Literature Study on Existing Smart Grids Experiences

REPORT

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ABSTRACT

This literature study has been executed in the framework of the CESEPS project that aims at developing knowledge about the actual performance of smart grid technologies, products and services in the context of end-users of local residential smart grid pilots. In this ERA-Net Smart Grids Plus project is assumed that a multidisciplinary approach is necessary that integrates technical aspects with learning from end-users and stakeholders to investigate the development and performance of residential smart grid projects, including the smart energy products and services (SEPS) implemented in these projects. To support the envisioned research of the CESEPS project this literature study captures existing experiences and knowledge about smart grid environments based on the three-layer model of marketplaces, technologies and stakeholder adoption. Therefore, the various chapters presenting findings from literature are structured along the ERA-Net three-layer research model (marketplaces, stakeholders and smart grid technologies). SEPSs and the possible effects of the design discipline on the realization of successful SEPSs are presented in the final chapter.

Incentives at **market level** for smart solutions are present; aggregators can operate on the spot markets (i.e. by energy arbitrage) and on the balancing markets. From a market-based perspective, one can argue that when the shares of renewables in the grid would increase to (very) high levels, their inherent fluctuations would cause more volatile spot market prices and higher imbalance prices, thus providing higher incentives, and possibly business models, for smart solutions. On the other hand, one can argue that before this is the case, stakeholders need to gain experience on these smart solutions because of the pivotal role the electricity system plays in our society. Whether the current market model is suitable for deploying smart grids, remains matter of discussion.

The main aim of the **stakeholder** analysis was to be able to explore the key findings regarding smart grids stakeholders' experiences in smart grids developments, and how these findings could feed into a multidisciplinary study of smart grids. One main focus was on the field of users. The term “users”, as described in current research, do not only have different labels (consumers/pro-sumers/end-users) but are also assumed to behave differently from each other.

Technology and corresponding systems are the basic principle for the development of SEPS. Therefor the potential level of flexibility of different technologies and systems was analysed. In terms of power supply or demand, most systems range with typical power connection values of households (~4kW). Depending on system configurations, EVs or PV systems may excel this value significantly. It is shown, that the investigated systems at residential level provide different potential for flexibility applications. Whilst existing systems like PVs, heat pumps or appliances provide limited controllability, especially the introduction of stationary BESS enables full flexibility for local optimization or ancillary services.

Finally, it has to be noticed that the current research efforts in the evaluations of SG performance are mainly based on technological perspectives, market perspectives, and in a very limited extent on end-user perspectives and the **SEPS** applied. Furthermore, there exists general consensus on the need to engage the end-users for the successful development of smart grids. Since actual SG pilots often reported on lack of empowerment, limited insights into management systems, and their high complexity, future approaches of SEPS should aim for a reduction of complexity which will result in an increase of acceptance of such products or services by end-users.

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ABBREVIATIONS AND ACRONYMS

Abbreviations & Acronyms	Meaning
AC	Alternating Current
AFC	Alkaline Fuel Cell
BESS	Battery Energy Storage Systems
BRPs	Balance Responsible Parties
CaPP	Car as Power Plant
CDH	Central Data Hub Model
CDSM	Centralized Demand Side Management
CESEPS	Co-Evolution of Smart Energy Products and Services
CHP	Combined Heat and Power
CPP	Critical Peak Pricing
CTA	Constructive Technology Assessment
DHW	Domestic Hot Water
DAM	Data Access-Point Manager Model
DC	Direct Current
DG	Distributed Generation
DIM	Delft Innovation Model
DLC	Direct Load Control
DR	Demand Response
DR-DB	Demand Bidding DR
DRES	Distributed Renewable Energy Source
DSM	Demand Side Management
DSO	Distribution System Operator
EE	Energy Efficiency
EMCS	Energy Monitoring and Control Systems
EMS	Energy Management System
EV	Electric Vehicle
FCEV	Fuel Cell Electric Vehicle
FFT	Fossil Fuel Technology
G2V	Grid to Vehicle Services
GHG	Green House Gas
HEMS	Home Energy Management Systems
HP	Heat Pumps
HVAC	Heating, Ventilation and Air Conditioning
IBDR	Incentive-Based Demand Response
IDM	Industrial Design Method
IDS	Innovative Design and Styling
IJ	Innovation Journey
LCA	Life Cycle Assessment
LMP	Locational Marginal Price
LU	Lead User study
MCFC	Molten Carbonate Fuel Cell
MDM	Multilevel Design Model
NP	Nuclear Power
O&M	Operations and Maintenance
PAFC	Phosphoric Acid Fuel Cell
PEMFC	Polymer Electrolyte Fuel Cell
PBDR	Price-Based Demand Response
PDPD	Platform-Driven Product Development
PMC	PowerMatching City
PSP	Pecan Street Project
PV	Photovoltaic
P2G	Power-to-Gas

RDM	Risk Diagnosing Methodology
RE	Renewable Energy
RTP	Real-Time Pricing
SEPS	Smart Energy Products and Services
SG	Smart Grid
SOC	State of Charge
SOFC	Solid Oxide Fuel Cell
SOFCR	Solid Oxide Fuel Cells Operating as Reformer
TCL	Thermostatic Controlled Loads
ToD	Time of Day
ToU	Time-of-Use Pricing
TRM	Technology RoadMapping
VPP	Virtual Power Plants
TRIZ	Theory of inventive problem solving (Russian acronym)
TSO	Transmission System Operator
V2G	Vehicle to Grid Services

”Mehr als die Vergangenheit interessiert mich die Zukunft den in ihr gedenke ich zu leben [1]”

[1] Quote by Albert Einstein

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PART I: INTRODUCTION

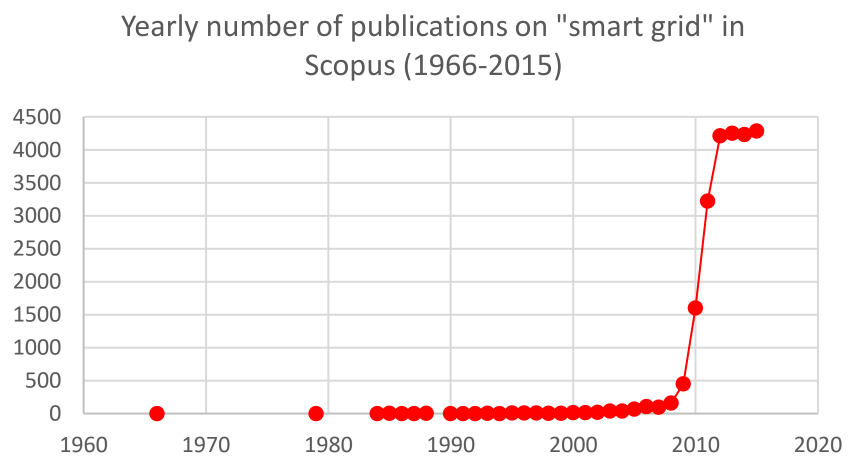
1 GENERAL INTRODUCTION[2]

The integration of intermittent renewable energy sources and decentralized energy production in existing electricity grids is a technical and organizational challenge. Often such a future electricity grid is referred to as a smart grid. However, after technical aspects, the second biggest challenge in smart grids development is to understand consumer behaviour in future grids as social acceptance and a more active role of energy consumers are of great importance for the success of smart grids. To overcome these challenges in the CESEPS research project *(Reinders et al., 2016)* it is investigated how knowledge about technologies, marketplaces, emerging user needs and their adaption, as well as needs of stakeholders in business and governance can be merged and implemented in smart energy product and services.

To be able to embed the CESEPS project well in ongoing research on smart grids and to be able to focus on specific research directions which have not been explored so far, it is necessary to first capture visions, approaches and research results of past smart grids projects and smart grids research with the aim to yield new knowledge by the future research in the CESEPS project. For this reason, a literature study has been executed with a focus on the three-layer model, see Section 1.2 for details, behind the CESEPS project, which covers the themes of marketplaces, stakeholders and technologies, in the context of smart energy products and services (SEPS). Another objective of this literature study is to develop a common framework for interdisciplinary research on smart grids to be executed by researchers with diverse background that collaborate in the CESEPS project.

This report presents the findings of this literature study which was executed in the period from August 2016 until January 2017 by researchers at eseia, Austrian Institute of Technology, University of Twente, Utrecht University, Wageningen University and Delft University of Technology. The report's chapter structure refers to the three-layer model in the context of SEPS, namely Chapter 2 will present findings from literature on smart grid marketplaces, Chapter 3 will discuss stakeholders, among which end-users, Chapter 4 will report on smart grid technologies, and Chapter 5 on smart energy products and services.

The literature study comprises a review of journal papers, conference papers, reports and websites of interest to the CESEPS project. Collected literature was stored at a centrally accessible share point at Austrian Institute of Technology and subsequently read and reported about by the various team members. According to a search in Scopus, which took place in June 2016, since 2008 the increase of publications on smart grid topics has led to a massive volume of more than 4000 publications per year in journals and peer-reviewed conference proceedings, see Figure 1. A more detailed search showed similar trends with preferences for certain technical topics, see Table 1. In the research team, it was therefore discussed which part of this publications should be included this literature study. It seemed logical to focus on publications from 2008 onwards with an emphasis on review papers on topics relevant to smart grid pilots. Moreover, it was observed, see Table 1, that in smart grid research publications on end users and their interaction with energy products and services were underrepresented



[2] A significant part of this chapter has been written by Angèle Reinders and Uche Obinna

Figure 1. Yearly number of publications found by applying search term “smart grid” in Scopus.

Table 1. Overview of total number of publications found by applying search term “smart grid” in combination with another search term in Scopus.

Topic	Scopus hits for Smart Grid AND ”Search term” (> from year)		
General	A total of ~25,000 publications found for Smart Grid since 1966 the first year in which this term was used, see Figure 1		
	Search term	**Number of hits**	**Publication years (> from)**
Marketplaces	Residential	1048	> 2003
	Commercial	495	> 2008
	Utility	3524	> 2005
	Buildings	1553	> 2007
Stakeholders	Prosumer	128	> 2009
	End user	427	> 2008
	Consumer	2044	> 2007
	Customer	1705	> 2005
Technologies and Methods	PV	627	> 2007
	Electric Vehicle	722	> 2009
	Storage	2501	> 2005
	Heat pump	166	> 2007
	Display	112	> 2007
	Wind	1427	> 2005
	Power management	262	> 2003
	Micro-CHP	21	> 2007
	Monitoring	2151	> 2003
	Simulation	4252	> 2002
Smart Energy Products and Services (SEPS)	Energy product	6	> 2009
	Smart appliance	114	> 2010
	Appliance	918	> 2003
	Home energy management system	137	> 2008
	Home energy management	222	> 2008
	Energy service	119	> 2009
	Demand side management	885	> 2008
	Demand response	664	> 2008
	Peak shaving	114	> 2008
	Forecasting	798	> 2008

1.1 A short introduction to the CESEPS project

CESEPS is an acronym which means Co-Evolution of Smart Energy Products and Services. In biology, co-evolution is the term for a long-term process by which several organisms evolve together while adapting to – and in time, changing – environments. Organisms make use of other organisms by building partnerships or by living on or in them, and have to adapt to their environments and to these relationships. These adaptations result in future generations with features more suitable for survival, often by improved mutual relationships – different organisms working better together- and sometimes these changes are that large that the next generations are so different that they may become different species. By applying this co-evolutionary thinking to the mid- and long-term development of smart grids, in the CESEPS project the ‘smart grid’ is seen as an environment and its energy technologies, ICT solutions, end users, and other stakeholders as complementary organisms having to collaborate to make the smart grid function as intended: flexible, energy-efficient, reliable and robust, sustainable, and cost-effective. In that sense the co-evolution of multiple compatible smart grid technologies are put in the context of society and product development from a process perspective.

Till now the introduction of the smart grid concept has been merely technical and has led to about 250 smart grid pilot projects in Europe *(Covrig et al., 2014, Giordano et al., 2011)*, at present leading to an estimated number of about 800 sites. According to the International Energy Agency *(IEA, 2011)*, a smart grid is an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users. Smart grids co-ordinate the needs and capabilities of all generators, grid operators, end-users and electricity market stakeholders to operate all parts of the system as efficiently as possible, minimizing costs and environmental impacts while maximizing system reliability, resilience and stability.

The CESEPS project focuses in particular on residential smart grid projects in two countries, namely Austria and the Netherlands, which both have a different profile in relation to the share of renewables in electricity consumption. For instance, with just 5.5 % the Netherlands shows one of the lowest shares of renewable energy in whole Europe while Austria is one of the front runners with on average 75 % of renewable energy and in some areas even 100 % thanks to a high penetration of hydropower and wind energy. It can be easily understood that these differences may result in different expectations and other technical specifications and operation of smart grid projects.

In the Netherlands, an increase in the number of smart grid pilot projects has been witnessed since 2008 resulting in more than 30 Dutch pilot projects running at present, half of them in residential areas. In Austria, these developments resulted in a similar number of projects. In these projects, new energy technologies are put into practice including photovoltaic systems, in-home energy displays, smart appliances, electricity storage and electric vehicles, and energy services such as billing, energy trading and energy management. Various new energy-related products and services, see Figure 2, such as smart meters, smart appliances, e-vehicles, and in-home automations are being offered in residential smart grid pilot projects. These products and services are expected to support the active participation of end users in balancing energy demand and supply in the electricity network. One well-known project is PowerMatching City in Groningen, which explores a smart grid from the perspective of energy technologies, ICT (PowerMatcher), end users and markets. Lessons learned from smart grid pilot projects such as PowerMatching City, SmartLowVoltageGrid in Austria, Smart Region Köstendorf and Eberstalzell in Austria or LochemEnergy in the Netherlands will support the present research.

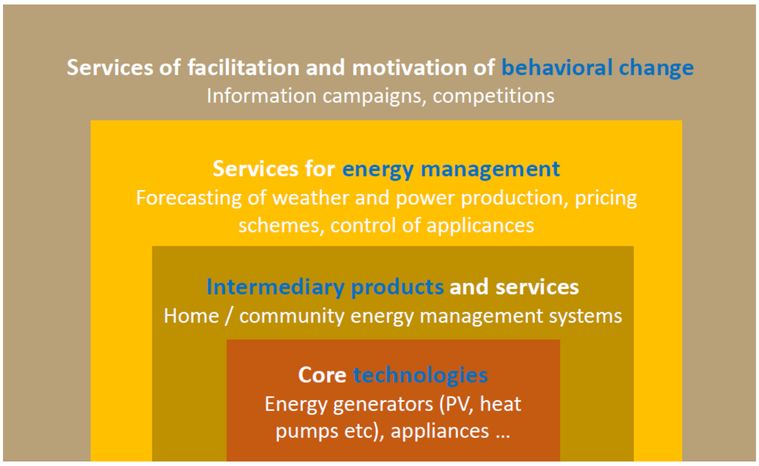


Figure 2. Conceptual framework for residential smart grid products and services.

Previous studies have concluded that separate energy technologies usually perform well, however to improve the functioning of the whole smart grid environment, the combination of energy technologies in one integrated system should perform also well. From that perspective end users need to be taken into account in the design of products and services that support active user involvement. The end users are empowered in the production and management of energy, and insights from other stakeholders involved in residential smart grid pilots are needed to complement existing experiences. These studies are relatively limited due to their low number of participants and therefore low statistical relevance. Moreover, there is a lack of evaluations of the marketplace of energy and energy products and services in smart grids from end users and multi-stakeholder perspectives. Due to the limited information, the development and performance of various energy-related products and services that could support a better participation of end users in future residential smart grids development are rather behind compared to other industries that develop technology-based products such as the ICT mobile sectors.

From a theoretical point of view the energy performance of smart grids at the low voltage level mainly depends on three factors: technical aspects, financial aspects, and human aspects. Technical aspects such as the configuration of an energy system, local climate and weather conditions, the appliances installed and the construction of dwellings are usually taken into account in the development of new smart grid projects. This also applies to financial aspects such as the type of pricing of electricity (dynamic or time-of-use), investment costs, and O&M costs. On the other hand, human aspects are usually given insufficient attention during the preparation phase of new smart grid projects. They include the interaction of residential end users with smart energy products and end user behaviour towards energy efficiency, local production of sustainable electricity and trading of electricity. So far, understanding of residential end users' behaviour in smart energy systems results from post-evaluative research in existing smart grid pilots that serve as Living Labs. In recent years, consumer research in the field of smart energy systems mainly focused on the technical feasibility and functioning of intelligent networks. Only a small part of this research *(Geelen et al., 2013a, Kobus et al., 2013, Obinna et al., 2016, Verbong et al., 2013, Wolsink, 2012)* considered the evaluation of the energy balance of households and the interaction of end users with smart energy and the necessary smart grid product-service combinations. This type of research has been explored only to a very limited extent; of the 219 EU projects in the field of smart grids which have been undertaken between 2001 and 2011 only 8 % is in the category of 'home application - customer behaviour' *(Giordano et al., 2011)*. Though this share is slightly growing the research team of the CESEPS project expects it still to be below 10% at present. Within this category of projects the focus is on smart meters, energy saving, and a smaller proportion on electric vehicles. Much of the research has a top-down approach in which the experiences of energy suppliers and energy distribution companies are the key element. Experimental research on end users in smart grid pilots and their needs and wishes as energy customers has been performed in only two projects with an emphasis on the analysis of monitoring data of energy flows in domestic smart energy systems. In the Netherlands, only two out of thirty smart grid pilots have been subjected to in-depth consumer research, and only one research activity exists in the field of multi-stakeholder analysis of smart grids. Also in Austria, a couple of customer-orientated research pilots (Consumer2grid, SmartWebGrid, etc.) exist, but in general these projects lack sufficient consumer focused evaluations. Therefore, it is very likely that our research will fill a void of knowledge and experiences in the smart grid research sector in Europe and probably also elsewhere.

1.2 The approach of the CESEPS project

To overcome the challenges and limitations that arose in the previous studies, we proceed with a co-evolutionary approach through which technology, marketplaces, emerging user needs and their adaption, will be merged using the three-layer research model for Smart Grid environments which is presented in Figure 3.

Technology

Smart grids host a large number of diverse energy technologies and ICT. In the framework of our research project we have selected a limited number of technologies, based on their relevance and impact in the local smart grids that will be evaluated and validated in more detail. These are smart grids' safety aspects and overall network reliability regarding their energy and power flows, energy-efficiency, local sustainable energy production and consumption, demand side management by self-consumption of energy generated in the smart grid pilot, forecasting techniques and mutual trading of energy with neighbours, controlled charging of electric vehicles (EV) by renewable energy sources and patterns of use.

Marketplace

Existing smart grid energy products and services will be evaluated as well as new solutions will be created in order to shape changing energy market structures with a focus on the 'good design' for energy products that support safe and reliable operation of local smart grids, demand side management and electric mobility in smart grids with a high penetration of renewables. From the perspective of energy markets, the microeconomics of smart energy products and services will be evaluated in terms of in terms of return on investments, Net Present Value and levelled costs of electricity in relation to real-time pricing versus time of use pricing. In particular, in the field of e-mobility financial comparisons will be made between electric charging and consumption of fuels in cars equipped with a combustion engine.

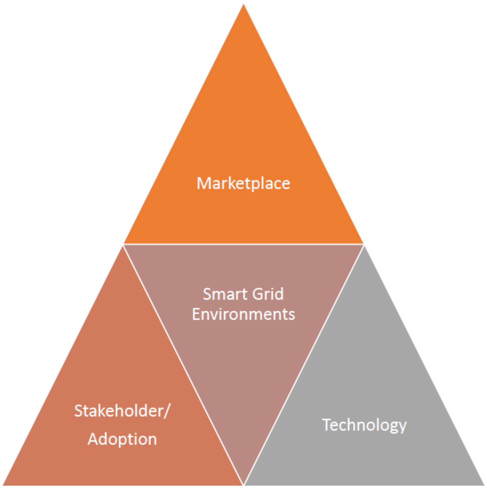


Figure 3. The three-layer research model which is applied in the CESEPS project.

Stakeholders/Adoption

Adoption of end users such as individual persons and communities is a significant issue which regards new features in smart grids such as demand side management, exchange of energy with other end users, a high penetration of renewable energy at a local level, the required flexibility for prosumer interactions and e-mobility. By interviews and observations of all smart grid stakeholders (both end users and utilities, policy makers, network operators et cetera) their experiences, expectations and modes of interaction between them, will be captured to understand the acceptance, preferences, and practices occurring during the pilot projects. Information resulting from these studies will subsequently be applied in co-evolutionary development of smart energy products and services.

1.3 Aims of the CESEPS project

CESEPS aims at developing knowledge about the actual performance of technologies in local smart grid pilots by monitoring and evaluating data from these projects and executing measurements on site. Complementary to the experimental approach, theoretical modelling of energy performance of smart grid technologies and their interaction will be established. The role of stakeholders and end users in local smart grid pilots will be explored by gaining insights into their needs and wishes for smart energy products and services, the needed changes in their energy practices, and contextual barriers encountered.

To realize these objectives, existing smart grid environments will be explored by evaluating the performance of energy products and services as well as end user perceptions and stakeholder processes. The research in this project will perform a comparative validation of smart grid technologies and concepts in more than four existing demonstration projects in the Netherlands under the umbrella of the Smart Energy Collective of DNV GL, such as PowerMatching City and pilots in the cities of Heerhugowaard, Lochem and others and in six ongoing pilots Austria called E-mobility on Demand, PlanGridEV, iWPP-Flex, EcoGrid EU, Hybrid-VPP4DSO, IGREENGrid, and others.

Adding to existing smart grid pilots, innovative technological concepts for e-vehicles with fuel cells, smart solar charging and other charging solutions will be developed within the framework of the Green Village of TU Delft, the Living Lab Campus of University of Twente and Vehicle2Grid in Utrecht. Besides comparative data analyses and user surveys this three-year project comprises various simulation activities to model existing and innovative smart grid energy products, using transient and static modelling, with time scales ranging from microseconds to 15 minutes.

1.4 End-user engagement in Smart Grids

The transition to smart grids would create electricity systems that enable consumers to make informed and empowered energy-related choices and make personal behavioural changes *(DeWaters and Powers, 2011, ECME, 2009)*. In this regard, evaluative studies and reports, such as *(EC, 2011b, ETP, 2010, IEA, 2011)* have highlighted the relevance of end-users in smart grids deployment. According to the International Energy Agency technology roadmap smart grids, end-users of the Smart grid must be involved on all aspects of relevance before and during the deployment, but also to allow for the end-

users feedback and requests for adjustments after the deployment and during the actual use and operation *(IEA, 2011)*. The report further stated that so far, end-users have not been adequately involved during the Smart grid planning process *(IEA, 2011)*. The European Technology Platform stated that since end-users (at the residential, service and industrial level) will ultimately determine the success of an energy system based on smart grids, it is very vital to promote active user participation in Smart grids *(ETP, 2010)*. The role of engagement and involvement of consumers in sustainable consumption is also acknowledged by the EC Task Force for smart grids. The task force stated that, "the engagement and education of the consumer is a key task in the process as there will be fundamental changes to the energy retail market. To deliver the wider goals of energy efficiency and security of supply there will need to be a significant change in the nature of customers' energy consumption" *(EC, 2011b)*.
Various studies on smart grids *(Gangale et al., 2013, Geelen et al., 2013a, Honebein et al., 2011, IEA, 2012, Mah et al., 2012, Verbong et al., 2013)* also re-affirm the important role electricity end-users at the low voltage household and residential areas are expected to play in the deployment of smart grids and its associated technologies. Honebein et al. stated that the success of Smart grid initiatives depends on customer action. They suggested that observing, understanding, and engaging consumers at the early stages of development of smart grid initiatives will support the realization of the full potential of Smart grids *(Honebein et al., 2011)*. In their views, a social roadmap for smart grids will be required to complement the technical roadmaps from the utility industry. This is their opinion, will provide a better understanding of end-user experiences, transform end-user relationships, and drive end-user engagement. According to Verbong et al. *(Verbong et al., 2013)*, the extent to which users are willing and able to accept and use smart grids determines the success of smart grids. Verbong et al analysed practices and perceptions of stakeholders on including users in smart grids experiments in the Netherlands. In their study, interviews were conducted with stakeholders related to smart grids and the energy sector. The study shows that Dutch smart grid stakeholders recognize the importance of active participation of residential end-users towards the successful implementation of smart grids. It however revealed that the focus in the Smart grids deployment is still mainly focused on technological issues and economic incentives. This is because end-users are often considered a barrier to smart grids deployment; hence, the use of economic incentives appeared the best instrument to solicit their participation in Smart grids *(Verbong et al., 2013)*. In their opinion, there currently exists a lack of clear proposal on how to really involve end-users, and support them as co-providers in the future electricity system. The study concluded that the current neglect of the role of end-users could be a potential obstacle to the introduction of Smart grids. They suggested that new innovative business models be developed to explore different options to involve users. This in their opinion will support end-users in embedding new smart grid technologies and options into their daily routines.
The important role of consumers in the success of smart grids was re-echoed by Gangale et al. *(Gangale et al., 2013)*. They stated that given the important role of end-users, it is important to observe them in their social context (e.g. household or community). This is in order to understand and involve them in the early stages of smart grids deployment. This is their opinion, will support them to successfully assume their new role as active participants in the electricity system. It will also support the future electric power system to deliver the expected goals. In recognition of the important role of end-users in Smart grids deployment, Ngar-yin Mah et al. *(Mah et al., 2012)* carried out a survey of end-users in Hong Kong to find out how they might respond to the opportunities that smart grid technologies offer. The study concluded that it is important to explore how the potential contributions of consumers in Smart grid technologies can be realized in order contribute to the transition towards a more sustainable energy future. According to Geelen et al. *(Geelen et al., 2013a)*, a transition to smart grids thus allows consumers to play an active role in energy provision. The study stated that end-users of electricity will shift from ordinary consumers who buy energy from an energy supplier to producers of energy, thereby actively taking part in the energy market. According to Geelen *(Geelen, 2014)*, energy stakeholders from the government and private sector try to involve residential end users in the supply and demand management of electricity in a smart grid. This is because they can become producers, and at the same time contribute to demand response (DR), which is considered a resource in the management of supply and demand *(Giordano et al., 2011, IEA, 2011)*.
From the foregoing, it can be observed that most studies on end-users in smart grids recognize the importance of an active involvement of end-users at the household and residential areas. This is apparently the reason why an increase in the interest in consumer engagement projects at European level and a strong focus on the residential sector has been witnessed in recent years *(Gangale et al., 2013)*. In a survey of consumers' engagement experiences in European smart grid projects, Gangale and colleagues revealed that projects involving end-users focus on two main objectives: 1) acquiring

deeper knowledge of consumer behaviour (observing and understanding the consumer), and 2) motivating and empowering consumers to become active energy customers (engaging the consumer). The first objective mainly involves collecting information on consumption patterns, needs and consumer experiences; exploring consumer response to new regulatory, technical and market solutions; and identifying consumer segments and early adopters. The second objective entails provision of information to consumers about newly introduced smart technologies/ applications; providing information about energy consumption; and investigating strategies aimed at behavioural change.

