-00018" [PM1] Post "Test" [PM2] Post "Informatie over Slimme meters" [hh M-HHP] Post "Community website gelanceerd - een kort verslag" [DG]	0 0 NA 0 1 0 0 0 0 0 0	11	1	575
	16	16-04-2012 20-04-2012	Post "Gebruiksaanwijzing slimme meter" [hh T-HHP] Post "Aanvulling op: Gebruiksaanwijzing slimme meter" [DG]	1 0	2	1	110
	17	27-04-12	Post "Contact Enexis ivm storing na montage slimme meters" [hh R-HHP]	0	1	0	128
May	18	03-05-12	Post "Even voorstellen: Daphne" [DG]	0	1	0	22
	19	11-05-12	Post "Contracten PMC fase II" [PM3]	0	1	0	34
	20	14-05-2012 14-05-2012	Post "Even voorstellen en een vraag over zonnepanelen" [hh J-µCHP] Post "<naam> & <naam>. Wie zijn wij?" [hh M-HHP]	0 0	2	0	108
	21	24-05-12	Post " Even voorstellen <naam> " [PM1]	0	1	0	25
June	22	31-05-12	Post " Uitbreiden van PowerMatching City" [PM4]	0	1	0	137
	23	08-06-12	Post "Energieberichten" [DG]	0	1	0	25
	24	12-06-2012 15-06-2012 15-06-2012	Post "Wie van de deelnemers gaan er mee naar de 2e fase?" [PM3] Post "Bericht verwijderd" [DG] Post "Energiebericht - April en Mei"[DG]	0 0 0	3	0	50
	25	20-06-2012 20-06-2012 22-06-2012	Post "Energiebericht – week 22 (27 mei – 2 juni)" [DG] Post "Energiebericht – week 23 (3 – 9 juni)" [DG] Post "Ervaringen met de Whispergen" [hh G-µCHP] Post "Inzicht in de meterstanden van de slimme meters" [hh C-µCHP] Post "Energiebericht – week 24 (10 -16 juni)" [DG]	0 0 5 0 0	5	5	86

Jully	26	28-06-2012 29-06-2012 30-06-2012 30-06-2012	**Feedback session community website (focus group - meeting)** Post "Succesvolle bewonersavond bij DNV KEMA" [hh A-μCHP] Post" PowerMatching City als duurzame topoplossing tijdens Rio+20" [DG] Post "Energieberichten - update" [DG]	NA 1 0 0	3	1	231
	27	03-07-12	Post "Wat levert teruglevering van stroom op?" [hh G-μCHP]	3	1	3	24
	28			0	0	0	14
	29	18-07-2012 19-07-2012 19-07-2012	Post "Energiebericht – week 25 (17 – 23 juni)" [DG] Post "Energiebericht – week 26 (24 – 30 juni)" [DG] Post "Energiebericht – Week 27 (1-7 juli)" [DG]	0 0 0	3	0	44
	30			0	0	0	8
August	31	01-08-2012 01-08-2012 02-08-2012 02-08-2012 03-08-2012 03-08-2012 03-08-2012 04-08-2012	Post "Update uitbreiding PowerMatching City" [PM4] Post "Energiebericht – week 28 (8-14 juli)" [DG] Post "Energiebericht – week 29 (15-21 juli)" [DG] Post "PowerMatching City wereldnieuws" [hh A-μCHP] Post "Foutmeldingen op Whispergen" [hhA-μCHP] Post "Met een Smile het energieverbruik uitlezen op je smartphone" [hh A-μCHP] Post "De zon schijnt 'voor niets' " [hh A-μCHP] Post "Energiebericht – week 30 (22-28 juli)" [DG]	4 0 0 0 7 0 2 0	8	13	144
	32	09-08-2012 09-08-2012	Post "Energiebericht – week 31 (29 juli – 4 aug)" [DG] Post "Virtuele zonnepanelen" [DG]	1 0	2	1	32
	33	17-08-12	Post "Energiebericht – week 32 (5 – 11 aug)" [DG]	0	1	0	125
	34	21-08-12	Post "Energiebericht – week 33 (12 – 18 aug)" [DG]	0	1	0	1
September	35	01-09-12	Post "Energiebericht – week 34 (19 – 25 aug)" [DG]	0	1	0	14
	36			0	0	0	30
	37	10-09-2012 14-09-2012	Post "Laatste Energiebericht" [DG] **Research activity: Questionnaire household appliances inventory sent out (questionnaire)**	0 NA	1	0	18
	38			0	0	0	8
	39			0	0	0	13

October	40			0	0	0	27
	41			0	0	0	15
	42	18-10-12	Post "Even voorstellen" [PM5]	1	1	1	46
	43	25-10-12	**Research activity: Gebruiksonderzoek Energiemonitor concept (meeting)**	NA	0	0	61
November	44			0	0	0	7
	45			0	0	0	8
	46			0	0	0	42
	47			0	0	0	0
December	48			0	0	0	0
	49			0	0	0	4
	50	11-12-12	Post "Verslag Gebruiksondezoek Energiemonitor" [PM6]	0	1	0	55
	51	20-12-12	Post "Nieuwsbrief 4 - December 2012" [PM5]	3	1	3	35
	52			0	0	0	6
January	1			0	0	0	42
	2	06-01-2013 06-01-2013	Post "Portal eruit?" [hh T-HHP] Post "Wat is jullie energieverbruik?" [hh A-μCHP]	5 7	2	12	136
	3			0	0	0	19
	4			0	0	0	46

J. Overview & categorisation of posts by end –users on the community website

Categorisation of posts by end-users on the community website and the amount of comments to the posts

Categorisation of posts by end-users on the community website and the amount of comments to the posts

	Posts	Comments		Posts	Comments		Posts	Comments		Posts	Comments		Posts	Comments
Request for information			Sharing experiences			Sharing energy consumption and production information			Introducing oneself			Other		
Manuals - Smart meter - Error codes μCHP	3	 0 [a] 7	Related to technical problems (and how they were solved)	2	1	Consumption Year overview Incl. Offer to help make overviews with degree days	2	11 I	ntroduction	2	12 [b]	Report of a meeting	1	1
How does it work - Feed-in tariff - Access to meter reading	2	 3 0	Reporting failure, question if others have the same problem	1	5	Production - by own PV system	1	2				News - PMC in the media - New product on the market for feedback via smart meter	2	0
Project developments - PV systems	1	2										General discussion on Smart grids	1	1
Total 6			3			3			2			4		

[a] Response in a new post

[b] Five of these comments are serious comments. Three comments were made by participants introducing themselves and one comment comments on one of these introductions. The other seven comments were made by means of a test when people managed to access the website.

NB three posts were assigned to 2 categories. One post was excluded from this overview because it was a 'test' post. Therefore the total adds up to 18 instead of 17, the amount of osts b artici ants.

K. Energy reports

In addition to the analysis of the measurement data for quantitative insight in the energy balance of PMC, the collected measurement data was used to make weekly Energy Reports for the households. These reports contained information about the energy consumption and production of the cluster of households over the previous week. The reports were made available to the participants via the community website.
The production of energy reports was done for two reasons. Firstly, they could provide end-users with community-level information about the consumption and production in the cluster, complementary to the existing Energy Portal. Secondly, the posting of the reports generated activity on the community website.
The reports were developed gradually as the data analysis progressed, based on the available data and resources for producing the reports. an example of the energy report of week 34 is included on the following pages.

Publicatie 31/08/2012

Energiebericht week 34

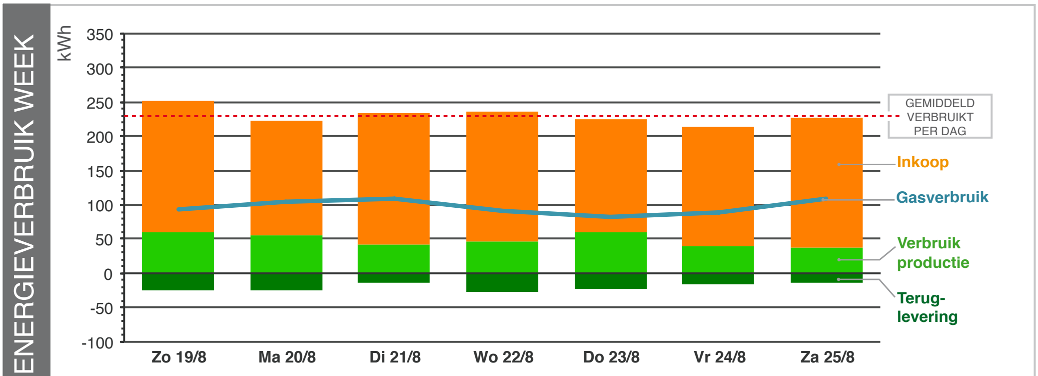
19 t/m 25 augustus 2012

Deze week was vergelijkbaar met de week ervoor. U verbruikte voor een groot deel uw eigen opgewekte zonne-energie. Uw wekte iets minder op en verbruikte juist iets meer. Voor de zondag, waarvoor we een overzicht van de dag maakten is goed te zien dat u overdag ook grotendeels die opgewekte energie benut.

