Energy Policy 52 (2013) 117–125

Contents lists available at SciVerse ScienceDirect

Energy Policy

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

Smart grids or smart users? Involving users in developing a low carbon electricity economy

Geert P.J. Verbong*, Sjouke Beemsterboer, Frans Sengers

School of Innovation Sciences, Eindhoven University of Technology, The Netherlands

HIGHLIGHTS

- ▶ State of the art of smart grids experiments in the Netherlands.
- ▶ Focus on role and position of users.
- ▶ Trend is to active involvement of users.
- ▶ Several barriers have been identified.

ARTICLE INFO

Article history:
Received in revised form
26 September 2011
Accepted 3 May 2012
Available online 28 May 2012

Keywords:
Smart grids
Users
Strategic niche management

ABSTRACT

This article analyses practices and perceptions of stakeholders on including users in smart grids experiments in the Netherlands. In-depth interviews have been conducted and smart grid projects have been analysed, using a Strategic Niche Management framework. The analysis shows that there is a clear trend to pay more attention to users in new smart grid projects. However, too much focus on technology and economic incentives can become a barrier. Some institutional barriers have been identified. New innovative business models should be developed to explore different options to involve users. The many pilot and demonstration projects that are taking shape or are being planned offer an excellent opportunity for such an exploration. Learning on the social dimensions of smart grids, and the international exchange of experiences can prevent a premature lock-in in a particular pathway.

1. Introduction

Future developments, such as the large scale introduction of intermittent low carbon energy sources (wind, PV) and new loads (Electric Vehicles, heat pumps) are expected to pose great challenges for the ageing electricity grids in the Netherlands. The simple solution is replacing the old cables and lines with heavier ones, that is, reinforcing the current grid infrastructure. Another solution for upgrading our electrical energy infrastructure is to introduce a more intelligent electricity grid, a 'smart grid'. Introducing information and communication technologies (ICTs) to the electricity grid, is supposed to add 'intelligence' to the grids, hence the name smart grid. Such smart grids offer many advantages: they improve both the physical and economic operation of the electricity system by making it more sustainable and robust, more efficient by reducing losses while at the same time offering economic advantages for all stakeholders. The electricity system is a critical infrastructure for modern society. Therefore, it is not surprising that the promise of smart grids has created a real hype. The EU, the USA and emerging economies like China have taken up the challenge of 'making the grid smart'; they have set up extensive R&D programs and are testing smart grids in practice. However, there is still great uncertainty about how such smart grids will look like.

In the past 30 years, the electricity sector has seen a shift from a system dominated by engineers to a more market based system. Recently, the beginning of a transition to a low carbon electricity network has become visible. Such a transition is a difficult and long process. The current system is still struggling with the changes that the liberalization process of the 1990s has introduced. This is to some extent due to huge sunk investments in technologies (power plants, cables and lines, transformer stations, etc.). The traditional centralized system where the electricity flows from large power plants through the transmission and distribution networks to the (passive) consumers displays a large inertia. Yet, also belief systems, social networks and capabilities play an important role (Verbong and Geels, 2007).

Visions on the future electricity system and the preferred development path differ greatly. They range from the development of a European Super grid to the construction of local, loosely linked micro grids. Because all these pathways are technologically feasible,

* Corresponding author. Tel.: +31 402472698.
E-mail address: g.p.j.verbong@tue.nl (G.P.J. Verbong).

0301-4215/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.enpol.2012.05.003

future transitions will be determined by economic, institutional and cultural dynamics (Verbong and Geels, 2010). Although currently, political considerations and economies of scale seem to favor large scale solutions, the emphasis in smart grid discussions focuses on local and regional solutions for the challenges electricity grids are facing.

The future electricity grid not only promises to be a radical technological, environmental and economic upgrade of the old system, it also will be a more pervasive technology, influencing the daily life of users. Users and smart grids have a somewhat uneasy relationship. Although users have not been actively involved in other grid innovations, they will likely play a pivotal role in the future of smart grids. The extent to which users are willing to accept changes in their homes and daily routines will not only shape what smart grids will look like, it will also have a considerable impact on the chances of successful implementation. Currently many pilot projects are taking place or are planned for the near future (Netbeheer Nederland, 2010; Taskforce Intelligente Netten, 2010). In the Netherlands 12 larger real life experiments (*Proeftuinen*) have started in 2012. Although the focus has been predominantly on technical learning, increasingly the various smart grid concepts are being confronted with social reality.

In this article, our goal is to shed light upon practices and perceptions of stakeholders on including users ('the social') in the transition process towards smart grids. To do so, in-depth interviews have been conducted with a large number of stakeholders and smart grid projects in The Netherlands have been analyzed, using the Strategic Niche Management (SNM)-framework. SNM focuses on experiments and niche developments during transitions. It argues that the creation of 'protected space' or niches is vital for the chances of promising radical innovations like smart grids to succeed (Schot and Geels, 2008). Specifically, this paper will try to answer the following research question: which visions on user perspectives in current and future smart grid experiments do stakeholders propagate. We will also briefly address the question to what extent user perspectives have been incorporated in current smart grid initiatives in the Netherlands.

Before we elaborate on smart grids as a concept in more detail, we will first discuss the theoretical and methodological part of our research. Next, we will present some outcomes from the stakeholder interviews, followed by a brief analysis of on-going smart grid projects in the Netherlands, focusing in particular on those projects that aim at user participation. Finally, some lessons will be drawn for current and future initiatives and we will reflect on the implications for the transition to a low carbon electricity economy.