1.5 End-users as co-providers in Smart Grids

Current studies have emphasized the need to involve end-users not just as energy consumers in smart grids, but as energy citizens *(Goulden et al., 2014)* or co-providers *(Geelen et al., 2013a, Van Vliet et al., 2012)*. Goulden et al. *(Goulden et al., 2014)* explored the role of end-users in electricity demand side management, and the contexts in which such roles might emerge. Using focus groups with novel scenario techniques, the study contextualized smart grid technologies in domestic settings. Two contrasting visions of smart grids were provided namely: a centralized system based on current institutional arrangements, and an alternative system based on decentralization of generation and control. The study employed the concepts of ‘energy consumer’ and ‘energy citizen’, to depict two forms of public participating in the future energy system: as energy end-users and energy system participants respectively. They conclude that the energy citizen holds out most promise advancing decentralization of generation and control, where the challenge of realizing the smart grid involves both institutional and technical aspects. Goulden and colleagues proposed that Smart grid designs look beyond simply the technology and recognize that a smart user who is actively engaged with energy is important for electricity demand-side management. This will require a shift from centralized, hierarchical paradigm which has defined the energy systems of the last century, where centralized generators increasing monitor and control end-user consumption. The conclusions by Goulden et al. corroborate similar findings by Wolsink *(Wolsink, 2012)*. Wolsink proposed a shift from ‘centralized demand side management’ (CDSM) to ‘DisGenMiGrids’ (distributed generation micro grids), where the distinction between generators and end-users is eliminated, and replaced instead by the kind of ‘co-management’ of resources. These findings are similar to the type of energy system users deployed by van Vliet et al. *(Van Vliet et al., 2012)*. Van Vliet and colleagues defined ‘co-management’ of resources by the kind of relationship between providers and consumers. Van Vliet et al. used the term “co-provider” to refer to a trend in which communities collaborate with utilities to achieve solutions in managing water, waste and electricity. The term implied a more active contribution by end-users, in contrast to being only consumers of resources (passive consumers to active contributors). The study revealed that the restructuring of infrastructures stimulates utilities to cooperate with end-users to develop environmentally sustainable systems. Van Vliet identifies three types :(i) customer; (ii) citizen–consumer; and (iii) co-provider. The citizen–consumer; and co-provider as used by van Vliet is similar to the energy citizen referred to by Goulden at al.*(Goulden et al., 2014)*.
In the context of Smart grids at the low voltage areas, Geelen et al. *(Geelen et al., 2013a)* used the terms “co-provision” and “co-provider” to refer to residential end-users’ role in contributing to demand and supply balancing of electricity in Smart grids. They stated that the transition to Smart grids, whereby end users shift to the role of co-providers, suggests that household energy management will involve:

1) Efficient use of electricity,
2) Planning and or shifting electricity consumption to moments most suitable for the energy system, for example, during the availability of locally generated energy or at periods of low electricity demand,
3) Producing electricity when it is favourable for the local grid, for example using a micro-co-generation unit,
4) Trading self-generated electricity that is not used by households.

Geelen et al. were of the view that the biggest challenge in smart grids transition is to develop a sustainable system of energy provision where local energy networks and co-providing end users operate in cooperation with larger scale utility companies *(Geelen et al., 2013a)*. This in their opinion will involve developing technologies that balance energy generation and consumption, but also a more active role of end-users in energy provision. The study suggests that for end users are to become co-providers, they will have to be empowered in relation to the four aspects of co-provision mentioned above. An important aspect of this empowerment is a change in energy-related behaviour. They stated

that an important challenge is to get the end user involved in such a way that she or he will play an active role and in that way directly contributes to the energy transition. This implies that the end user perspective should be involved in technical innovations within smart grids; in creating conditions for smart energy products and services; as a guideline for institutional and social innovation.
At the moment, limited knowledge exists regarding to what extent a co-provider role has been facilitated in smart grids deployment. The following section will explore current products and services in smart grids. These products and services facilitate an active participation of residential end users in smart grids. The section will also highlight to what extent these products and services have supported a co-provision role for end-users in smart grids.

1.6 Current Smart Grids products and services for households

One of the new scenarios or possibilities of smart grids is the development of new products and services. These smart grids related products and services will have to support end-users in their role as co-providers in the management of the electric power system *(Geelen, 2014)*.
Smart grid products and services have been described in various ways by different studies. For instance, Kobus et al. *(Kobus et al., 2013)* refers to these products and services as smart energy technologies, which aim at reducing or shifting energy demand of household end-users. Examples include Energy Management Systems (EMSs) and smart appliances. A study by Geelen et al. *(Geelen et al., 2013a)* classified current products and services for the residential end users as: micro-generators, smart appliances, energy storage systems, smart meters, dynamic pricing and contracting, and energy monitoring and control systems. Energy monitoring and control systems are also referred to as Home Energy Management Systems (HEMS) *(Geelen et al., 2013a, van Dam et al., 2010, van Dam et al., 2012)*.
These categories of products and services will be briefly described below:

Micro-generation

Micro-generation technologies support households to produce their own electricity. Examples are photovoltaic solar panels, micro-cogeneration units and small wind turbines *(Geelen et al., 2013c)*.

Smart meters

Smart meters refer to digital electricity meters that accurately measure consumption and production of electricity and communicate these data to the energy supplier.

Energy storage

Energy storage systems support the use of energy at times other that when they are generated or bought from the grid. The surplus energy can be stored in the form of electrical energy in batteries and as heat in hot water tanks or storage heaters.

Dynamic pricing and contracting

Dynamic pricing, also known as time-variable pricing, provides an opportunity to involve the end users in the management of the smart grid.

Smart appliances

A smart appliance helps a user to select the most desirable time for consuming electricity, for example, by taking into account weather forecasts and electricity prices. Smart appliances can be programmed and communicate with energy management systems regarding the best times to operate.

Energy monitoring and control systems

Kobus et al. *(Kobus et al., 2013)* list them as Energy Management Systems (EMSs) or Home Energy Management System (HEMS) and smart appliances. EMSs do not only give real-time feedback, but also include feed forward on the availability of sustainable electricity or electricity prices, historical and normative comparisons of demand patterns, goal setting and other persuasive techniques to improve the effectiveness of the EMS. Some EMSs can also automatically switch appliances on or off for energy saving purposes. For example, smart plugs that are used as stand-by killers.

1.7 End-users interaction with Smart Grid products and services

Although smart grids are still in an early stage of development, in recent years, societal implementation has gained momentum through the deployment of smart meters and small and medium scale smart grid pilots *(Naus et al., 2015, Stephens et al., 2013, Verbong et al., 2013, Wolsink, 2012)*.
In the opinion of Geelen et al. *(Geelen et al., 2013c)*, the success of consumer-driven smart grid solutions, including new products and services will also depend on consumer value and adoption. They asserted that technology and behaviour have to complement each other, to facilitate energy efficiency in a household. Along with societal implementation, scientific research on the use and effects of smart energy technologies is rapidly growing *(Naus et al., 2015)*.

Studies have shown that some of the energy products and services available today do not address the needs and demands of end-consumers. Also in smart grid pilots, end users do not always have little control over their consumption. This reduces the active participation of end-users and creates hurdles in full scale roll-out of smart grids. For instance, a study by Geelen et al. *(Geelen et al., 2013a)* on end-user experiences with products and services in the PowerMatching City Smart grid pilot project in the Netherlands revealed that the implemented products did not provide the necessary feedback required by end-users to be more active in their energy management. They lacked a sense of control and energy feedback that could support them in adjusting their energy related behaviour. Several end users reported that they wanted to change their behaviour in order to lower their energy consumption or utilize the electricity that is produced in PowerMatching City, but felt insufficiently enabled to do so. Geelen and colleagues therefore concluded that in order to support end-users as co-providers in the future energy system, it is important to address behavioural change in addition to technological improvements. Geelen et al assert that product and service design that supports end-users in their role as co-providers in a Smart grid is still missing.
Currently, various innovative smart energy technologies have been introduced both in households and Smart grid projects to support efficient use and generation and monitoring of locally generated electricity. However, there is still limited knowledge with regards to the way households interact with smart energy technologies and how the technologies have influenced the energy performance of these households.

1.8 Reflections from literature

Although the importance of end-users in smart grids deployment has been recognized in existing literature, there is currently limited information with regards to the end-user and stakeholder involvement in smart grid projects. Namely smart grids deployment is still mainly focused on technological issues and economic incentives. With regards to the engagement of end-users in smart grids, the focus in literature has been on the involvement of end-users as energy consumers in the future electricity system. Only a handful of studies *(Geelen et al., 2013a, Kobus et al., 2013, van Dam et al., 2012)* have explored the role of users as co-providers in smart grids. These studies have however been limited to individual pilot projects and only a small group of residential end-users involved in these pilots. The importance of supporting end-users as co-providers or energy citizens in the electricity system is also stressed in the literature. However, there are limited insights from literature on how this co-provider role can be fostered. It is still not clear from the literature on how to really involve end-users, and support them as co-providers in the future electricity system. Various products and services that could facilitate a co-provider role for end-users in Smart grids have been implemented in smart grid projects. End-user experiences also show that current products and services have not always supported an active role for end-users in smart grids. Learning processed in the context of smart grids and associated products and services will be required to improve existing smart grid products, and support the generation of knowledge and ideas for new products and services to be applied in residential smart grid pilots.
Therefore, it is assumed that a multidisciplinary approach is necessary that integrates technical aspects with learning from end-users and stakeholders to investigate the development and performance of residential smart grid projects, including the energy products and services implemented in these projects.

1.9 Further reading

Given the situation sketched above, this report’s chapter structure refers to the three-layer model of the ERA-Net Smart Grids Plus program in the context of the CESEPS project. CESEPS aims at developing knowledge about the actual performance of technologies in local smart grid pilots by monitoring and evaluating data from these projects and executing measurements on site. Complementary to the experimental approach, theoretical modelling of energy performance of smart grid technologies and their interaction will be established. The role of stakeholders and end users in local smart grid pilots will be explored by gaining insights into their needs and wishes for smart energy products and services, the needed changes in their energy practices, and contextual barriers encountered.
To support the envisioned research of the CESEPS project this literature study captures existing experiences and knowledge about smart grid environments based on the three-layer model of marketplaces, technologies and stakeholder adoption.
Therefore Chapter 2 will present findings from literature on smart grid marketplaces, Chapter 3 will discuss stakeholders, among which end-users, Chapter 4 will report on smart grid technologies, and

Chapter 5 on smart energy products and services. Finally, this report will be completed by conclusions presented in Chapter 6.

PART II: MARKETPLACES

2 INTRODUCTION TO MARKETPLACES[3]

To accelerate smart grid deployment, the European Commission *(EC, 2011a)* has proposed to focus on five challenges:

a) developing technical standards,
b) ensuring data protection for consumers,
c) providing continued support to innovation for technology and systems,
d) guaranteeing an open and competitive retail market in the interest of consumers, and
e) establishing a regulatory framework to provide incentives for Smart Grid deployment.

This chapter will provide a literature review on the last two of these five challenges. First, all markets where smart grids possible can reap benefits are discussed in general. Subsequently, an overview will be given of literature focusing on business models enabling capturing these benefits from the markets. Finally, institutional and regulatory frameworks are discussed.

2.1 Market places in the energy sector

As characteristics of electricity markets are to a large extent factual, there is not much scientific discussion about these. Among many others, *(Garnier and Madlener, 2014, Hiroux and Saguan, 2010, Neuhoff et al., 2013, Scharff, 2015, Stifter et al., 2016, Ventosa et al., 2013)* described the basic characteristics of electricity markets.
In competitive electricity markets, which are the dominant design for electricity markets in Europe, there are several competing parties on both the generation and the retail side. In addition, individual consumers can choose between different retailers *(Scharff, 2015)*. Within this design of competitive electricity markets, one can differentiate between zonal and nodal pricing. In nodal pricing (or locational marginal pricing), which is incorporated in the electricity system of the Unites States, prices are set at different nodes in the system (places where supply and demand meet). In zonal pricing, used in the EU electricity markets, prices are the same in the entire zone, not taking transmission limits into account. Therefore, critique on zonal pricing is that it does not stimulate optimal placement of variable renewable electricity production *(Neuhoff et al., 2013, Wang et al., 2015)*. For example, in Germany much wind electricity production is located in the north, but the transmission line does not have the capacity to transfer this electricity to the south, resulting in congestion losses *(Neuhoff et al., 2013)*.
Figure 4 shows how different electricity commodities are related to different markets, thereby presenting a basic overview of the market architecture regarding physical trading of electricity.

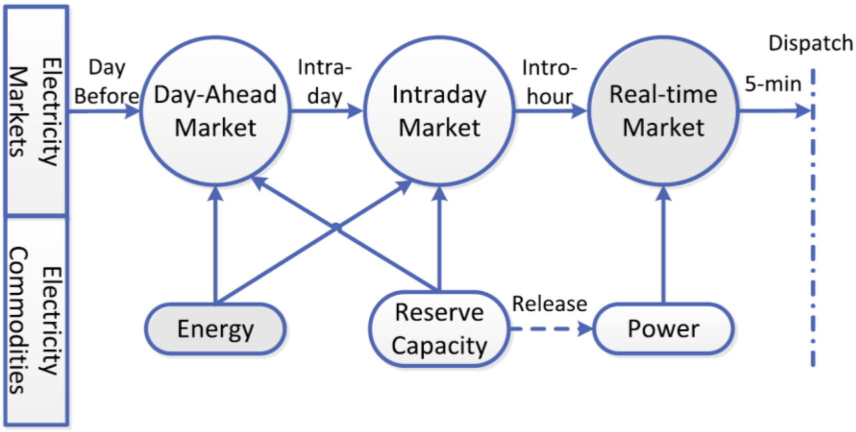


Figure 4. Basic architecture of a common modern power system (Wang et al., 2015)

In the Day-Ahead market, market participant place biddings for generating or consuming a certain amount of electricity in a given hour of operation for the following day. Usually market clearance is settled at noon. The Intraday market works similarly, but closer to the period of delivery (i.e. one hour *(Wang et al., 2015)*). Together, they form the spot market – a market where commodities are traded

[3] A significant part of this chapter has been written by Wouter Schram and Wilfried van Sark

immediately or on the spot. In general, the Day-Ahead market dwarfs the Intraday market. In 2015, 566 TWh was traded on the European Power Exchange (EPEX; Germany, Austria, Luxembourg, France, United Kingdom, Netherlands, Belgium, Switzerland), while 59 TWh was traded in the Intraday market, although the Intraday market grew faster (26 % versus 20 %) (EPEX SPOT 2016). The Real-time market, or balancing market, is a single-buyer market (the buyer being the Transmission System Operator, TSO), that ensures the balance between supply and demand as a result of different than expected supply or demand. Generally, this is divided in primary, secondary and tertiary reserve market *(Rebours, 2008)*.

Besides physical trading, there is also an opportunity for forward market, which would occur before trading in the Day-Ahead market. This cannot be seen as one central market, but encompasses long-term bilateral contracts and financial trading *(Koliou et al., 2014, Scharff, 2015)*. In financial trading, price risks can be hedged: commitments are settled by financial payments instead of physical delivery or withdrawal of energy *(Scharff, 2015)*.

1.1.1 Financial trading

To deal with electricity price volatility, financial products can be designed to decrease associated financial risks. Derivatives are contracts between two parties with opposing views on the market, who are willing to exchange certain risks *(Bajpai and Singh, 2004)*. An example is the *Contract for Differences*, where two parties agree on an electricity quantity (MWh) and a strike price (€/MWh). If the spot market price is above the strike price, the seller pays the difference between these prices to the buyer, and vice versa when the spot price is below the strike price. In this way, both the seller and the buyer have hedged their exposure to the spot price.

The relevance of financial trading for the CESEPS project is limited. The increase on renewables in the energy mix is associated with increase of price volatility, while smart grids might decrease this price volatility*(Zakeri and Syri, 2015)*. However, the relation between smart grids and financial trading is indirect since trading takes place on financial markets and no physical transactions are involved. Therefore, attention for this topic in scientific smart grid literature is limited.

1.1.2 Day-ahead Market

In the Day-ahead Market, actors place bids to supply energy and offers to consume energy both during a fixed period (normally one hour) of the whole following day *(Scharff, 2015, Wang et al., 2015)*. Bids are sorted by ascending price, resulting in the so-called *merit order* (Figure 5). Offers are sorted by descending price. The quantity of the offers with the highest willingness-to-pay are coupled with bids with the lowest willingness-to-sell (i.e. the lowest bids). This is repeated until remaining the offer with the lowest the willingness-to-pay has a lower price than the bid with the highest willingness-to-sell. In general, the marginal price of the last matched bid represents the market clearing price; all bids that are matched receive this price – a combination of uniform and marginal pricing. This provides incentives to suppliers to bid as low as possible, close to their marginal cost and thereby ensuring economic efficiency *(Scharff, 2015)*.

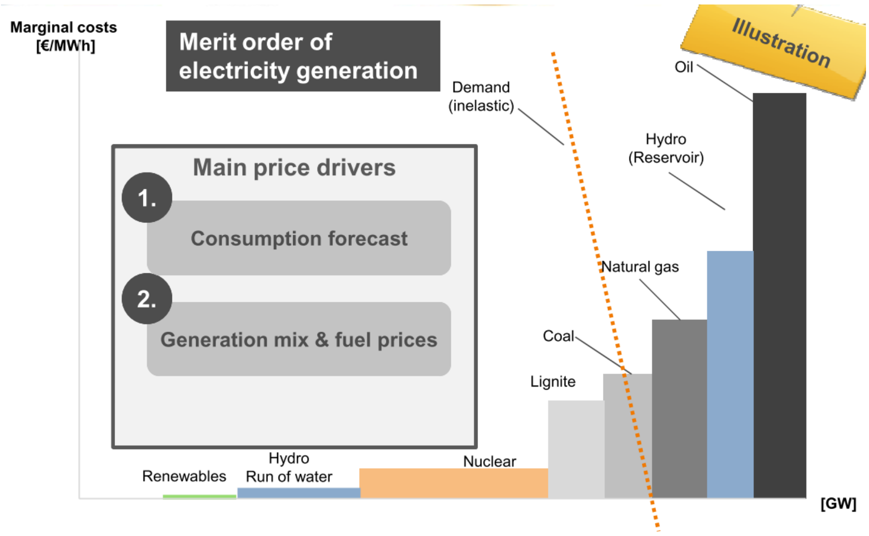


Figure 5. Merit order (EPEXSPOT, 2016)

1.1.3 Intraday Market

Figure 6 shows how countries in Europe organize their Intraday markets. In the Intraday Market, bids and offers are matched much closer to the time of delivery of electricity *(Garnier and Madlener, 2014)*. This way, new information on supply and demand side (e.g. changed forecasts of renewable electricity production) can be incorporated. In Europe, two ways of organizing the intraday markets are prevalent: series of (discrete) auctions, or continuous trading *(Scharff, 2015)*. In discrete auctions the market mechanism is the same as in the Day-Ahead market, with as only difference timing of the market clearance. In continuous trading, bids and offers are matched directly when corresponding price levels exist, on first-come-first-serve basis. Hence, in the Intraday market price settlement is based on pay-as-bid, in contrast to the uniform pricing of the Day-Ahead market. This happens one offer at a time, so in fact there is one auction per trade. Austria and the Netherlands, the countries of most interest in this project, both incorporate continuous trading.

In both the Day-Ahead and the Intraday Market, opportunities for smart grid products and services lie in energy arbitrage; enabling to shift demand to periods where prices are lower (e.g. delay operations until the night), or shift supply to periods where prices are higher (e.g. by storing produced electricity upon to sell it at a later point in time). According to both analytical as market data analysis performed by Garnier & Madlener *(Garnier and Madlener, 2014)*, smart services operating on the Intraday market can capture more value than services operating on the Day-ahead market.

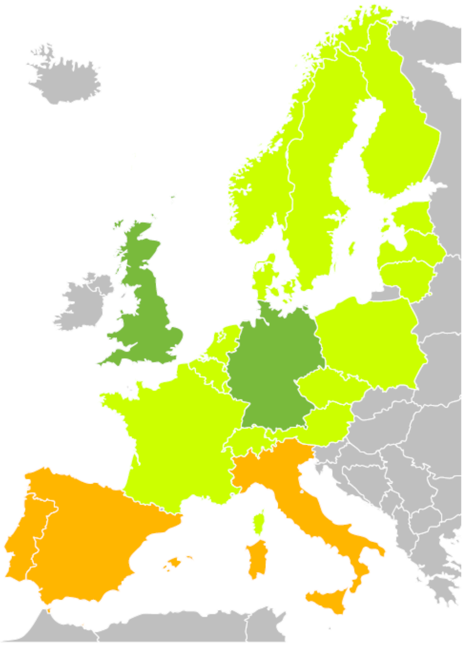


Figure 6. Different designs of Intraday markets in Europe in 2015. Orange coloured countries have discrete auctions, light green coloured countries have continuous auctions, and dark green coloured countries have a combination of both (for grey coloured countries design is unknown) (Scharff, 2015).

1.1.4 Balancing markets

The transfer of electricity takes place on much smaller time scales than the spot markets operate (i.e. hour scale for the Day-Ahead market, and hour or 15 minutes for Intraday markets). Hence, even when all parties would exactly follow the generation or consumption of electricity that was forecasted on the spot markets, still mechanisms should exist to account for uncertainties and fluctuations within the periods of delivery. Furthermore, all kinds of deviations from the forecasted electricity flows can arise. Examples are volatility in renewable electricity production due to not correctly forecasted weather fluctuations, different than expected consumption, unexpected or unplanned outages of power plants and individual generation units, failures in the transmission, etc. *(Scharff, 2015)*. The TSO is responsible for maintaining the grid frequency at 50 Hz in Europe. This can be done by activating spinning reserves; in many systems, generators are obliged to have a certain percentage of their capacity available as spinning reserve for frequency control *(Rebours, 2008)*. Furthermore, a TSO can contract balancing service bilaterally *(Scharff, 2015)*. A third way is to organize balancing markets. This happens through settlements between the TSO and Balance Responsible Parties (BRPs). All generation and consumption in the electricity grid has to be assigned to a BRP, that draw up programs relating to their expected aggregated electricity supply and demand *(Koliou et al., 2014)*. When there is a difference between committed and actual generation or consumption, imbalance occurs *(Scharff, 2015)*. Parties can submit bids to the TSO offering upward or downward regulation capacity for certain periods of time. In case of imbalance, the TSO uses this capacity starting from the cheapest bids, and the compensation price is set at the price of the most expensive backup capacity that is needed to solve the imbalance. This differs from the spot markets because of the existence of a single-buyer: the TSO *(Scharff, 2015)*.

Although some differences between countries exist (sometimes due to semantics) *(Scharff, 2015)*, most countries operate with a primary, secondary and tertiary reserve markets. On the generation side, the frequency control capacity in Europe is around 3 GW (0.8 % of peak load) for primary control, 20 GW (4 %) for secondary control and 21 GW (4.2 %) for tertiary control *(Lilliestam and Ellenbeck, 2011)*. This is excluding spare capacity (36 GW) and demand response (25 GW, at that time). Figure 7 gives an overview of the timescales on which these controls operate, and the impact they have on the system frequency (note that in the United States the grid frequency is 60 Hz). *Primary reserve* is the automatic and instant use of turbine speed within ~15 seconds to maintain balance between generation and consumption in a synchronous area *(UCTE, 2009)*. *Secondary reserve* maintains balance between generation and consumption within a block or control area, and makes use of a centralized automatic generation control, making adjustments to generation in the time-frame of seconds to ~ 15 minutes *(UCTE, 2009)*. Tertiary reserves are not operated automatically, but is defined as the re-scheduling of generation meant to free secondary control after around 15 minutes *(UCTE, 2009)*. It is used in case of incidents that cause permanent activation of secondary control reserves (i.e. system contingencies in **Error! Reference source not found.**).

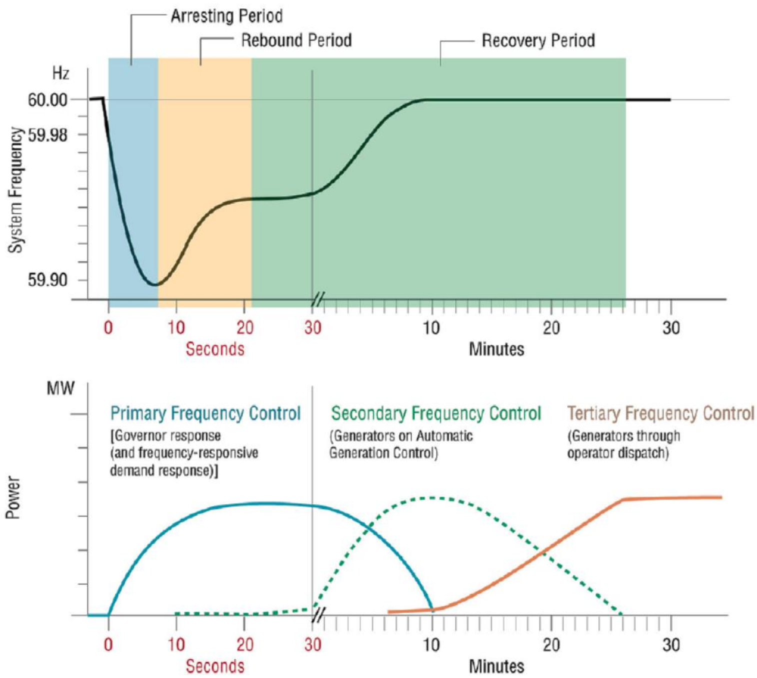


Figure 7. Overview actions of primary, secondary and tertiary control as response to a sudden loss of generation (Akhil et al., 2015)

Table 2 shows relevant characteristics of the different markets for smart grid services. The TSO sets requirements for parties to operate in different markets. In Germany, a party should have a minimum of 1 MW capacity available to operate on the primary reserve market, 5 MW to operate on the secondary reserve market, and between 5 and 25 MW for operating on the tertiary market. In the next paragraph, we elaborate on how these different markets can be translated to business models.

1.1.5 Challenges

Koliou et al. *(Koliou et al., 2014)* see some challenges for smart grid development related to markets:

- Inequality of market entry opportunities in wholesale and retail markets;
- Transmission and distribution tariff remuneration structure;
- Regulation impeding participation in balancing markets;
- Lacking cooperation between different stakeholders (TSOs, DSOs, aggregators and consumers);
- Missing outline of technical requirements of demand side participation;
- Specification of aggregation standards and requirements.

Table 2. Overview relevant market characteristics for smart grid services. Adapted from Koliou et al. (Koliou et al., 2014)

Market		Spot		Balancing		
		Day-ahead	Intraday	Primary	Secondary	Tertiary
Financial compensation	Energy (€/kWh)	V	V		V	V
	Capacity (€/kW)			V	V	V
Event trigger		Economic dispatch	Economic dispatch	System imbalance	System imbalance	System contingency
Response time		1 day ahead	Minutes to hours	≤1min to ≤15 min	< 30 s to > 15 min	
Duration		1 hour	1 hour	Up to 15 min	Up to 30 min	Up to hours

Esterl, Kaser, and Zani *(Esterl et al., 2016)* determine some barriers for cross-border balancing markets. Examples are the absence of harmonization regarding activation of balancing energy and standard products, absence of clear rules concerning transmission capacity, determining a suitable pricing mechanism and the allocation of costs and benefits.
Cambini et al. *(Cambini et al., 2016)* provide some recommendations to enable smart grid investments *(Cambini et al., 2016*) :a) low distribution-sector market concentration; b) use of incentive-based regulatory schemes; and c) the adoption of innovation-stimulus mechanisms are key enablers of SG investments. According to the study, Austria performs well on all of these indicators. The Netherlands on the other hand, can make some improvements. Firstly, the market concentration is medium instead of low. The authors label market concentration of a country as low when the three largest DSOs combined serve less than 60% of the markets. In the Netherlands, the three largest DSOs (Stedin, Liander and Enexis) server more than 60% of the markets, which hampers competition according to Cambini et al. Furthermore, they state that innovation-stimulus mechanisms are absent in the Netherlands. Options to improve this would for the regulator to provide a premium to decrease the weighted average cost of capital of an investor, or to adjust the revenues (e.g. providing specific rewards when certain performance targets are met).