In dit bericht vind u een overzicht van de PMC community als geheel, incl. dagverloop (pag. 1 - 3), een specificatie voor de huizen met micro-WKK (pag. 4 - 6) en een specificatie voor de huizen met warmtepomp (pag. 7 - 9).

Hebt u vragen, opmerkingen, suggesties?
We horen ze graag via de community website:
powermatchingcity.wordpress.com,
of een e-mail naar Powermatchingcity.GCS@dnvkema.com.

COMMUNITY OVERZICHT

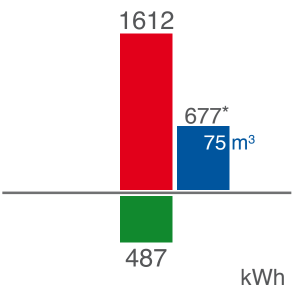


[o.b.v. meetgegevens elektriciteit van 19 huizen en meetgegevens gasverbruik van 10 huizen geëxtrapoleerd]

Verbruik vs productie

De verhouding tussen energieverbruik en productie in de huizen in PMC.

TOTAAL VERBRUIK



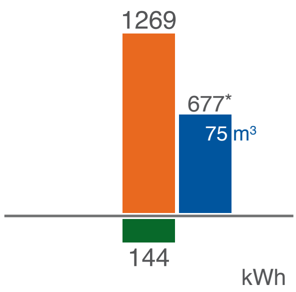
PRODUCTIE

De productie was 30% van het totale elektriciteitsverbruik. Vorige week was dat 43%. Het gasverbruik, 677 kWh, was ook ongeveer 30% van het totaalverbruik, net als vorige week.

Inkoop vs teruglevering

De verhouding tussen wat u in PMC hebt ingekocht en wat u hebt teruggeleverd.

INKOOP



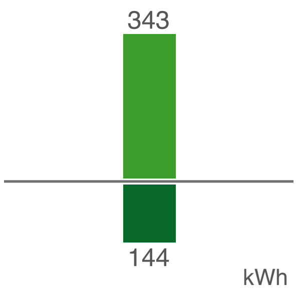
TERUGLEVERING

De hoeveelheid teruggeleverde energie was 144 kWh, 11%.van wat was ingekocht. Dat is de helft van vorige week (20%).

Verbruik eigen productie

De hoeveelheden van de in PMC geproduceerde energie die u zelf verbruikt en teruggeleverd hebt.

VERBRUIK EIGEN PRODUCTIE



TERUGLEVERING

Het grootste gedeelte van de geproduceerde energie hebt u deze week zelf verbruikt, 70 %. Dat is vergelijkbaar met vorige week (68%).

* Het gasverbruik is omgerekend naar kilowatturen. 1 m3 gas komt overeen met 8,972 kWh. Dit gasverbruik is alleen het gasverbruik van het verwarmingssysteem, dus verbruikt door micro-WKK en/of aanvullende CV ketel. Het gasverbruik is gemeten voor 10 huizen en geëxtrapoleerd voor een schatting van de gehele groep. Specificatie naar de groepen met micro-WKK en warmptepomp is (nog) niet mogelijk.

TOTAAL
70
kWh 10

Hoeveelheid per week

Hoeveelheid per dag

VERBRUIK
Elektriciteit

COMMUNITY

TOTAAL ELEKTRICITEIT
1612
kWh 230
[o.b.v. 19 huizen, waarvan gegevens beschikbaar zijn]

TOTAAL GAS
677
kWh 97
[o.b.v. meetgegevens 10 huizen, geëxtrapoleerd naar 19 huizen]

WARMTEPOMP
85
kWh 12
[o.b.v. 12 huizen met warmtepomp]

GEMIDDELD VERBRUIK

PER HUIS

TOTAAL ELEKTRICITEIT

HOOGSTE VERBRUIK
130
kWh 19

85
kWh 12

LAAGSTE VERBRUIK
13
kWh 1,9

WARMTEPOMP
7,1
kWh 1,0

TOTAAL GAS
36
kWh 5,1

Kijkend naar het gemiddelde verbruik per huishouden zijn zowel elektriciteit als gasverbruik zo goed als gelijk ten opzichte van vorige week. Dat geldt ook voor het verbruik van de warmtepompen.
Deze week waren er weer 19 in plaats van 21 huishoudens waarvan er voldoende meetgegevens waren voor dit energiebericht.

PRODUCTIE

COMMUNITY - TOTALEN

TOTAAL
487
kWh 70
[o.b.v. 19 huizen, waarvan gegevens beschikbaar zijn]

micro-WKK
25
kWh 3,6
[o.b.v. 7 huizen met mWKK]

EIGEN ZONNEPANELEN
135
kWh 19
[o.b.v. 4 huizen met eigen panelen]

VIRTUELE ZONNEPANELEN
327
kWh 47
[o.b.v. 19 huizen]

PER HUIS - GEMIDDELDEN

micro-WKK
3,2
kWh 0,5
[o.b.v. 7 huizen met mWKK]

EIGEN ZONNEPANELEN
34
kWh 4,8
[o.b.v. 4 huizen met eigen panelen]

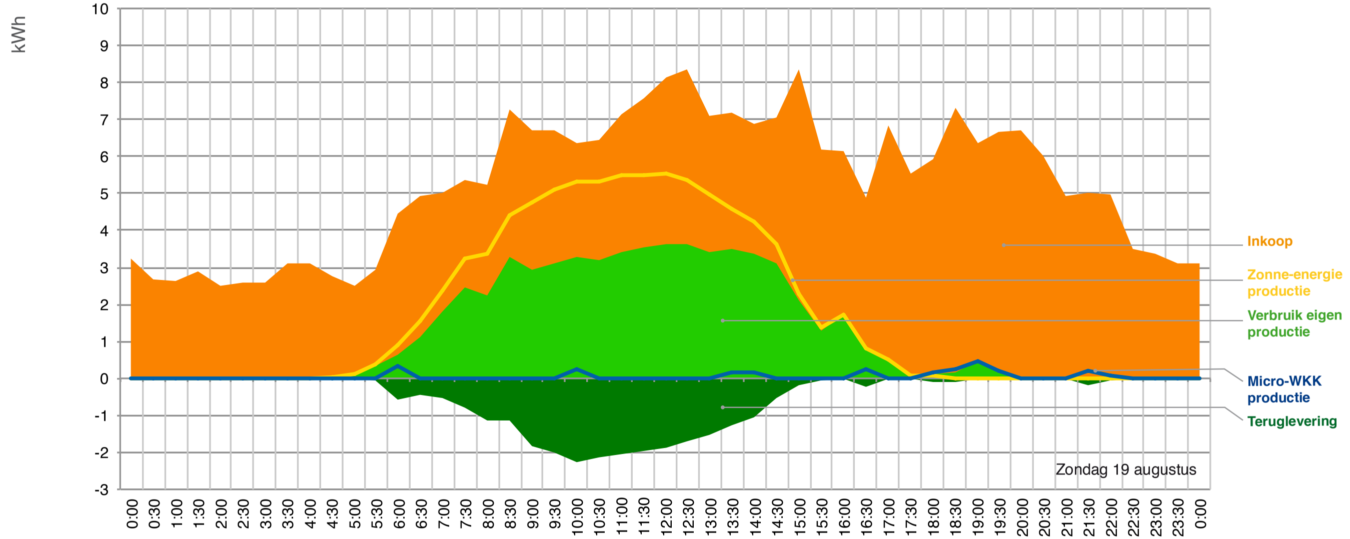
VIRTUELE ZONNEPANELEN
17
kWh 2,5
[o.b.v. 19 huizen]

Kijkend naar de gemiddelden per huis, is te zien dat er minder zonnige dagen zijn. Er werd namelijk weer minder zonne-energie geproduceerd. De productie door de micro-WKKs was iets lager dan vorige week.