2. Theory and methodology

This paper draws upon the theoretical framework of Strategic Niche Management (SNM). SNM uses a multi-level perspective (MLP) on transitions, radical shifts in socio-technical systems. Transition processes are the outcome of interaction processes between multiple levels: the landscape, regime and niche level. Radical innovations mature in niches which through government protection or specific market demand provide protection for new technologies in the initial growth phase, when they are still unable to withstand normal market pressures. If a niche grows successful, it can cause the dominant regime to change. However, this is only possible if sufficient tension is built up in the regime creating a window of opportunity for the niche. This tension can be created either by pressure from external factors that is the landscape level or by tension from within the regime. The current electricity regime, consisting of the technological system, the actor networks and rules (institutions) is facing both internal and external pressure (Geels, 2004; Verbong and Geels, 2007; Schot and Geels, 2008).

SNM focuses on processes that are internal to the niche development. SNM has identified three processes that play a key role in the successful development of a niche technology. They are (1) articulation of expectations and visions, (2) building of social networks, (3) first and second order learning processes (Kemp et al., 1998; Geels and Schot, 2010). Paying attention to these processes improves the chances of successful niche development. In our analysis we will focus on the articulation of expectations, in particular we have asked stakeholders, actors involved in smart grid development, their visions on smart grids.

However, several SNM-studies have shown that positive niche processes are a necessary but not sufficient condition for the success of niches (Raven, 2005; Schot and Geels, 2008). The interaction with the regime (or regimes) is also important, e.g., using instabilities in the regime or seizing opportunities in the broader societal context. Lack of attention to the social embeddedness of new technologies is considered one of the reasons renewable energy innovations have failed to leave the niche stage in the Netherlands. Other reasons are the related technology push character of innovation trajectories and the lack of long-term guarantees and stability by government policy (Verbong et al., 2008).

The aim of SNM is to support a transition to more sustainable ways of production and consumption, in this case to a low carbon electricity regime. In the discussions on smart grids the assumption seems to be that smart grids are (almost) synonymous with a low carbon electricity regime. How radical a shift to smart grids will be is not yet clear. In fact, there is no consensus on what a smart grid is. Some actors actually advocate small technological changes to optimize present systems while their framing includes mobilizing the hyped term 'smart grids'. This is a regime optimization and not a regime shift, a radically novel sociotechnical configuration. As mentioned in the introduction, there are diverging pathways the development of future electricity system can follow (Verbong and Geels, 2010). However, we have asked the stakeholders we have interviewed about their ideas and definition on what constitutes a smart grid and almost all point to novel socio-technical configurations. The most striking deviation from the current practices is an active role and participation of users in future electricity systems.

Despite the management promise, SNM has been mainly used as an analysis tool. Important lessons from past experiments are the need to take a broad approach: to learn also on the social and environmental benefits expected from smart grids, the cultural and psychological meaning of such grids, market pressures, complementarity with existing infrastructures and systems of the project. In particular the role of users often has been neglected, as e.g., SNM-studies on mobility have pointed out (Hoogma et al., 2002). It is also crucial to make sure that lessons learned are transferred to follow-up projects. Finally, SNM scholars point to the importance of reflexivity, that is, the ability to question the often implicit dimensions.

The recent revival of local energy initiatives in many countries has put the question of public engagement in energy provision on the research agenda (Burgess, 2008). Although the need of user and community participation in energy provision and services has been recognized, the implementation is not straight-forward. Devine-Wright and Devine-Wright (2009) give an analysis of the Titanic Mill project in Yorkshire. This project tries to combine a sustainable energy provision with participatory forms of governance. They conclude that the envisioned co-provider role of the residents suffers from not realistic expectations and uncertainty, but also from a lack of a clear proposal how to really involve the residents. The expertise to encouraging greater resident community engagement is missing (Devine-Wright and Devine-Wright, 2009).

A pivotal part of user involvement is the way users and the system interact. Hargreaves et al. have investigated how households react on feedback from smart energy monitors. They conclude that there is no simple cause-effect relationship between the provision of feedback and rational decision making in regard to energy demand. They show that the way the monitors are domesticated, that is become part of the normal daily routines, is crucial. The monitor is not a neutral technology. Not only does esthetic appearance matter, but it also becomes part of domestic negotiations on energy consumption. This can lead to greater co-operation and a feeling of empowerment, but also turn into conflicts and feelings of disempowerment. Last but not least: the assumption that households are willing to change behavior in order to enable an efficient and effective grid management is an unproven one (Hargreaves et al., 2010).

Walker and Cass provide a systematic exploration of the different options of user involvement. They have analyzed different modes of implementation of renewable energy in the UK. They distinguish five modes: public utilities, private suppliers, community, households and business. Each mode involves a different configuration of technology and social organization. They propose a set of 4 dimensions ('sets of questions') to characterize the 'software' of the social organization: (1) the function and service of the generated energy; (2) the ownership and return on investments; (3) the management and operation and (4) infrastructure and networking, also including the institutional arrangements (e.g., regulation). This set of questions provides a very useful starting point for analyzing the different roles of the public and of the organization of energy provision systems in general (Walker and Cass, 2007).

In this article, users refer both to individual consumers and households. Including a social, user perspective in pilots on smart grids will allow actors to learn at an early stage from the experiences and attitudes of the consumers and citizens. Ideally, these experiences will be used to mobilize users as drivers for smart grid concepts. But even if this fails, it is expected that the adoption of a user centered perspective reduces the chances that users will act as barriers to change (Schot and Geels, 2008).

The empirical data have been derived from 37 interviews with stakeholders related to smart grids and the energy sector. Data from stakeholders have been collected by a series of semi-structured interviews. The semi-structured nature of the interviews gave the stakeholders the opportunity to present first their ideas on smart grids, without being guided too strongly. This approach is especially fruitful when covering a topic that is still in an experimental phase, such as smart grids. The interviews focused on the visions and expectations of the stakeholders, the envisioned or expected role of users and the organization of user participation.