2.2 Business models for smart grids

The fluctuations in electricity or capacity prices on the spot and balance markets are not reflected by the in general constant retail electricity prices. An example of how consumers can be motivated to adjust their demand to improve economic efficiency is by providing incentives for demand response. Demand response (DR) is defined as “changes in electrical usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized” *(USDE, 2006)*. Figure 8 shows how the connection between DR and the different markets can be made.
Regarding price-based DR, there are three main pricing options: time-of-use (ToU) pricing, real-time pricing (RTP) and critical peak pricing (CPP) *(Stadler et al., 2016, Weck et al., 2016, Wissner, 2011)*. ToU pricing offers different prices at peak and off-peak time *(Khan et al., 2016)*. A common example is a day and a night tariff. Sometimes also a medium tariff level exists. The high tariff reflects prices of

peak demand, that reflect higher marginal generation costs. In contrast to ToU, CPP is a pricing scheme that only gives price incentives at few days in a year: the days with highest demand. These peaks represent relative very high generation costs. RTP reflects the day-ahead or intraday spot market prices the most. In RTP, consumers receive information of hourly prices shortly (i.e. one hour or one day) before the actual use. Incentive-Based DR reflects the right of the grid operator to cut loads to some extent *(Wissner, 2011)*. Weck et al. *(Weck et al., 2016)* see direct load control, defined as opportunity for electricity supplier or system operator to reduce load by remotely shutting down household appliances on a short notice, as the most promising Incentive-Based DR.
Behrangrad *(Behrangrad, 2015)* makes the distinction between DR measures, and energy efficiency measures. Together these two categories of services form Demand Side Management (DSM). In the past, the biggest barrier for DSM deployment were of technical nature, but smart grid developments have changes this. Important accelerators are grid-device two-way communication, remotely controllable smart appliances, cloud-based aggregation mechanisms and energy storage *(Behrangrad, 2015)*. Although energy efficiency does not require information technology, it can be stimulated by smart grid developments: smart meters can give insight in where energy use can be decreased *(Wissner, 2011)*. According to Aghaei and Alizadeh *(Aghaei and Alizadeh, 2013)* energy efficiency on the other hand, see energy efficiency programs as *subcategory of* demand response programs, together with be further divided into market-driven DR programs (e.g. to reduce generation costs or electricity price volatility) and network-driven DR programs (e.g. aimed at reducing capacity investment).

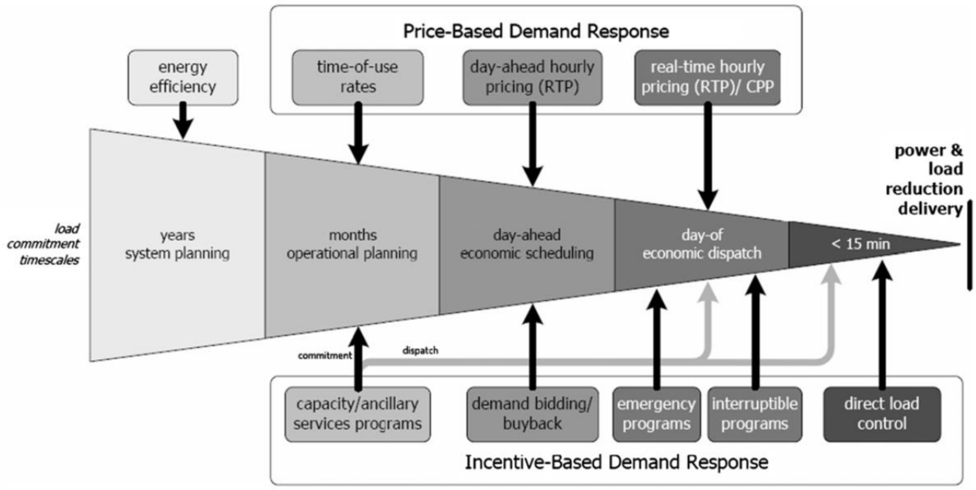


Figure 8. Connection between DR incentives and markets (Wissner, 2011)

1.1.6 Business models

Although different definitions of business models exist, most include the creation and capture of value *(Niesten and Alkemade, 2016)*. Business models for smart grids can be divided by a) the economic value of smart grids in general (e.g. cost-benefit analyses), and b) business models of specific smart grid product or service (groups). Moretti et al. *(Moretti et al., 2016)* provides an overview of studies focused on the former. **Error! Reference source not found.Error! Reference source not found.** provides a full overview of the studies they investigated, sources can be found in Moretti et al. *(Moretti et al., 2016)*.
The variations in results of individual studies is striking; within the 17 studies analysed (nine papers and eight reports), costs varied between 0.03 and 1143 million Euro per year, and benefits between 0.04 and 804 million Euro per year. On average, costs exceed benefits by 59.1 million Euro per year. Reasons for these variations include the scope of the different analyses, electricity prices, choices for inclusion or exclusion of different tangible or intangible costs and benefits, how intangible costs and benefits should be valued (especially in cost-benefit analyses), the time horizon, discount rates, capacities and utility operating characteristics. The associated average reduction in CO_2 emissions is 89 g CO_2 / kWh, again with a notable range from 10 to 180 g. Variations were caused by a country's grid mix (reductions were larger in countries with high shares of fossil fuel), assumption about levels of penetration of renewable energy, and system boundaries (reduction per kWh were higher if studies focused on a segment of the electricity grid mix instead of the full mix).

Several studies provide an overview and or classification of possible business models for smart grid services *(Behrangrad, 2015, Livieratos et al., 2013, Niesten and Alkemade, 2016)*. Based on their review of 45 scientific articles and 434 European and American smart grid pilots, Niesten and Alkemade divide smart grid services into three categories: vehicle to grid and grid to vehicle services (V2G and G2V), DR services, and services to integrate renewable energy *(Niesten and Alkemade, 2016)*. Overlap exists: G2V can be used to integrate renewable energy, and V2G to provide DR services.
Per category, they see value for the consumer, value for the system operator, or value for the service provider / aggregator. In V2G energy actors sell electricity that is stored in electric vehicle (EV) batteries on the electricity spot market or to the system operator. In G2V actors buy electricity from the grid at times that this is relatively attractive. Both is done through EV aggregators: parties that manage a fleet of EVs to be able to operate on different markets. Niesten and Alkemade see value for the consumer in lower pricing of electricity, EV battery, or parking and some value when offering energy and ancillary services. For system operators, they see lower system costs, improved grid stability, improved leveling of load. Lastly, for service provider or aggregators they (somewhat) see lower costs for energy provision. Value for the consumer regarding DR includes lower electricity bills, better power quality, while most studies that focus on value for the system operator mention lower congestion costs, fewer operating reserves and lower required investment in transmission lines or network improvements *(Niesten and Alkemade, 2016)*. Service providers can benefit through avoided investment in generation capacity and lower spot price volatility and sourcing costs. Regarding services to integrate renewables, few studies report benefits for the consumer. Value exists when receiving financial incentives for installing renewable energy, and possible lowering of energy bills through dynamic pricing and offering balancing services. The value of smart grid services lies mostly with the system operator, for example dynamic pricing, as well as electricity storage, can lower grid capacity requirements and increase grid flexibility. Also, service provider can profit from dynamic pricing by reduced capacity requirements. An important recommendation from the study is that business models can mainly be profitable when aggregator companies collect large amount of loads *(Niesten and Alkemade, 2016)*.

Table 3, Overview of smart grid impact assessment studies. CBA = Cost-benefit analysis, GHG = Green House Gas, LCA = Life cycle assessment. Adapted from: (Moretti et al., 2016)

Methodology	System boundary	Smart grid characteristics		Country / region	Discount rate (%)	Tangible / intang. costs
		Cost (M€ / year)	GHG (gCO_2/ kWh)			
CBA / Mult-obj. operational scheduling	Three DR programs (Demand Bidding, Ancillary Services and DRSP) combined with wind generation		169	Canada		Both
CBA	Fully functioning SG	1.84	196	USA		Tang.
CBA	Whole Power Industry	.59		Czech	8	Tang.
CBA	Whole Power Industry	2.55		EU	8	Both
CBA	Yokohama-wide energy system	.97	275	Japan		Both
Estimation based on energy savings forecast	TSO and DSO		169	Hungary		Both
LCA and eco-cost estimation	Home energy management system production, use and disposal			Netherlands		Both
CBA (only benefits reported)	Generation, TSO, DSO and consumption			USA		Tang.
Transaction cost				USA		Both
CBA	Fully operational SG	.03		USA		Tang.

Estimation based on ICT devices penetration	Electricity sector		551	USA	5	Both
CBA	Electricity sector	87.6		Denmark	5	Both
Estimation on historical data and future scenario	Electricity sector		520	China		Tang.
CBA	Distribution network	1143		UK	3.5	Both
Estimation	Electricity sector			Australia		Both
CBA	Distribution network			UK	3.5	Both
CBA	Electricity sector			South Korea	6	Tang.

Livieratos et al. *(Livieratos et al., 2013)* provide a somewhat different classification of actors that benefit; they group energy service providers and system operators in one category (electric utilities) and add society as a whole as benefactor, see Figure 9**Error! Reference source not found.**.
Behrangrad *(Behrangrad, 2015)* sees much potential for DSM business models. Similar to Niesten and Alkemade *(Niesten and Alkemade, 2016)*, he finds that most business models are related to system operators. Attractiveness of business models is in most cases correlated with renewable energy penetration. Technical and financial risks associated to the different business models should still be investigated more, as well as the impact of prosumers (actors that both consume and produce electricity). Possible solutions for arising challenges may be found in changing market designs, for example capacity markets *(Stadler et al., 2016)*.

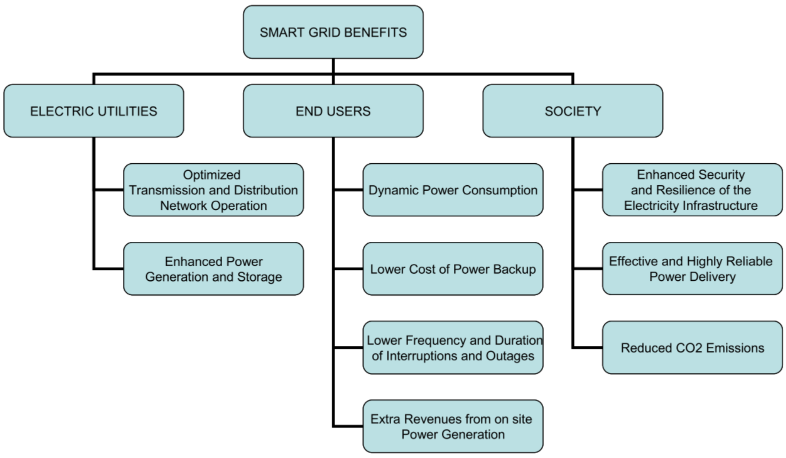


Figure 9. Classification of smart grid benefits for different groups (Livieratos et al., 2013)

1.1.7 Challenges

Khan et al. *(Khan et al., 2016)* elaborate on challenges related to for the development of business models on DSM in general. They see the development of an advanced communication structure as the main challenge. A second challenge they see is interoperability: on the consumers' side, many stakeholders have to communicate, and currently there is a lack of standard protocol for machine to machine communication. Thirdly, there is the challenge of security and privacy: detailed and continuous information from consumers is needed, which can be sensitive information. Fourthly, scalability can be an issue. More and more information traffic is needed, and the communication infrastructure should be capable to accommodate this. Fifthly, load forecasting, which is important for DSM, faces the complexity of human behaviour, because of the lack of availability of historic data, possible errors in weather forecasting model and consumers who have both smart and traditional meters. Finally, the challenge of complexity: many different entities should be developed with various functional requirements.
More specific, Weck et al. *(Weck et al., 2016)* investigate demand response in the Netherlands and find 11 challenges / barriers. These are categorized into four labels, namely:

- Customer barriers: uncertain benefits to consumers, privacy concerns, lack of interest.
- Technical barriers: the need of new billing system, the creation of new demand peak and the need for development control appliance.
- Regulatory barriers: the need for a new allocation and reconciliation process (not based on current household electricity profiles), the Dutch law prohibiting dynamic network tariffs and Dutch law obliging DSO to offer services to all customers, despite not all customers present a business case for DR from a DSO perspective
- Institutional barriers: uncertainty in benefits and low prices on balancing markets.

2.3 Conclusions

Whether the current market model is suitable for deploying smart grids, remains matter of discussion. Incentives for smart solutions are present; aggregators can operate on the spot markets (i.e. by energy arbitrage) and on the balancing markets. From a market-based perspective, one can argue that when the shares of renewables in the grid would increase to (very) high levels, their inherent fluctuations would cause more volatile spot market prices and higher imbalance prices, thus providing higher incentives, and possibly business models, for smart solutions. On the other hand, one can argue that before this is the case, stakeholders need to gain experience on these smart solutions because of the pivotal role the electricity system plays in our society. Various challenges and barriers have been described in this chapter. Furthermore, as can also be observed in this chapter, many smart grid pilot projects exist which include a market places perspective. The next step is to scale up these projects to gain more experience on interactions that can play a role on a higher level.

PART III: STAKEHOLDERS

3 STAKEHOLDERS[4]

3.1 Introduction

"Smart grids" is an umbrella term for several promising technologies for which large investments are made for their research and development. Currently, they are applied in experiments across the globe. Numerous pilot projects in which the different smart grids technologies provide experiences in practice to many stakeholders, and in some projects the users experience the smart grids in their daily lives. Despite the surge of attention to smart grids in research (see Chapter 1), most research mainly focuses on techno-economic aspects of the smart grids. Recently there has also been an increase of studies paying attention to the social actors in smart grid developments. This chapter provides an oversight of these recent insights on social aspects of smart grids, based on the following research question:

What are the key findings regarding smart grids stakeholders' experiences in smart grids pilot developments, and how can these findings feed into a multidisciplinary study of smart grids?

The answer to this question is provided by a focus on smart grids from two key themes which are relevant for understanding the social aspects of smart grids, which are identified as: Users (Section 3.2) and Stakeholders (Section 3.3). In each section, separate research questions are formulated and the key findings and answers based on these questions will be presented.
In Section 3.2, it will be explained how users are identified in the current research, with which theoretical frameworks and what the main user experiences are (with regards to DSM). In Section 3.3, the stakeholders and their roles, (power) relations and expectations with the advent of smart grids are focused upon.
The data generation was as follows: For section 3.2.1 papers have been retrieved from the Scopus database by combining the search key words "smart grids" with the widely-accepted user typologies in smart grids research: Prosumers, end-users and consumers. By limiting the results for this section to social sciences and scientific articles, the retrieved amounts of papers were respectively 5, 10, and 38, and after further analysis (=manual reading) further reduced to: 4, 8, and 24. Especially in the case of the prosumer, there were not much papers available on Scopus. Therefore, an additional search has been performed for articles related to prosumers in other search engines (Google scholar, Science direct). Other relevant papers were found by prior literature searches. For section 3.2.2, which focuses specifically on DSM experiences, the relevant findings from the papers thus assembled were selected. In the section 3.3, the ample research focusing on smart grids stakeholders and their roles in the innovation processes in the energy sector were retrieved from various research documents of institutions such as Ecorys. Finally, based on these two key themes, a conclusion about the key findings and how these key findings (insights) can feed in a multidisciplinary research will be presented.

3.2 Users

In this chapter, the key findings in social-scientific research regarding the users will be presented by answering two core questions:

How are users characterized and what are the main theoretical frameworks applied in the studies? (Section 3.2.1)

What are the main findings regarding user acceptance with specific smart grids products and services in pilot projects, especially with regards to DSM strategies? (Section 3.2.2)

In section 3.2.1, the characterizations of users and their assumptions in current studies are identified. Moreover, the theoretical frameworks regarding the users on which these studies build, are described. In section 3.2.2. the main findings with regards to user experiences in specific smart grids products and services are presented, hereby special attention is paid to user experiences with DSM strategies.

[4] A significant part of this chapter has been written by Esin Gultekin and Barbara van Mierlo

1.1.8 Assumptions about users

In the following sections, the user typologies as they are embedded inside the selected articles will be presented. In each section a description of how the user are approached inside the studies will be provided accompanied with on which types of studies these insights are based upon, with an oversight of the relevant literature. In short, for the purposes of this section, the retrieved papers are read to 1) understand how they approach user typology and also to 2) select papers for section 3.2.2.

Consumers

Table 4 shows the papers in which users are regarded as consumers. Most of these papers approach the consumers as traditional consumers, as they are situated in the current electricity system; they that are faced with new emerging smart technologies and changes in the energy system e.g. *(Fell et al., 2015, Horne et al., 2015b, Michaels and Parag, 2016)*. The main assumption is that the consumers either have to adapt to or adopt the emerging smart technologies, but scholars make different statements about how consumers will either adapt or adopt.

Often the decision-making with regards to adapt/adopt is assumed to be primarily an issue for the consumers themselves but their potential choices and preferences are already taken into account, such as the assumption that consumers primarily desire a lower energy bill. Sometimes this potential consumer acceptance is also assumed to be trigged via smart grids technologies. E.g. Lopes et al. mention that consumers' adoption of the smart grids is dependent on technical features that the smart grids can offer to the consumers to use energy more efficiently *(Lopes et al., 2016)*. Balta-Ozkan et al. mention that smart homes might allow consumers to use energy more efficiently and enhance consumers' comfort *(Balta-Ozkan et al., 2014)*. Horne et. al mention that smart meters have the potential to enable consumers to control their energy use and thus reduce their energy bills *(Horne et al., 2015b)*. Thus, the consumers are approached as personas which respond to the technical offers to enhance their energy use efficiency and therefore reduce their bills.

Other scholars, instead of consumers' choice, place the emphasis on consumers' conformity to accept smart grids. For instance, Broman et al. mention: "for smart grids to function optimally (…) the consumer must be willing to accept that (part of) their electricity will be remotely controlled" *(Broman Toft et al., 2014)*. Thus, whereas most scholars agree that consumers are faced with the decision to either adapt or adopt the smart grids, they have different visions with regards the achievement of consumers' adaption/adoption.

More critical studies question the notion of the consumers in several ways. Schick et al. question the notion of consumer flexibility in smart grids by stating that consumers are merely expected to use smart products (such as electrical vehicles of smart heat pumps) whereas acting flexibly is delegated to other significant stakeholders in the energy systems, such as demand aggregators. This makes, according to the scholars, that the 'flexible consumer' becomes actually 'inflexible' *(Schick and Gad, 2015)*. Another remark has been made by Goulden et al., who state that consumers are not per se exclusively tied to a certain persona of 'consumers or 'prosumers' but can act as both, at different occasions *(Goulden et al., 2014)*. Ballo et al. noticed that often the voice of consumers and consumer organizations have had minimal influence in particular smart grids developments *(Ballo, 2015)*.

Some studies which use the term consumers in quantitative or simulations studies of smart grids, model the consumers as an energy producing and demanding entity. For those studies, consumers can also be defined as enterprises for instance *(Fabrizio et al., 2017, Sonnenschein et al., 2015)*.

Moreover, based on Table 4, it can be seen that the consumers in the context of smart grids are foremost studies based on visions regarding the smart grids, rather than the users in real smart grid environments. Exceptional studies which include real-life smart grids users are *(Döbelt et al., 2015, Joo and Kim, 2016, Kessels et al., 2016)*. The method which is often used are online-based surveys which include scenarios towards which the (potential) consumers have to respond.

Prosumers

The definition of the prosumers differs in complexity in the papers. According to Michales and Parag *(Michaels and Parag, 2016)*, the term prosumer has traditionally been used to address consumers which also produce and sell energy. A definition that provides an example for this definition of the prosumer is suggested by Rathnayaka et al.: "Prosumers in the energy value network are economically motivated actors, who not only consume energy, but also generate green energy and share the surplus with the main utility grid or other energy consumers" *(Rathnayaka et al., 2014)*. another persona which is related to this prosumer definitions, is the so-named citizen, proposed by Wolsink, who again acts as a co-producer, but now especially in micro grids environments *(Wolsink, 2012)*.

Table 4 Oversight of papers which are retrieved for Consumers, author: Esin Gültekin

	Smart grids (SG) concept	Method	Data	Consumers in study	Subject
(Fabrizio et al., 2017)	Micro SG	Simulation	Case study	Loads in system	Quantitative architecture: for monitoring
(Lawrence et al., 2016)	Smart buildings	Q&A article	Prior research	Buildings	Building integration in SG with new tech.
(Michaels and Parag, 2016)	Visions Dynamic pricing	Online survey	N=509	Public	Public perception of DSM programs
(Zhou et al., 2016)	SG deployment	Statistical	Panel data	Public	Policy research (polycentric governance)
(Kessels et al., 2016)	Dynamic pricing	Meta-review	Articles & pilots	Real user response	Effectiveness of various pricing schemes
(Joo and Kim, 2016)	Service focus	Interviews, N=41	Case study: Korea	Real users in testbed	Policy effect on user adoption
(Vesnic-Alujevic et al., 2016)	Visions SG	(Policy) Document analysis	Policy documents	Critique on consumers' notion	How SG are portrayed in EU policy documents in discourses, and claims.
(Raimi and Carrico, 2016)	Visions SG	Online survey	US public, n=305 (via Amazon)	Public	Understanding the public's beliefs and Expectations
(Büscher and Sumpf, 2015)	Visions SG	Semi structured interviews	N = 8 experts	Traditional consumers in energy system	Sociological discussion on social mechanisms (trust issues)
(Döbelt et al., 2015)	Visions SG	Online survey & focus groups	N=240, N=15 Case: Austria	Real users in test panels of SG	Consumer privacy concerns
(Horne et al., 2015a)	Visions smart meters	Vignette experiments (2 scenarios)	N = 360, via Amazon	Public	Understanding how norms emerge in response to smart meters
(Sonnenschein et al., 2015)	Electric vehicles	Simulation	Agent based control techniques	Loads in system	Automatic decision making units, based on observations in a future SG can support local demand/supply matching.
(Schick and Gad, 2015)	Visions SG	(Policy) Document analysis	Case study: Denmark	Critical stance towards duties consumers	How users are being (re) imagined in the Danish Smart Grid.
(Ballo, 2015)	Visions SG	Document analysis & interviews	N=13 informants Case study: Norway	Traditional consumers in energy system	Imaginaries of the future SG
(Fell et al., 2015)	Visions Dynamic pricing	Statistical analysis: Online survey	N=2000	Public	Public (potential) acceptability of different DSM tariffs in Britain
(Broman Toft et al., 2014)	Visions SG	Online survey Scenario based	Denmark, Norway, Swiss. N=3000	Public	Effect of opt-in opt-out policies on SG acceptance
(Balta-Ozkan et al., 2014)	Vision SG, smart home	Focus group discussions	6 discussions, 2 per country. N=30 people	Public	Techno-economic barriers for smart home adoption

(Rawlings et al., 2014)	Dynamic pricing	Calculation: Energy use	Figures from databases	SME as consumers	Opportunities for DR, in SME sector
(Goulden et al., 2014)	Visions SG	Focus group Discussion	4 x N=18 people	Public as personas (consumers/prosumer)	Energy engagements based on persona's (consumers / prosumer-citizen)
(Ida et al., 2014)	Visions SG, EV	Statistical analysis: online survey	Case: Japan	Public (random households)	Consumers' stated preferences and willingness to pay (WTP) for PV & HEMS, hybrid electric vehicles,
(Skjølsvold, 2014)	Visions SG	Document analysis	Documents between 98'-08'	Imaginations of consumers	Retrospection of prospects of smart grid Technology (technology debate)
(Powells et al., 2014)	Dynamic energy usage	Qualitative study	186 home tours	Carriers of social practices, ,load as social phenomena	Assessing flexibility as characteristic of social practices which shape electricity demand curves.
(Stragier et al., 2013)	HEMS, scenario based	Development of architecture for HEMS	Interviews, diary studies	Public	describes a user-centric methodological process that is valid in the development of a home energy management system

Besides consuming/producing energy, the prosumer is now also expected to be engaged in more tasks, the so-named 'prosuming activities' *(Michaels and Parag, 2016)*. According to Michaels and Parang, these include tasks such as micro generation, demand reduction, load shifting, storage and other related ancillary services.

Rekik et. al also stress the role of the prosumer in so-named virtual power plants (VPP) in which the prosumers act as trade partners with energy suppliers. They state, by joining a VPP, the prosumers will also contribute to the "resilience and efficiency of the electricity system through responsible interaction with the grid state" *(Rekik et al., 2016)*. Thus, besides engaging in prosuming activities, the prosumer also has a role in the VPP as a trade partner. With regards to the VPP, there are different models possible in which the role and the position of the prosumer can differ based on VPP architecture. Another expectation with regards to the prosumer, is that it the smart technology is also expected to have an impact on culture and lifestyles as well *(Bigerna et al., 2016)*. An important remark has been made by Wolsink (2010) as cited by Verbong (2013). They mention that there are still "a lot of uncertainty on the identity of the future prosumers" and that the prosumer is mainly defined by traditional actors inside the current electricity system such as energy companies, networks operators and policy makers *(Verbong et al., 2013)*.

Table 5 and Table 6 list the publications dealing with end users as Prosumers. In Table 5, three papers overlap with the papers in Table 4; these are *(Büscher and Sumpf, 2015, Lawrence et al., 2016, Michaels and Parag, 2016)*.

Table 5. Oversight of papers which are retrieved for Prosumers via Scopus, author: Esin Gültekin

	Smart grids (SG) concept	Method	Data	Prosumer in study	Subject
(Rekik et al., 2016)	*VVP in SG environment*	*Simulation (ant colony)*	*Simulation, Case: Tunisia*	*Prosumer, as they are expected to behave in VVP/SG environment.*	*Virtual power plant deployment in SG*

Table 6. Oversight of papers which are retrieved for Prosumers via Google scholar, author: Esin Gültekin

	SG concept	Method	Data	Prosumer in study	Subject
(Bigerna et al., 2016)	*Not uniform (see method)*	*Literature review*	*Articles*	*Hybrid figure, actively involved*	*Socio-economic acceptability of smart grids*
(Rathnayaka et al., 2014)	*VPP in SG*	*Theoretical model*	*none*	*Prosumers combined in VPP*	*Goal oriented prosumer community groups in SG*
(Verbong et al., 2013)	*Visions SG*	*Interview (stakeholders)*	*Stakeholders- Dutch pilots projects*	*Is defined by energy companies, network operators and policymakers*	*Perceptions and practices of stakeholders,*
(Wolsink, 2012)	*Visions Micro grids*	*Theoretical*	*None*	*Citizen, as co-producer*	*Present a research agenda on social acceptance of distributed generation in smart grids*

End-users

The end-user is positioned as someone who is merely responsive to information and feedback from the smart grids. More specifically, the responsiveness is often discussed as the responsiveness to different tariff structures in Demand response (DR) or Demand side programs (DSM). For instance, Eid et. al (2016) discuss different types of DR, and incentive structures related to the end-users *(Eid et al., 2016)*. Koliou et. al (2015) state that the responsiveness of end-users to demand response programs is perceived as the source of flexibility in the energy sector. In a similar vein, in all of the papers which make a reference to "end-users", the users are discussed in relation to demand side management (DSM) strategies *(Koliou et al., 2015)* (Table 7).

Besides the association between end-users and demand response/demand side management strategies, the end-users are also seen as active players in the smart grids, who have to decide to adapt or adopt. For instance, Stagier et. al (2013) mention that end-users may have certain wishes and desires and therefore he develops an approach to incorporate the consumers' preferences in the development of smart user products (such as HEMS) *(Stragier et al., 2013)*. Eid et. al (2016) formulate that the end-users are enabled to participate in the energy market based on different tariff structures *(Eid et al., 2016)*. Except for the Stagiers et. al (2013) study, it can be concluded that end-users are foremost described in terms of their responses to tariffs.

From the articles retrieved via Scopus, *(Kessels et al., 2016, Stragier et al., 2013)* showed an overlap with other tables, and one paper is unavailable.

Table 7. Oversight of papers which are retrieved for End-users, author: Esin Gültekin

	Smart grids (SG) concept	Method	Data	End-user in study	Subject
(Eid et al., 2016)	Focus on DR	Theoretical	Examples of cases	'passive' end-user	Overview and examples of DR
(Koliou et al., 2015)	Focus on DR	Quantitative (economics)	-	Reponsive end-user	DSO motives for demand response
(Machidon, 2015)	Smart tech (broad)	Theoretical	Research	User prone to hazards (e.g. privacy)	Critical stance towards social implications
(Ogunjuyigbe et al., 2015)	Focus on DR	Quantitative (simulation)	-	User in persuasive system	a persuasive smart energy

					management system
(Connolly, 2014)	Smart energy system	Quantitative (economical)	Case: Ireland	User demands	Energy transition (broad assessment)
(Barbero and Pereno, 2013)	Focus on SG's	Theoretical	Case: Piedmont	Limited choice of end-users	Address environmental and social issues regarding SG and end-users

Theoretical frameworks

In some of the above-mentioned studies, theoretical frameworks are used to study how users are embedded in smart grids environments. One of the theories which is frequently used throughout social scientific research, focusing on smart grids is the social practice theory (as developed by Elizabeth Shove, Anthony Giddens & Theodore Schatzki). The social practice theory has recently became more prominent in social scientific studies focusing on energy issues, such as the study of energy consumption and changes in energy usage *(Naus et al., 2014)*. Other examples of studies which employ the social practice theory are: *(Barnicoat and Danson, 2015, Friis and Haunstrup Christensen, 2016, Nicholls and Strengers, 2015, Powells et al., 2014)*.