DAGVERLOOP TOTAAL COMMUNITY

Zondag 19 augustus

DAGVERLOOP
ENERGIEVERBRUIK EN -PRODUCTIE



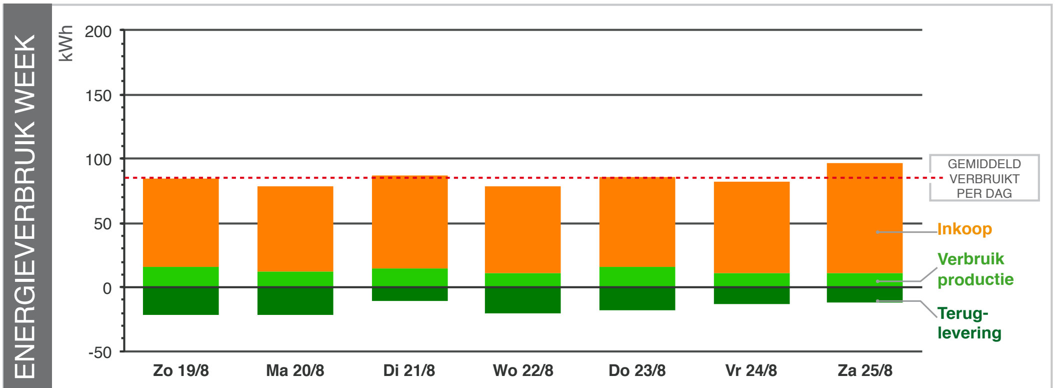
[o.b.v. meetgegevens van 19 huizen]

Deze grafiek geeft het verloop over de dag aan van energieverbruik en opwekking.
De waarden zijn op basis van het energieverbruik van een half uur, in kilowatturen.

Deze zondag waarvan het energiegebruik in de grafiek hierboven staat was weer een prachtige dag. Dat is te zien in de zonne-enegieproductie. De productie bleef wel een stuk onder het verbruik. Een van de huizen met eigen zonnepanelen is niet meegenomen in de grafiek. Daarom is de totaalproductie wat lager dan vorige week.
Qua energieverbruik is te zien dat het meeste van de opgewekte energie door uzelf is verbruikt. Verder was het verbruik overdag het hoogst wanneer ook de zonnepanelen het meest opleveren.
Het patron is vergelijkbaar met vorige week. Het energieverbruik neemt vanaf ca. 6 uur ‘s ochtends toe. Tegen het eind van de middag zit er een lichte ‘dip’ in het verbruik en om 23.30 uur lijkt iedereen weer te slapen. Zullen er mensen zijn geweest die omdat de zon scheen ook hun (af)wasmachine of andere grote energieverbruiker aangezet hebben? Gezien het aanhoudende zomerweer gebruikt u weinig warmte en produceerden de micro-WKKs niet veel. De energie die ze produceerden werd terugeleverd aan het net. Waarschijnlijk kregen ze daar een goede prijs voor en besloot de energiecomputer de mWKK in te schakelen.

Over deze grafiek:
In deze grafiek staat energieverbruik en -productie van één dag weergegeven, de zondag van de week. Het gaat om totalen van de Power Matching City community in kilowatturen (kWh) per half uur. Naast de bekende elementen van de weekoverzichten (in oranje, lichtgroen en donkergroen), zijn er twee extra lijnen. De gele lijn geeft aan wat de productie van de zonnepanelen (virtuele + eigen panelen) was, de blauwe lijn de productie van de micro-WKKs. Opgeteld geven ‘Verbruik eigen productie’ en ‘Inkoop’ het totaalverbruik op een bepaalde tijd aan.

OVERZICHT HUIZEN MICRO-WKK

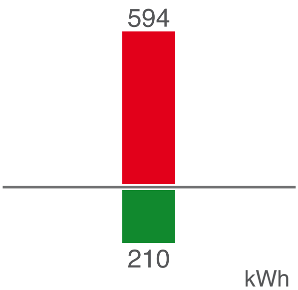


[o.b.v. meetgegevens van 7 huizen met micro-WKK]

Verbruik vs productie

De verhouding tussen energieverbruik en productie in de huizen met warmtepomp in PMC.

TOTAAL VERBRUIK



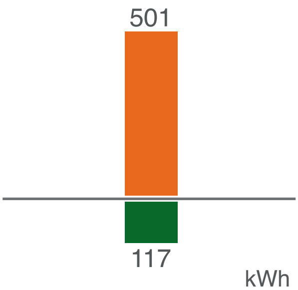
PRODUCTIE

De productie door micro-WKKs en zonnepanelen (eigen en virtuele) was deze week 35% ten opzichte van het totaalverbruik. Vorige week was dat 49%.

Inkoop vs teruglevering

De verhouding tussen wat is ingekocht en wat u hebt teruggeleverd.

INKOOP



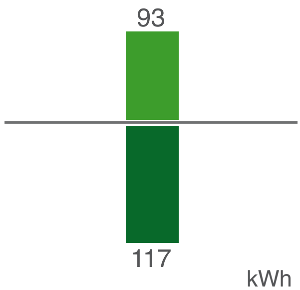
TERUGLEVERING

De teruglevering van elektriciteit was 23% van wat er ingekocht is. Dat is wat minder dan vorige week, met 37% teruglevering t.o.v. de hoeveelheid ingekochte energie.

Verbruik eigen productie

De delen van de in PMC geproduceerde energie die u zelf verbruikt en teruggeleverd hebt.

VERBRUIK EIGEN PRODUCTIE



TERUGLEVERING

Van de geproduceerde elektriciteit werd iets minder dan de helft, 44%, door u zelf verbruikt. Dat is minder dan vorige week (39%).
Er werd 56% teruggeleverd.

TOTAAL
70 — Hoeveelheid per week
kWh 10 — Hoeveelheid per dag

VERBRUIK

Elektriciteit

COMMUNITY

TOTAAL

594

kWh 85

[o.b.v. 7 huizen met micro-WKK waarvan gegevens beschikbaar zijn]

GEMIDDELD VERBRUIK

PER HUIS

TOTAAL

HOOGSTE VERBRUIK: 104 kWh 15

85 kWh 12

LAAGSTE VERBRUIK: 33 kWh 4,7

Het gemiddelde elektriciteitsverbruik in de huizen met micro-WKK is licht gestegen ten opzichte van de voorgaande week. Hetzelfde huishouden verbruikte weer het minst, 32 kWh, vergelijkbaar met vorige week. Het meest verbruikende huishouden is ook hetzelfde, maar zij verbruikten iets meer dan vorige week (104 t.o.v. 93 kWh).

PRODUCTIE

COMMUNITY - TOTALEN

TOTAAL

210

kWh 30

[o.b.v. 7 huizen met micro-WKK waarvan gegevens beschikbaar zijn]

micro-WKK

25

kWh 3,6

[o.b.v. 7 huizen met mWKK]

EIGEN ZONNEPANELEN

73

kWh 10

[o.b.v. 2 huizen met eigen panelen]

VIRTUELE ZONNEPANELEN

112

kWh 16

[o.b.v. 7 huizen]

PER HUIS - GEMIDDELDEN

micro-WKK

3,2

kWh 0,5

[o.b.v. 7 huizen met mWKK]

EIGEN ZONNEPANELEN

36

kWh 5,2

[o.b.v. 2 huizen met eigen panelen]