The process of selecting stakeholders started by consulting known experts in the domain. Further stakeholders were found using 'snow-balling' as method. This resulted in a group of about 40 stakeholders that have been approached for an interview. 37 Stakeholders agreed to participate in an interview that lasted on average between 1.5 and 2 h. The interviewees represented governmental organizations from multiple levels (12), public and private research organizations (8), utility companies in the electricity and gas sector (11), and other organizations, including NGO's (12). An important issue is that some stakeholder groups are still missing, in particular the users. Users were difficult to find. First of all, there are hardly any users, but surprisingly organizations that usually represent users such as the '*Consumentenbond*' (Organisation of consumers) were not willing to participate. As a proxy for users, therefore we have interviewed a few actors representing residents and the built environment. We also included a few researchers, doing research on energy related consumer behavior.

To assess the involvement of users in on-going experiments an inventory has been made of smart grid projects in the Netherlands. This resulted in a list of 27 smart grid projects. Projects are characterized as an experiment when they include a physical test setup to implement the technology practically in a local situation and/or involve users in project activities. Several of the projects and initiatives have become part of the Dutch Smart Grids program, that support 12 projects.[1] As these projects still are in in an early phase, we will focus on the role of users in the design of the projects. An extensive description and analysis of these experiments is beyond the scope of this article.

3. Dimensions of a smart grid

The challenges for future electricity grids come both from the supply side and the demand side. On the supply side, new forms of renewable distributed generation (DG) will put pressure on the current energy system for two reasons. First, natural resources as wind and sun lead to a less stable electricity supply, bringing along strong fluctuations on a daily and seasonal basis. When wind energy became a notable influence on the grid, it led to increases in net volatility (Guerrero et al., 2010). The danger for net instability has increased with the increasing use of wind energy as wind speeds fluctuate heavily and because wind conditions tend to be optimal at night, when demand is low. Second, an increase in decentralized generation capacity will introduce reverse flows from the local generation unit to the transformers.

Although the focus in smart grid discussions has been mainly on the need to integrate DG, increasingly attention is turning to the demand side, because a further electrification of energy demands and introduction of new loads are envisioned. Prime examples of new loads are electric vehicles (EV) and heat pumps. Households in the Netherlands consume up to 4000 kW h yearly. In new urban areas without natural gas connection and heat pumps with additional electric heaters, this is already substantially higher (Van Eck, 2010). The addition of EV's is expected to almost double the current average electricity demand per household, facilitating a potential shift to an all-electric society.

In summary, pressure on the system is related to volatility and capacity of the infrastructure. In the Netherlands an additional pressure on the electricity regime is presented by the ageing of the current electricity infrastructure. A substantial part of the cables and lines have been in use for 50 years or longer and will need to be replaced in the nearby future (Netbeheer Nederland, 2010). The long life span of the infrastructure illustrates the importance of investments in electricity infrastructures: the choices of today will have a very long impact at least on the technological dimension of the electricity system. Once, the infrastructure is available it will (continued to) be used (Kaijser, 2003).

To deal with these challenges smart grids are propagated as a necessity, both technologically and financially. An intelligent grid promises to take care of these problems by shifting from following demand (in the current system the generation of electricity always follows changes in demand) to a supply driven system, that is demand has to follow generation. This introduces the need for more local balancing of supply and demand, including more measuring and monitoring of flows and the use of communication tools to maintain net stability. It also can increase the number of active players involved, but this depends on the organization of the future smart grid (Larsen and Petersen, 2009).

[1] For more details on these projects: http://www.agentschapnl.nl/content/factsheets-proeftuinen-intelligente-netten Accessed 6 April 2012 or contact Agency.nl.

Proponents hail smart grids as a promise to solve almost every thinkable energy issue: they will enable a transition to a sustainable energy system; even with the increased complexity they will be cheaper for society; and, they will lower energy consumption by actively involving consumers.

Despite these promises, it is unclear what 'smart grids' exactly constitute, how they should be implemented, and what their effect will be on the reliability and costs of the electricity system. However, it is clear that future electricity systems will be different from the current 'dumb' ones (The Economist, 2004). Taking into account the high expectations, it is likely that results will be disappointing.

There are many definitions of a smart grid, e.g., in the report of the EU platform (European SmartGrids Technology platform (ESGT), 2006). Chandler provides a definition that puts emphasis on the role of the user:

"A smart grid generates and distributes electricity more effectively, economically, securely and sustainably. It integrates innovative tools and technologies, products and service, from generation, transmission and distribution all the way to consumer appliances and equipment using advanced sensing, communication, and control technologies. It provides customers with greater information and choice, including power export to the network, demand participation and energy efficiency" (Chandler, 2008).

From this, it can be deducted that the technological dimension of smart grids includes distributed generation, measurement and control equipment (sensors and smart meters), innovative consumer appliances and communication tools. There is a close link to the development of domotics and home automation. One specific technology often mentioned is the use of storage, e.g., batteries, to balance demand and supply. This option, although technologically feasible, increases losses, is financially not (yet) attractive and faces several institutional barriers (Van Vlimmeren, 2010).

The social dimension of smart grids generally involves the introduction of some kind of Demand Side Management (DSM). Usually, smart grids are accompanied by the introduction of DSM to allow demand to follow supply. DSM is an old instrument developed to shift loads from peak periods to periods where demand is much lower. However, the use of DSM for households is relatively new. In order to make DSM work some form of flexibility has to be introduced. Options are shifting the use of washing and drying machines, freezers and refrigerators. These appliances have to become smart as well, that is they have to be able to be managed from a distance. Flexibility from these kind of appliances is limited (a maximum of about 25%, including all wet appliances and a part of the cold appliances, De Jonge, 2010), but EV's could provide much more flexibility, explaining the enthusiasm among smart grids proponents for including EV's in smart grids projects. Another crucial technological component to enable DSM is the smart meter, sending data from the users to the networks and in the opposite direction.

