Energy Policy 61 (2013) 151–161

Contents lists available at ScienceDirect

Energy Policy

journal homepage: www.elsevier.com/locate/enpol

Empowering the end-user in smart grids: Recommendations for the design of products and services

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HIGHLIGHTS

- Overview of products and services for residential end-users in smart grids.
- Evaluation of extent to which end-users are empowered to adopt a co-provider role.
- Products and services often focus on technical functionality and financial incentives.
- Behavioral aspects and social context would have to be taken into account more.
- Design recommendations are proposed to empower end-users in becoming co-providers.

ARTICLE INFO

Article history:
Received 5 January 2013
Accepted 27 May 2013
Available online 9 July 2013

Keywords:
Smart grid
Product-service design
User behavior

ABSTRACT

In discussions on smart grids, it is often stated that residential end-users will play a more active role in the management of electric power supply and demand. They are expected to shift from a passive role as consumer of electricity to an active role as co-provider. In this article, the extent to which current technologies, products and services empower end-users to take up an active role as co-providers is evaluated. Based on a review of literature and related pilot projects, current approaches were found to be driven by technical and financial considerations. There appears to be a lack of product and service design that supports end-users in their role as co-providers in a smart grid. This is reflected in the lack of thought given to how the end-users' process of behavioral change can be supported to enable the transition from consumer to co-provider. Several recommendations are provided for product and service designers towards fostering the role of co-provider, which comes under under: (a) user interaction needs, (b) approaches to behavioral change and (c) community initiatives and management of resources. Designers are considered to play a bridging role between policy making and engineering, while facilitating involvement of end-users in the design process.

1. Introduction

In the ongoing transition from a centralized electricity grid towards a more decentralized and intelligent electricity system, also known as smart grid, residential end-users are expected to play a more active role in the management of the electric power system. This transition of the electric power system is stimulated by national and international policy goals, such as the EU 20-20-20 directive (European Commission, 2010) and national and European smart grid stimulation programs.[1] In many of the European subsidized smart grid pilots which relate to smart meters and pricing schemes, the emerging end-user role is being investigated (Giordano et al., 2011).

Technology development increasingly allows households to become producers of electricity by implementation of micro-generators such as photovoltaic solar systems. Local cooperatives with groups of houses sharing micro-generator production are also emerging. Two examples from The Netherlands are Texel Energy and Grunneger Power.[2] These cooperatives aim to organize the production of local renewable energy and aim to balance supply and demand to optimally utilize locally produced energy.

As households locally produce renewable energy, energy stakeholders from the government and private sector try to involve residential end-users in the supply and demand management ofelectricity in a smart grid (see e.g. Giordano et al., 2011,

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[1] See ec.europa.eu/energy/grants/index_en.htm.

[2] More information about these projects is available at www.texelenergie.nl and www.grunnegerpower.nl.

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http://dx.doi.org/10.1016/j.enpol.2013.05.107

International Energy Agency, 2011). The term smart grid refers to an electricity production and consumption infrastructure 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 a growing overall 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.

The contribution of end-users to balance supply and demand in smart grids is often referred to as demand response (DR). Demand response refers to changes in electricity consumption by end-users in response to supply conditions (see e.g. Giordano et al., 2011). 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.

In respect to a shift in the role of end-users from passive consumers to active contributors, the term "co-provider" was introduced by Van Vliet et al. (2005). Van Vliet et al. 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. The restructuring of infrastructures stimulates utilities and end-users to act together in order to establish environmentally sustainable systems.

In the context of this article, the term co-provision will be used to refer to the role of residential end-users in contributing to balance supply and demand of electricity in smart grids. This implies that in addition to using energy efficiently, households would have to use electricity at appropriate times in suitable amounts. Some would also generate electricity. In smart grids with advanced metering and energy feedback systems households would additionally be able to trade electricity.

As described by Verbong et al. (2012) stakeholders in the Dutch energy sector recognize the importance of active participation of residential end-users towards the successful implementation of smart grids. A threat posed towards the implementation of smart grids was however observed in the stakeholders' tendency to focus on technological solutions and a predominant view that end-user involvement should be based on economic incentives.

In terms of social acceptance of smart grids, the broader context of energy use in households needs to be taken into account (Shove et al., 2007; Wolsink, 2011). Social acceptance of smart grid technologies could be improved when technological developments go hand in hand with development of a social context for smart grids (Honebein et al., 2011).