VIRTUELE ZONNEPANELEN

16

kWh 2,3

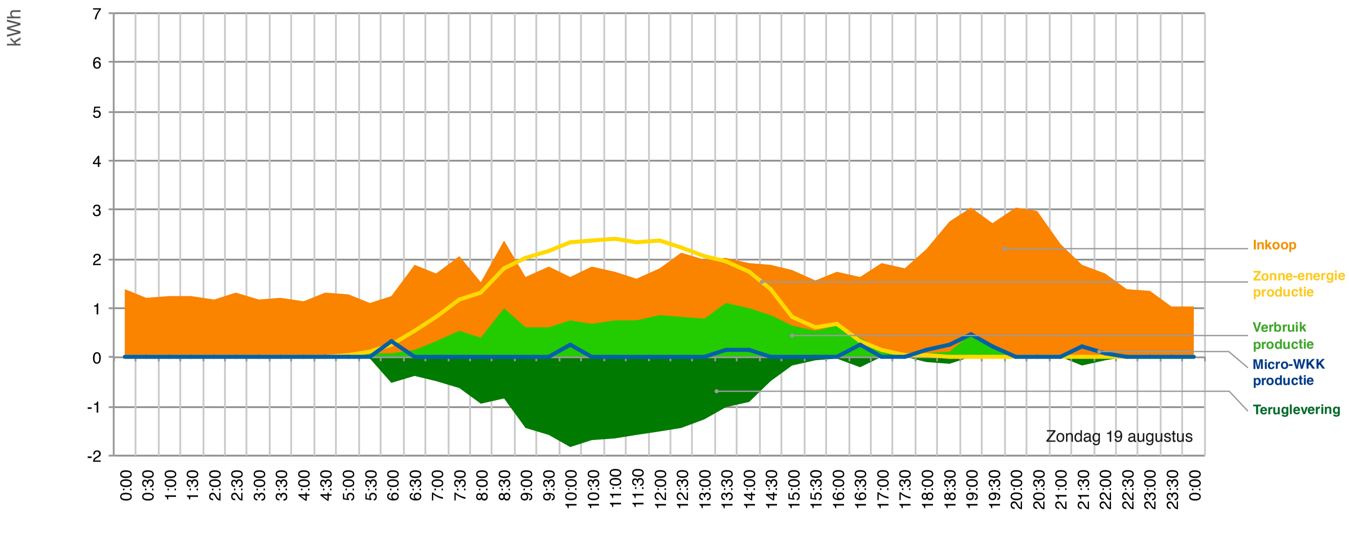
[o.b.v. 7 huizen]

De micro-WKKs produceerden iets minder dan de week ervoor, maar het lag rond dezelfde hoeveelheid als de weken hiervoor (rond de 3 kWh). Voor de huizen met micro-WKKs en virtuele zonnepanelen kwam de productie overeen met 23% van hun verbruik. Voor de huizen met ook eigen zonnepanelen kwam dit neer op wel 65% (gemiddeld, dus aangenomen dat ze beide evenveel produceren).Deze percentages liggen lager dan vorige week gezien de lagere zonne-energieproductie.

DAGVERLOOP HUIZEN MET MICRO-WKK

Zondag 19 augustus

DAGVERLOOP
ENERGIEVERBRUIK EN -PRODUCTIE



[o.b.v. meetgegevens van 7 huizen]

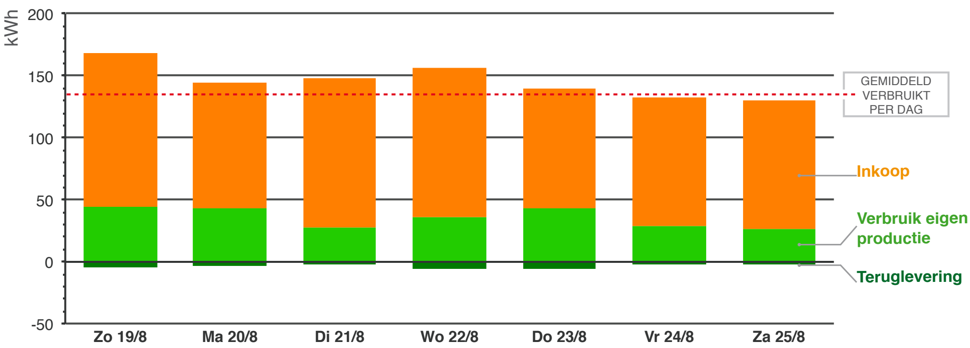
Deze grafiek geeft het verloop over de dag aan van energieverbruik en opwekking.
De waarden zijn op basis van het energieverbruik van een half uur, in kilowatturen.

Opvallend aan deze grafiek is dat hij behoorlijk verschilt van het dagverloop van PMC als geheel (pagina 3). Het verloop is vergelijkbaar met dat van vorige week. De piek in energieverbruik is 's avonds tussen ongeveer half zeven en negen uur.
Omdat er minder huizen meetellen in deze groep is het totaalverbruik hier lager dan in het dagelijks overzicht van PMC als geheel. Als u pagina 9 bekijkt met het dagelijks verloop van de huizen met warmtepomp ziet u dat het verloop van PMC als geheel (en dus de vorm van de grafiek) vooral door hen bepaald werd.
Qua opwekking is te zien dat u overdag de geproduceerde zonne-energie gebruikte. Toch werd het grootste gedeelte van de opgewekte energie verkocht. Meestal zien we dat de micro-WKKs hun energie meteen terugleveren. Om 19.00 uur wordt het echter gebruikt. Er was blijkbaar meer warm water nodig dan voorhanden, dus de micro-WKK aansloeg en dus sloeg aan en produceerde ook elektriciteit.

Over deze grafiek:
Om de huishoudens met micro-WKK te kunnen vergelijken met de huishoudens met warmtepomp staat hierboven het dagelijks verloop binnen de groep met micro-WKKs voor de eerste zondag van deze week. Per half uur wordt het aantal kilowattuur (kWh) aangegeven. Naast de bekende elementen van de weekoverzichten (in oranje, lichtgroen en donkergroen), zijn er twee extra lijnen. De gele lijn geeft aan wat de productie van de zonnepanelen (virtuele + eigen panelen) was, de blauwe lijn de productie van de micro-WKKs.

OVERZICHT HUIZEN WARMTEPOMPEN

ENERGIEVERBRUIK WEEK

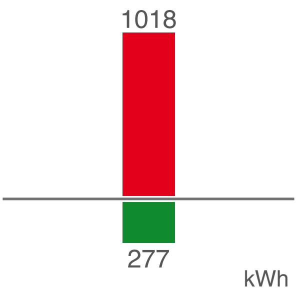


[o.b.v. meetgegevens van 12 huizen met warmtepomp]

Verbruik vs productie

De verhouding tussen energieverbruik en productie in de huizen in PMC.

TOTAAL VERBRUIK



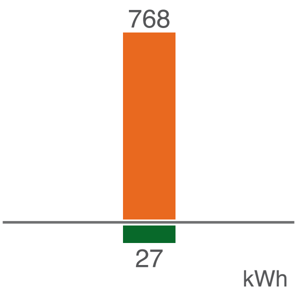
PRODUCTIE

De productie bij de huizen met warmptepomp was 27% van het verbruik. Dat is minder dan vorige week (40%).

Inkoop vs teruglevering

De verhouding tussen wat u in PMC hebt ingekocht en wat u hebt teruggeleverd.

INKOOP



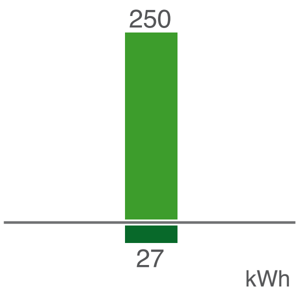
TERUGLEVERING

De teruglevering van elektriciteit was 3% van wat er ingekocht is.
Dat is minder dan vorige week (7%).

Verbruik eigen productie

De delen van de in PMC geproduceerde energie die u zelf gebruikt en teruggeleverd hebt.