DSM and the use of smart meters and appliances intervene directly in the daily routines and practices of consumers. In doing so, they put the user at the center of the technology (Steg, 2008; Pron-van Bommel, 2010). Successful introduction of smart grids will require support of users and households. There are several reasons mentioned in the literature why consumers might be willing to accept smart grids and change their behavior. One argument has been that consumers are willing to change their behavior for environmental reasons. This has been the main argument to convince the public to accept smart meters. The idea is that providing consumers (households) with detailed feedback on their energy consumption will lead to a reduction in energy use. The literature suggests that a reduction in energy consumption of between 5% and 15% is possible (Burgess and Nye, 2008; Darby, 2006; Van der Beek, 2010). Recent trials show a mixed picture: trials in the US gave a demand reduction between 4% and 15%, but similar experiments in the Ireland and the UK only resulted in a reduction of only 3% (Hardy, 2012). Due to a lack of long term experiences it is yet unclear to what extent these effects are temporary or lasting and users are returning to their old practices (Nyborg and Røpke, 2011).

Price incentives present another argument for users to change their behavior (Benders et al., 2006). At the moment consumers pay a flat rate for energy use. However, actual costs to supply electricity are higher during peak hours than off-peak Smart grids would allow for real time pricing, enabling consumers to reduce their energy bill if they can respond to variable energy prices. For the energy companies and network operators, benefits result from a lower peak in energy demand, requiring fewer investments in production and transport capacity. Also here, empirical evidence for the potential of financial stimuli is at best mixed. Larsen and Petersen (2009), Huygens (2011) show that current price benefits for a consumer are limited, less than 0.5%. Furthermore, substantial reductions in energy use face several social and technical barriers and limitations.

Besides the limited flexibility in demand, it has been unclear whether consumers (households) are willing to accept changes in their energy behavior. In particular, privacy is considered an issue that can block successful introduction of smart grids and DSM. Detailed data on electricity consumption gives involved actors a lot of information on user behavior. Previously, the privacy issue has been an argument for the Dutch government to renounce plans for obligatory implementation of smart meters in the Netherlands (Energieraad, 2009; Kema, 2010).

Next to the privacy issue, there are several other institutional and social barriers to behavioral change with regard to energy use. Huygens (2011) identifies three main barriers for active participation of consumers. First, active consumers are limited in their options to sell the electricity they generate. For example, it is currently not allowed to sell the electricity directly to one's neighbor. Second, there are hardly any variable pricing schemes for electricity. The existing price differentiation schemes (day-night tariffs) are also being criticized by consumer organizations for lack of transparency; the exact advantage, if there is any at all, is not clear. Third, active consumers have to pay (proportionally) for the transmission, while the large generators, who feed in into the transmission network do not have to pay. This provides the large energy companies with an unfair advantage over local generators. The costs for upgrading transmission networks are still being 'socialized' over all consumers, while local generators do not get a reward for the services they provide to the system, e.g., local balancing and reduction of losses (Huygens, 2011)).[2]

Social acceptation already has been mentioned as a very important factor. Wüstenhagen et al. (2007) distinguish between three types of acceptation: socio-political, community and market acceptation. According to Wolsink (2010) social political and market acceptation are the most difficult ones in the case of smart grids. Acceptation of institutional innovation in the field of renewable energy has been notoriously difficult in the Netherlands. Market acceptation is linked to the definition and allocation of roles in the new markets and the degree of control by energy companies. This strongly relates to the question of ownership and control of data flows generated by smart meters. For acceptation it is important to know what options consumers have to organize themselves and what kind of institutional adaptations are needed to enable new roles for individuals and collectives of consumers

[2] Although there is a political debate on this issue in the Netherlands, it has not yet been settled (fall 2011).

(Wolsink, 2010). There is still a lot of uncertainty on the identity of the future 'prosumers'. Up to now, this identity has been defined mainly by energy companies, networks operators and policy makers, the traditional actors in the electricity system (Wolsink, 2010).

Summarized, smart grids have mainly been defined in technological or economic terms. Although there are many assumptions and suggestions on how consumers might behave or might be willing to accept new technological options, there is still a knowledge gap with regard to actual attitude of consumers towards smart grids and how they are going to integrate these options in their daily life.

4. Interviews

In this section we will discuss the main topics that structured the interviews (see the theory and methology section). First we briefly present the visions on smart grids; next, we focus on the envisioned role and position of users in smart grids in general and pilot projects in particular.

4.1. Visions on smart grids

In general, the interviewed stakeholders expressed a positive attitude towards smart grids. There is a general consensus that smart grids present a 'paradigm shift' towards demand side management, a more active role for the consumer, and flexible pricing. Smart grids are considered a preferred option over the present 'copper plate' alternative that extends the grid by putting more and/or heavier cables in the ground.

Ambiguity exists on the conceptual nature of smart grids. Smart grids are used as an umbrella term covering a multitude of aspects. This does not only imply that people do not exactly know what it is but also that they will have to discover how to use it. "The question is not what a smart grid is, but what it can do" (DSO). As can be expected, disagreement exists on the practicalities of designing a smart grid: i.e., who should be the dominant actor, how should costs and benefits be allocated, who bears which responsibilities, etc. Consequently, the development and exploitation of smart grids can take different forms depending on the organizational structure of the new regime. It can vary from a smart Super Grid to an assembly of loosely connected regional grids. Smart grids can be dominated by the current incumbents or by new entrants, like small innovative firms or new municipal or provincial utilities or some hybrids forms within those extremes (Verbong and Geels, 2010).

Contested is the role of gas in the new regime. The Dutch energy regime has been shaped to a large extent by the availability of natural gas. Households in the Netherlands usually consume more energy in the form of gas for heating and cooking than electricity. However, a gas grid does not fit in proposals for a CO_2 neutral neighborhood. At the same time, the large scale introduction of micro-CHPs could place the gas actors in a central position in a more decentralized regime. A few stakeholders present natural gas as a transition fuel, that is the increased use of natural gas can be regarded as a first step towards a low carbon electricity economy. In the future the substitution by biogas is proposed as theway of greening an energy regime with gas.