Despite the differences, these studies have in common that they draw attention to the fact that current energy patters are difficult to change due to the routinized nature of practices which are embedded in everyday lives of people, who also share a social context with others *(Naus et al., 2014)*. For example, Nicholls et. al (2015) shows that there are so-named family peaks in households with children *(Nicholls and Strengers, 2015)*. Powell et. al (2014) also mention that peaks are actually the results of practices and should be understood accordingly *(Powells et al., 2014)*. Similarly, in the articles of Naus et. al (2015) it is also affirmed that different practices (such as cooking and washing) have different flexibilities, that is their potential to be adapted based on smart grids and DSM tariffs *(Naus et al., 2015)*. Friis et. al (2016) place the emphasis on dependency of DSM strategies on practices, in which they state: "Collective rhythms have an important influence on the flexibility of daily practices. Some daily practices (like preparing dinner and showering) are so closely related to institutional rhythms like work and school hours that they are not even considered as subject to time shifting by the participants" *(Friis and Haunstrup Christensen, 2016)*.

Another framework which is employed in one study, is the informational governance theory, which draws attention about how information (instead of authority) is changing and re-shaping the structures of governance. Based on this theory one of the findings is "that new information flows provided to households does not automatically result in the development of more sustainable domestic energy practices" *(Naus et al., 2014)*. Having mentioned that, in the following sections user experiences and acceptance issues with regards to smart grids, will be presented.

1.1.9 User experience and demand side management (DSM)

Demand side management (DSM) interventions basically aim to shift and decrease energy usage based on providing various possible tariff schemes to the users or prosumers. In general, there are two important methods to accomplish this, which are the price-based demand response interventions and controllable demand response interventions *(Eid et al., 2016)*.

In the price-based Demand response (DR) programs, as explained in chapter 2, there are different options for setting tariffs for the users of the smart grids, which are: time-of-use (ToU) pricing, real-time pricing (RTP) and critical peak pricing (CPP). Another type of DSM is the so-named demand bidding DR (DR-DB), in which the energy supplier sets an event and the 'prosumers' bid to reduce their energy for an incentive, which can be determined by the user. The second category includes methods such as direct load control (DLC), which gives third parties (energy suppliers, aggregators or DSO's) the authority to make direct changes in energy supply to the users, by simply changing the times of supplying. Though, having mentioned the most important DSM interventions, this list is non-exhaustive since there is not yet a dominant design and new designs may be proposed in the near future.

Thus, different options and scenarios exist which all used with the aim to change the patterns of energy usage. However, in order to understand how 'effective' these strategies actually are in reducing and shifting energy patterns of the users, it is important to highlight the demand side perspective,

which are user experiences. Foremost, the most important argument upheld in the literature to study users' experiences, is the expectation that only a wide adoption of smart grids and accompanied DSM interventions in different layers of the society will make the investment in smart grids become financially attractive *(Faruqui et al., 2010)*. These scholars also mention that only the investment in smart meters (excluding the HEMS, smart applications etc.) in European homes would already cost around 51 billion euros *(Faruqui et al., 2010)*.
With regards to the topic of user experience, the topic of –acceptance- plays a major role as a re-occurring topic throughout research, i.e. *(Balta-Ozkan et al., 2014, Barnicoat and Danson, 2015, Bigerna et al., 2016, Broman Toft et al., 2014)*. User acceptance is studied from different angles, but can largely be classified as two types of studies which will be explained next. In the first category, the study focuses on effects of DSM interventions in real life pilot projects, which is among others described with specific details such as the reduction or shift in energy-usage. In the second category, the focus is on 'perceptions' of users regarding visions and/or expectations of smart grids and DSM tariffs (Figure 10).
The first category contributes to understand how effective DSM strategies are in real-life settings, whereas the second category aids to understand how user might perceive future technologies. By far, most studies (in numbers) are concentrated in the second category. Krishnamurti et al. also affirm that: "to date there is little evidence of how effective widespread demand–response programs would be" *(Krishnamurti et al., 2012)*, which is still relevant. A possible explanation can be that pilot data is very difficult to retrieve. As mentioned in former section, the insights in this section is derived from the relevant papers from Section 1.1.8. These are supplied with additional papers which are retrieved via searches from other article databases (e.g. Sciencedirect, Google scholar).

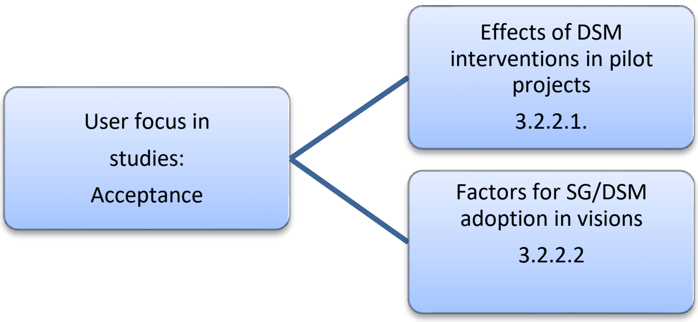


Figure 10. User focus in studies: acceptance, author: Esin Gültekin

Effects of DSM interventions in pilots

In the first category, there are only two studies that are both published in 2016, which show how DSM strategies have unfolded in practice. They focus on different effects, the first study focuses on actual behaviour change (a) whereas the second study focuses on changes in price (b), by the means of DSM interventions.

DSM interventions and energy behaviour

Kessels et al. (2016) focus on the question how to make users shift, adapt and adjust their energy use based on various DSM schemes *(Kessels et al., 2016)*. In their study, they do not only conduct a survey regarding the insights of prior research, but also show results from real-world pilot projects. Their inquiry is guided by four main hypotheses, which are derived from a literature survey and 'tested' based on real life pilot projects. However, this testing is not a usual statistical testing, but rather these hypotheses simply guide the assessment of the real-life pilot project results. The hypotheses presented focus on the effect of different factors are on actual energy demand shift in time or energy demand reduction. The hypotheses and their results from real life projects will be presented next.
Hypothesis 1, predicted that the number of time blocks of electricity pricing schemes should be limited and prices should not be updated too frequently, and found support from the projects as presented:
Hypothesis 2 predicts that the response of end users to extraordinary events will be better when they are announced timely and are limited in duration. This hypothesis also found some support in a project entitled eTelligence, in which 20%-30% changes in electricity consumption has been achieved *(Kessels et al., 2016)*.

Hypothesis 3 states that: In order to convince end users to change their energy end-use behaviour, price spreads should be considerable. The results derived from real life projects varied considerably *(Kessels et al., 2016)*.
Finally, hypothesis 4 is formulated as follows: For complex and/or unpredictable pricing schemes automatic control should be applied in order to increase the responsiveness of end users. This hypothesis found also some evidence in the real life projects *(Kessels et al., 2016)*.
Based on these outcomes, the authors conclude that DSM schemes have the potential to change energy consumption behaviour within households. However they also state that "in order to work effectively, the dynamic tariff should be simple to understand for the end users, with timely notifications of price changes, a considerable effect on their energy bill and, if the tariff is more complex, the burden for the consumer could be eased by introducing automated control" *(Kessels et al., 2016)*.

DSM interventions and energy bills

Eid et al. present also some results derived from real life projects in their study as well *(Eid et al., 2016)*. Their results are based on a pilot project in France, conducted by Voltalis in Brittany. Based on these results it could be concluded that as well as DLC in which customer are automatically enrolled in (but can opt-out) and ToU combined with CPP, could both attain a reduction of approximately 10 percent on their electricity bills. This makes both strategies similarly effective, in terms of energy usage reduction.

Factors for smart grids/DSM adoption

In the previous sections, some results from real life pilots where presented. Gangale et. al (2013) study showed that there is an increase in European projects which engage the users in their smart grids projects and that the focus is increasingly on the residential sector as well *(Gangale et al., 2013)*. Moreover, in these smart grids pilot projects in Europe, different price schemes have been tested, but as stated in the study of Kessels. et. al (2016), the results have been lacking so far and Kessels et al. (2016) contributed to fill this gap *(Kessels et al., 2016)*.
Thus, having concluded that the results of real life smart grids projects have been lacking so far, there is yet a second type (Figure 10) of studies which approach this subject from a different perspective. Instead of focusing on 'real' results, these studies ought to find out about consumers' perceptions with regards to DSM concepts and scenario's. The results from this second type of studies will be presented next.
Based on these studies several factors have been identified which also (have the potential to) influence consumers' acceptance (Table 8). In general, two factors seem to re-occur in these studies, these are identified as the role of information/education or 'electricity literacy' and the role of trust/privacy, on consumers' acceptance and/or adoption. These factors can also be identified as "hard" factors versus "soft" factors, since education/information exposal is more concrete compared to 'trust'/'mistrust'. Both of these topics will be explained further based on the insights and results from the above-mentioned studies.

Knowledge/misconceptions/information deficit

A couple of studies focuses on the role of information provision from the smart grids to (potential) users, in order to assess which effects it has on user acceptance/adoption of the smart grids. For instance, Lopes et. al (2016) found out that users respond better to DR in the cases where technologies are more sophisticated to use, accordingly they state: "specifically those integrating large volumes of information and automatically reprogramming appliances based on price information" enhance the user response to demand response *(Lopes et al., 2016)*. Related to this, the so-named electricity literacy of users is also seen as an important factor. That is, the knowledge that users have with regards to the electricity markets (in which they are expected to become a prosumer and actively participate in) influences their behaviour significantly.
Faruqui et al (2010) in a similar vein, state that the user response is indeed depended on methods which are used to stimulate DR. The scholars define that this ranges from "ToU tariffs with reminders to consumers and the use of ''traffic lights'' or SMS messages to indicate periods of high prices, to full dynamic pricing with enabling technologies such as smart thermostats and always-on gateway systems." *(Faruqui et al., 2010)*. Additionally, they also address studies which found that, indeed, a stronger DR is present in situations where the HEMS are more sophisticated in providing information and expensive.
Krishnamurti et. al (2012) draw attention to the misconceptions based on wrongful information which (potential) users tend to possess when discussing smart grids *(Krishnamurti et al., 2012)*. They found that potential consumers have a positive attitude towards smart grids, but that they are based on unre-

alistic expectations and misconceptions, which is likely to results in disappointment and distrust (towards energy companies), according to the scholars. So, they address the issue that gaps in knowledge can prevent user from taking fully informed decisions.

Table 8 Factors for smart grids /DSM adoption, author: Esin Gültekin

	DSM: type	Installed ?	Success?	Factors:	Method & Data	Subject
(Eid et al., 2016)	TOU / DLC (real usage, by reference)	Y (references)	5-10% Met DLC & TOU = France	-initial investment -coordination -flexibility (user)	Document Analysis	Examples of DR in Europe & related challenges
(Buchanan et al., 2016)	TOU & DLC (visions)	N	N/A	Barriers: -Distrust -Mixed feelings -No interest	Focus group	British public's responses to (i) smart meters and (ii) three' smart service' concepts: automation, community rewards, and gamification
(Barnicoat and Danson, 2015)	TOU/RTP (visions)	N	N/A	Barriers: -less control -complexity -doesn't understand tariffs	Interviews, Case: Scotland, n=19 households (elderly)	perceptions, attitudes and behaviour of older people to energy use, smart technologies and associated developments.
(Krishnamurti et al., 2012)	DSM & SM (visions)	N	N/A	-miss-conceptions leading to distrust	Interviews & survey	Descriptive research about (potential) user perceptions
(Lopes et al., 2016)	TOU/DLC (visions)	25,6% uses TOU in survey	TOU: 68% DLC:34,9%	-lack of info / education -lack of motivating prices	Online Survey Case: Portugal	detailing preferences towards smart technologies and demand response actions.
(Büscher and Sumpf, 2015)	N/A SG in general	N	N/A	+trust -complexity	Expert interviews	The role of trust for acceptance
(Fell et al., 2015)	TOU & DLC	N	N/A	-trust	Survey, case: GB	Public (potential) acceptability of different DSM tariffs in Britain
(Balta-Ozkan et al., 2014)	N/A SG in general	N	N/A	-trust	Focus group(s)	Techno-economic barriers for smart home adoption
(Michaels and Parag, 2016)	Demand-shift/decrease	N	N/A	-	Online Survey	Public perception of DSM programs
(Döbelt et al., 2015)	N/A SG in general	N	N/A	-	Survey & focus group Case: Austria	Consumers' privacy concerns, trustworthiness of third parties
(Faruqui et al., 2010)	TOU	N	N/A	-HEMS (sophistication)		Importance of SG (DSM) adoption for success SG
(Gangale et al., 2013)	N/A SG in general	N	N/A	-trust	Survey	Consumer engagement in SG projects in EU

(Raimi and Carrico, 2016)	N/A SG in general	N	N/A	-negative role knowledge for ac-ceptance	Survey	Understanding the public's beliefs and expectations

Building further on the last statement, Buchanan et al. show that in some countries, such as Britain, consumers' knowledge regarding smart metering alone is already very low, they show that 76 % of British consumers self-report that they know very little to nothing about smart products *(Buchanan et al., 2016)*. Barnicoat et al. especially focus on the elderly users and their study also show that these groups of users do not yet understand how the DSM structures work *(Barnicoat and Danson, 2015)*. Both scholars indicate this as a barrier for user adoption/acceptance, whereas Horne et al. also state that disappointments and broken trust relations with third parties can lead to anti-technology norms *(Horne et al., 2015a)* (see next section).

In contrast to these findings, other scholars, i.e. *(Büscher and Sumpf, 2015, Raimi and Carrico, 2016)*, found that the role and education enforced to users, can also be ineffective in the aim to achieve higher user adoption/acceptance. Raimi et al. show that consumers exposed to knowledge about smart grids do not automatically enjoy higher rates of (user) acceptance *(Raimi and Carrico, 2016)*. In contrast, they show that more knowledge is related to more concerns (also related to trust) on the user-side *(Büscher and Sumpf, 2015, Raimi and Carrico, 2016)*. In the following section, the role of trust is discussed into more detail.

Trust/Privacy/Control

Having discussed the role of knowledge, there are studies which advocate the role of trust instead of knowledge. This implies that the amount of knowledge actually has to be reduced in order to enable grasp the most relevant information. Buscher et al. state that "trust is identified as the basic mechanism of change and stability in the transformation of the energy system" *(Büscher and Sumpf, 2015)*. Gangale et al. (2013) maintain a similar opinion and also address the importance of trust not only for consumer acceptance, but also 'good-will' of the users *(Gangale et al., 2013)*. Simultaneously, they identify the lack of trust in consumers in Europe as one of the core challenges to overcome to enhance acceptance *(Gangale et al., 2013)*. Building further on distrust, the factors which influence acceptance are: privacy violations, issues of security, loss of control and autonomy, mistrust of energy suppliers, and disruption to daily household routines.

The role of control, besides trust, also plays a major role. For example, in the study of Lopes et al., it appears that the majority of respondents (65.1 %) was not willing to accept direct load control from the energy companies, albeit in a hypothetical future scenario setting *(Lopes et al., 2016)*. Only 34.9 % were willing to accept control of their appliances *(Lopes et al., 2016)*. In the same study, it was also found that 30 % was unwilling to accept ToU in their daily lives. Moreover, Naus et al. show how householders are less willing to cooperate with other households (horizontal cooperation) and with energy companies (vertical cooperation) with regards to three energy intensive practices: energy monitoring, renewable energy production and time-shifting *(Naus et al., 2015)*.

In a n=509 survey based in Israel, Micheals et al. provide results which are similar, namely: "Israelis show little interest in distance controlled appliances and prefer responding personally to tariff structures" *(Michaels and Parag, 2016)*. Buchanan et al. also detect a wide mistrust to energy suppliers in their focus group studies *(Buchanan et al., 2016)*. In the Portuguese context, people who are positive towards demand shifting are less willing to accept load control by energy suppliers *(Lopes et al., 2016)*.

One major implication of the increased privacy risk perceptions in relation to smart products according to Horne et al. is that it can provoke opposition which is stable across different demographic characteristics and create anti-technology norms across society *(Horne et al., 2015b)*. More specifically, based on their results, Horne et al. conclude that the frequency of data collection does not disadvantage user acceptance, but the ability to infer consumer information from this data does. They also show that the ability to sell user data and demand control by suppliers, enhances the development of norms against smart metering. McKenna et al. assert that the usage of personal data can be minimized and discuss several methods accordingly *(McKenna et al., 2012)*.

In major contrast with these results, the studies of Fell et al. (2015) and Döbelt et al. (2015) show that in their studies DLC is actually preferred above ToU. More specifically, research by Fell et al. shows that despite the lack of control associated with less acceptance, direct load control (DLC) is in some occasions favoured over ToU by consumers *(Fell et al., 2015)*. In Austria, Döbelt et al. also conclude

that consumers, in contrast to former insights, do trust energy companies *(Döbelt et al., 2015)*. A possible explanation given by the authors is that the energy prices are rather stable in Austria, compared to other EU countries.
Finally, Barnicoat et al. mentions that the ultimate goal to attain energy demand shift/decrease may be problematic in households which are already energy poor *(Barnicoat and Danson, 2015)*. Which makes that the attempt to achieve energy usage shift/decrease should be assessed within social context to enhance consumer welfare.

3.3 Stakeholders in smart grids

With the advent of the smart grids the roles of the stakeholders are prone to change due to new technological developments. In order to achieve more understanding regarding who the stakeholders are and how their roles may evolve, the following questions are formulated:

Which stakeholders are involved in smart grids pilot developments and what are their roles? (Section 3.3.1)
What are the key findings with regards to stakeholders' relations and what are the expectancies regarding their relations in the light of smart grids developments? (Section 3.3.2)

1.1.10 Who are the stakeholders and what are their roles?

The question who the stakeholders are, is a very complex question, since there are very major players as well as many little players involved and the energy system is prone to change. In this section the focus will be upon the stakeholders which either play –decisive- roles with regards to the smart grids, or are envisioned to become so, according to policy/research insights. However, before discussing the stakeholders in the smart grids developments, the current main stakeholders will be presented. This is necessary to understand how the transition from the current system towards the new system will be.
In most countries, as in the Netherlands, the dominant energy system is centralized top-down system which has the following value chain: There are parties which are responsible for electricity generation (1), followed by the national electricity transmission system operator (TSO), which is Tennet and maintains the grids for 110 kV and higher. These are again linked to regional players which maintain the electricity grid per region, between the range of 10 kV and 110 kV (2), followed by the distribution companies which supply electricity to the users. Of course, there are also other parties involved which are responsible for measuring ("MV-meetverantwoordelijken"), but by far the most important distinction between stakeholders for the sake of this section, can be made by: Generation – TSO – DSO's and consumers.
In the Netherlands major players in the electricity generation sector are: NUON, Essent, Eneco, E.ON Benelux and Engie. The TSO for 110 kV and high is state-owned Tennet, which therefore has a monopolistic power. Moreover, the Netherlands is divided into seven regions, which belong to one of these DSO's: RENDO Netwerken, Cogas Infra en Beheer, Liander, Enexis, Stedin, Westland Infra and Enduris. In 2004, the energy market has been liberalized in the Netherlands which makes that citizens are free to choose their energy suppliers, since then, many new parties have entered this market. Currently there are approximately 40 energy suppliers actively operating at the Dutch electricity market.
In the Dutch smart grids sector, not only 105 stakeholders are identified which are somehow involved in the smart grids projects, but also in the R&D programmes of smart grids products have been identified and published by the "who is who guide", published by the Netherlands Enterprise Agency in 2014:

- Smart grids engineering,
- Grid operation,
- Consultancy related to smart grids,
- ICT solutions concerning smart grids,
- Energy supply and energy services,
- Energy and smart grids research.

According to Gangale et al., DSO's are the leading companies in initiating the smart grids pilot projects in which consumers are engaged (47 %), followed by energy providers (25 %) *(Gangale et al., 2013)*. This, they explain, is related to the nature of the DSO's which are highly dependent on consumer engagement. Next, stakeholders involved in projects that focus on consumer engagement in the Netherlands will be explored. In the Netherlands, there are in total 30 projects, but only a smaller share of

them focus on consumer engagement and the smart home concept in residential sectors, these are mentioned in Table 9.
From these 10 projects, three are initiated by a cooperation organisation, in which other parties are involved later. One by a company specialized in providing a wide array of services to the maritime, oil & gas and energy industries, one construction company, another one by a taskforce, and the rest is initiated by distribution system operators (DSO's).

1.1.11 Stakeholders in the light of smart grid developments

The question how the stakeholders (current, old, stakeholders as well new stakeholders) will become affected in the light of smart grids, depends on how the markets will evolve with the advent of the smart grids (see also Chapter 0). Power markets are changing all over the EU *(EC, 2016)*, a few of these new developments are, among others, as mentioned in the reports: "Increased integration of intermittent renewable energy sources, peak demand with the rise of electric vehicles and electric heating, assimilation of distributed energy resources and of energy from prosumers, deployment of smart meters" *(EC, 2016)*. It is also mentioned that another new development is that consumers are expected to become prosumers. These, non-exclusive list of new energy market dynamics makes that the roles of the stakeholders, in the light of the future energy market scenario's, are revised for numerous purposes such as policy making for changing the regulatory frameworks in which the stakeholders operate. These are necessary since, as it is stated in EU policy report: "current remuneration schemes of Distribution system operators (DSO's) are typically incentivising traditional grid expansions over more efficient solutions"*(EC, 2016)* .
Available sources, mostly focus or anticipate on the (future) roles of the stakeholders, thereby focusing on the issues which tasks should be taken up by the regulated DSO's versus stakeholders from the private sector (i.e. energy companies and ICT firms) *(Ecorys, 2014)*
This has a few important reasons, for example, the DSO's are often leading the smart grids pilot projects *(Gangale et al., 2013)* or have a significant role in these pilots (Section 1.1.10). Moreover, the DSO's, as regulated institutions, haves to deal with a paradigm shift in which the regulation framework will also become outdated *(EC, 2016)*. Therefore thorough assessments are needed to prepare the DSO's for its new and changing responsibilities, such as handling the data from smart grids (source) and cooperation with the TSO (especially relevant for flexibility services), i.e. *(EC, 2016, Ecorys, 2014)*. Next, the relevant tasks and responsibilities and potential role(s) of the relevant stakeholders therein will be presented.

Table 9 Oversight of consumer engagement pilots and involved stakeholders, by author: Esin Gültekin

Pilot project	Initiated by:	Other known involved stakeholders (e.g. ICT firms)
Texel cloud power	Cooperation: Texel Energie	Alliander, Capgemini
Samen slim met energie	Enexis and Cooperation: DEH	Shifft
Goese proeftuin	Heijmans	Woningstichting RWS, DELTA, Marsaki
Lochem energie	Cooperation: Lochem energie	LochemEnergie, Locamation – prepares and supplies measurement, control and safety equipment, main contractor, University of Twente, Eaton industries, Alliander
Power Matching city	DNV GL	DNV GL, ICT Automatisering, TNO, Essent, Enexis, Gasunie, Technical University Eindhoven, Technical University Delft, Hanze University of Applied Sciences.
Energie koplopers	Essent & Liander	Essent, Liander, IBM, ICT Automatisering, NRG031 & Muncipality of Heerhugowaard
Hoog Dalem	Stedin	Stedin, ABB, Heijmans & Dutch telco KPN

Couperus	Stedin	Stedin Netbeheer, Itho Daalderdorp, Staedion, SWY (Vestia), Eneco, TNO, IBM, Province of Zuid-Holland.
Jouw energie moment	Enexis	Enexis, Fudura, Shifft, TNO, Senfal, Technolution
Rendement voor iedereen	Taskforce Innovatie Regio Utrecht	Hogeschool Utrecht, Taskforce Innovatie Regio Utrecht, LomboXnet, Icasus, Eemflow Energy, Stedin, Ecofys, DNV KEMA, Capgemini, Universiteit Utrecht, Rijksuniversiteit Groningen

In the Ecorcys report, based on 30 stakeholders interviews, not only there are 5 services identified in which the roles of the DSO's but also the appropriateness of different market mechanisms are assessed in monopolistic and/or free market structures, these main services are identified as (Source: *(Ecorys, 2014)*):

- Flexibility services (e.g. flexible generation, DSM, DR etc.)
- Infrastructure provision for electric vehicles (EV's)
- Energy efficiency services
- Ownership & management of metering equipment
- Data handling (three main models: DSO model, central data hub (CDH) model, data access-point manager (DAM) model.

Since these research reports, written for policy recommendations, are built on and assess future scenarios and the possible roles of the stakeholders therein based on several issues. Namely, they detail several policy options and discuss the roles in the light of these future scenarios of possible future markets (regulated versus competitive/liberal). Although recommendations are made, it has to be mentioned that these are not inconclusive and will probably be discussed even further in the following years, in which the energy transition(s) are ought to take place in the energy system.
The recommendations and conclusions in the reports discuss several policy options in different possible market structures, which is a regulated versus a competitive market. From this it could be derived that the topic of future (expected) roles of the involved stakeholders is a very complex one and there are not yet 'dominants' design which can inform this paradigm shift, but research merely focuses on to prepare to revise outdated elements.

3.4 Conclusions

Smart grids have been studied throughout different scientific fields. In this chapter the focus was upon existing social scientific research with regards to the users and stakeholders. The main aim was to be able to explore the key findings regarding smart grids stakeholders' experiences in smart grids developments, and how these findings could feed into a multidisciplinary study of smart grids.
Based on literature review we conclude that users, as they are described in current research, do not only have different labels (consumers/pro-sumers/end-users) but are also assumed to behave differently from each other. Disregarding some ambiguousness and overlapping we arrived at the following user typology presented as attributes. The most prevalent type are the consumers, who are supposed to adapt/adopt to new developments in the energy system, such as smart grids. The prosumers are seen as users who consumer and (co-)produce energy, engage in various pro-suming activities and are sometimes also seen as potential active players on energy markets in VPP's. Prosumers' most important attribute is their 'pro-activeness' inside the new energy system, which differs from passive consumers (who merely have to accept/adopt) to end-users which are responsive to DSM tariffs albeit relying more or lesser on the smart grids, towards the prosumer which is a knowledgeable, pro-active user, producer, trade partner in the new energy system.
Most studies lack a consistently used theoretical framework to study the (potential) roles of users. Most Applied theory is the social practice theory. Based on the social practice theory, the scholars often address the issue that users are not isolated 'atoms' but are tied do routinized behaviours which are not only depended on the household, but even on out-house institutionalized rules and norms (e.g. school/work time), and are therefore not easy to change.
Furthermore, based on the papers which focused upon user experiences (with a special attention to demand side management), it appeared that in most papers the issue of 'acceptance' of the smart grids widely discussed. It also appeared that few studies build on real life experiences based on smart grids projects, but most studies focus upon future scenarios and (online) surveys. The only two papers which build on real life experiences come to contradictory findings. Users' knowledge with regards to

smart grids (such as an abundance of feedback information) is both shown to enhance acceptance and to create confusion, and in some contexts people prefer demand load control (the ability of energy suppliers to control user consumption) while they reject it in others.
The literature review has also shown that the future roles of stakeholders are foremost mentioned in policy reports. The future roles of the stakeholders are only discussed in some policy reports with a special focus on the role of the distribution system operators. From these reports, it seems that uncertainties still exist with regards to market structures (natural monopoly versus competition), task delegation, necessity of new (data handling) institutions etc. In the Dutch context, the distribution system operators also have a leading role in the smart grids pilots (Table 9). However, again, there very little knowledge with regards to the exact roles of the stakeholders inside smart grids pilot projects, and as facilitators of the renewable based de-centralized energy transition(s).