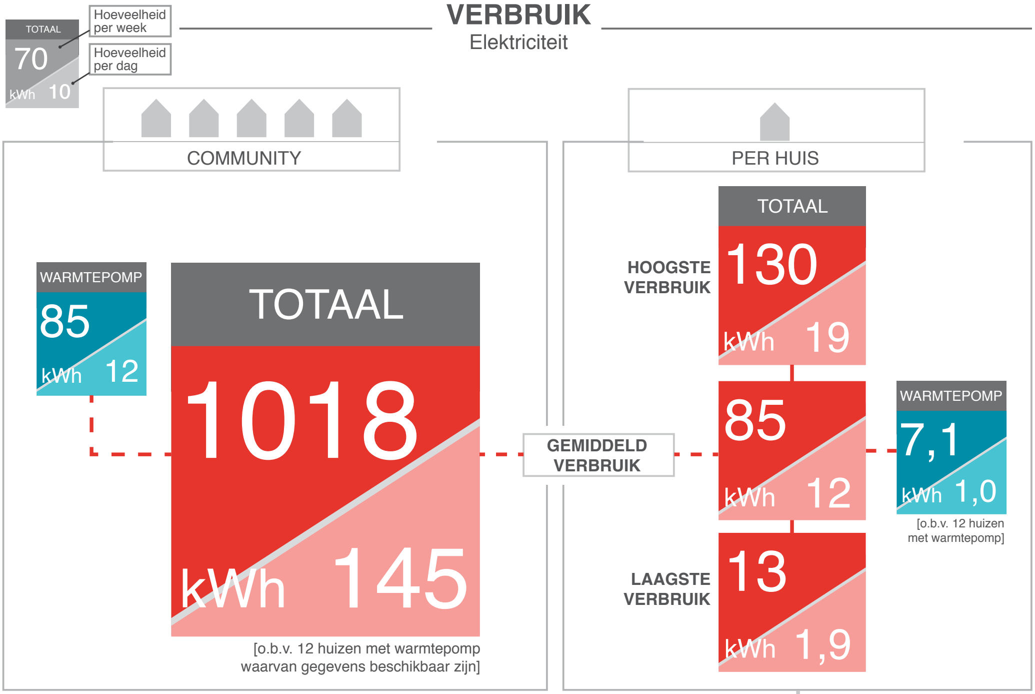
VERBRUIK EIGEN PRODUCTIE



TERUGLEVERING

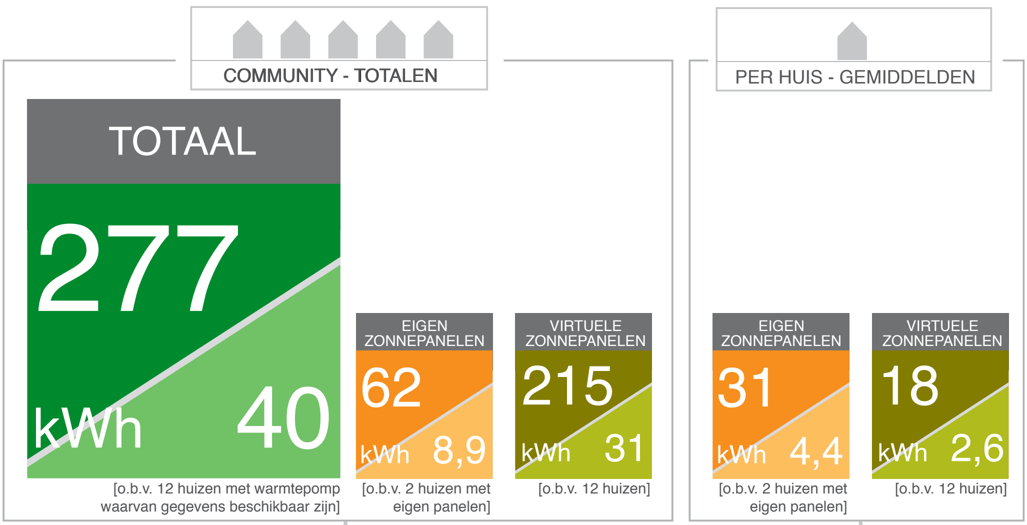
90% van de geproduceerde energie werd door u zelf benut, vergelijkbaar met vorige week (89%). U verbruikte meer van de geproduceerde energie zelf dan de groep met micro-WKKs.

VERBRUIK
Elektriciteit



Het gemiddelde elektriciteitsverbruik, 85 kWh, lag iets hoger dan het verbruik van de micro-WKK huishoudens. Verder is het gemiddelde verbruik gelijk ten opzichte van vorige week. De warmtepompen verbruikten deze week iets minder elektriciteit. Dat verbruik kwam overeen met 8% van het totale elektriciteits-verbruik. Het meeste en het minst verbruikende huishouden waren weer dezelfde als vorige week.

PRODUCTIE

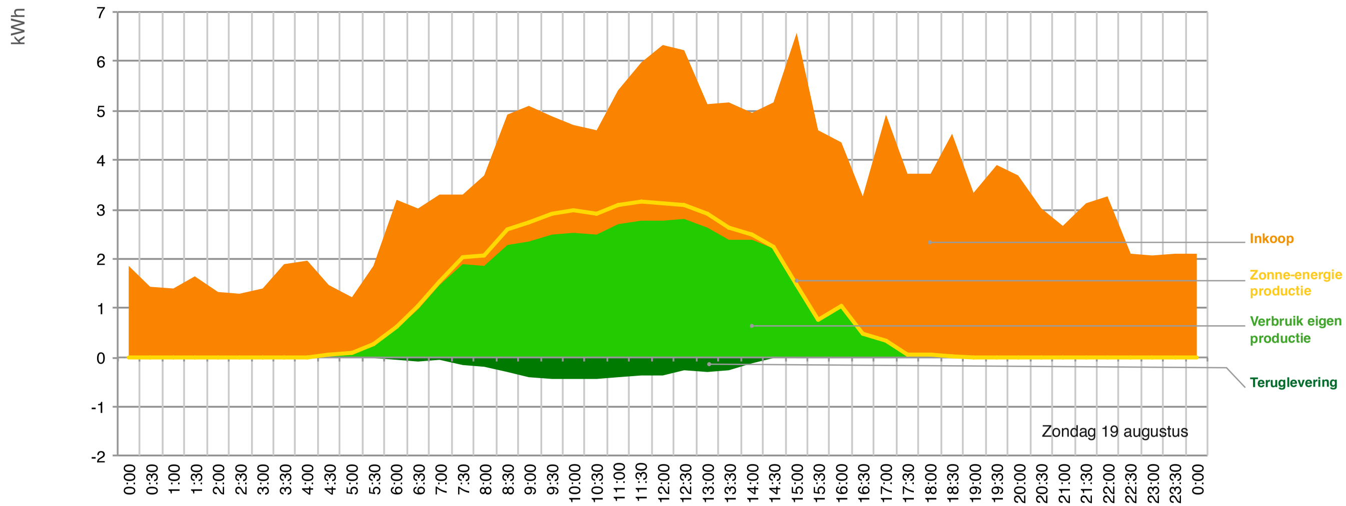


De elektriciteitsproductie voor de huishoudens met warmptepompen kwam van de zonnepanelen. De opbrengst was lager dan vorige week. Uitgaande van het gemiddelde verbruik, konden de huizen met virtuele zonnepanelen in 21% van hun energievebruik voorzien. Voor het ene huis dat deze week meegerekend werd kwam dat uit op 58%.

DAGVERLOOP HUIZEN MET WARMTEPOMP

Zondag 19 augustus

DAGVERLOOP
ENERGIEVERBRUIK EN -PRODUCTIE



[o.b.v. meetgegevens van 12 huizen]

Deze grafiek geeft het verloop over de dag aan van energieverbruik en opwekking.
De waarden zijn op basis van het energieverbruik van een half uur, in kilowatturen.

Het dagverloop van de huizen met warmtepompen laat zien dat vanaf 6 uur ‘s ochtends de energievraag toeneemt. Om 22.30 lijkt u allen weer te slapen.
De opgewekte zonne-energie werd bijna helemaal door u zelf verbruikt. Dit is een groot verschil met de huishoudens met micro-WKK, zij leverden het grootste gedeelte terug (zie pagina 6).
Omdat er minder huizen meetellen in deze groep was het totaalverbruik hier lager dan in het dagelijks overzicht van PMC als geheel. Het energiegebruik in de huizen met warmtepomp is terug te zien in het dagverloop van PMC totaal (vorm van de grafiek, zie ook pagina 3).

Over deze grafiek:
Om de huishoudens met warmtepomp te kunnen vergelijken met de huishoudens met micro-WKK staat hierboven het dagelijks verloop binnen de groep met warmtepompen voor de eerste zondag van deze week. Per half uur wordt het aantal kilowattuur (kWh) aangegeven. Naast de bekende elementen van de weekoverzichten (in oranje, lichtgroen en donkergroen), zijn er twee extra lijnen. De gele lijn geeft aan wat de productie van de zonnepanelen (virtuele + eigen panelen) was, de blauwe lijn de productie van de micro-WKKs.