Other differences in visions relate to the issue who should be the leading actor in the implementation process, the utilities or the network operators. Energy suppliers, on the one hand, have the opportunity to contact each customer individually, yet they create a dispatched network. On the other hand, street-by-street roll out by network operators allows an optimal network by building a smart grid network in an entire (local) community at once, allowing for autonomy from the central grid at cost of losing freedom to chose energy supplier.

Although smart grids are claimed to be in the interest of the end-user, there is some ambiguity to that. First, smart grids include a communication layer which is expected to enable the supply of services to the end-user. Other elements that support smart grid developments are the promise to increase the lifespan of the old system and to allow gradual replacement of the old system without many outages. Despite potential benefits to the end-user it is clear that service providers and system operators have their own incentives to support smart grid developments as well. So, despite all promises, it is not so clear which interests are primarily served by smart grid developments. The interviewees portray a picture of a promising yet highly uncertain future for smart grids.

Generally, a smart grid is accepted as an enabling technology, allowing the introduction of new loads and mass connection of distributed generation units to the grid. Nonetheless, from an innovation studies perspective smart grids present themselves as a system innovation, meaning they include "...large-scale transformation in the way societal functions such as transportation, communication, housing, feeding, are fulfilled" (Geels, 2004, p. 2). Despite individually acknowledging the importance of the social, interviewees expressed that the market is still too much focused on the technological elements of the smart grid.

4.2. Visions on user involvement

In general, stakeholders expect that energy will become a more prominent theme for end-users. They expect that together with the relative proportion of the income spent on energy, attention will rise as well. Reasons given for an increase in energy expenditures focus primarily on an increase in demand. In particular loads such as heat pumps and electric vehicles are expected to have a large impact on the electricity demand. Perceptions of low interest are supported by the observation that despite advertising, few people switch energy supplier in a liberalized energy market (10,4 in 2010, EDSN, 2010). The challenge for stakeholders is therefore to motivate end-users to play a more active role in their home energy management, to induce behavioral change.

Inducing behavioral change requires long term engagement of end-users and a need to focus on changing routines. There are different views advocated to induce behavioral change. They correspond to different types of incentives that underlie them. Generally they involve some kind of feedback and economic incentive. With regard to feedback, an end-user will need to gain insight in the energy use of appliances. Next, the end-user will need help with interpreting that data. Only then it becomes possible to advise a customer how to save energy by changing behavior. Although most people will not be very interested, some end-users do want to know more about their energy use in comparison to other households and about the effectiveness of energy saving measures. Using feedback mechanisms is grounded in the idea that it allows steering in consumption (Hargreaves et al., 2010). To improve effectiveness, feedback mechanisms can be complemented by some form of economic incentive. In doing so, smart grids will 'force' users to make micro-economic decisions with regard to energy use, and buying and using appliances. Although most interviewees have a firm belief in economic incentives, it is unclear to what extent they will actually lead to the envisioned behavior.

Regarding incentives, two main perspectives can be distinguished from the interviews. The dominant perspective describes the user as 'homo economicus': an entity which acts rationally according to self interest to maximize its economic benefit.

As flexible pricing and DSM can reduce energy costs, introducing price incentives will lead to lower energy use at times of peak load. The market mechanism will 'automatically' engage users. As mentioned, empirical evidence suggests that the monetary push currently is too weak to persuade actors to change behavior (Hargreaves et al., 2010). Some interviewed stakeholders claim emotional incentives to be equally necessary because "…early adopters will consider self-sufficiency or a green image to be much more important than lowest costs" (DSO).

The discussion among actors who adhere to the dominant 'economic' perspective can semantically be divided between a group who claims that users should reap the benefits of participation and a group who claim that users who refuse to adapt should be punished with higher costs. Although both arguments adhere to the same (market) mechanism, they take a different approach. In doing so, claims about benefits to the consumers could be accused of misleading users, even if only to prevent a worse situation. Although smart grids might lead to short term benefits, in time, the proportion of income that users will spend on energy is bound to rise. Benefits are therefore relative to a *future* state without a smart grid. Compared to the current state, smart grids will not prevent a more expensive energy bill. An overly positive approach could be very harmful to public acceptance when smart grids have been introduced and prices do still rise. One interviewee talks about price signals, which allows the consumer to choose whether or not to conform. This seems to be a more neutral framing.

4.3. Users as barriers

Even though most stakeholders firmly believe in an economic incentives approach, their primary focus is to remove market barriers. In this context, several interviewees perceive end-users as a potential barrier to the successful development and implementation of smart grids. Barriers that were mentioned include the domain of privacy, the degree of control, lack of interest or time, and the difficulty to change routine behavior.

The perception of end-users as barriers to change is representative for a technocratic view on users and user behavior. Statements claiming that "…to consumers the *perception* of a potential outage is more important than actual time this occurs" (governmental agency) or that "…an overrule button is necessary to give people the *feeling* of control" (DSO) show a typical contempt for users that is present among many interviewed stakeholders. Approaching users from a centralized top-down perspective increases the likelihood that they will act as barriers. Resistance is more likely when users have to adapt to previously thought out technological solutions to fit their perceived needs. Some interviewees display a more self-critical perspective, by pointing to their own sector as cause. One interviewee explains that they do not grasp that it is the sector itself that is responsible, by "communicating to the market that you can 'steer' consumers from a distance".