Further research in CESEPS

Based on the available research, the uptake of the following subjects can be recommended. First of all, there is a large lack of ‘real’ assessment of users: assessing users in ‘real’ smart grids pilots can provide very valuable knowledge to understand the user-stakeholder embeddedness in smart grids pilot projects, and its contribution to the ongoing energy transitions. This will also provide more clarity regarding the users, beyond the typologies & assumptions in theory. Real result of DSM interventions is also a new area, in which not so many contributions have been made so far. However, it is very important to understand the user experiences with smart grids. Moreover, another topic which needs more attention is besides –what- the stakeholders will do, also –how- this manifests in the real-life examples of pilot projects. This is necessary to understand which stakeholders are key taking decisions and what the consequences of these decision are for users etc. Assessing the power relations, its consequences on among other user(s), design choices for smart grids etc. will also be valuable since this is also not analysed so far either.

PART IV: TECHNOLOGIES

4 TECHNOLOGIES[5]

4.1 Introduction

This chapter focuses on the main systems and technologies at the prosumer level. In Section 4.2 an overview is given of residential distributed energy resources, next in Section 4.3 energy storage in the form of batteries and hydrogen is discussed. Electric vehicles, DC grids and heat pumps are the topics of Sections 4.4, 4.5 and 4.6. Finally, this chapter also discusses thermostatic controlled loads (TCL) with thermal storages in Section 4.7 after which it is completed with conclusions. First though certain basic terms such as flexibility and controllability is explained in this introduction.
The term flexibility can be described along to the definition from Eurelectric:

"On an individual level, flexibility is the modification of generation injection and/or consumption patterns in reaction to an external signal (price signal or activation) in order to provide a service within the energy system. The parameters used to characterize flexibility in electricity include: the amount of power, modulation, the duration, the rate of change, the response time, the location etc."

This definition stresses mainly two aspects:

- Controllability, and
- Characteristics.

Due to the transformation of consumers toward prosumers, flexibility in terms of energy and/or power could be sourced from a range of systems available. In general, the aspect "controllability" of flexibility can be categorized according to Figure 11**Error! Reference source not found.** *(CCMC, 2014)*).

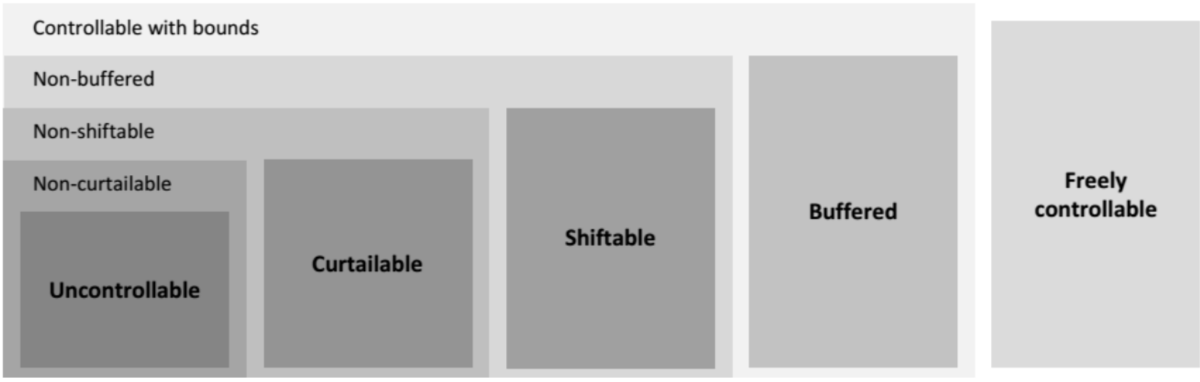


Figure 11. Categorization of flexibility sources in terms of controllability (CCMC, 2014)

Whilst in the past energy resources at customer level was mainly uncontrollable, new technologies enable different extents to which energy resources can be controlled. This scheme can be applied e.g. on customer loads. Figure 12 provides a more detailed overview of the controllability of flexibility at prosumer level and how it can be categorized. The focus of this figure is on differ types of loads in terms of flexibility. Depending on the specific load, curtail ability, shift ability and storability can be distinguished. Additionally, uncontrollable Systems are also part of the whole system.
Besides this schematic and general characterizations of resources, metrics can be introduced to specify a certain resource with respect to its capability, or "characteristics". In *(Lund et al., 2015)* different approaches for defining flexibility in terms of characteristics are discussed where the three main aspects identified are:

- Ramp magnitude,
- Ramp frequency,
- Response time.

[5] A significant part of this chapter has been written by Stefan Uebermasser, Felix Lehfuss and Carla Robledo

Additionally, for DR resources the following more detailed characteristics are also important for modelling the resource:

- Ramp up / down,
- Max power / min power / discrete / continuous,
- Energy / Capacity / duration,
- Recovery / rebound,
- Availability.

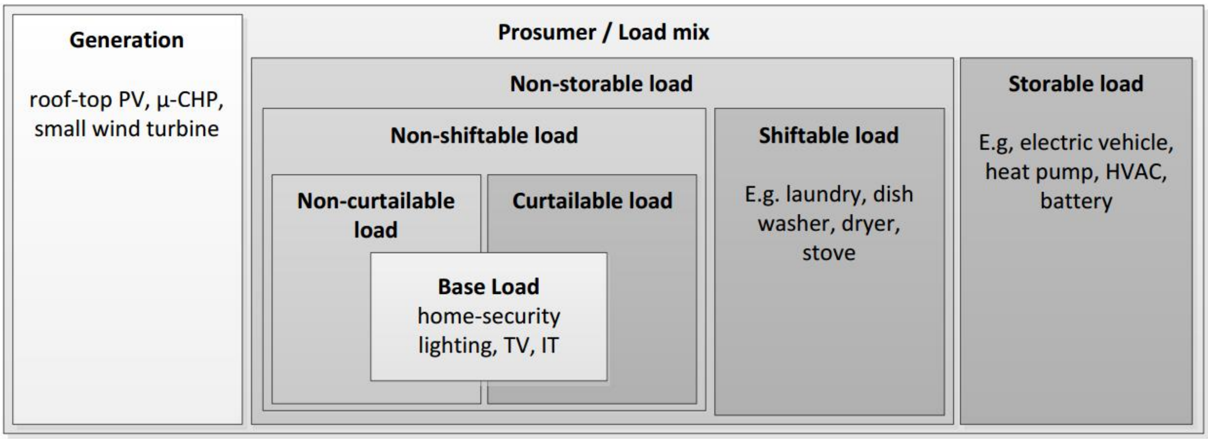


Figure 12. Prosumer - Generation and load in terms of controllability (He et al., 2013)

While generators and large resources can be described by the first characteristics, smaller responsible demand resources might need to be characterized using more details. In the case of aggregation of resources, restricting criteria (e.g., max power, duration) can be overcome due the statistically varied properties of the pooled resources. The following chapters provide a description of the main prosumer systems along to these categories.

4.2 Overview of residential distributed energy resources[6]

Residential distributed energy resources provide electricity to households and can be divided in photovoltaic (PV) systems, urban wind turbines and micro-CHP. Below PV systems are discussed in the context of flexibility and availability.

1.1.1 Photovoltaic Systems (PV)

Technical capabilities of providing flexibility

Photovoltaic Systems (PV), since they are generators, are not a classical DR resource in the sense of controllable load. But since they can be also controlled in a sense of varying their output of active and reactive power, they can be incorporated as a distributed renewable energy resource (DRES) on the demand side.

Control capabilities include

- the possibility to reduce the active power output;
- the possibility to increase active power output to the maximum available from the primary energy source (solar irradiation) if the system has been curtailed before;
- the variation of the output of reactive power (e.g., ancillary services like reactive power provisioning or voltage control). Typically grid codes give the range of operation, where the operation point may or may not impact the active power output.

In combination with a HEMS system generated power could be charged into battery, used for shift able load (e.g. heating) or in-feed into the system, since changing the total net power used from the electricity network.

[6] The content of this chapter refers directly to IEA-DSM Task 17 about Roles and potentials of Flexible Consumers and Prosumers *Stifter M., R. Kamphuis, M. Galus, et al. IEA DSM Task 17: Roles and Potentials of Flexible Consumers and Prosumers. IEA DSM 2016.*.

Availability

Figure 13 gives the production of a domestic PV-system over a year at the specific location of Vienna, Austria. It can be seen, that there are significant variations over the seasons in a year, over the hours in a day. Only during approximately half of the operational time power is generated. The generation duration curve for the data is shown in Figure 14.

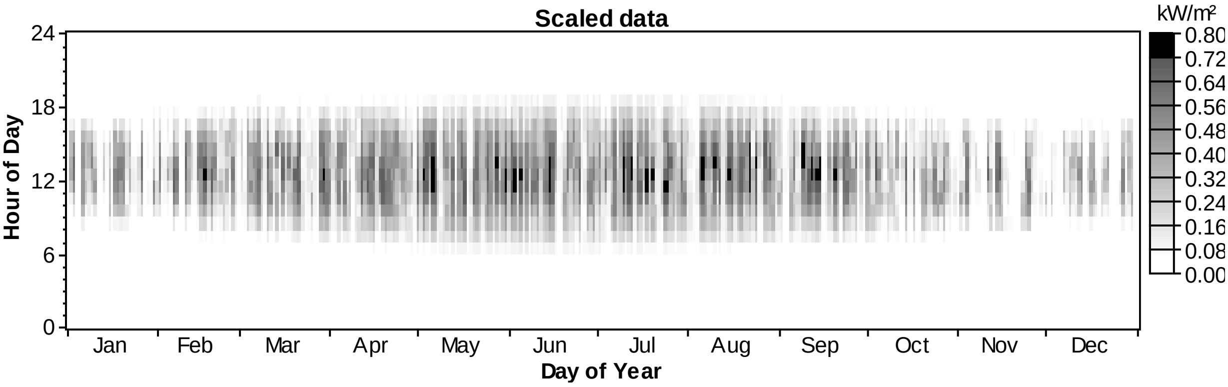


Figure 13. Generation of a 1 kW PV-system over a year

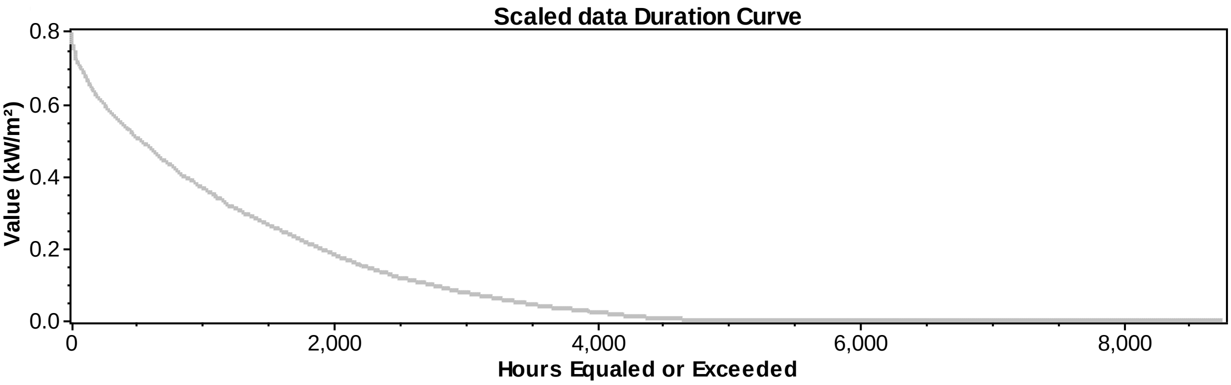


Figure 14. Generation duration curve of 1 kW PV-system over a year

1.1.2 Energy Storage Systems

The main challenge that faces the power sector, in sustainable future energy networks that no longer depend on fossil resources, is fulfilling the necessity of safety and flexibility. Fossil fuels, in all states of matter, have the advantage of having high energy density, allowing them to be efficiently transported over long distances. This gives them the versatility to be used when and where they are needed. Clean and efficient energy storage systems will be key in future energy systems that will be based on renewable intermittent power generation.

1.1.2.1 Battery Electric Storage Systems

Apart from DR, the EU-commission *(EC, 2015)* states that self-generation and self-consumption are the cornerstones to aid and supplement the existing electricity infrastructure. Electric Energy Storage or Battery Energy Storage Systems (BESS) can be counted as a flexible or storable load. Depending on the operational strategy of the storage system BESS can fulfil various DR services. Because the energy is not consumed but stored, flexibility of storage systems is very high with respect to their operational limits (e.g. maximum charging/discharging power, capacity).

Typical home energy storage systems operate 'locally' to store on-site or self-generated electricity from PV or other sources. A typical strategy is to store surplus generation and use it later to supply the local demand, to increase the self-coverage or direct-use of the PV system. Discrimination has to be made between consumer owned storage and district storage.

Availability

Typically, BESS are well available for providing flexibility. However, it must be considered for which purpose the batteries have been installed at the first place. If the BESS have been installed in order to increase self-consumption, the availability for other flexibility purposes like control reserves is limited to some extent. Intelligent algorithms can harvest the flexibility left besides the main use case of self-consumption. Aggregators have already taken advantage of it in several European countries like Germany or Switzerland. Furthermore, different requirements arise when trying to use BESS for self-consumption and network services, such as resolving congestions. In such cases, the availability of BESS appears to be almost not existent unless an emergency option is implemented so that the network operator can take advantage of the BESS at all times.

SmartStorage

Within Enexis *(de Groot et al., 2013)* and Stedin *(Stedin, 2016)* in the Netherlands two pilots have been conducted and one is to be implemented in 2017. A SmartStorage unit pilot close to a transformer station has been setup by Enexis to gain experience in using district storage to support DSO activities. In Hoogdalem, Stedin has rolled out a test with consumer electricity storage. Version 2.0 of Jouw Energie Moment is to be implemented in 2017 in the neighbourhood Meulenspie in Breda *(ENEXIS, 2016)*. The pilots consist of 35 Tesla Powerwalls as battery storage system, heat pumps, solar PV panels, and an innovative energy-computer, that manages the heat pump and battery given certain criteria. This could be when electricity is cheaper or to use it with locally produced energy. The prosumers can choose, based on electricity prices, when to set their load-shifting appliances.

Energy Storage vs. Demand Response

BESS are anticipated as complementary to the need for demand flexibility, since they can be used to help balance, store or mitigate the energy system. There are differences between storage systems and demand response, which one is clearly the capital costs for BESS.

In Figure 15 a simplified input and output flows of power to a) a battery system and b) demand response resource is shown. A battery has the basic operation mode of charging and discharging, where a DR resource has only the ability to use or not use energy, while some have the ability to offer continuous or discrete levels of energy use in-between. One major difference is, that the DR resource's 'discharges' is dependent on the user behaviour's demand. Since this is a stochastic behaviour (which can somehow be described statistically) the energy level or state of charge (SOC) is usually not known. Other differences between these two technologies are shown in **Error! Reference source not found.**

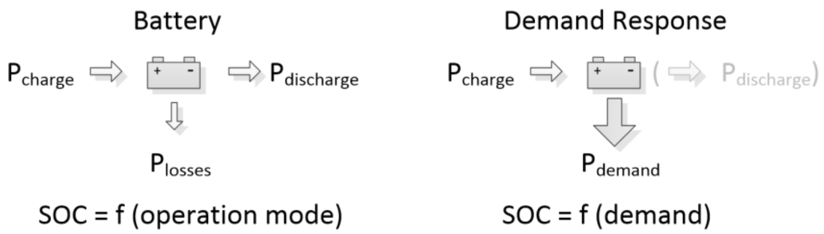


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Figure 15. Power input and output of a) Battery Storage System and b) Demand Response Resource

Table 10. Battery operation vs. demand response requirements

Category	Battery	Demand Response
Operation	charging / off / discharging	(forced) charging / off
Self-discharging	(small) losses	losses = customer demand
SOC range	determined by previous operation	usually unknown available capacity
Rated power	charging = discharging	usually withdraw > charging
Storage time	short to long term	(short term) "shifting"
Availability	dispatch-able	external factors (demand, T, …)
Purpose	dedicated system	part of demand side (load)
Control	energy management system	simple control (e.g., thermostat)

Objective	storage of electric energy	shifting of energy
Scale Levels	small to large / utility scale	settlement, building, households Large scale = industrial services
Capital costs	High	Low (with ICT in place)

1.1.2.2 Hydrogen Storage System

Hydrogen (H_2) is a high-quality energy carrier that can provide the flexibility needed by the power sector. The hydrogen economy comprises all the processes that involve the production, delivery, storage, conversion, and applications of hydrogen, which are at different stages of technological advancement *(Niaz et al., 2015)*. The use of hydrogen as fuel in transportation has been considered the main disruptive field of application in the hydrogen economy, but it has also great potential to provide energy to all sectors, including residential and industrial areas. For example, it can be used to store renewable energy at utility scale, in stationary fuel cell systems for buildings, back-up power, or distributed generation or even blending it into existing natural gas pipelines to increase the output of renewable energy systems (for example by avoiding curtailment of renewable energy and using surplus energy to produce hydrogen). The latter technology, known as Power-to-Gas (P2G) is not new, but lately, it has received a lot of attention by electricity and natural gas companies, given the rapid growth in installed wind power capacity and interest in the near-term market readiness of fuel cell electric vehicles (FCEVs) *(Melaina et al., 2013)*.
Hydrogen is the most abundant element in the universe, but it is usually found in the earth bounded to other elements, like oxygen and carbon and not in its molecular form, H_2. In order to obtain its molecular form, it is needed to invest energy in producing it, which is why it is an energy carrier and not a source of energy. It can be produced by reformation of fossil resources such as natural gas, oil and coal, as well as renewable resources, like biomass, and also by water splitting using electricity *(Nikolaidis and Poullikkas, 2017)*. Depending on the source of energy that is used to produce hydrogen, if renewable or not, a lower or higher carbon footprint on the carrier will be obtained, respectively. Currently, hydrogen is being produced on large scale and based on mature technologies in industry, since it is used as feedstock within the refining and chemical industries to convert raw materials into chemical or refinery products. Even though in the short and medium term, production from fossil fuels will continue to be dominant for economic and technological reasons, it is expected that in the long term, hydrogen will be obtained from renewable energies *(Moliner et al., 2016)*.
Electricity generation using hydrogen can be fulfilled by means of fuel cell technology. Fuel cells are energy conversion devices that convert the chemical energy of a reaction directly in electrical energy. The basic physical structure or building block of a fuel cell consists of an electrolyte layer in contact with a porous anode and cathode on either side *(EG&G, 2000)*. The electrochemical reaction takes place at the electrodes that are fed with gaseous fuels continuously producing an external electrical current. Fuel cells are classified based on the electrolyte and fuels used. Listed below, are five main fuel cell technologies commercially available:

- Polymer Electrolyte Fuel Cell (PEMFC),
- Alkaline Fuel Cell (AFC),
- Phosphoric Acid Fuel Cell (PAFC),
- Molten Carbonate Fuel Cell (MCFC),
- Solid Oxide Fuel Cell (SOFC).

Table 11 displays the main characteristics of these technologies.

Table 11: Fuel cells classifications. Sources: (Lucia, 2014)

Characteristics	Polymer electrolyte	Alkaline	Phosphoric Acid	Molten carbonate	Solid oxide
Fuel cells operating temperature [ºC]	40-80	65-220	205	650	600-1000

Electrolyte	Hydrated polymeric ion exchange membrane	Mobilized or immobilized potassium hydroxide in asbestos matrix	Immobilized liquid phosphoric acid in SiC	Immobilized liquid molten carbonate in $LiAlO_2$	Perovskites (ceramics)
Electrodes	Carbon	Platinum	Carbon	Nickel and nickel oxide	Perovskite and perovskite/metal cermet
Catalyst	Platinum	Platinum	Platinum	Electrode material	Electrode material
Interconnect	Carbon or metal	Metal	Graphite	Stainless steel or nickel	Nickel, ceramic or steel
Charge carrier	H^+	OH^-	H^+	CO_3^+	O^-

Based on their properties, there are some fuel cells better suited for certain applications than others. PEMFC are commonly used for portable or vehicle power supply, as well as for residential micro combined heat and power (CHP). Instead, MCFC and SOFC are best suited for stationary power, given that they operate at high temperature *(Choudhury et al., 2013)*.

It is not the intention of this study to review the different hydrogen production methods as well as storage, distribution and use of hydrogen, as there are numerous publications that do so *(Niaz et al., 2015, Nikolaidis and Poullikkas, 2017, Wu et al., 2016, Zhang et al., 2016)*. Instead we want to highlight the role of hydrogen and fuel cell electric vehicles in future smart grids.

Role of hydrogen in future smart grids

By employing fuel cell technology, hydrogen can be used with high efficiency and zero or near-zero emissions at the point of use *(Gupta, 2009)*. In particular, PEMFCs combine hydrogen and oxygen from the air to produce DC power, water and heat *(EG&G, 2000)*. With all mentioned before, it can be stated that hydrogen technologies have the potential to link different energy systems, such as power and heat supply, energy storage and transportation. A schematic representation of today's energy system and a potential low-carbon energy system of the future, as envisioned by the IEA is presented in Figure 16Figure 16.

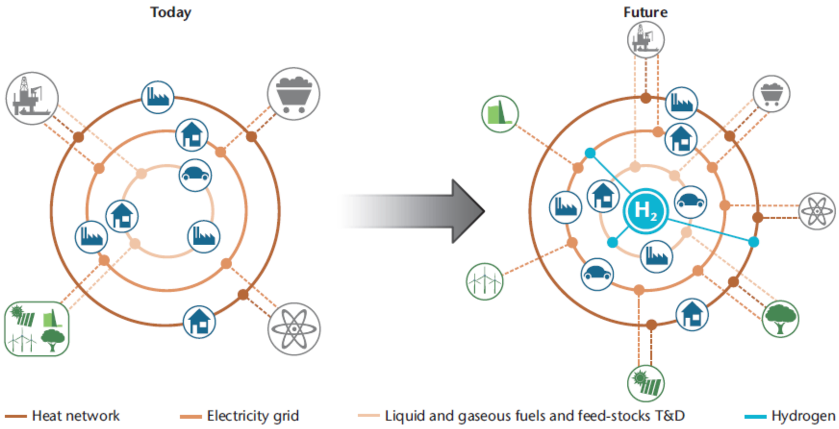


Figure 16: Energy system today and in the future. Source: IEA (2016)

One of the main features that can be observed in Figure 16, is that at present, the heat and electricity network run parallel to each other with very few interaction among each other, but in the future, this could change by introducing hydrogen as the energy vector that connects different layers of infrastructure. In future energy networks, the transportation system will be closely integrated, as it will also act as the utility-scale energy storage system to enable the distribution of dispatchable energy. Both battery electric vehicles and hydrogen fuel cell electric vehicles can interact and complement each other to provide a fully reliable energy storage system.

Zhang et al. have examined the roles of fuel/electrolysis cells from a technology perspective in the development of future smart energy networks and the transition towards the hydrogen economy *(Zhang et al., 2015)*. They conclude that the solution for future energy systems could be the integration of electrical grid, fuel grid (hydrogen grid) and thermal grid. In this way, the smart energy networks must possess the ability to dispatch energy via different grids. The fuel cells create the energy flows from hydrogen to power and heat, while the electrolysis technologies are used to enable the energy flows from electrical power or heat to hydrogen. They also state that the development of power-to-gas technology is significant in the construction of the hydrogen infrastructure, which itself is currently presenting a challenge to the deployment of fuel cell electric vehicles.

Hydrogen can be used for multiple purposes, such as in small amounts on-board FCEVs to enable long-distance and free carbon emissions driving or it can be stored in large quantities over long periods of times to provide inter-seasonal storage of energy. This could facilitate the integration of high shares of renewable energy into the energy system for power and heat, that would otherwise be curtailed in times when supply is greater than demand *(EC, 2010)*. It could also provide the opportunity to connect the world in a whole energy system, by producing hydrogen at regions with high levels of wind and sun radiation and shipping it by boats, or transporting it by trains and trucks to the final destination for use.

1.1.3 Battery Electric Vehicles

Technical capabilities of providing flexibility

Energy demand for battery electric vehicles[7] (BEV or EV) is dependent on the range and driving behaviour of the users. The charging process can be controlled using various mechanisms, from simple on/off controls to continuously adjustable set points of the charging power *(Galus et al., 2013)*. Mostly, such charging algorithms aim at relieving network stress and avoiding congestions or the need for grid expansion. Currently available EVs provide options for controlled charging on the basis of the standard IEC 61851 *(IEC, 2003)*. Even if IEC 61851 was not intended or designed for fulfilling smart charging or demand response applications, it provides a significant degree of freedom in controlling the charging activities of EVs. As a follow-up to IEC 61851 the standard ISO 15118 *(ISO, 2015)* or OCPP *(OCPP, 2016)* are some of the options which will provide extended smart charging capabilities in the near future.

Currently available EVs show specific differences in their charging behaviour and their impact to the local power grid. Deviations exist in respect to maximum and minimum of accepted charging power, usage of phases and time delays. All investigated cars showed also a distinct deviation of the power set point and the power which was actually consumed by the car. This fact has a direct impact to DR applications and is caused by the on-board charge controller of the individual car. The figures below (Figure 17) show characteristic behaviour of the initial phase of a charging process and a step-down procedure. In general, the characteristics of charging EVs can be described as averaged values as shown like in Table 12 (the values do not apply for fast charging capabilities).

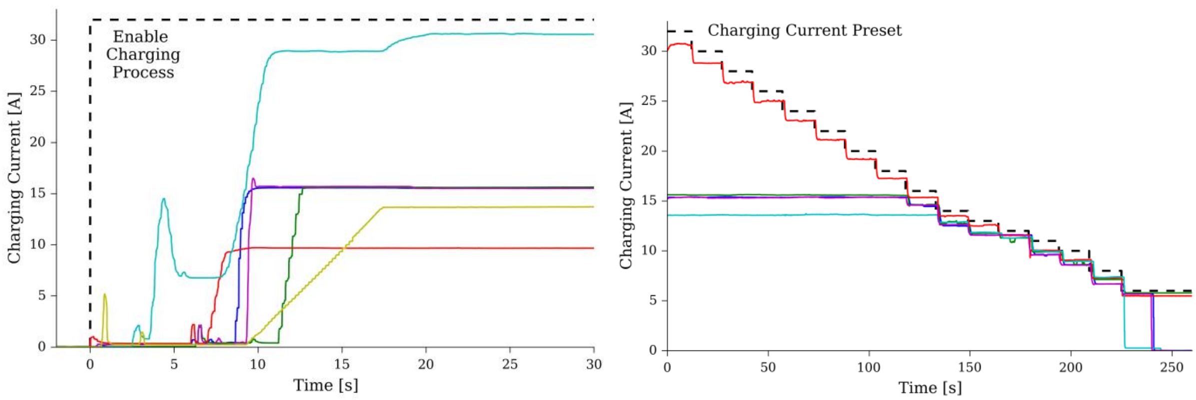


Figure 17. Behaviour of different cars charge controllers a) during the initialization of a charging process and b) when decreasing the charging current stepwise

Table 12. Example characteristics for charging EVs

[7] The term battery electric vehicle (or electric vehicle) used for this report, means an automobile which drive-train is an electrical motor (one or more), using electrical energy stored in rechargeable batteries.

Maximum charging current	16 A
Minimum charging current	6 A
Time delay for initialization of the charging	7 sec
Time delay for a positive change of the charging current	2 sec
Time delay for a negative change of the charging current	1 sec

The impact of EV charging on the electricity grid depends on the number of cars at a certain location, the available charging power at the spot and the total energy demand needed to charge the batteries. Different studies show that charging when arriving at home (end-of-day) has less impact on networks than a controlled charging scheme which incentivizes charging to a fixed moment in time, e.g. 22h because of a transmitted signal of low prices. However, in general, any uncontrolled charging leads to large disadvantages in the power system such as increase of peak load or network overloads *(Silva et al., 2011)*. In general, pilot project show that technical capabilities are already applicable to EV in order to take advantage of this flexibility sources. Even simple ripple control technology or charging schemes based on local voltage measurements can be applied. Since EVs are basically BESS which change locations, the capabilities of providing different flexibility measures are very good.