Summary

Current discourse on smart grid deployment expects residential end users to play a more active role as co-providers in the electric power system. Their electricity consumption and production is considered a resource for balancing supply and demand in an electric power system with distributed generation. This means that, in addition to using energy efficiently, they, for example, have to adjust their consumption patterns to the production patterns of locally available and intermittent energy generation.

This thesis explores how the technological and social contexts of smart grids can shape the role of residential end-users as co-providers in the electric power system. The main objective was to formulate implications for the development of products and services that support end-users in taking up a co-provider role.

Problem statement

Currently end users are mostly geared and encouraged toward efficient energy use. In a smart grid situation however, households would additionally be required to adjust their electricity consumption schedule, produce electricity and trade electricity to coordinate with general production patterns within the grid. The transition from passive consumer to active co-provider thus requires a shift in the mindset and behavior of end users. Although products and services can facilitate the transition, little is known as to how they can empower end users to take up a co-provider's role.

Theoretical framework

The theoretical framework in this thesis builds upon two perspectives on the role of products and services in shaping end user behavior: technology-behavior interaction and social psychological models of behavioral change. It describes the performance of a smart energy system resulting from the interactions between end user and technology at the household and community levels, as well as the interactions between end users themselves. The framework builds on the premise that the interaction between end-user and technology determines the performance of a system. Social-psychological models of behavior change, using factors such as motivation, ability and opportunity, guide the analysis of end user behavior.

Current smart grid related products and services

Based on literature review and existing smart grid pilot projects the extent to which current smart grid-related products and services enable residential end users to act as co-providers was examined. The resulting synopsis shows that end users' transition to smart grid operation has typically focused on technical solutions and financial incentives. It identifies a need for a more integrated approach to smart energy system design. To ensure the adoption of smart products and services, the behavioral aspects and social context for residential end users as co-providers also have to be taken into account. The study proposes a model of integral design for smart energy systems consisting of four layers: core technologies, intermediary products and services, services for energy management, services to facilitate and

motivate behavioral changes.

Field studies in two pilot projects

A series of field studies were carried out in two pilot projects in which households were equipped with smart energy technology: PowerMatching City and Energy Battle. During both projects a product-service combination was implemented that was new for the households and aimed at enabling one or more aspects of co-providing end-user behavior. The field studies were exploratory and qualitative in nature because of the newness of the research topic and the small sample sizes of the pilot projects.

Field studies in PowerMatching City

In the PowerMatching City pilot project twenty-two households were connected in a smart grid. Each was equipped with heating systems that could be controlled remotely by the PowerMatcher coordination mechanism. They all had either a micro-cogeneration unit (μCHP) or a hybrid heat pump (HHP). Additionally, half of the households installed smart household appliances, namely a dishwasher and a washing machine. They produced electricity via the μCHPs as well as via photovoltaic solar systems.

The research into PowerMatching City was divided in three studies concerning: the energy balance in the cluster, engagement of end users as co-providers and social interactions in the community.

The goals for the first study in PowerMatching City were to quantify the energy balance for the cluster households, to compare summer to winter and to compare to each other the two types of heating systems installed in the households. To this end the measured data for self-production, consumption and delivery to the grid were analyzed, visualized and expressed in indicators describing the relations between consumption, self-production, purchase from, and delivery to, the grid. The results were evaluated for self-sufficiency at the household level. The analysis furthermore indicated that changes in end user behavior could potentially contribute to simultaneous matching of supply and demand in the smart grid, in addition to optimizing the settings for automated matching of supply and demand.

The second study in PowerMatching City investigated the extent by which the smart energy system enabled end users as co-providers. The interaction between end users and smart energy system was evaluated, as well as the motivations and ability of the end-users to participate in the system as co-providers. Research methods included interviews, questionnaires, focus groups and design sessions. Besides insight into the end-user experiences, the study also provided directions for further development of products and services. During the first phase of the project, smart energy technology in the households had limited effect on the ability of end users to more actively manage their home energy. The system was technically functioning and the households expressed satisfaction with the heating systems. The end users however also exhibited lack of understanding of, and control over, the system's operation to ascertain the achievement of their households' energy related goals, such as energy saving or time-shifting appliance use to match local production. During the project's second phase, an improved interface was made available via a display on a tablet-pc. It provided end-users with information about system operation and ideal times for appliance use. In PowerMatching City, if given the opportunity and if they perceived it as meaningful, end users demonstrated interest in, and propensity for, becoming more active co-providers in the electric power system.

The third study in PowerMatching City focuses on social interactions between the households. Past research suggests that social influence is a powerful means to stimulate behavioral change. The twenty-two participating households represented a distinct community of people sharing a common ground and interacting with each other through the smart grid. The study investigated interest in, and potential for, social interactions between the participants to support them in a co-provider role. Through spontaneous past interactions participants sought to better understand how the system worked, solve problems or compare system performance between households. Half of the households expressed interest in social interactions with other participants while most of them rated web-based exchanges useful in facilitating communication related to energy practices at the community level. The high initial interest sparked by the introduction of the online platform did not match actual usage because of the low number of incentives offered for using it. The results suggest that to leverage social interaction via a community website, participants first have to be acquainted with each other, establish a common ground and shared goals. There have to be incentives for joining in a conversation, such as project developments or information shared among fellow community members or provided by a moderator. Furthermore, the community's joint performance, such as its energy balance and comparisons between households could also catalyze communication.

Field study Energy Battle

In contrast to the studies of PowerMatching City, the study in the Energy Battle pilot project concerned a short-term intervention. It generated insight into the potential for game context in combination with energy feedback to engage households in saving energy. During the pilot, student households competed for highest energy savings over a four-week period. Additionally they could win a prize by participating in a related online game. The 17 participating houses achieved savings of up to 45%, with an overall average of 24%. The levels of savings were not maintained when the intervention stopped. A main lesson from this study is that the intervention provided a context for energy saving activities, both for households motivated by winning and for those merely interested in their energy saving possibilities. Household members motivated each other and worked cooperatively to achieve the (temporary) energy saving goal. The challenge in designing a product-service combination such as Energy Battle is to facilitate long-term energy savings. Guidance in what behaviors to change or investment decisions to make is important here. Integration of a game in a larger program to motivate behavioral change should also be considered in order to achieve long-term impact.

Conclusions

Pursuant to the research findings, this thesis suggests that combinations of products and services for end users in smart grids have to achieve balance between structural solutions made possible by smart energy technologies and engagement of end users in their households' energy management according to their needs, goals and capabilities. The information and control provided for interaction by the products and services tested during the field work, defined the ways in which end users were enabled and motivated to adjust their energy-related behaviors.

Based on the research suggestions for the design of products and services were formulated within four themes:

1. Designing user interfaces as a key to provide insight into and control over home energy system operation. This includes providing insight at the community grid level.
2. Using leverage from social interactions in product and service design, to increase motivation and ability for co-provision.
3. Using an integral and user-centered approach in order to address both behavioral and technical aspects to achieve optimal performance of smart grids at the household level.
4. Developing products and services as part of an experiential learning process for both developers and end-users. This requires involving different types of end-users, early in the process, as co-creators rather than a adopters of new products and services.

Relevance

The research in this thesis takes a step beyond economic and technical approaches to smart grid deployment by exploring the social aspects of smart energy technology. It provides insight into the, still little explored, end user side of smart grids at the household level. This research may thus contribute to the discussion on how end users can meet expectations and actively take charge of the management of supply and demand in the electric power system. Furthermore, the results highlight the need for of an interdisciplinary, user-centered and design-driven approach to smart grid deployment. The knowledge resulting from this research may inspire the next generation of smart grid products and services.

Samenvatting

Uit de discussie over intelligente netten is op te maken dat huishoudens verwacht worden een actievere bijdrage te leveren aan het management van het elektriciteitsnet. Nu er steeds meer hernieuwbare en decentrale energiebronnen op het net worden aangesloten, worden energieverbruik en - productie in huishoudens gezien als een middel om de benodigde balans tussen vraag en aanbod te onderhouden. Voor huishoudens betekent dit dat ze niet alleen efficiënt met energie om moeten gaan, maar dat ze bijvoorbeeld ook hun verbruikspatroon aanpassen op de fluctuerende opbrengst van wind- en zonne-energie. De nieuwe rol van eindgebruikers kan worden omschreven als 'prosumenten', wat aanduidt dat ze in plaats van 'passief' producten en diensten afnemen ook zelf een bijdrage leveren aan, in dit geval, een goed functionerende energievoorziening. In dit proefschrift is onderzocht hoe de technische en sociale context van intelligente netten een dergelijke actieve rol van eindgebruikers kan vormgeven. De hoofddoelstelling van dit onderzoek was om aanbevelingen te doen voor de ontwikkeling van producten en diensten die eindgebruikers in hun nieuwe rol in het energiesysteem ondersteunen.