The approach adopted in this study originates from the discipline of industrial design, in which the design of products and affiliated services, also called product and service design, is concerned with the development of artifacts aimed to support people in fulfilling their needs at the household level. A distinction can be made between material and immaterial artifacts, respectively, referred to as products and services. Often combinations of products and services are created to provide additional value for an end-user (Roozenburg and Eekels, 1998; Van Raaij et al., 1999). An example is a car sharing system, which provides the benefit of having a car at one's disposal, but avoids the effort and costs of maintenance. Similarly, a home heating system with a service contract is an example of a product-service combination in the area of energy management.

Over the past years, several pilot projects have been initiated in Europe with the objective to execute field tests with smart grid products and services in participating households. Examples of such projects include PowerMatching City (Bliek et al., 2010), Energy@Home, Linear and Jouw Energiemoment.[3] Often these smart grid products and services have been implemented as a means to enable the households to take part in the management of the electric power grid. Therefore the main research question for the study outlined in this article is: "To what extent do the current products and services empower residential end-users to become co-providers in the energy system?"

This article is organized as follows. Section 2 describes the implications of a co-provider role for household energy management. Section 3 addresses the relevance of addressing behavioral change in addition to technological improvements. In Section 4 the effects of current smart grid products and services on household energy behavior are discussed. Section 5 provides recommendations for product and service designers towards fostering the role of co-provider. Finally, in Section 6 an overall conclusion is presented and future research needs are discussed.

2. Co-provision: Beyond efficient energy use in households

The ways in which end-users monitor and control their home energy consumption, referred to here as household energy management, usually concerns efficient use of energy. The expression "efficient energy use" in this study refers to the amount of effort expended by users in a household to reduce energy consumption and the extent to which energy efficient appliances are utilized. Energy efficiency of appliances refers to the energy that is required to provide a given service, for example 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.

The transition to smart grids, whereby end-users shift to a role of co-provider, 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, smart grid would then be geared towards:

1. Using electricity efficiently.
2. Planning or shifting electricity consumption to moments that are favorable 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 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 make household energy management more complex than when it is limited to the case of "efficient energy use". 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-provider.

[3] Information about the example projects can be found online: PowerMatching City—www.powermatchingcity.nl, Jouw Energiemoment—www.jouwenergiemoment.nl, Linear—www.linear-smartgrid.be, Energy@Home—www.energy-home.it.

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 presence 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 the electricity use 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 least investment cost, maximum benefit scenario (Ellis and Jollands, 2009; Eichhammer et al. 2009). At the same time, differences in behavior of end-users have been found to contribute to the variability in household energy consumption levels (Lutzenhiser, 1993; Sanquist et al., 2012). Sanquist et al. (2012) found that more than 40% of the electricity consumption in households could be contributed 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 by behavioral changes.

When household members do not understand how to efficiently utilize a technology and 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 gains 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 act 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).

4. Current products and services for the residential end-users

As described above, household energy consumption and production is related 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.

Fig. 1 depicts a framework for an electricity grid with distributed generation on household and community level. The figure schematically shows how the categories of smart grid products and services can be viewed across the household and community level. Balance between supply and demand can be achieved on each level, aggregating demand and supply from lower levels. For simplicity the 'main' grid is depicted as the higher level after community level, though additional levels and interconnections may exist in reality.

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 micro-generation in households 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 technology, 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

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

Categories	Examples	Type of co-providing behavior involved (Consumption/production/timing/trading)	Product, service or combination	Impact on behavior
Micro-generators	*Electricity:* • Photovoltaic solar system • Wind turbine *Electricity and heat:* • Micro-cogeneration unit • Fuel cell	• Production • Timing, when the micro-generator 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:* • Hot water storage in home • Storage heaters • 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. kW h) • 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 (functions on background)	• Does not stimulate behavioral changes without intermediary devices, like HEMS that visualize energy flows
Dynamic 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 in 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 to appliance level • Gas measurement—often combined with 'smart thermostat'	As intermediary technology can support: • Consumption • Production • Timing	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

		• Trading Energy monitoring and control systems doing so, are hardly available. Most focus on energy saving		feedback interaction and visualization required for different target groups • When used to change behavior, have to take into account processes of behavior change persons go through • Long-term effects not clear
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 (functioning on background)	• Fully automated system without feedback information appears not to support co-providing behavior

unit for local energy supply. The matching of supply and demand then takes place at the community level, rather than on 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 from the installation of micro-generators. When information was given about what hours were best for making use of solar energy on a day, 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.