Vehicle-to-Grid (V2G)

The charging direction can be in principle reversed as to feed energy back into the network when needed. For such a use case the technical capability is also already apparent, similar to the case of BESS. However, there are concerns mostly about battery lifetime degradation. Hence, the capabilities are currently limited by the battery management systems. The degradation costs are opposed to revenues for providing services like peak power or balancing reserves. In the Netherlands in Utrecht, the Lomboxnet *(LomboXnet, 2016)* pilot was started by Stedin for a V2G power application, which is part of a regional electrical energy system also including local charging of PV-systems. Other investigations show a substantial potential to provide local or even system wide reserves for balancing purposes, e.g. for renewable energy sources infeed *(Galus and Andersson, 2012)*.

Availability

Figure 18 shows fleet charging profiles for different penetration levels (of approximately 6000 cars) when individual EVs have the opportunity to charge also at locations away from home, e.g. workplace. In general, one can see, that the availability of EVs is high. Especially during night time when EV users arrive from work, there is a large demand for energy, which could be basically shifted to later times. In the figure, the needed charging power decreases as more and more EVs are fully recharged in the night hours. However, the vehicles typically stay connected during the night, resulting in a large, aggregated resource that could be used when recharged based on a different scheme *(Galus, 2012)*. The spread within the shown profile accounts for different summer and winter demands. The spikes in charging are due to the higher charging level of 43 kW *(Stifter and Ubermasser, 2013, Ubermasser and Stifter, 2013)*. An intelligent control scheme could be used to ensure that energy demands for individual travels are met while enough space is left in the individual batteries to perform balancing services scheduled by an aggregator. In summary, vehicles are parked more than 90 % of the time, making the resource highly available for flexibility usage.

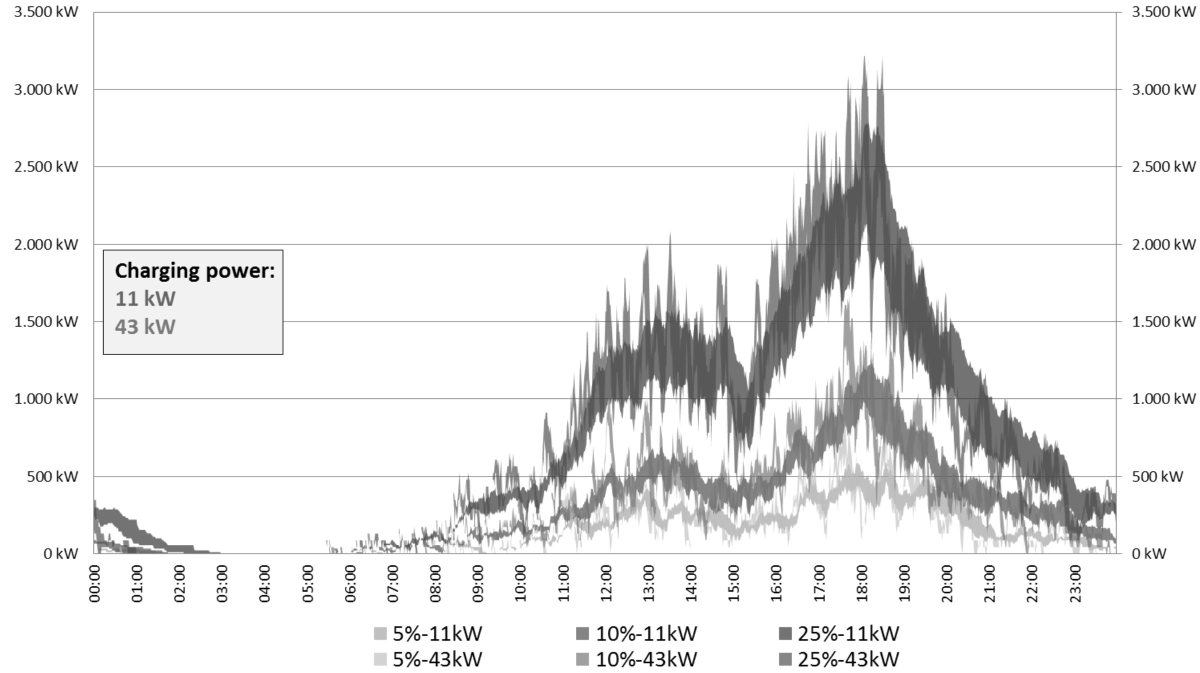


Figure 18. Impact of different charging powers for approx. 6000 cars forr summer and winter and opportunity charging (Ubermasser and Stifter, 2013)

1.1.4 Fuel cell electric vehicles

Fuel cell electric vehicles[8] (FCEVs) are today a reality thanks to years of research and development, and commitment of governments and car manufacturers to provide clean alternatives in the transportation sector. Relevant drops in cost of PEM fuel cells in the last years have been mainly due to the individual advances in key areas, such as the development of durable membrane electrode assemblies with low platinum group metal content *(Debe, 2012)*. A census of over-the-road vehicles from the DOE revealed that there are currently 2227 active hydrogen FCEVs over the world and 932 planned vehicles for 2020. 84 % of the fleet are passenger vehicles, 5 % are scooters, 5 % buses and the rest 6 % are light commercial vehicles and other types. The main problem hindering the wide implementation of FCEVs is the limiting hydrogen infrastructure today available. Since the number of actual FCEVs is relatively small compared to other types of vehicles, the business case for hydrogen refuelling stations is negative at the moment. As a consequence, infrastructure companies are hesitant to invest in hydrogen refuelling stations. Nonetheless, there are numerous initiatives being carried out to promote the use of FCEVs, mainly in USA, Europe and Japan *(Wind, 2016)*.
The main companies commercializing fuel cell electric vehicles are Hyundai, Honda, Toyota and Mercedes Benz. Even though there are numerous concept cars by other companies, in Table 13 the cars that are in series production and available for customers are briefly summarized. The new trend in passenger vehicles is to combine PEMFC stacks with high power batteries (to store regenerative braking energy and assist the FCEV in times of acceleration) and to store hydrogen compressed at 700 bar in carbon-fibre reinforced tanks.
Since these cars have a similar driving performance in terms of refuelling time and driving range to conventional cars, they can provide the same mobility service but at lower carbon emission levels. Furthermore, they have powerful fuel cells on board that could act as power generators when parked. In such a way, FCEVs could provide vehicle-to-grid services as it will be discussed in the next section.

Table 13: Characteristics of selected FCEVs available for customers in 2017.Sources: Self assembled with information from car manufacturers websites.

[8] The term FCEV used for this report, means an automobile which drive-train is an electrical motor (one or more), using a hydrogen fuel tank to store energy and a, onboard fuel cell for generating electricity.

FCEV	Driving Range [Km]	Recharging Time [min]	FC Power [kW]	Battery	Year Available	Cost to buy/lease in 2016-17
Hyundai ix35 Fuel Cell / Hyundai Tucson Fuel Cell*	594	3	100	Li-Polymer 0.95 kWh	2012	Europe: €66978.23 Lease USA $499 p/month, Initial payment $2999
Toyota Mirai	500	5	114	NiMH 1.6 kWh	2015	$57500 Lease USA $349 p/month, Initial payment $2499
Honda Clarity Fuel Cell	589	5	103	Li-ion kWh unknown	2016	7,660,000 yen ($68273) Lease USA $369 p/month, Initial payment $2868
Mercedes Benz GLC F-Cell	500	3	No information available	Li-ion 9 kWh	2017	Not yet announced

*Name in the US.

Demonstration FCEV-V2G at The Green Village in The Netherlands

The Green Village at TU Delft in The Netherlands has the vision to create a sustainable, lively and entrepreneurial environment where to discover, learn and show how to solve society's urgent challenges *(van Wijk, 2013)*. One of its projects is the Car as Power Plant (CaPP), which is focused on using hydrogen fuel cell cars for electricity, heat and water production, besides providing the typical use of mobility. Cars are being used only 5 % of the time for transportation. So, when parked, the fuel cell in the car can produced electricity from hydrogen in a cleaner and more efficient way than the current electricity system – with useful 'waste' products, like heat and water. The produced electricity, heat and water can be fed into the respective grids or be used directly in our houses or offices *(van Wijk and Verhoef, 2014)*. The component lines of the projects are mainly three: FCEVs to provide vehicle-to-grid services, hydrogen production from renewable energies like solar or wind, and smart grids system integration, providing connection between residential houses and FCEVs.

Through the CaPP project, a Hyundai ix3 FCEV has been adapted with an external plug-out able to deliver up to 10 kW and has been connected for the first time to the Dutch national grid. Current experiments are being carried out to evaluate the operation of such V2G connection, as well as simulations on the system to evaluate sizing of the different components and the possibilities of the services such connection could provide. For example, Fernandes et al. reported on the hydrogen production in CaPP and performed thermodynamics calculations showing the achievable efficiencies when FCEVs are used as power plants *(Fernandes et al., 2016)*. They concluded that solid oxide fuel cells operating as reformer (SOFCR) significantly reduces the exergy destruction, resulting in an improvement of efficiency over 20 % compared to catalytic reformer-based systems and that approximately 60 % trigeneration exergy efficiency is achieved in SOFCR-based systems.

1.1.5 Heat pumps

Technical capabilities of providing flexibility

Heat pump[9] (HP) operation can be shifted to times where electricity surplus exists from e.g., renewable energy sources. Thermal energy can be buffered either by activating a thermal storage capacity, often offered by the masses of the house to be heated or by applying higher temperatures to the buffer storage for room heating and domestic water. The latter is inherently connected to potential reduction of the HP efficiency (due to higher operation temperatures) and increase in storage losses *(Günther et al., 2014)*. Heat pumps have a number of operational constraints. Modulating the power, i.e. operating the heat pump on partial load, leads to a lower energetic efficiency. Furthermore, wear increases if heat pumps have too many start/stop cycles.

[9] A heat pump uses a small amount of external electrical power to accomplish the work of transferring thermal energy from the heat source to the heat sink.

Constraints on flexibility are the available storage buffer size and the decreasing temperature due to longer operation times and inefficiency, backed up by direct electric heating. Higher temperature increases the load shifting potential *(Günther et al., 2014)*. A study *(Cooper et al., 2013)* shows that uneven operation of air source HPs because of DR participation reduces the efficiency or COP by about 5 % and increases the power consumed by 10 % to 25 % (Figure 19).
Manufacturers of HPs are starting to enable an external control signal. Two approaches exist: either to increase the set point of the temperature, or to start heating prior to reaching the lower temperature set point of the storage buffer or the temperature buffer of the house itself. A so called 'SmartGrid Ready' product can be found from, amongst others, Ochsner *(OCHSNER, 2016)* and IVT *(IVT, 2016)*.

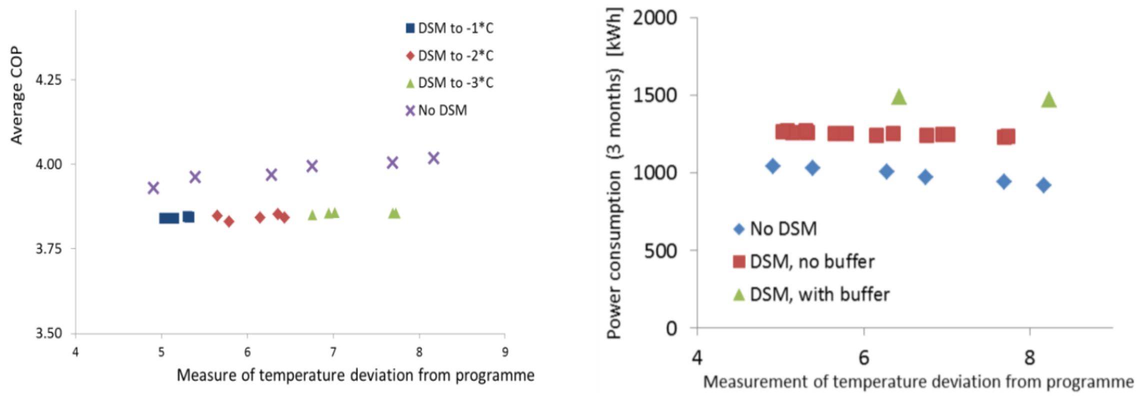


Figure 19. Air Source HP a) performance and b) power consumption (Cooper et al., 2013)

Availability

For utilizing a HP as a flexible load the operation times have to be considered. Typically, in the winter seasons the heat pump is used for heating and alternatively for warm water, where in the summer season only warm water is produced. Hence, the availability for demand side management is substantially decreased in summer time. Figure 20 shows the operation intervals for a typical sole-water HP over one year for every 15 minutes of the day. For system efficiency, it would be optimal for the HP to run over the entire heating period. For reserve reasons and also at low temperatures where the additional direct electric heating is activated, it is not always in operation and therefore not always available as a DR resource. However, the activation time can be shifted to some extent, i.e. minutes, which offers some flexibility that can be harvested.

The Netherlands: PowerMatchingCity

Figure 21Figure 21 is from the buffer optimization in the Hoogkerk living lab case *(PowerMatchingCity, 2016)* at residential customers using the B-Box strategy. Via a stepwise combinatorial approach filling, the central heating system the heat-buffering strategy is calculated within the required comfort constraints of the users. On the X-axis the time of day (0-24) is shown.

The cost gain depends on the price pattern (red). For typical price patterns in the Netherlands the cost benefit is about one third from prefilling the buffers. Pilot projects like *Couperus* and *PowerMatchingCity* have significant amounts of heat pumps controlled by PowerMatcher *(Kok et al., 2012)* for use cases pertaining to DSO and BRP operation. In the pilot *Your Energy Moment* (Enexis), heat pumps are utilized to gain experience with consumer behaviour within a dynamic tariff setting.

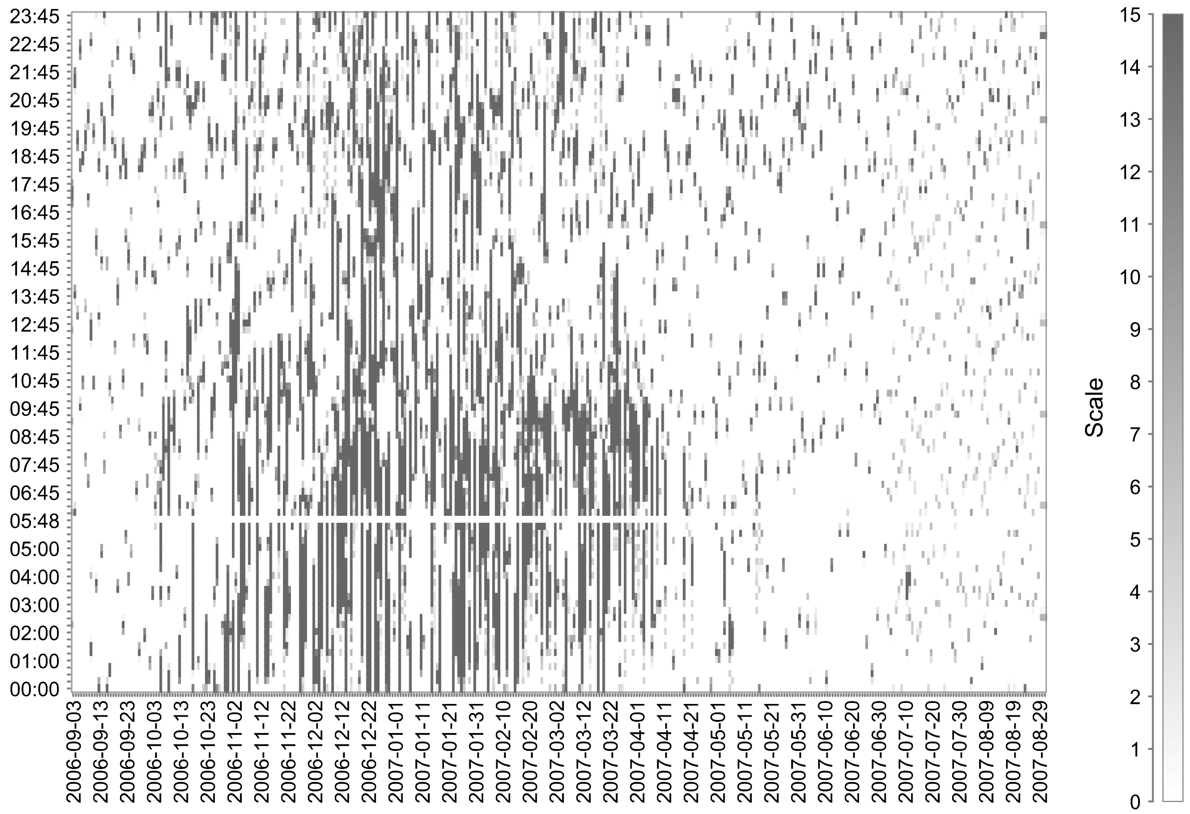


Figure 20. Duration heat map for a typical sole-water HP for heating and warm water. It shows how long the HP has been on for the interval, where the color of one interval indicates the utilization within the interval (Zottl and Huber, 2009).

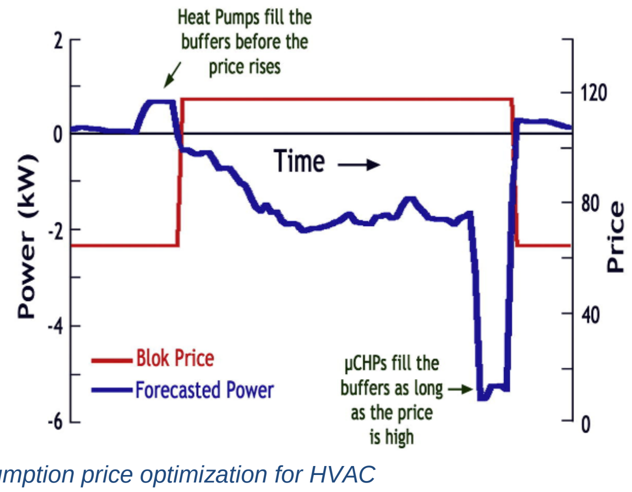


Figure 21. Electricity consumption price optimization for HVAC using heat buffers and forecasted power (Hoogkerk, 2012)

U.S.A.: gridSMART Project

The US demonstrated the flexible operation of HVAC equipment in approximately 200 homes using a distributed control approach with the AEP Ohio gridSMART® project *(AEP-OHIO, 2014)*. The project implemented a double-auction, real-time market that accepted bids and cleared supply and demand every 5 minutes. The supply was a function of the nodal locational marginal price (LMP) from the regional wholesale market so the equipment responded to energy and flow constraints from the bulk power system. They also responded to local distribution feeder constraints that could be imposed by temporarily setting the feeder capacity limit so that it was below the actual power flow on the feeder. The households were able to individually set their comfort sensitivity to price with a smart thermostat. The greater the comfort, the smaller the temperature dead-band about the desired setting. The greater the economy, the larger the temperature dead-band. A software agent in the thermostat bid into the

market based on these household preferences. The occupants were also able to override or change the settings at any time.
Figure 22 shows the operations display for the system. The top chart indicates the power flow on the feeder over time. The second chart indicates the state of the population of HVAC units in each market cycle over time. The third chart shows the market clearing price. And the last chart depicts the observed temperature averaged over all of the participating households.

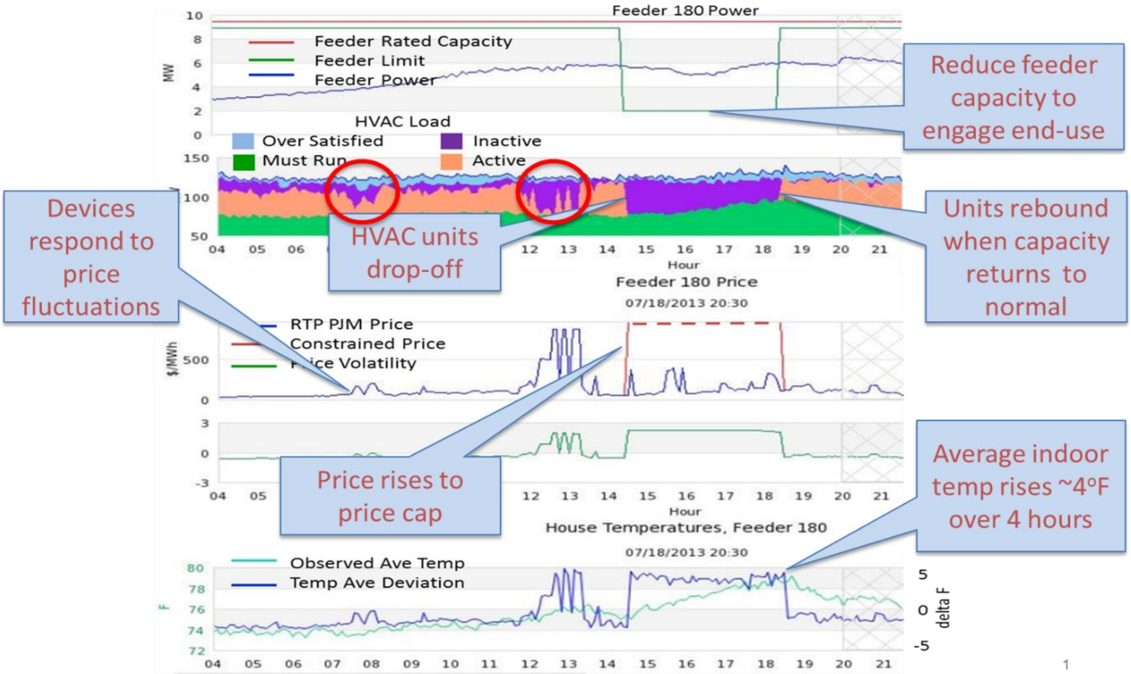


Figure 22. Operations dashboard for AEP Ohio gridSMART demonstration project

The project successfully demonstrated how independent decision-making can work to satisfy regional and local objectives without direct control. For example, as market prices rise, some HVAC units did not run. As market prices rose to the price cap, all bidding equipment stopped running. Operational behaviour such as a deterioration in the amount of HVAC load to drop out over time were also witnessed as was a small amount of household fatigue based upon a rise in thermostat overrides if the duration of a feeder capacity event was too long.

1.1.6 Thermostatic controlled loads with thermal storages

Thermostatic controlled loads (TCL) are usually operated between an upper and lower thermal limit by sensing the actual temperature by sensor. Such loads typically include boilers, for domestic hot water (DHW) or large cooling plants like refrigerated warehouses. If the limits are exceeded the thermostat controller starts or stops the cooling or heating process. The activation time can be in the rage of seconds to several minutes, depending on the characteristic of the load.

1.1.6.1 White goods and appliances

Technical capabilities of providing flexibility

From the power view point, white goods like washing machines and dishwashers have to be considered, since their potential for automated DR is substantial especially on a short timescale during the water heating cycle. The impact of the DR action on the quality of the primary consuming process however provides a risk factor.

Availability

The availability of white goods and appliances is, like for many equipment types, largely dependent on the use case. AS long as automated schemes are used, the availability is very high, since white goods are used in almost every household or larger living community, i.e. shared facilities. However, the flexibility can only be used when the white goods are used, i.e. when they are switched on. This poses some challenges in taking advantage of the flexibility of these sources.

Driven by requirements on proper operation of the washing program and optimal use of detergents manufacturers do not allow interruptions. Only the whole washing program can be shifted *(Cheng et al., 2014)*.
Figure 23 gives an example of the typical power consumption of a washing process.

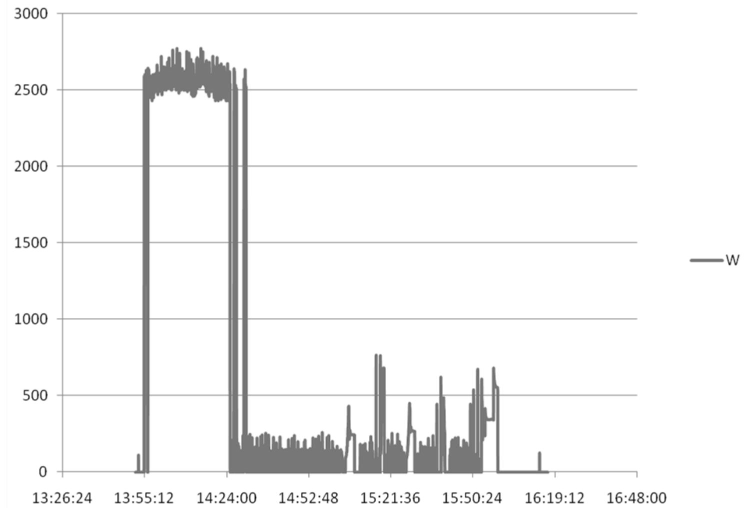


Figure 23. Typical power consumption profile of a washing machine (active power in Watt)

We can assume 2 to 2.5 kW during 30 minutes is the major DR-potential. From an energy perspective, studies showed that potential exists particular in combination with interaction or changes in consumer behaviour, by shifting the start of the operation (e.g. washing machine or dishwasher) in times of low energy prices or avoiding curtailment of PV ("Washing with the sun").
The power and energy potential in domestic refrigerators is small also due to the recent reduction in consumption achieved by the manufacturers. A characteristic power consumption pattern is shown in Figure 24. A future use case could be providing rotating inertia to stabilize the frequency.

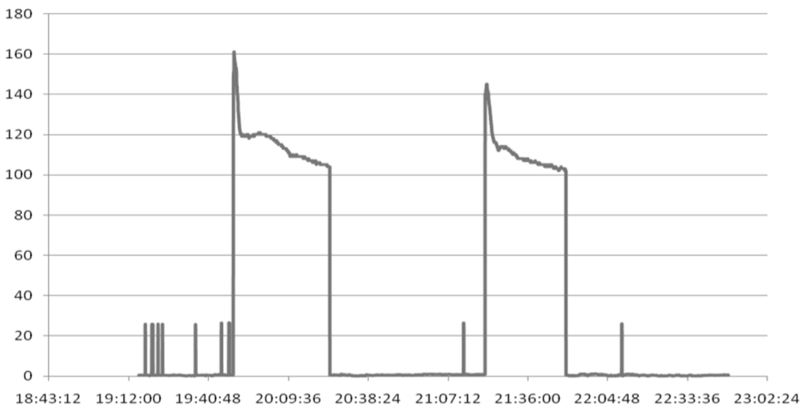


Figure 24. Domestic refrigerator electricity usage profile (active power in Watt)

1.1.6.2 Thermal storages
Storage decouples the process of provisioning and consuming the energy. The main objective is to serve the consumer's requirements for the various forms of energy (warm water, heating, cooling, driving range, etc.), which must include some reserve for managing higher than normal consumptions. Otherwise the consumer's experience would be negative and counteract DR participation.
Figure 25 shows the charging and discharging of a boiler thermal process with alternative increased upper bounds for the control operation area. Trade-offs to higher self-discharge in terms of decreasing degree of efficiency have to be evaluated against such a mechanism. The same principle can be applied to cooling or freezing processes, altering the lower operational limits.

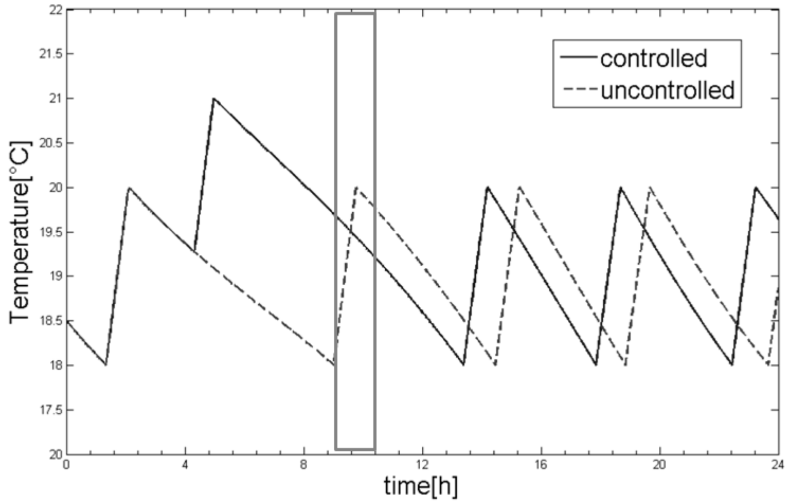


Figure 25. Building Management System shifting heating load by preheating a building. The load is shifted from the time interval marked with the green frame to 4h in the morning (Palensky et al., 2011)

Availability

In general, the availability of TCL with thermal storages is very good, similar to other types of local storages. The availability depends largely on the use case and the requirements. Ripple control, boilers and thermal storages can be used to reduced peak load in distribution networks or reduce demand based on electricity prices. Besides these well-known use cases, boilers can be used for provisioning of control reserves *(Galus et al., 2011)*. The availability decreased rather fast, when more than one use case should be implemented simultaneously.