Stakeholders believe that intelligence should be distributed at the end-user to enable participation. At the same time, they believe that end-users should remain free to decide how to participate. Freedom includes the choice to maintain energy use in situations of shortage but also which data to communicate and at what moment. It is considered unlikely that end-users will trust an external party with control over home electrical appliances, yet, at the same time users might not want to manually have to switch off appliances whenever this is more efficient. In this context stakeholders mentioned the issue of control, the amount of control that users should have over the system. Control is a multi-dimensional topic dealing with data-ownership, privacy, complexity of the system, responsibilities, risks, etc. The introduction of smart grids seems to be a trial balancing functionality and control.

One option to reduce complexity and still give the users the idea that they are in control is by developing systems that make those decisions for the user, including an opportunity to interfere. One of the interviewees uses the analogy of a car with a 'sports' and a 'comfort' setting. At the same time, systems need to be easy to use. To give an alternative example, when buying new appliances, users cannot be expected to register every product they buy with their energy supplier. Instead, alternatives need to be developed, such as automatic registering at purchase.

Regarding price risks, it is perceived that most consumers will behave risk averse. Other stakeholders are expected to take away the risk for end-users. Nonetheless, it is expected that economic gains can seduce users into more active behavior. Subsequently, the proposition to end-users should be transparent, economically attractive, and simple.

4.4. Organization of users in the electricity regime

Most stakeholders assume that the current division of tasks between actors in the regime more or less will remain the same. To them the transition to low carbon systems is mainly perceived as a technological one. Discussions focus in particular on the role and responsibilities of the network operators. However, a few stakeholders mention that users in the future not only will be more active in managing their home system and interacting with utilities, but that they might also start their own energy companies—either as collectives/communities or singlehandedly as a stock market traders aided by (fully) automated systems buying and selling their own energy for time dependant APX prices. In this context a variety of organizational forms is mentioned: private companies, 'aggregator' companies organizing a group of user cooperatives, public-private partnerships, taking care of investments and/or, operations and maintenance. This is in line with the different roles identified by Walker and Cass (2007). One researcher explicitly states that research on business models is needed to explore all options. In this context several regulatory and institutional barriers are mentioned, e.g., selling electricity directly to your neighbors, 'virtual' balancing between parties not directly linked by the distribution network and awarding value to services proved by users for making demand more flexible.

4.5. Users and experiments

In relation to experiments, several interviewed stakeholders expressed difficulty finding enough people to participate in experiments as result of a lack of interest. The difficulty to find enough participants is considered more difficult when the experiments are larger. This is especially frustrating as larger projects are needed to test out how users respond to smart grids.

With regard to the involvement of users in experiments, two main strategies to roll out smart grids came up during the interviews. A first strategy, favored by DNOs, to get reliable information on user behavior is to include all types of users, and not just those that are interested already. In this strategy, it will be necessary to learn how to 'seduce' users to participate. Involving all users would be necessary if implementation is preceded via a street by street rollout. This is considered to have efficiency benefits, yet poses more difficulties with regard to experimentation and acceptation.

A second strategy, supported by the utilities, considers involvement of early adopters or lead-users to be sufficient during the development phase. Limiting the experiments to users that are intrinsically motivated makes it easier to find participants.

Unfortunately, it will make the outcomes of the experiments less applicable to society at large.

Despite these differences in strategy, there is a general consensus that users (even interested users) need to be triggered to get actively involved in their energy use. Several strategies to get users involved have been mentioned during the interviews; they include: working together with housing corporations, focusing on the ease of the system, using the competitive nature of people, feelings of independence, community feelings, and, naturally, monetary rewards. Behind different strategies lie different perspectives on the optimal incentives, taking into account that behavior is guided by routines and that people are easy going. Monetary rewards take into account the premise that people are rational agents pursuing maximum gain. Competitiveness, independence and community feelings spark emotional drivers as basis for human action. Clearly, this does not mean that these drivers are mutually exclusive. Interestingly, sustainability has not often come up as driver. At times it was even questioned whether to include it at all. This might have to do with the notion that sustainable development is perceived as costing money, thereby being contradictory to monetary rewards. Finally, little attention was paid during the interviews to behavior in current experiments. To a large extent this is due to the fact that very few experiments have been finished so far. Yet, it also shows that to stakeholders, the main issue is how to get users to be involved in the first place.

5. Smart grid experiments

From the smart grid experiments that have been analyzed for this paper, nine projects also included a user experience component. We will discuss biefly only two contrasting projects, one with a more economic perspective and one with a more radical organizational structure, and present some general findings.

5.1. Flexines (Groningen)

The project is linked to the high profile project Powermatching City, Hoogkerk (also part of the national Smart Grids program). It aims to support consumers in making choices in a smart grid situation with variable prices through a self-learning management system. Flexines wants to incorporate peer to peer transactions between users of the system and introduce new energy services or business models (Morris et al., 2005). The initiative started from the premise that households will in time develop to 'prosumers'. To deal with the net consequences of this expected development, Flexines develops an electronic infrastructure aimed at DSM, which will include a 'self-learning' comfort management system. Power in this system should lay with the user. Consequently, the system should facilitate DSM according to the wishes and values of the consumer. The project started in 2009 and is expected to finish in 2012. Expected results from a user perspective focus on critical success factors for user adoption, wider societal implementation, and several quality, stability, and price related aspects that indirectly involve a user perspective.

5.2. Cloud power (Texel)

This a bottom-up experiment based on a community of energy users that individually and collectively try to green their energy use. This project on Texel uses its special location, an island just north of the province of North-Holland, and fits in several initiatives of inhabitants on the island to become more or less sustainable and energy independent. Demand and supply is organized via a 'cloud' allowing them to exchange energy. To do so, smart meters, home energy systems, and an energy management system are installed and distributed generation units are connected to the grid. The goal is to strive towards self-sufficiency with renewable energy sources. This is expected to be achieved by inducing energy efficiency and behavioral change.