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 with low electricity prices, i.e. at night usually. 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 smart energy system to produce the required heat for the household at times favorable for operation of the smart grid.

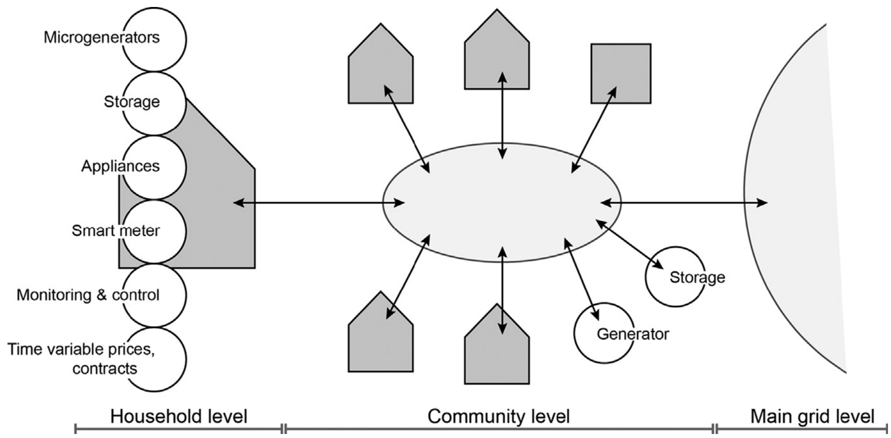

Fig. 1. Schematic overview of the categories of products and services per level.

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.

4.3. Smart appliances

Smart appliances are appliances that can be programmed and that communicate with energy management systems about appropriate hours to operate. Appliances in 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 the best time is to operate. The timing of the trigger signals may depend on the service that is contracted at a utility company, for example based 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 moment when 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 on the device. The interaction takes place through a thermostat or via a more elaborate home energy management system.

An elaborate home energy management system, as sometimes used to control the heating system, could also make remote control of white goods possible. The pilot project 'Jouw Energiemoment' ('Your energy moment') does this for example[3]. 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 hours for energy use and can adjust the planning of the washing machine.

Research results about the effect of smart appliances on household energy behavior are not available yet, since these appliances are only recently available. Studies on smart appliances have focused on drivers and barriers for adoption (Mert and Tritthart, 2009; Paetz et al., 2012). Effects of smart appliances 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).

4.4. Smart meters

The term smart meter refers to digital electricity meters that accurately measure consumption and production of electricity and communicate this data to the energy supplier. The 'smart' aspect of these meters is basically the ability to communicate the data it measures. As such it is 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 the end-user interacts with and has therefore little effect on energy related behavior (Darby, 2010). An intermediary product or service that displays energy feedback information would be required.

4.5. Dynamic pricing and contracting

One of the means to involve the end-users in the management of the smart grid is dynamic pricing, also referred to as time-variable pricing. The idea behind dynamic pricing is that the varying costs of electricity provision are conveyed to the end-users, so that they pay for and get a sense of the real costs of energy provision at the time they ask for 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 a flat rate or only differentiated for 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 of 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 variable tariffs 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.

4.6. *Energy monitoring and control systems*

4.6.1. *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 system. Intermediary devices can facilitate interaction between end-users and technology. Van Dam refers to such devices as Home Energy Management Systems (HEMS), described 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 to 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 can stimulate reduction of energy consumption. Ehrhardt-Martinez et al. (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. Success of a program was found to be more likely when the designers of a program 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 in achieving goals by monitoring progress in the achievement of a goal, 5% electricity savings for example, and by providing tips to achieve a 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 described by 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 (Kobus et al., 2012).

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 with. Furthermore, the applications increasingly make use of challenges to achieve household-level goals as well as competitions between households (e.g. Foster et al., 2010; Geelen et al., 2012; Petersen et al., 2007; Shifft, 2012).

4.6.2. *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 over the day on minute basis. 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 technology, 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.