Probleemdefinitie

Op dit moment wordt van huishoudens niet verwacht dat ze rekening houden met de momenten waarop ze elektriciteit verbruiken. In intelligente netten kan van huishoudens verwacht worden dat ze hun verbruikspatroon aanpassen, zelf elektriciteit produceren en eventueel verhandelen, op basis van de energiebalans in het net. Een transitie van passieve consument naar prosument vraagt dus om een andere manier van huishoudelijk energiemanagement. Verschillende soorten producten en diensten zouden eindgebruikers kunnen ondersteunen in hun nieuwe rol. Hiervoor is echter nog weinig concrete kennis uit veldstudies waarin huishoudens de zogenaamde 'slimme energietechnologie' gebruiken.

Theoretisch kader

Het theoretische kader van dit proefschrift is gebaseerd op twee perspectieven op hoe producten en diensten gedrag beïnvloeden: modellen van technologie-gebruiker interactie modellen en sociaal-psychologische modellen van gedragsverandering. Het onderzoeksmodel beschrijft de prestaties van een intelligent energiesysteem als het resultaat van de interacties - het samenspel - tussen eindgebruikers en technologie alsmede sociale interactie tussen eindgebruikers. Die interacties vinden zowel op huishoudniveau als op buurt of groepsniveau plaats. De factoren in de sociaal-psychologische gedragsmodellen, zoals motivatie, bekwaamheid en gelegenheid worden gebruikt voor analyse van eindgebruikersgedrag.

Bestaande producten en diensten voor huishoudens

Op basis van literatuuronderzoek en bestaande proefprojecten is onderzocht in hoeverre de bestaande producten en diensten eindgebruikers ondersteunen in een rol als prosument. Uit het resulterende overzicht blijkt dat huidige product- en dienstontwikkeling voornamelijk is gericht op technische oplossingen en financiële prikkels. Ook geeft het aan dat een integralere aanpak voor het ontwerp van intelligente energiesystemen belangrijk is. Voor succesvolle adoptie van een prosumentenrol zullen ook gebruikersgedrag en sociale context van eindgebruikers in het ontwerp moeten worden meegenomen. Op basis van deze studie is een model voor integraal ontwerp van intelligente energiesystemen voorgesteld dat bestaat uit vier lagen: kerntechnologieën, bemiddelende producten en diensten, diensten voor energie management en diensten om gedragsverandering te faciliteren en stimuleren.

Veldstudies in twee proefprojecten

In twee proefprojecten zijn veldstudies uitgevoerd: PowerMatching City en Energy Battle. In beide projecten werden product-dienst combinaties geïmplementeerd die gericht waren op het mogelijk maken van een of meer aspecten van energiemanagement voor een prosument. De veldstudies zijn exploratief en kwalitatief van aard vanwege de nieuwheid van het onderwerp en de kleine aantallen deelnemers.

Veldstudies in PowerMatching City

In het PowerMatching City project zijn 22 huishoudens in een intelligent netwerk aangesloten. Elk huishouden werd voorzien van een verwarmingssysteem, een micro-cogeneratie systeem (micro-WKK) of een hybride warmtepompsysteem (HHP), dat aangestuurd kon worden op basis van het PowerMatching City coördinatiemechanisme. Daarnaast zijn bij de helft van de huishoudens 'slimme apparaten' geïnstalleerd, een vaatwasser en een wasmachine. De huishoudens produceerden energie via de micro-WKKs en zonnepanelen.

Het doel van de eerste studie in PowerMatching City was om de energiebalans van het cluster huishoudens te kwantificeren, om de prestaties te vergelijken tussen zomer en winter en tussen de twee soorten verwarmingssystemen. Meetgegevens voor de zelfgeproduceerde elektriciteit, elektriciteitsvraag van en -levering aan het netwerk zijn geanalyseerd, gevisualiseerd en uitgedrukt in indicatoren die de verhoudingen tussen verbruik, productie en teruglevering omschrijven. De resultaten suggereren dat er ruimte is om vraag en aanbod beter op elkaar af te stemmen. Dit kan door de instellingen van het coördinatiemechanisme aan te passen, maar ook het gedrag van de huishoudens kan hier aan bijdragen.

In de tweede studie is onderzocht in hoeverre de geïmplementeerde technologie de eindgebruikers faciliteerde in hun rol als prosument. De onderzoeksmethoden bestonden uit interviews, vragenlijsten en ontwerpsessies. Behalve inzicht in de ervaringen van de eindgebruikers leverde dit inzichten op voor verdere ontwikkeling van producten en diensten. In de eerste fase van het project functioneerden de geïnstalleerde verwarmingssystemen naar tevredenheid van de eindgebruikers. Tegelijkertijd gaf men aan onvoldoende inzicht in en controle te hebben over hoe het slimme energiesysteem werkt. Ze willen met het systeem hun eigen doelen, zoals energiebesparing of het verbruik van eigen opgewekte energie, kunnen nastreven. In de tweede fase werd een verbeterde interface geïntroduceerd op een tabletcomputer. Hiermee kregen de huishoudens meer inzicht in de werking van het systeem, alsmede de informatie om hun apparatuur te gebruiken op ideale tijden met betrekking tot kosten of beschikbaarheid van duurzame energie. De huishoudens in PowerMatching

City hebben laten zien dat ze, wanneer ze de gelegenheid krijgen en het als zinvol ervaren, graag een rol als prosument op zich te willen nemen.

De derde studie in PowerMatching City focust op sociale interactie tussen de huishoudens. Eerder onderzoek suggereert dat sociale interactie met, en informatie over, anderen een belangrijke rol speelt in het motiveren van gedragsverandering. De 22 deelnemende huishoudens vormden een specifieke groep met een gezamenlijke interesse vanwege hun deelname in het intelligente net van PowerMatching City. Het onderzoek richtte zich op de interesse en mogelijkheden voor sociale interactie tussen de deelnemers als ondersteuning in hun rol als prosumenten. Deelnemers zochten voornamelijk contact om hun begrip te vergroten over hoe de verwarmingssystemen werkten, problemen op te lossen of prestaties van de systemen te vergelijken. Ongeveer de helft van de huishoudens had interesse in sociale interactie en het merendeel stond positief tegenover een online platform om dit te faciliteren. De initiële interesse bleek zich in praktijk echter niet om te zetten in veel activiteit op de geïntroduceerde community website. Op basis van deze studie kan gesteld worden dat om een community website succesvol te maken, deelnemers elkaar eerst moeten leren kennen om gezamenlijke uitgangspunten en doelen te formuleren. Er moeten daarnaast incentives zijn voor interactie. Die kunnen gevormd worden door, onder andere, ontwikkelingen in het project en informatie over persoonlijke of groepsactiviteiten door deelnemers of een moderator. Daarnaast zou de gezamenlijke prestatie van de groep een basis kunnen zijn voor interactie, zoals hoe men gezamenlijk de energiebalans beïnvloedt of vergelijking van prestaties tussen huishoudens.

Veldstudie Energy Battle

In tegenstelling tot de interventies in PowerMatching City, was Energy Battle een interventie van korte duur. Deze studie gaf inzicht in de mogelijkheid om eindgebruikers te motiveren voor energiebesparing in een spelcontext gecombineerd met energieverbruiksinformatie. Tijdens de Energy Battle streden studentenhuizen om de hoogste energiebesparing over een periode van vier weken. Daarnaast konden ze een prijs winnen door mee te doen aan een online game, gekoppeld aan de behaalde energiebesparing. De 17 deelnemende huizen hebben besparingen tot 45% behaald, met een gemiddelde van 24%. Deze hoge besparingen werden niet volgehouden na afloop van de interventie. Een belangrijke les van deze studie is dat de interventie een situatie creëerde om bewuster met het energieverbruik bezig te zijn, zowel voor degenen die wilden winnen, als degenen die slechts hun mogelijkheden om energie te besparen wilden verkennen. Huisgenoten motiveerden elkaar en werkten samen om hun (tijdelijke) besparingsdoelstelling te halen. De uitdaging voor een product-dienstcombinatie zoals Energy Battle is om besparingen op de lange termijn te behalen. Het is daarvoor belangrijk dat richting gegeven wordt aan de opties voor gedragsverandering en investeringen. Verder moet overwogen worden om deze interventie onderdeel te laten uitmaken van een breder programma.