The interesting aspect from a user perspective is that 'cloud power' in Texel is set up as a cooperative, to which 2800 households decided to opt in. Consequently, there is a voluntary and democratic base, which is expected to increase motivation for active participation. The flexibility of allowing for a diversity of (future) projects to be included improves the chances that initiatives will be organized from a user perspective. The project challenges the view that all consumers prefer abundant and uninterrupted supply, at lowest costs, free from price fluctuations. Depending on the participant, 'cloud power' allows participation on multiple drivers, i.e., financially, environmentally, or independence.

From a regulatory perspective, 'cloud power' is based on the assumption that the owners of the grid have the obligation to serve those connected. Hence, participants only pay the regular fee for connection and are not troubled with additional investments in infrastructure. In practice this perspective challenges the power structure of the energy sector.

With regard to the Dutch Smart Grid program, there is a clear tendency to focus more on user aspects. Out of 12 projects supported, all but one pay explicit attention to user involvement, although in some projects the users are companies or offices.

This brief analysis shows that there is a clear trend to pay more attention to users in new smart grid projects. This user perspective focuses heavily on behavioral change. Starting from a user perspective is expected to increase the cooperation of citizens. However results on user involvement are still very limited, thus, claims on the benefit of putting users central mainly come from related technologies, like smart meters or wind energy, or from countries, as the UK. Putting users central does not always correspond with freedom of choice. This can be a major institutional barrier for the implementation and the success of pilot projects.

6. Conclusions

Smart grids are generally perceived as the solution for the many challenges for our electricity systems and the pathway to a low carbon electricity economy. How this pathway will unfold, is uncertain. Looking at the current trends, the most likely outcome is an upgraded version of the current electricity system (Verbong and Geels, 2010). Whatever pathway will be selected, future systems will be different from the current ones in a few aspects: they will be more hybrid, in terms of the location and type of generation; lower carbon because of a larger contribution of renewable energy sources; more complex and vulnerable; and less hierarchical. These changes will have an impact on society at large and on users in particular.

Despite all efforts to curb demand by providing feedback and increase efficiency, electricity demand of users will rise substantially. The electrification of society continues by the introduction of electric mobility (cars, but also bicycles), heating (in particular for the Netherlands) and the amount of electric appliances (outstripping efficiency improvements in each single appliance). As a result, energy bills will rise, not only because of increasing demand and rising energy prices, but also because of the large investments needed for generation capacity, infrastructure, smart meters and displays, adaptations in (new) appliances and home energy management systems.

Users have to embed these new technologies and options into their daily routines. This is not straightforward: sustainability and costs are relevant but often not decisive drivers in the domestication process. There is a large range of responses to incentives (technologically or financially) to influence consumption. Social variables like daily routines, individual preferences and social relations in a household seem to be more important for the energy demand and for efforts to influence this, e.g, by smart meters (Hargreaves et al., 2010; Hardy, 2012). In fact, there are many societal forces that drive us in an unsustainable direction. With regard to smart grids, it is important to pay attention to changes in social practices as result of a further electrification of the home that might offset efficiency benefits that currently drive smart grid development. A promising line of research to tackle this issue is social practices approach, proposed by Shove. This approach aims to fill the gap left by researchers and policy makers who are considered to focus primarily on efficiency in innovations for sustainability. Not the acquisition of a technology is considered most important but the domestication of that technology, i.e., the way it is embedded in daily household practices. This leads to a (co-)evolution of technology with social practices, changing routines and concepts of normal behavior (Shove, 2004, 2012).

Although users have become more central in smart grids projects, the focus in the smart grids community is, maybe not surprising, still mainly on technological issues and economic incentives. From this perspective users are often regarded as a potential barrier to smart grids deployment and financial incentives the best instrument to persuade or seduce the users. Selection of stakeholders might have led to some bias in visions and expectations; nonetheless, it is clear that smart grids have not yet become a societal issue. Looking for solutions, we should start at the services the energy system delivers and not at technological options to improve this system. Users, their daily routines and their social context (e.g., household or community) should be taken more seriously. Next to the socio-cultural dynamics, institutional issues, the rules, are crucial as well, in particular the organization of our future electricity system. Cass and Walker provide a useful set of questions to incorporate these aspects in the design and management of smart grids experiments. The many pilot and demonstration projects that are taking shape or are being planned offer an excellent opportunity for such an exploration. The main threat is that the focus remains too much on technology and the protection of the vested interests. Broad learning, learning on all dimensions of smart grids, and the international exchange of experiences can prevent such a lock-in. However, a first step should be to reflect on the question to what extent users should act as solution in pathways to a low carbon economy.

Acknowledgment

This article has been written as part of the EOS Trein project (Transition Roadmap Energy Infrastructures in the Netherlands with financial support of the Dutch Ministry EL&I; we thank DNV Kema for their contribution and two anonymous reviewers for their comments and suggestions.

References

Benders, R.M.J., Kok, R., Moll, H.C., Wiersma, G., Noorman, K.J., 2006. New approaches for household energy conservation. In search of personal household energy budgets and energy reduction options. Energy Policy 34, 3612–3622.

Burgess, J., Nye, M., 2008. Re-materialising energy use through transparent monitoring systems. Energy Policy 36, 4454–4459.

Chandler, H., 2008. Empowering variable renewables: options for flexible electricity systems. OECD/IEA.

Darby, S., 2006. The Effectiveness of Feedback on Energy Consumption: A review for Defra of the Literature on Metering, Billing and Direct Displays. Environmental Change Institute, University of Oxford.

De Jonge, S.F., 2010. Business Models for Demand Side Management: Cost and benefits for actors in the future Dutch electricity regime. Eindhoven, TU Eindhoven, MSc. Thesis.

Devine-Wright, P., Devine-Wright, H., 2009. Public engagement with community-based energy service provision: an exploratory case study. Energy and Environment 20 (3), 304–317.

EDSN, 2010. Energie Data Services Nederland.