An second example of a system that uses automation to control appliances is ‘Jouw Energiemoment’ (see also Section 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.

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 elements of a smart energy system cannot be seen separated 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 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 furthermore influence the interaction with a smart energy system, as in the case of variable tariffs and automated control. Fig. 2 depicts the relation between the aforementioned elements. An additional layer is added concerning the facilitation of change processes, which are addressed in the next section.

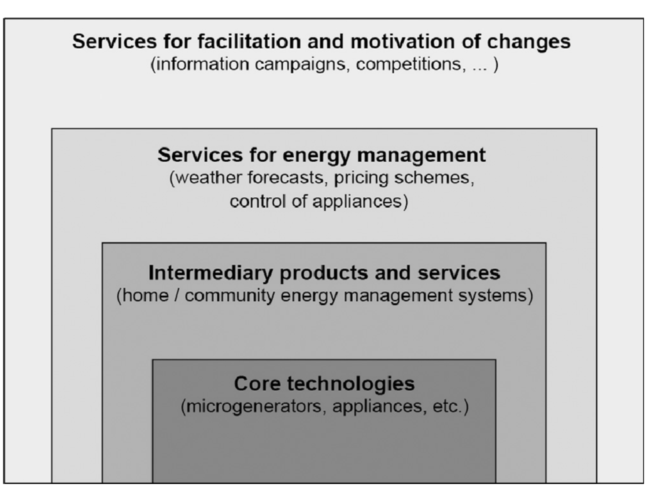

Fig. 2. Relation between products and services making co-provision possible.

The overview of smart grid products and services for end-users also shows that little is known 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 is needed to address cognitive and social aspects to empowering residential end-users in becoming co-providers. In the next section three design directions for product and service development are discussed.

5. Design recommendations

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

5.1. Supporting user interaction in a smart energy system

In cases such as PowerMatching City, having an automatic energy management system, there appears to be a lack of feedback for end-users. Creating awareness on 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 through a HEMS, as discussed in Section 4.6. A HEMS could provide insight into how the household 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 on household level, HEMS 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 they are a part of. Moreover, information at 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 in 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 a HEMS. The HEMS should enable end-users to understand the decisions being made by the household energy system, such as when the dishwasher will be turned on. 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 HEMS 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 at 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 might be required in terms of behavior 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 high charging costs.
- Relate energy feedback information to the electric power system at 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. 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.

5.2. Guide processes of behavioral change

Strategies to facilitate behavioral change from the social sciences could be applied in product and service development in order to facilitate end-users to shift from passive consumers to 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 the innovation (Rogers, 2003). The adoption of the role of co-providers, accompanied by the implementation of related products and services can be considered as 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 a co-provider. This adoption process can be facilitated in several ways, for example by media campaigns and communication with experts or peers. Also products and services can 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 (see 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 end-user and electric power system. For example, an end-user who usually does the laundry at night would after implementation of a smart energy system be able to benefit from lower electricity tariffs during day time because of local photovoltaic solar energy production. To do so, the end-user would have to adjust his or her routines and plan washing machine operation 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 changes and 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 perform 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).

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.

5.3. Support 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 households connected in a smart grid. The influence of the community on household energy practices, was reviewed by Gardner and Stern (1996) and further 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 end-users in 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) describe 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 who due to 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) argue that designers should rather than translate new technology to end-users, learn from end-users for new directions of technology development. This approach is similar to the recommendation of Gardner and Stern (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' 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 in order to tailor them 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 forms of communication that are suitable for a particular group of end-users is dependent upon the context it will be used in. Ideally, community-based systems should be self-sustaining in the sense that an external mediator is eventually 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.

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 study 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 presented in this article 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.

Acknowledgements

The study presented in this article was made possible by the IPIN subsidy program of the Dutch Government. The authors acknowledge the project team PowerMatching City for the valuable insight into the design and implementation of the project's smart energy system.

References

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

Allcott, H., 2011. Social norms and energy conservation. Journal of Public Economics 95, 1082–1095.

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

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. Innovative Smart Grid Technologies Conference Europe (ISGT Europe) 2010, 1–8, IEEE PES.

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.

CER, 2011. Electricity Smart Metering Customer Behaviour Trials (CBT) Findings Report—CER11080a. The Commission for Energy Regulation, 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. Journal of Applied Social Psychology 27, 588–601.