Switzerland – Boiler for Demand Response

The objective of the project WARMup was to make an economic assessment of the versatility of thermal storage facilities. In the project the thermal inertia of boilers and buildings was used to take advantage of different prices for energy at different times of the day. The added value potential of optimal management of the thermal storage unit was determined by its flexibility being assessed on all the prevailing markets through optimal commercial transactions. All simulations were focused on an operation without limitations of use for the inhabitants.

For this purpose, an ex-ante simulation with the aggregated use of 5000 units and 22 flats with real market data was carried out. It simulated optimal use of the boiler and trading on the day ahead or intraday market and found a cost reduction and additional income of 40 CHF per flat (-5 %) compared to the base use profile for the boilers. All simulated capacity trades were offered at the ancillary service market and a trade was only counted as accepted if it would have been in the real world.

95 % of boilers in Switzerland are already ripple controlled, but remote control is not possible for individual units.

India – Thermal Storage in Hotels, Commercial Complex and IT Parks

A private utility in Mumbai (Tata Power) has successfully demonstrated use of thermal storage for peak shifting in hotels, commercial complex, IT parks etc. The consumers have installed this technology at their premises and are able to achieve savings in their electricity bill by taking advantage of ToD and peak shifting. All this was possible without compromising on the comfort of the guest/visitors/users. This utility was successful in enrolling thermal storage of about 15000 TR- Hours which would achieve shifting of more than 3.6 MU of electricity from peak to off peak.

With increasing economic growth, there would be significant increase in commercial complexes, IT Parks and Hotels in the country. There is a significant potential for DR using thermal storage in India.

1.2 Conclusions

In this chapter the overview of residential distributed energy resources provides information regarding the controllability and characteristics of the main distributed energy systems. Based on the individual technical parameters the eligibility of the system types can be evaluated for SEPS applications. Following the categories of controllability shown in Figure 11 at the beginning of this section, the energy resources described in this section can be assigned in the order shown in Table 14. Regarding the characteristic of resources, Table 15 provides a summary of exemplary values for individual systems.

Table 14. Resource assignment in terms of controllability

Controllability	Resource Type	Comment
Curtailable	PV System	Can be also controlled in a sense of varying their output of active and reactive power
Shift able	Heat pumps	Operation can be shifted to times where electricity surplus exists from e.g., renewable energy sources. Can be coupled with
	White goods and appliances	white goods like washing machines and dishwashers have potential for automated shift able activation
Buffered	Thermal storages	decouples the process of provisioning and consuming the energy within customer defined boundaries (temperature)
	Battery Electric Vehicles	The charging process can be controlled using various mechanisms, from simple on/off controls to continuously adjustable set points of the charging power
	FCEV	
Freely Controlla-ble	Battery electric storage sys-tem	energy is not consumed but stored, flexibility of storage systems is very high with respect to their operational limits (e.g. maximum charging/discharging power, capacity)
	Hydrogen storage system	

Table 15. Characteristics of resources

Resource Type	Demand side (example)	Supply side (ex-ample)	Availability	Reaction time	Duration
PV System	n.A.	3 – 10 kW	Depend on weather and time of the day	seconds	Depend on weather and time of the day
Heat pumps	4,5 kW	n.A.	Fully available till temperature crite-ria is met	seconds	Fully available till temperature crite-ria is met
White goods and appliances	3 kW	n.A.	Customer de-pendent	seconds	Process depend-ent (non-inter-ruptible)
Thermal stor-ages	4,5 kW	n.A.	Fully available till temperature crite-ria is met	seconds	Fully available till temperature crite-ria is met
Battery Electric Vehicles	11 kW	n.A.	Customer de-pendent	seconds	Limited by battery max. capacity and customer
FCEV					
Battery electric storage system	5 kW	5 kW	Fully available (limited by SOC)	seconds	Limited by battery max. capacity
Hydrogen stor-age system					

The availability and activation duration of all the investigated systems is somehow limited either by technical parameters or by the needs or influence of customers. In terms of power supply or demand, most systems range with typical power connection values of households (~4kW). Depending on system configurations, EVs or PV systems may excel this value significantly. The two summary tables show, that the investigated system at residential level provide different potential for flexibility applications. Whilst existing systems like PVs, heat pumps or appliances provide limited controllability, especially the introduction of stationary BESS enables full flexibility for local optimization or ancillary services.

PART V: SMART ENERGY PRODUCTS AND SERVICES

5 SMART ENERGY PRODUCTS AND SERVICES[10]

5.1 Introduction

At present, many smart grid technologies have reached a level of maturity which allows their implementation to real life applications, such as residential smart grid pilots. A smart grid however is more than a technical system. Namely the adaptation of end users to new smart energy technologies and the acceptance of new smart grid services and business models will create interesting challenges. One of the new scenarios or possibilities of smart grids is the development of new energy products and services. These smart grids related products and services will have to support end-users in their role as co-providers in the management of the electric power system *(Geelen, 2014)*.

Well-designed smart grid systems containing smart energy products and services could hence reduce the complexity of these new energy technologies and might increase the acceptance and understanding by end users.

In this chapter, we explore the existing literature on energy products and services in residential smart grids. Furthermore, we will analyse the available literature on design-driven approaches, with examples of the evaluation of smart energy products and services with these approaches. This chapter is structured as follows. Section 5.2 begins with presenting the existing definitions of smart energy product and services (SEPS). In section 5.3, the SEPS currently used in selected SG pilots which focus on end-users, will be illustrated. Section 5.4 continues with the literature on 'design-driven approach', as a valid method to support and promote the acceptance of SEPS by the end-users. Finally, examples of when and why design-driven approaches have been used to develop SEPS, will be presented.

5.2 What are smart energy products and services?

The rapid development of ICTs applied to home management, distributed energy production, storage and electric mobility, sets the basis for the creation of smart energy systems and smart grids. A smart energy system includes distributed energy production and storage technologies which enable demand response of appliances for the matching of supply and demand *(Geelen, 2014, Lund et al., 2012, Mathiesen et al., 2015)*. For the successful transition towards smart energy systems, the challenge consists in developing a sustainable energy system based on the cooperation between local energy utilities, co-providing end-users, and larger scale utility companies. In the transition to a smart energy system, household energy management concerns more than efficient use of energy, choosing the energy provider and paying the energy bill. It also leads to combining energy needs for electricity, heating, and transportation in new ways. When end-users shift to a role of co-provider (also referred to as prosumer in Chapter 3), also demand response and production of electricity will be combined *(Rathnayaka et al., 2014, Rathnayaka et al., 2011, Wolsink, 2012)*. As mentioned in Chapter 1, in a smart energy system, household energy management by the co-producers would then involve the following four aspects: *(Geelen et al., 2013a, Watson, 2004)*.

1. Efficient use of electricity;
2. Planning or shifting energy consumption to moments that are favourable to the energy system (e.g. use of sustainable energy when available);
3. Storage, and energy production at times which are convenient to the local grid;
4. Trading self-produced electricity that is surplus to household management.

In order to implement the four aspects of co-provision above-mentioned, several smart energy products and services for the residential end users have been developed and tested in pilot projects. However, at the moment, limited knowledge exists regarding to what extent a co-provider role has been facilitated in smart grids deployment. In Chapter 4, different smart grid technologies have been presented. In the CESEPS project, it is important to clarify the difference between a technology and a product to avoid confusion and to define a framework of common understanding.

Products

The term product can have many different definitions, depending on the field of use. A product can be seen from a technical perspective according to the definition by Souchkov: *a product is a technical system composed of a number of components that deliver specific functionality. A technology is a pro-*

[10] A significant part of this chapter has been written by Moreno de Respinis, Uche Obinna and Angèle Reinders

cess that enables producing this functionality (Souchkov, 2013). For instance, according to this definition, a technical system like a PV system can be considered a product. A product can also be defined from a system perspective like Joore's description: *products refer to tangible, inextricably linked technical systems, physically present in place and time (Joore, 2013).* Joore speaks also about product-technology systems as *objects made up of technical components, characterized by generally fulfilling one clearly distinguishable function*. A typical example of product-technology systems is an electric vehicle. A more generic and accepted definition of a product embedded in a bold business context is given by *Goedkoop et al.* as *a tangible commodity manufactured to be sold. (Goedkoop et al., 1999)*.
A definition which is better embedded in the context of product development is given by Eger et al. describes a product as; a in series or in mass produced object that is created by men. The description extends to the functionality, features, form giving and meaning of such an object, as well as its packaging *(Eger et al., 2004)*.
Finally the utility function of a technical object can be integrated with the cultural background, moral values, and emotions of its intended users *(Krippendorff, 1989)*. This represents a view point on products which is common among industrial designers. Various directions in the field of industrial design explore products' aesthetics and perception by users with the aim to generate positive emotions among end users *(Desmet, 2002, Eggink, 2013, Green, 2002, Schifferstein and Hekkert, 2008)*.

Product-Service Systems

In the formulation of the term SEPS, the word service is used in the context of products. For smart grid developments, it is therefore necessary to explore what a service is and what a product-service combination, or a product-service system, is. Goedkoop et al. proposed a generally accepted definition of service which reads as follows: *a service is an activity (work) done for others with an economic value and often done on a commercial basis (Goedkoop et al., 1999)*.
Next to this definition Cagan defines *a service as an activity that enhances experience; it requires an array of products to deliver its core activity. (Cagan, 2002)*
A product-service system *is then defined as a system of products, services, supporting networks and infrastructure that is designed to [be]: competitive, satisfy customer needs, and have a lower environmental impact than traditional business models'*. An example of product-service system is a car-sharing system. The car-sharing is a use-oriented product-service system that supports individuals to retain the benefits of car use by sharing vehicles *(Baines et al., 2007, Boughnim and Yannou, 2005, Geum and Park, 2011, Hara et al., 2009, Mont, 2002)*. The product is a public car, which is designed for multiple uses, whereas the service is the provision of mobility function *(Geum and Park, 2011)*.
In a car-sharing, customers use cars whenever they need, paying for the use of cars. The payment can be calculated based on a variable basis such as per kilometre or per unit of time *(Geum and Park, 2011)*. The product (car) has the function of recognizing ID card, payment system, or time (or kilometre) checking system.
Basic concept of car-sharing is that customers purchase the mobility function instead of a car. It is a form of shared utilization where individuals gain the benefits of private cars without the costs and responsibilities of ownership *(Shaheen et al., 1998)*. It is especially useful for people who drive infrequently, as it eliminates the need to buy cars *(Wimmer et al., 2008)*
The company offering the car for use remains the owner of the car, and the responsible party for the management of the car *(Geum and Park, 2011)*. Basic illustration of a car-sharing system is shown in Figure 26Figure 26. Another example of a product-service system is a food catering business.
Naturally the provision of services requires good communication between suppliers and clients. As such with the emerge of internet and wireless communication means, product-service systems have been rapidly increasing.
There are also other definitions of product-service systems. One is an integrated combination *of tangible products and intangible service designed and combined so that they jointly are capable of fulfilling final customer needs (Tukker and Tischner, 2006).* Joore describes a product-service system as made out of a physical and an organizational component, and gives as an example an electric transport service *(Joore, 2013)*. In a review by *Baines et al.* a product-service system has been defined as *a market proposition that extends the traditional functionality of a product by incorporating additional services (Baines et al., 2007).* Generally in the field of design for sustainability product-service systems emphasis is on dematerialization or servitization, that is 'sale of use' rather than the 'sale of product', and can embrace sustainability *(Baines et al., 2007, ELIMA, 2005)*.
For the purpose of this review, we will consider products and services as:

- **Product:** in series or in mass produced object that is created by men, which has a certain functionality, features, form giving and meaning;

- **Service:** an activity (work) done for others with an economic value and often done on a commercial basis; and
- **Product-service system:** tangible products and intangible service designed and combined so that they jointly are capable of fulfilling final customer needs.

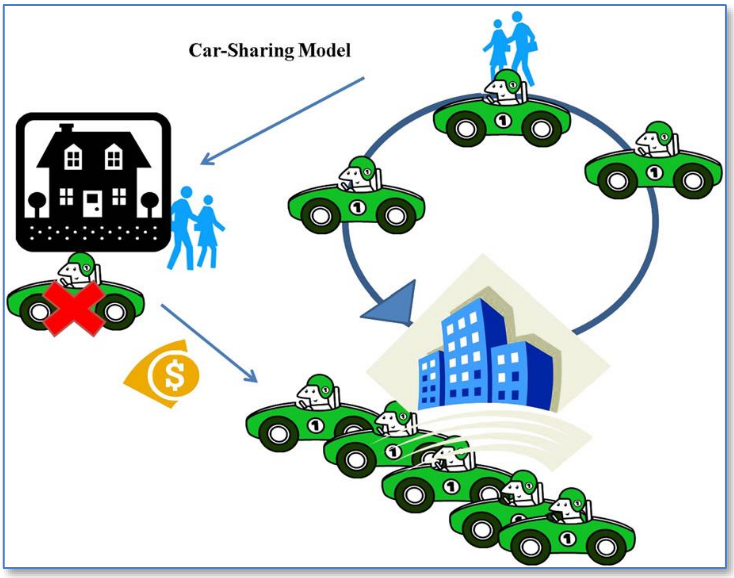


Figure 26. Basic illustration of a car-sharing model (Geum and Park, 2011)

Smart Energy Products and Services

In residential smart energy systems, a whole set of products and services is involved, and performs in a concerted fashion. These smart energy products and services (SEPS) can be grouped in five categories, considering how energy related behaviour might be shaped in relation to the four aspects of co-provision, i.e. consuming, planning, producing and trading *(Geelen et al., 2013a)*. Those categories *(Geelen et al., 2013a, Kobus et al., 2013, van Dam, 2013)* are:

- Distributed generation (Micro-generators and Storage systems);
- Smart appliances;
- Smart meters;
- Energy monitoring and control systems, user interfaces;
- Time variable prices and contracts.

Where micro-generators and storage systems can be considered as part of distributed generation. Apart from this categorization also a Universal Smart Energy Framework *(USEF, 2015)* exists. This is a framework for smart grids by and for the energy industry, and such not well covering user or prosumer needs. Each of the SEPS categories shown above is described in detail below.

Distributed-generation

Distributed generation can be defined as power generation within distribution networks or on the customer side of the network, that is, at the point of consumption *(Ackermann et al., 2001)*. With DG, households can produce and store their own electricity and/or heat. DG includes technologies for the production of electricity e.g. solar PV, micro wind turbine; storage devices e.g. batteries, fly-wheels; micro co-generation units for the production of heat and electricity, see also Chapter 4. DG and electricity trading can also occur at the community level. *(Geelen et al., 2013a)* An illustrative example of distributed generation is shown in Figure 27.

Smart appliances

'The term "smart appliance" means a product that uses electricity for its main power source which has the capability to receive, interpret and act on a signal received from a utility, third party energy service provider or home energy management device, and automatically adjust its operation depending on both the signal's contents and settings from the consumer (AHAM and ACEEE, 2011). Basically, what makes an appliance smart is the ability of the appliance to automatically adjust and optimise its operation based on information from the user, or from sources other than the user *(Wilkenfeld, 2014)*. Otherwise said, a smart appliance helps a user to select the most desirable time for consuming electricity,

for example, by taking into account weather forecasts and electricity prices. Smart appliances can be programmed and communicate with energy management systems regarding the best times to operate. The development of advanced sensors and the transition from electromechanical controllers to electronic controllers with the same – and more – functionality, have opened up the gate to smart home appliances already from the late '90ies. Originally the focus of intelligent home appliances was on improving domestic comfort and security, then the attention moved to energy efficiency or performance *(Badami and Chbat, 1998)*. The first appliances to become smart have been refrigerators/freezers, dishwashers, clothes washers/dryers, room air conditioning, vacuum cleaners, and kitchen cooktops. In the early 2000's, a smart appliance refers to two aspects of communication with the appliance, 1) the interaction with a remote controller such as a smartphone or tablet (a home energy management device), and 2) the interaction with the smart grid, responding to utility signals *(Grogan, 2012)*. Nowadays smart appliances operate themselves by integrated software and they are expected to become more interactive with other appliances and devices by the so-called Internet-Of-Things *(EC, 2016)*.

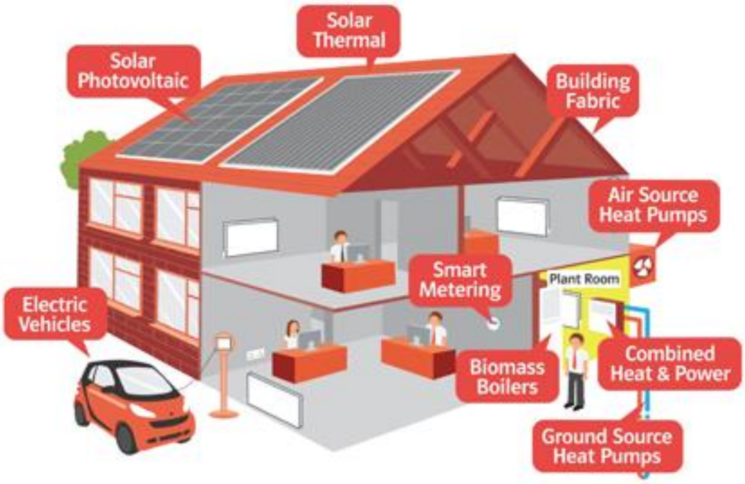


Figure 27. Schematic example of microgeneration technologies. Image from eonenergy.com (e.onEnergy, 2017)

Examples of smart appliances are dishwashers or washing machines that are running at convenient moments for instance when the sun is shining and electricity is generated in a sustainable way, which happened in the project Your Energy Moment using advanced forecasting algorithms *(RVO, 2015)*. Electric vehicles are also a typical case, since they can be seen as both a distributed generation (because of their battery) and a smart appliance (their charging can be controlled smartly), see Chapter 4.

Dynamic pricing

Dynamic pricing are electricity prices that include real-time marginal price. Dynamic pricing represents the volatility of real-time prices *(Hogan, 2014)*, see also Chapter 2. Pricing mechanisms are considered services based on the use of certain SEPS such as smart meters and energy monitoring systems. Dynamic pricing, also known as time-variable pricing, provides an opportunity to involve the end users in the management of the smart grid. An example of a hypothetical pricing scheme is shows in Figure 28Figure 28.

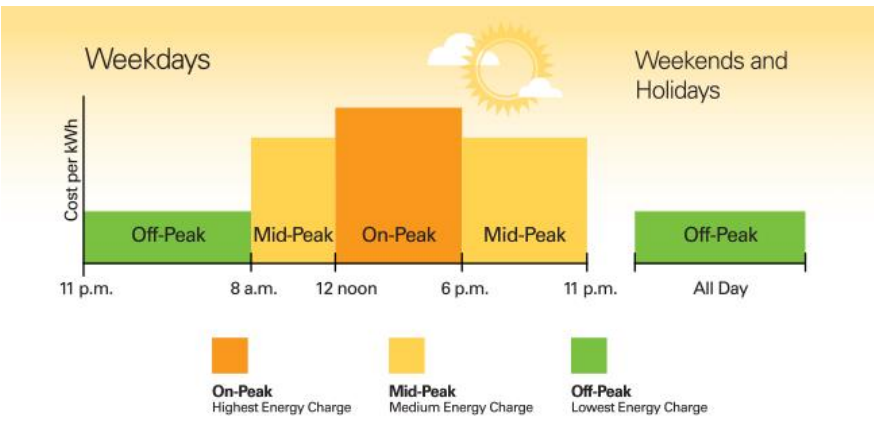


Figure 28. Example of a hypothetical pricing scheme with three different hourly tariffs. Image from Southern California Edison, available in (Alter, 2016).

In a smart grid community with distributed generation, smart appliances and electric vehicles, dynamic pricing schemes are an integral part of the system. As the end-users become a stakeholder in the energy market, the varying costs of electricity provision are conveyed to the end-users. However it has been highlighted that the response of end- users to dynamic pricing differs per end-user segment *(Faruqui et al., 2010)*. Therefore, to stimulate active engagement and co-providing behaviour, business propositions others than price alone have to be proposed *(Geelen et al., 2013a)*.

Energy monitoring and control systems, user interfaces

Kobus et al. *(Kobus et al., 2013)* list them as Energy Management Systems (EMSs) or Home Energy Management System (HEMS) *(Zhou et al., 2016* and smart appliances. EMSs do not only give real-time feedback, but also include feed forward on the availability of sustainable electricity or electricity prices, historical and normative comparisons of demand patterns, goal setting and other persuasive techniques to improve the effectiveness of the EMS. Some EMSs can also automatically switch appliances on or off for energy saving purposes. For example, smart plugs that are used as stand-by killers.

A technical definition of energy monitoring and control systems (EMCS) is '*the sensors, transmitters, data acquisition, and data processing performed at the user (building) level as well as data and control systems that are more global to full control schemes. The EMCS may also have a global supervisory controller to perform high-level tasks*' *(Hatley et al., 2005)*. In order to provide the end-users with interaction and control on the smart products, intermediary devices are necessary. Originally energy monitoring and control systems were simply electricity consumption data given at higher frequency than the energy bill. It was discovered that information about energy consumption could stimulate savings *(Hargreaves et al., 2013, Ueno et al., 2005)*. However, in a smart grid context - including distributed generation, smart appliances, dynamic pricing and contracting - also the amount and complexity of information increase, and so does the need for interaction and control by the users. Successively the design and development of energy monitoring and control systems included the management of appliances, feedback mechanisms, and controlling production and consumption. It has been proposed that, in order to achieve the given goals, the active participation of the end-users is required *(Geelen et al., 2013a)*. In order to achieve engagement, a successful program consists in taking the user's needs into account in the design of the program itself *(Lewis et al., 2012, van Dam, 2013)*.

A photographic example of a user interface for an energy monitoring and control system is shown in Figure 29.

Figure 29. Photographic example of a user interface for an energy monitoring and control system. Image from (PowerMatchingCity, 2016)

Smart meters: Smart meters refer to digital electricity meters that accurately measure consumption and production of electricity and communicate these data to the energy supplier. Their introduction began at the beginning of the new millennium and as a top-down approach, from governments or utilities, initially triggered by needs for accurate billing purposes, or government energy-savings targets *(Benzi et al., 2011, Geelen et al., 2013a)*. Electricity smart meters can be combined with gas, heat, and water meters and as such hold a potential to implement domestic energy savings and other energy-related services, as long as an efficient interface with the end user can be implemented *(Benzi et al., 2011, Dalvi et al., 2016, Hargreavesn et al., 2010, Ueno et al., 2005)*. A schematic example of a smart meter as a part of an energy monitoring and control system is included in Figure 30.

Figure 30. Schematic example of a smart meter as a part of an energy monitoring and control system. Image from (Laitinen et al., 2013)

Home Automation for Smart Energy Systems: Home automation performs the planning and the real-time countering of demand response programs within premises**.** In order to become widely accepted by the households, the smart grid has to foster safety, efficiency, comfort, and ease-of-use, compared to the existing. While interactivity, monitoring and control are necessary to guarantee autonomy and customization, the complex management of the residential smart grid requires automation of certain devices or functions. The premises under which home automation performs the planning and the real-time countering of demand response programs are:

- system conditions and price value signalled by the utility *(Bliek et al., 2010)*,
- the comfort level and priority set by the end-user *(Khan et al., 2015)*.

The interaction and communication of the home energy management systems and home automation are enabled by integrated wireless technology and network *(Jacobsen and Mikkelsen, 2014, Lobaccaro et al., 2016)*.
A summary of the categories of SEPS, considering how energy related behaviour might be shaped in relation to the four aspects of co-provision, i.e. consuming, planning, producing and trading is provided in Table 16.

Table 16. Categories of products and services in a smart energy system (Geelen et al., 2013a)

Categories	Examples	Type of co-providing behaviour involved (Consumption, production, timing, trading)	Product, service or combination	Impact on behaviour
Distributed generation: **Micro-generators**	Electricity: - Photovoltaic solar systems - Wind turbine Electricity and heat: - Micro cogeneration unit - Fuel cell - Solar heating and cooling	- Production - Timing (when production is controllable) - Trading (excess production, or reaction to market stimulus)	Product	Intermediary technology required for visualization and interaction - Awareness of energy production - Shift consumption to match production
Distributed generation: **Energy storage**	Electricity: - Batteries - Electrolysers Heat: - in home hot water storage - storage heaters - shared storage on buildings or neighbourhood	- Production, based on stored energy - Timing - Trading		
Smart appliances	- micro-cogeneration units - electric vehicles - heat pumps - air conditioners - dish washers - washing machines - clothes dryers - freezer/refrigerator	- Consumption - Timing	Product	- in combination with intermediary devices supports load-shifting
Smart/digital meters	- electricity meters (frequency ranges from seconds to day intervals) - gas meters - meters that allow for breakdown to appliance level (usually part of a monitoring and control system)	Supportive due to measurement and signals transmission to: - Timing - Trading	Product-service combination (functions on background)	- in combination with intermediary devices supports behavioural change
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	Service	- Shifts electricity consumption resulting in lower electricity use during peak hours (timing) - Rebound effect may occur resulting in higher consumption during low price hours - Dynamic pricing in combination with in-home displays reinforces load shifting

Energy monitoring and control systems	- Sensors and energy monitoring systems, ranging from household aggregate to break-down to appliance level - Gas measurement, often combined to a smart thermostat	As intermediary technology can support: - Consumption - Production - Timing - Trading	Product-service combination	Intermediary technology required for visualization and interaction - Stimulates awareness - Necessitates customization to adapt to users' needs and wishes
Home automation for smart energy use	- Energy services gateway (PMC) - Steering of deferrable load (smart appliances)	- Consumption, by smart appliances - Production, when controllable - Timing - Trading	Product-service combination (functions on background)	Fully automated system without feedback information appears not to support a co-providing behaviour

5.3 SEPS in selected residential SG pilots with focus on end-users

According to the JRC report 'Smart Grid Projects Outlook 2014', 459 smart grid demonstration, research and other projects were undergoing at the European level in that year *(Covrig et al., 2014)*. At the moment, more than 700 projects can be counted in Europe. Comparable numbers can be estimated for Asia and America. A comprehensive inventory of 219 SG projects in Europe has been performed by Giordano et al. *(Giordano et al., 2011)*. In their report, they highlight the need to complement the realization of technological infrastructures with new business models and practices, new regulations, as well as changes to consumer behaviour and social acceptance. For SGs to deliver their envisaged benefits however, they mention that cooperation among the many different stakeholders which are involved must be arising. A following study by Gangale et al. uses project data found in the catalogue annexed in the JRC Report to support the analysis of trends and developments *(Gangale et al., 2013)*. Their analysis reveals that 145 projects at European level have end-users as a focus. Those are characterized by the pursuit of two main objectives: gaining deeper knowledge of consumer behaviour, and motivating and empowering consumers to become active energy customers.

One of the first and largest projects for the development of a smart grid has been executed by the Italian distribution system operator (DSO) Enel. An overview of the legal and regulatory situation and the implementation status of smart meters in Europe is shown in Figure 31. With four consecutive projects (Telegestore, 2001; Smart Info, 2008; Energy@Home, 2009-2011, ADDRESS, 2008-2012), Enel launched a 1,000 households trial of an in-home display connected to the smart meter, to show consumption and prices. Then Enel integrated the Smart Meter/Smart Info with the Energy Management device (e.g. Energy Box, Energy Butler etc.) which performs automatic energy management in the household and represents the consumer's gateway toward the electricity market. Finally, the focus went on the establishment of a market layer for Demand Response. In the Demand Response platform, participants can interact with each other to buy and sell load flexibility at the community level. The platform is led by an aggregator, and its profitability is linked to the number of participating costumers. They found out that in-home displays encouraged 57 % of the involved consumers to change their behaviour. According to the report, one of the project's focus is in fact the engagement of costumers *(Lombardi et al., 2013)*. However, an accurate description of the customers' feedback is missing. Also, it has not been reported on whether a feedback loop with the end-users has been incorporated in the further design of the products and services.