Energieraad, 2009. Geen verplichte slimme energiemeters (No forced smart meter introduction). 〈http://www.energieraad.nl/newsitem.asp?pageid=10465〉, (accessed 1 September 2011).

European SmartGrids Technology platform (ESGT), 2006. Vision and strategy for Europe's electricity networks of the future, Brussels. EUR 22040.

Geels, F.W., 2004. Understanding system innovations: a critical literature review and a conceptual synthesis. In: Elzen, B., Geels, F.W., Green, K. (Eds.), System Innovation and the Transition to Sustainability. Theory, Evidence and Policy. Edward Elgar, Cheltenham, pp. 19–47.

Geels, F.W., Schot, J., 2010. Managing sustainable innovation journeys. In: Grin, J., Rotmans, J., Schot, J. (Eds.), Transitions to Sustainable Development. New Directions in the Study of Long Term Transformative Change. Routledge, New York, pp. 80–92.

Guerrero, J.M., Blaabjerg, F., Zhelev, T., Hemmes, K., Monmasson, E., Jemeï., S, Comech, M.P., Granadino, R., Frau, J.I., 2010. Distributed generation. Toward a new energy paradigm. IEEE Industrial Electronics Magazine, March 2010, 52–64.

Hardy, J. (ed.) 2012. Policy, Regulatory and Social Aspects of Smart Grids and Application, 2012. UKERC Workshop Report.

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.

Hoogma, R., Kemp, R., Schot, J.W., Truffer, B., 2002. Experimenting for Sustainable Transport. The Approach of Strategic Niche Management. Spon Press, New York.

Huygens, A., 2011, De consument en de (on)vrije elektriciteitsmarkt, in: Pron-van Bommel, S., (Ed.), 2010. De Consument en de Andere Kant van de Elektriciteitsmarkt. Amsterdam, UvA, pp. 96–135.

Kaijser, A., 2003. Redirecting infrasystems towards sustainability. What can we learn from history? In: Biel, A., Hansson, B., Mårtensson, M. (Eds.), Individual and Structural Determinants of Environmental Practice, 2003. Ashgate, Aldershot, pp. 152–179.

Kema, 2010. Smart Meters in the Netherlands, Revised Financial Analysis and Policy Advice, Arnhem.

Kemp, R., Schot, J., Hoogma, R., 1998. Regime shifts to sustainability through processes of niche formation. The approach of strategic niche management. Technology Analysis and Strategic Management 10, 175–196.

Larsen, H., Petersen, L.F., 2009. Risø Energy Report 8: The Intelligent Energy System Infrastructure for the Future. Risø National Laboratory for Sustainable Energy, DTU.

Morris, M., Schindehutte, M., Allen, J., 2005. The entrepreneur's business model: toward a unified perspective. Journal of Business Research 58, 726–735.

Netbeheer Nederland, 2010. Road map smart grids. August 2010.

Nyborg, S., Røpke, I., 2011. Energy impacts of the smart home—conflicting visions. ECEE 2011 Summer Study: Energy Efficiency First: The Foundation of a Low-carbon Society, 1849–1860.

Pron-van Bommel, S, (Ed.), 2010. De Consument en de Andere Kant van de Elektriciteitsmarkt. Amsterdam, UvA.

Raven, R., 2005. Strategic Niche Management for Biomass. A Comparative Study on the Experimental Introduction of Bioenergy Technologies in the Netherlands and Denmark. Eindhoven, TU/e, PhD Thesis.

Schot, Geels, 2008. Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. Technology Analysis and Strategic Management 20 (5), 537–554.

Shove, E., 2004. Efficiency and consumption: technology and practice. Energy and Environment 15, 1053–1065.

Shove, E., 2012. Energy transitions in practice: the case of global Indoor climate change. In: Verbong, G., Loorbach, D. (Eds.), Governing the energy transition. Reality, Illusion or Necessity? Routledge, pp. 51–74.

Steg, L., 2008. Promoting household energy conservation. Energy Policy 36, 4449–4453.

Taskforce Intelligente Netten, 2010. Op weg naar intelligente netten. Discussiedocument van de Taskforce Intelligente Netten. Ministerie van Economische Zaken. Juli, 2010.

The Economist, 2004. Building the Energy Internet. The Economist, 11 March, reprint from Economist.com.

Van der Beek, E., 2010. Opportunities for Energy Saving in the Dutch Household Sector, Eindhoven, TU/e, MSc Thesis.

Van Eck, T., 2010. Het grote energieboek voor duurzaam wonen. Kwestie van organiseren en doen! Teus van Eck.

Van Vlimmeren, Y., 2010. The Introduction of Local System Services: The Case of Storage in the Low Voltage Network. TU/e, Alliander N.V. Eindhoven.

Verbong, G., Geels, F.W., 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.

Verbong, G.P.J., Geels, F.W., Raven, R.P.J.M., 2008. Multi-niche analysis of dynamics and policies in Dutch renewable energy innovation journeys (1970–2006):

hype-cycles, closed networks and technology-focused learning. Technology Analysis and Strategic Management 20 (5), 555–573.
Verbong, G., Geels, F.W., 2010. Exploring sustainability transitions in the electricity sector with socio-technical pathways. Technological Forecasting and Social Change 77, 1214–1221.
Walker, G., Cass, N., 2007. Carbon reduction, 'the public' and renewable energy: engaging with socio-technical configurations. Area 39, 458–469.
Wolsink, M., 2010. De homo economicus onder stroom. Energie-opwekking en-gebruik in smart grids, 1in: Pron-van Bommel, S., (Ed.), 2010. De Consument en de Andere Kant van de Elektriciteitsmarkt. Amsterdam, UvA, pp. 136–163.
Wüstenhagen, R., Wolsink, M., Bürer, M.J., 2007. Social acceptance of renewable energy innovation: an introduction to the concept. Energy Policy 35, 2683–2691.