Darby, S., 2010. Smart metering: what potential for householder engagement? Building Research & Information 38, 442–457.

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. Proceedings of the National Academy of Sciences of the United States of America 106, 18452–18456.

Dobbyn, J., Thomas, G., 2005. Seeing the light: the impact of microgeneration on our use of energy. Sustainable Consumption Roundtable.

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. American Council for an Energy Efficient Economy, Research report no. E105.

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. Report for the European Commission Directorate-General for Energy Efficient Electronics.

Ellis, M., Jollands, N., 2009. Gadgets and Gigawatts, Policies for Energy Efficient Electronics. International Energy Agency, Paris.

European Commission, 2010. Energy 2020 — A Strategy for Competitive, Sustainable and Secure Energy. Communication from the Commission. COM (2010) 639 final.

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 Efficiency 1, 79–104.

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

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

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. Journal of Design Research 10, 102–120.

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.

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, pp. 33–42.

Guerra-Santin, O., Itard, L., 2010. Occupants' behaviour: determinants and effects on residential heating consumption. Building Research & Information 38, 318–338.

Gustafsson, A., Katzeff, C., Bang, M., 2009. Evaluation of a pervasive game for domestic energy engagement among teenagers. Computers in Entertainment 7.

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. International Journal of Distributed Energy Resources 4, 253–263.

Honebein, P.C., Cammarano, R.F., Boice, C., 2011. Building a Social Roadmap for the smart grid. The Electricity Journal 24, 78–85.

International Energy Agency, 2011. Technology Roadmaps—Smart Grids. OECD/IEA.

Jégou, F., Manzini, E. (Eds.), 2008. Collaborative Services—Social Innovation and Design for Sustainability. Edizioni POLI.design, Milan.

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

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.

Lockton, D., Harrison, D., Stanton, N.A., 2010. The design with intent method: a design tool for influencing user behaviour. Applied Ergonomics 41, 382–392.

Lopes, M.A.R., Antunes, C.H., Martins, N., 2012. Energy behaviours as promoters of energy efficiency: a 21st century review. Renewable and Sustainable Energy Reviews 16, 4095–4104.

Lutzenhiser, L., 1993. Social and behavioral aspects of energy use. Annual Review of Energy and the Environment 18, 247–289.

Mert, W., Tritthart, W., 2009. Get smart! Consumer acceptance and restrictions of Smart Domestic Appliances in Sustainable Energy Systems. In: Transpose Midterm Conference, Muenster.

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 Utilities Fortnightly. March 2007, 44–66.

Owen, G., Ward, J., 2010. Smart Tariffs and Household Demand Response for Great Britain. Sustainability First, London.

Paetz, A.-G., Dütschke, E., Fichtner, W., 2012. Smart homes as a means to sustainable energy consumption: a study of consumer perceptions. Journal of Consumer Policy 35, 23–41.

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. International Journal of Sustainability in Higher Education 8, 16–33.

Rogers, E.M., 2003. Diffusion of Innovations, fifth ed. Free Press, New York.

Roozenburg, N.F.M., Eekels, J., 1998. Produktontwerpen, Structuur en Methoden. Lemma, Utrecht.

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

Shifft, 2012. Social Energy.

Shove, E., Watson, M., Hand, M., Ingram, J., 2007. The Design of Everyday Life. Berg Publishers, Oxford.

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

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 44, 38–45.

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. VaasaETT, Global Energy Think Tank, Helsinki.

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

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

Van Raaij, W.F., Antonides, G., Oppedijk van Veen, W.M., Schoormans, J.P.L., 1999. Product & Consument, first ed. Lemma, Utrecht.

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

Verbong, G.P.J., Beemsterboer, S., Sengers, F., 2012. Smart grids or smart users? Involving users in developing a low carbon electricity economy. Energy Policy 52, 117–125.

Verplanken, B., Wood, W., 2006. Interventions to break and create consumer habits. American Marketing Association 25, 90–103.

Wilson, C., Dowlatabadi, H., 2007. Models of decision making and residential energy use. Annual Review of Environment and Resources, 169–203.

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

Zachrisson, J., Boks, C., 2012. Exploring behavioural psychology to support design for sustainable behaviour research. Journal of Design Research 10, 50–66.