Conclusies

De resultaten van het onderzoek in dit proefschrift suggereren dat voor het ontwerp van product-dienstcombinaties voor prosumenten een balans nodig is tussen structurele oplossingen via technische systemen en betrokkenheid van eindgebruikers op basis van hun behoeften, doelen en capaciteiten. De wijze waarop interactie tussen techniek en gebruiker is vormgegeven in de proefprojecten bepaalde op welke wijze eindgebruikers in staat werden gesteld, en gemotiveerd, om hun gedrag aan te passen.

Op basis van het onderzoek zijn ontwerpaanbevelingen gedaan binnen vier thema's:

1. Het ontwerp van de gebruikersinterface is cruciaal voor het geven van informatie en controle over de werking en prestaties van het energiesysteem van het huishouden en van het (lokale) netwerk.
2. Gebruik van sociale interactie, direct of indirect, in product-dienstcombinaties kan bijdragen aan motivatie en bekwaamheid om als prosument op te treden.
3. Een integrale ontwerpbenadering waarin de eindgebruiker centraal staat is belangrijk om rekening te houden met zowel de gedragsaspecten als de technische aspecten die bijdragen aan de uiteindelijke impact van het ontwerp.
4. Product- en dienstontwikkeling moet gezien worden als onderdeel van een leerproces voor zowel ontwikkelaars als eindgebruikers over het invullen van de rol van prosument. Dit betekent dat verschillende types eindgebruikers vroeg in het proces moeten worden betrokken als mede-ontwikkelaars.

Relevantie

Dit proefschrift geeft inzicht in de ervaringen van eindgebruikers met slimme energietechnologie. Het draagt daarmee bij aan de discussie over hoe zij een actieve rol op zich kunnen nemen in intelligente netten. Daarnaast is het belang van een interdisciplinaire en ontwerpgerichte aanpak benadrukt. De resultaten van de veldstudies kunnen mogelijk inspiratie bieden voor de volgende generatie producten en diensten voor prosumenten in intelligente netten.

Publications resulting from this work

Journal articles

Geelen, D., Reinders, A., Keyson, D., 2013. Empowering the end-user in smart grids: Recommendations for the design of products and services. Energy Policy 61, 151–161.

Geelen, D., Keyson, D., Boess, S., Brezet, H., 2012. Exploring the use of a game to stimulate energy saving in households. Journal of Design Research 10, 102–120.

Book chapter

Geelen, D., Keyson, D., 2012. Using Energy: Beyond individual approaches to influence energy behavior, in: Reinders, A., Diehl, J.C., Brezet, H. (Eds.), The Power of Design: Product Innovation in Sustainable Energy Technologies. Wiley.

Conference papers

Geelen, D., Vos-Vlamings, M., Filippidou, F., Van den Noort, A., Van Grootel, M., Moll, H., Reinders, A., Keyson, D., 2013. An end-user perspective on smart home energy systems - The case of PowerMatching City, in: 4th European Innovative Smart Grid Technologies (ISGT) Conference. Copenhagen, Denmark.

Geelen, D., Scheepens, A., Kobus, C.B.A., Obinna, U., Mugge, R., Schoormans, J.P.L., Reinders, A., 2013. Smart energy households' field tests in The Netherlands with a design-driven approach, in: 4th European Innovative Smart Grid Technologies (ISGT) Conference. Copenhagen, Denmark.

Geelen, D., Reinders, A., Keyson, D., 2011. Involving end-users in smart grid technology: A community-based approach for behaviour change, in: Roozenburg, N.F.M., Chen, L.L., Stappers, P.J. (Eds.), Diversity and Unity: Proceedings of IASDR2011, the 4th World Conference on Design Research.

Geelen, D., Brezet, H., Keyson, D., Boess, S., 2010. Gaming for energy conservation in households. ERSCP-EMSU Conf.

Acknowledgements

Although there is one name on the cover of this book, there are many people that contributed directly and indirectly to this thesis.

To start with the most directly involved in the research and writing process: my supervisors Angèle Reinders and David Keyson. With their constructive ideas and comments, they gave me the confidence to pursue this thesis to the end.
Angèle, thank you for structuring, putting me with my feet back on the ground when I drifted off and challenging me to also include an energy analysis.
David, thank you for your help with untangling unclear thoughts, the editing sessions early morning and late in the evening, and challenging me to continue designing even on an abstract level.

Han Brezet, Prof. B. invited me into the world of academic research. But also encouraged me to be in touch with practice in Friesland via Cartesius Institute, in Groningen and in Rotterdam. Thanks for opening up all these pathways and letting me to find my own. And.. if not for you and Yoram Krozer, I could have missed the greatest opportunity of my life.

During my time as a PhD-researcher I've worked in several projects:
Livinggreen.eu; This project about demonstrating and promoting the sustainable renovation of heritage buildings provided the springboard for my research about resource consumption in households. It was a pleasure to work with the people from all these different organisations, the partner organizations, to exchange ideas about practicing and promoting sustainable renovation and, not the least, to have some drinks after a long day of discussions.
Especially for the TU Delft crew, Marcel Crul, Sietze Meijer, Vera Franken and Wouter Kersten, thanks for the great team work!

PowerMatching City: The content of this project was extensively addressed in the pages of this thesis. I've enjoyed learning about this complex topic and interacting with all the different people involved. Albert van de Noort, thank you for inviting me into the project. Mijntje de Caluwé and Maike,van Grootel for placing my work into the bigger picture.
Manon Vos-Vlamings, your research work has been an enormous source of information for this thesis. I very much appreciate our discussions about how to best set up both our researches and making sense of the results afterwards.
And all the participating households, thank you for your openness to answer all our questions and work together on concepts for products and services. Without your goodwill this project and research would have been impossible.

Energy Battle, was a small project at the time I was involved. Stefan

Versluijs, thank you for the opportunity to use Energy Battle as a research case and the attempts after to set up a second version. I've appreciated our discussions and your insights from practice as you continued developing your platform.

Via graduation projects, I've had great help from students. Faidra Fillipidou processed and analysed the energy data in PowerMatching City. Here graduation project formed the basis for Chapter 5. Furthermore Loucas, Jose and Edoardo brought inspiration with their specific design challenges.

Then, colleagues and friends in the DfS office and around, it's hard to name you all but lets give it a try...Sietze, Ana Laura, Duygu, Andreas, Arno, Feng, Jotte, Shauna, Georgia, Uchechi, Elif, Carien, Vera, Satish, Ana, Renee, ... Thanks for the nice lunches, dinners, games and whatever other activities we organized inside and outside the office.

My family, Corry and Jan & Yvette, ik hou van jullie. Thanks for your endless support and confidence....and for putting things in perspective whenever needed, each in your own way.

Manuel, amor de mi vida, thank you for never giving up on me and helping me with the final details of this thesis. You taught me to take advantage of the opportunities you get, because not all of us get those chances.

About the author

Daphne Geelen (1980) obtained both her bachelor's and master's degree in Industrial Design Engineering at Delft University of Technology. During her studies she worked as an intern in several design studios in Santiago de Chile. After graduation in 2006, she worked as a researcher for Cartesius Institute in Leeuwarden, with a focus on solar powered product design.
In 2008 she started her PhD research at the Design for Sustainability section at the Faculty of Industrial Design Engineering. At the same time she worked for the 'Livinggreen' project. This European Union funded project aimed to promote and demonstrate sustainable renovation of cultural heritage buildings in North West Europe. She co-organised 'Livinggreen Labs', a series of workshops using design techniques to stimulate knowledge exchange between end-users and professionals. Currently she works at Enexis B.V. and is involved in research about the potential effects of smart meters on energy saving in households.