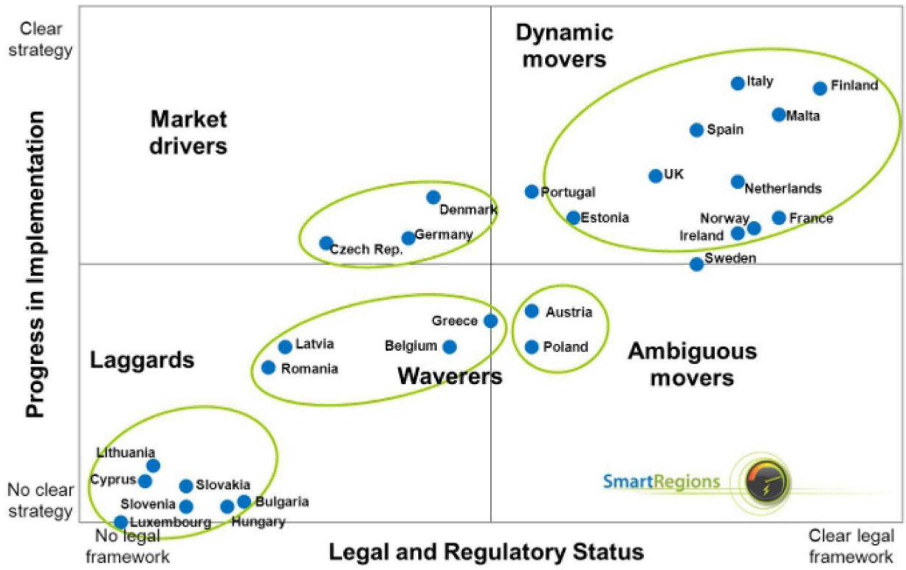


Figure 31. An overview of the legal and regulatory situation and the implementation status in the EU countries and Norway. The assessment takes into account the legal framework, roll-out plans and the number of existing smart meters and their functionalities Image from (Laitinen et al., 2013)

Similar to the project led by Enel of Italy, also in Model city Manheim the installation of smart meters with in-home interfaces and dynamic pricing have been coupled. The focus in the pilot was to tackle the initial scepticism of the end-users towards dynamic pricing. Thus, the project worked on a voluntary basis, where participants have the freedom to choose whether or not to react to the information displayed by the energy box installed in their homes, e.g. displaying varying electricity prices. Furthermore, if they choose to respond to dynamic pricing, there is no financial risk for customers as they are guaranteed not to pay more than they would have under the old pricing scheme. It has been reported that customers are more likely to sign up for a program where electricity providers cannot remotely limit the use of any home appliances *(Ellabban and Abu-Rub, 2016, Giordano et al., 2011)*. These initial warranties helped to mitigate consumer fears and encourage participation to the demand response program. However, mechanisms of integration of end-users into the design of project was missing. Thirty-five SG pilots have been realized in The Netherlands between 2008 and 2016. Those which focused on acceptance of SEPS by end-users are listed below.

PowerMatching City

The pilot was designed to optimize the autonomous reaction of individual smart appliances to market mechanisms. It successfully used heat pumps and u-CHP to decouple electricity and heat production, from heat consumption. Measurements from heat pumps, u-CHPs, and electric vehicles indicates the technical feasibility of allowing demand to follow production (nowadays it is the other way around) *(Klaassen et al., 2016)*. PMC system is designed to optimize the reaction of individual smart appliances to market mechanisms, and the coordination is controlled by an autonomous multi-agent-based system optimizer called PowerMatcher *(Wijbenga et al., 2015)*. The process occurred via household smart appliances designed to autonomously decide whether to switch on or off, e.g. following market input. However, this flexibility must not be at the expenses of the end users' comfort nor system's energy efficiency. Proper coordination of smart appliances, and storage – of heat in buffer tanks, and electricity in batteries – enable this flexibility while meeting the constraints. Via an online portal, end users are given information about their energy consumption. End-users feedback was of a high level of acceptance and perceived comfort. However, they reported 1) a lack of support in achieving energy-savings goals, 2) no decision-support information on the payback-time of investments, 3) lack of information at the device level, 4) need for a dialog between end-users, 5) need for creation of a bidirectional, interactive relationship between households and product and services. Finally, cost-savings for the end-users were not achieved *(DNV-KEMA, 2013, Geelen et al., 2013a, Obinna et al., 2016)*. The feedback above have been addressed and improved in part in the second phase of the project *(DNV-GL, 2015)* leading to the design of a new user interface.

Lochem Energie

This pilot is a local-government-supported local energy initiative. The goal of the pilot is two-fold: 1) to encourage residents to generate own electricity, reduce consumption, and use shared electric vehicles; and 2) to test the effects of demand, supply and manageability on the local grid. The residents have access to real-time data from the grid, for example on favourable times for charging the electric cars. An overload stress test has been conducted with the aim to identify possible unexpected problems. As part of the feedback to the SEPS, participating end-users reported on their high complexity *(Obinna et al., 2016)*.

Texel Energy

This project has been initiated by a cooperative on the island Texel. Being an island, the main objective of the community was to strive for self-sufficiency. The participants were provided with weather forecast data and estimated renewable electricity production by the solar photovoltaic systems and the wind turbine. Data concerning energy self-sufficiency were not given, however as a result the households achieved 10 % reduction of gas consumption and 5 % reduction of electricity consumption. A shifting of consumption away from peak hours was also achieved, however not quantified. End-users reported on lack of empowerment, and limited insights into the HEMS *(Obinna et al., 2016)*.

Jouw EnergieMoment (Your EnergyMoment)

This Dutch private-lead pilot has the objective to investigate the ability and willingness of households to embrace demand response. Further objectives include gaining experience with social, technological, and economical means to promote flexibility in the energy consumption of the end-users. Similar to the case of PMC, two programs were offered to the users: (1) consumption of locally produced energy or (2) minimizing costs. 90 % of the respondents opted for the latter option, and in total 10 % of the consumption moved away from peak hours. According to the DSO who managed the project, this achievement happened while preserving comfort. End-users reported on lack of empowerment, and limited insights into the HEMS *(Obinna et al., 2016)*. End-users reported high complexity of SEPS, which were perceived as too technical *(Obinna et al., 2016)*.

Profit for Everyone

The focus of this SG pilot was on energy savings and optimal use of locally produced solar energy. During the project, a series of new, up-scalable and user-supported services test-bed for the optimal use of solar photovoltaic energy and energy savings, have been developed and tested. Co-creation and investigation of services using the residents are the starting point. As a result, four services have been designed and developed:

- E-car4all, a booking system to share an e-vehicle,
- Insight4all, energy production and consumption data at household level,
- Advice4all, advices the optimal time to use electricity, based on the production of the PV system,
- Flex4all, offers the ability to program remotely the start of a smart appliance.

To summarize, there is general consensus on the need to engage the end-users for the successful development of smart grids. However, while the smart grid properly functions from a technical point of view, end-users of actual SG pilots often reported on lack of empowerment, limited insights into the HEMS, and high complexity of SEPS.

Besides the projects taking place in the Netherlands, several smart grid pilot and demonstration projects have been implemented the United States of America. However, the focus of smart grid projects in the USA is on reducing peak electricity load. Therefore, most of the projects focus on the deployment of Smart meters and Advanced Metering Infrastructure (Netbeheer, Nederland, 2012). However, an interesting project focusing on end-user engagement is currently taking place in the United States of America. The Pecan Street Organization is, currently executing this project known as the Pecan Street pilot, in Austin Texas. A brief description of the project and the implemented technologies is given below.

Pecan Street

The Pecan Street Project (PSP) is a public-private non-profit organization. PSP is seen as a sort of platform for researchers to test out new technologies and products in a safe test bed. In addition, PSP is a socio-technical platform that facilitates peer-to-peer transactions between individual residents generating and consuming locally produced and locally circulating energy *(Nagasawa et al., 2012)*. Several different home energy management systems are being trialled along with different setups for charging electric vehicles *(McLean et al., 2016)*. The project seeks to show the benefits of the smart grid to the households. This is attempted via a highly visible rollout of integrated end-user systems such as HEMS that can manage the energy usage of numerous consumer systems including appliances, consumer electronics, and electric vehicles. It is considered as a bottom-up approach to the smart grid, with new technologies being deployed in tandem with consumer input *(Nagasawa et al., 2012)*.

The Pecan Street Smart Grid pilot is being carried out in Austin, Texas, USA. The pilot started in 2010, and is still on-going. Technologies implemented in the participating homes include: energy management systems, distributed solar photovoltaic energy, plug-in electric vehicles, smart meters, distributed energy storage, smart appliances, in-home displays, programmable communicating thermostats *(Obinna et al., 2017)*. Over 1,000 participating households share their home or businesses' electricity consumption data with the project via green button protocols, smart meters, and/or a home energy monitoring system *(PSP, 2015, Rhodes et al., 2014)*.

A comparison of user experiences between the Pecan Sreet Project and the PowerMatching City project in the Netherlands revealed similar insights regarding the use of implemented technologies *(Obinna et al., 2017)*. End-users in both pilots appeared to have preference for technologies that automatically shift their energy use, since this requires minimal effort from them. Obinna and colleagues mentioned that most of the participants in both projects were satisfied with the system implemented, which made them to become more aware and conscious of their energy behaviour. However, most participants in both pilots were not always capable of using the implemented technologies, such as smart programmable thermostats. This is mainly due to complexity in comprehension of feedback. End-users in both pilots preferred automatically-controlled technologies that shift their energy use to manual technologies. This is because automatic technologies require minimal effort to operate. Insights from this study that the interaction between end-users and new energy technologies still remains challenging.

With regards to the energy performance of the households participating in both projects, their study concluded that existing Smart Grid set-ups, local climate and related needs for heating and cooling, the average capacity of installed energy generating technologies and the prevailing energy behavior largely influenced the pattern of households' electricity generation and consumption.

5.4 Supporting methods for SEPS: A design-driven approach

As shown in the previous sections, the engagement of end-users is necessary for the successful development and deployment of smart grids. Therefore, recently a growing attention is paid on researching SGs from an end-user perspective *(Gangale et al., 2013, Orillaza et al., 2014, Park et al., 2014, Stragier et al., 2010, Swaminathan and Ting, 2013, Yunus et al., 2015)*. Yet, the acceptance of smart energy products and services remains a great challenge. At present, many smart grid technologies have reached a level of maturity which allows their implementation to real life applications, such as actual residential smart grid pilots. The embracement of these new technologies by the users can be understood on the basis of the technology acceptance model, described elsewhere in this review. A second important factor which affects the acceptance and diffusion of smart grid technologies, products and services, is described by the network externalities and motivation theory. According to the theory, when a network effect is present the value of a product or service is dependent on the number of others using it *(Lin and Lu, 2011)*. There is also a third factor which influences the success of products and services with their end-users: the design factor. Design reduces the complexity of energy systems containing all sorts of new products and services with complicated user interfaces (containing complex information). Better product design therefore increases acceptance and understanding by the users. According to Reinders and Diehl a closer insight in energy technologies in relation to appropriately matched design processes is necessary to better embed energy technologies in industrial product design, and therefore lead to more optimal products (and services) *(Reinders et al., 2013).*

In the SG context, the current research efforts in the evaluation of the performance of SEPS come with a certain degree of separation between the technological push, the market pull, and the end-user perspective. A research gap in the bridging of the fields has been identified as a great challenge, and a proposed approach to tackle the challenge is the evaluation of energy products and services from a design-driven perspective. *(Geelen et al., 2013a)* The overall aim of design research is to enable the development of successful products and services, *(Blessing and Chakrabarti, 2009)* in other words: to create value for end-users. With this approach, the technical functionality and financial incentives provided by the current product and services are complemented with behavioural aspects and the social context of the end users.

One can expect the development of SG products and services to happen more smoothly and effectively if technological development, market demand, and end user expectation are to be synchronized and contribute in a concerted fashion. This multidisciplinary approach is the framework in which industrial design engineers and industrial product designers operate. Their main tool, industrial design methods (IDMs), plays an important role in product development processes. Specifically, IDMs convert market needs into detailed information for the manufacturing of new products (and services). *(Reinders et al., 2013)*. These IDMs include: 1) Platform-Driven Product Development (PDPD), 2) Innovative Design and Styling (IDS), 3) Delft Innovation Model (DIM), 4) Theory of inventive problem solving (TRIZ (Russian acronym)), 5) Multilevel Design Model (MDM), 6) Constructive Technology Assessment (CTA), 7) Innovation Journey (IJ), 8) Technology RoadMapping (TRM), 9) Lead User study (LU), and 10) Risk Diagnosing Methodology (RDM). These IDMs will be further explained in the following sections.

In the context of product development, the design of a successful product is one which takes into account the five aspects of the so-called innovation flower. Those aspects are technologies, finance, society, human factors, and design and styling. The innovation flower is shown in Figure 32. Hence, one can consider as innovative those energy solutions, which are based on these five aspects.

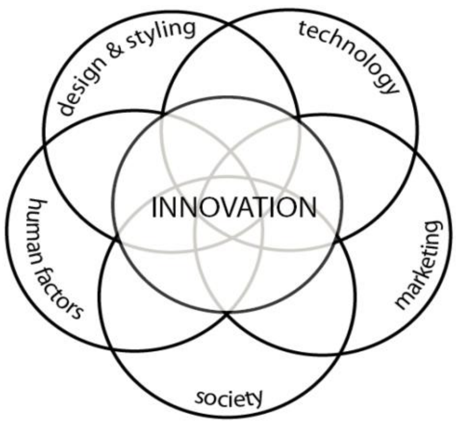


Figure 32. Innovation flower of industrial product design (Reinders et al., 2013)

In 2013 and 2014 IDMs were applied in two students' design projects at the faculty of Industrial Design Engineering, University of Twente (The Netherlands) in the framework of the course 'Sources of Innovation' *(Obinna et al., 2014)*. This course positions product development in the context of the innovation flower and provides theory about innovation processes and useful tools for the design of innovative technology-based products related to emerging technologies, such as Smart Grids *(Obinna et al., 2014, Reinders et al., 2013)*. Students involved in this project were given the task of designing new innovative products that can be applied in or around Smart Grid households, and which stimulates energy efficient behaviour. The products are also expected to be aesthetically appealing to household end-users and at the same time, stimulate energy-efficient behaviour in a durable, intuitively understandable and comfortable way.

The design approach, was based on a standard design process developed by Pahl and Beitz *(Pahl et al., 2007)*. This approach, which is widely used in design engineering comprises the following phases: task clarification, conceptual design, embodiment design and detail design. The first three phases comprise of optimization of the working principles of the product, while optimization of the final layout and form is done in the last three phases (Figure 33).

This project yielded about 41 different products that can be applied in and around smart grid households to increase user awareness about energy use and support energy-efficient behaviour. Some of the resulting product concepts are presented in Figure 34.

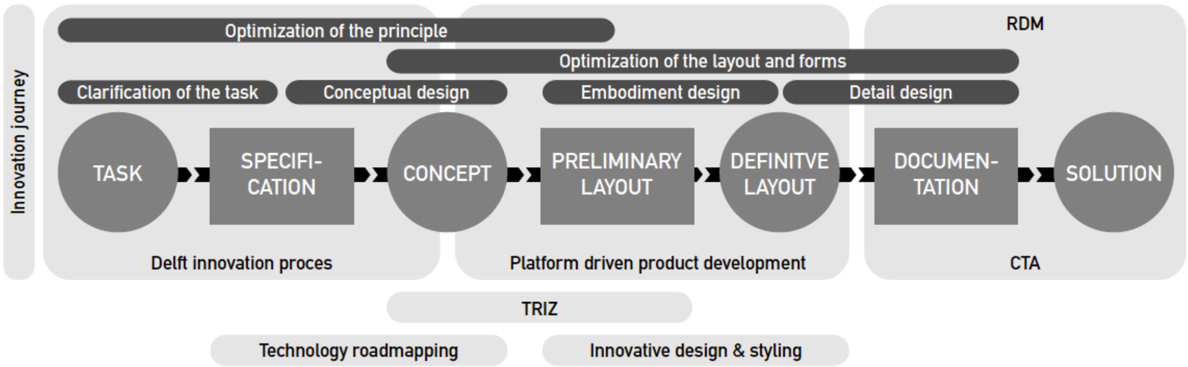
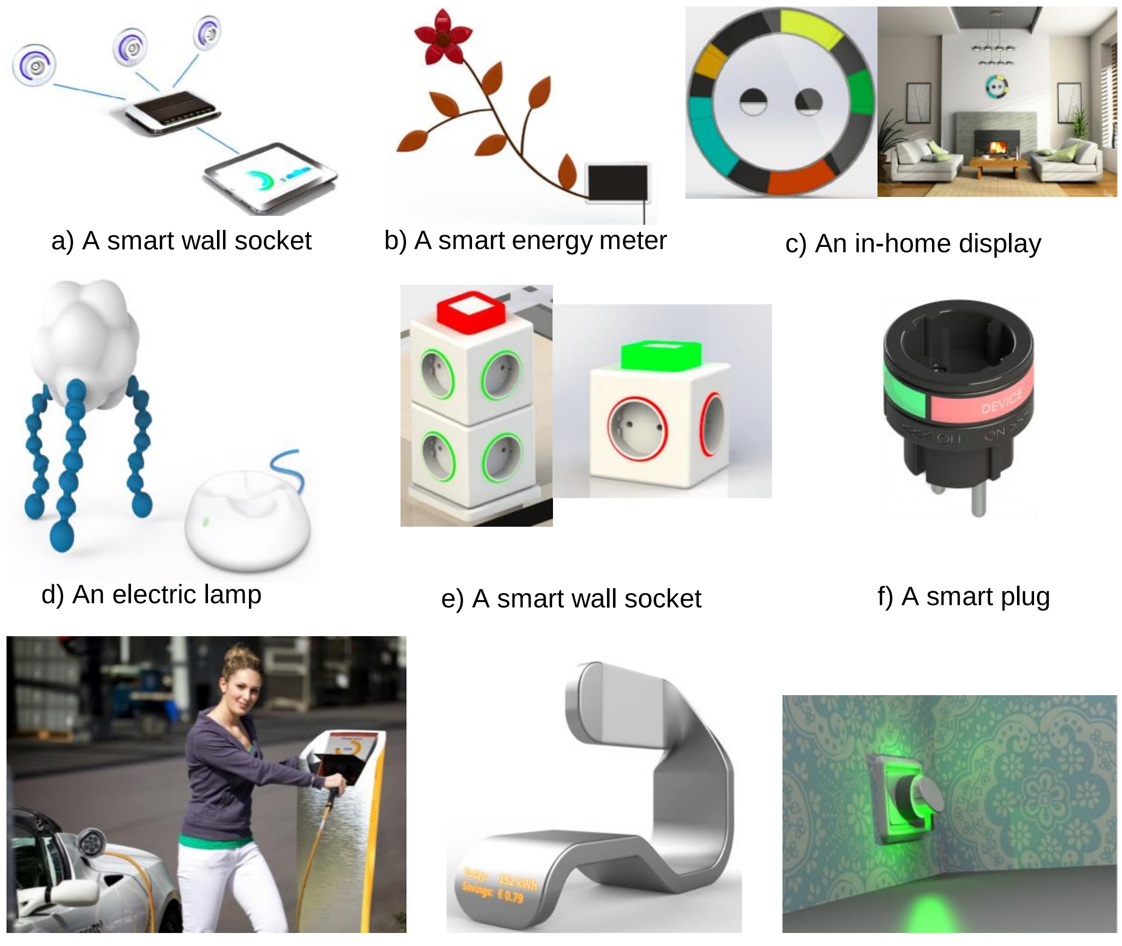


Figure 33. Basic industrial design method of Pahl and Beitz (Pahl et al., 2007)



a) A smart wall socket b) A smart energy meter c) An in-home display
d) An electric lamp e) A smart wall socket f) A smart plug
g) A charging station h) A smart thermostat i) A smart plug

Figure 34. Product concepts from students' design project at the University of Twente using IDMs. Source: (Obinna et al., 2014)

The predominant IDMs employed in the design project are briefly described below:
1) Platform-Driven Product Development: This IDM increases variety, accelerates development and reduces complexity in product development. This method was mainly used to divide the functional concepts of the products into different modules that could be applied on other product platforms, thereby creating the basis for a wide range of smart energy products. It was used mostly in this project make product design or parts of it easier implementable for future designs.
2) TRIZ: This is a Russian acronym that means “the theory of inventive problem solving *(Altshuller and Shulyak, 1996)*. It contributes to product innovation by using 40 inventive principles to solve contradictions in the design process. It includes several methods that support various stages of the idea generation process. TRIZ was mostly used in the concept development phase, to identify problems and contradictions within the design. These contradictions could impact negatively on the functionality of products.
3) Delft Innovation Method: This method combines internal strengths of technology with external opportunities in the market *(Buijs, 2003)*. The method is made up of four phases: a strategy formulation stage, a design brief phase, a product development phase, and a product launch and use phase. It was applied mostly in the initial phases of the design project to define search areas related to smart grids technology and the developments around energy efficient products.
4) Technology RoadMapping: This method establishes correlation between identified market needs and trends with existing and emerging technologies for a specific industry sector, to improve existing products and develop new ones. It supported the exploration of the market and the current and future state of technological possibilities in the area of smart energy products. It was used mainly applied in the embodiment design phase to assess how various smart grid technologies will develop in the near future.
The sequential application of these IDMs helped to identify and incorporate technological, societal,

market and end-user aspects in the design of the innovative product concepts presented in this study The application of IDMs in the design projects supported a detailed exploration of technological possibilities, the opportunities that exist in the energy market and end-user preferences *(Obinna et al., 2014)*.
Reinders and co-workers proposed to involve the customers directly in the design process of the SG products and services *(Geelen et al., 2013b, Geelen et al., 2013c)*. By investigating PowerMatching City and other SG projects in the Netherlands, they reported that its initial development followed a top-down approach, driven by a technological push. This approach ensured a high end-user satisfaction with the degree of living comfort afforded by the smart energy system. However, the user interface a) was seen too difficult to actually stimulate action, b) did not provide sufficient control, and energy feedback to support an active contribution to the balancing of supply and demand. Hence the full potential of demand response was not realized. In this case the product might have been engineered properly, but not designed properly. *(Geelen et al., 2013b, Geelen et al., 2013c)* A separate study by Obinna et al. confirms the observations: to the opinion of the interviewed stakeholders, current products and services offered in residential smart grid pilots are functionally attractive, but often too technically complex for the understanding of end-users. Hence, the general view held by respondents is that end-users should be the starting point in the development of smart grid products and services at the residential areas *(Geelen et al., 2013a, Obinna et al., 2016)*. In the second phase of the SG pilot, input from the end users was incorporated into the design, implementation and evaluation of an improved user interface. As a consequence, it began to be used more effectively by the end users, and a higher degree of acceptance and satisfaction was achieved *(DNV-GL, 2015)*.
It is a known phenomenon that the dynamics of technological development involves a series of exchanges between technology and society *(Deuten et al., 1997)*. According to Deuten et al. social projects foster the acceptance of new products by teaching people about the benefits of technology for society. However, a design-driven approach would have included the end-user perspective already in the initial phase, thus holding great potential to save time and reduce the costs of the development of HEMS.
This example shows also that, while important, the demonstration of technical viability is only one component of a credible and successful business case. The investment required to commercialize a technically viable product will be justified only if the technical, market and business case are all attractive *(Ashby and Johnson, 2013)*.

5.5 Conclusions

In this chapter on literature about smart grids products and services (SEPS), definitions of SEPS are discussed, leading to the following descriptions of a product, service and product-service system which will be applied in the CESEPS project. A product is; a in series or in mass produced object that is created by men, which has a certain functionality, features, form giving and meaning. A service is an activity (work) done for others with an economic value and often done on a commercial basis. And a product-service system comprises tangible products and intangible service designed and combined so that they jointly are capable of fulfilling final customer needs.
Further it is explored which SEPS are currently used in SG pilots, what sort of research activities have been taken place in SG pilots, which supporting methods have been used for the users' acceptance of SEPS, and when and why a 'design-driven approaches' has been used to develop SEPS.
Common SEPS are distributed generation systems, smart appliances, smart meters, energy monitoring and control systems, user interfaces, time variable prices and contracts. These categories of SEPS have been described and discussed to develop a general framework for the CESEPS project.
It is noticed that the current research efforts in the evaluations of SG performance are mainly based on technological perspectives, market perspectives, and in a very limited extent on end-user perspectives. Furthermore, there exist general consensus on the need to engage the end-users for the successful development of smart grids. Several reports exist which focus on how to engage them. However, end-users of actual SG pilots often reported on lack of empowerment, limited insights into the HEMS, and high complexity of SEPS. On the basis of this information, a research gap can be observed between endeavours to actively involve end-users and the design process of smart energy products and services. That is the case for the evaluation of smart energy products and services from a design-driven perspective as well as regarding end-user perceptions.
In Chapter 5 it is suggested that design approaches could at the same time reduce the complexity of SEPS for end-users and increase the acceptance of these new energy technologies by end-users. Several examples of designs using SEPS are shown in combination with the design methods applied.

In general it can be concluded that the design of a successful product is one which takes into account the five aspects of the so-called innovation flower. Those aspects are technologies, finance, society, human factors, and design and styling. Hence, one can consider that this also applies to SEPS. Designs of SEPS will be successful if based on these five aspects.

PART VI: CONCLUSIONS

6 CONCLUSIONS

This literature study has been executed in the framework of the CESEPS project that aims at developing knowledge about the actual performance of smart grid technologies, products and services in the context of end-users of local residential smart grid pilots.
Although the importance of end-users in smart grids deployment has been recognized in existing literature, there is currently limited information with regards to the end-user and stakeholder involvement in smart grid projects. Namely smart grids deployment is still mainly focused on technological issues and economic incentives. With regards to the engagement of end-users in smart grids, the focus in literature has been on the involvement of end-users as energy consumers in the future electricity system. Only a handful of studies *(Geelen et al., 2013a, Kobus et al., 2013, van Dam et al., 2012)* have explored the role of users as co-providers in smart grids. These studies have however been limited to individual pilot projects and only a small group of residential end-users involved in these pilots. The importance of supporting end-users as co-providers or energy citizens in the electricity system is also stressed in the literature. However, there are limited insights from literature on how this co-provider role can be fostered. It is still not clear from the literature on how to really involve end-users, and support them as co-providers in the future electricity system. Various products and services that could facilitate a co-provider role for end-users in Smart grids have been implemented in smart grid projects. End-user experiences also show that current products and services have not always supported an active role for end-users in smart grids. Learning processed in the context of smart grids and associated products and services will be required to improve existing smart grid products, and support the generation of knowledge and ideas for new products and services to be applied in residential smart grid pilots.
Therefore, it is assumed that a multidisciplinary approach is necessary that integrates technical aspects with learning from end-users and stakeholders to investigate the development and performance of residential smart grid projects, including the energy products and services implemented in these projects.
To support the envisioned research of the CESEPS project this literature study captures existing experiences and knowledge about smart grid environments based on the three-layer model of marketplaces, technologies and stakeholder adoption. Therefore, Chapter 2 presents findings from literature on smart grid marketplaces, Chapter 3 discusses stakeholders, among which end-users, Chapter 4 reports on smart grid technologies, and Chapter 5 on smart energy products and services (SEPS) and the possible effects of the design discipline on these SEPS.
Chapter 2 concludes with the following: Whether the current market model is suitable for deploying smart grids, remains matter of discussion. Incentives for smart solutions are present; aggregators can operate on the spot markets (i.e. by energy arbitrage) and on the balancing markets. From a market-based perspective, one can argue that when the shares of renewables in the grid would increase to (very) high levels, their inherent fluctuations would cause more volatile spot market prices and higher imbalance prices, thus providing higher incentives, and possibly business models, for smart solutions. On the other hand, one can argue that before this is the case, stakeholders need to gain experience on these smart solutions because of the pivotal role the electricity system plays in our society.
In Chapter 3 the focus was upon existing social scientific research with regards to the users and stakeholders. The main aim was to be able to explore the key findings regarding smart grids stakeholders' experiences in smart grids developments, and how these findings could feed into a multidisciplinary study of smart grids. Based on literature review we conclude that users, as they are described in current research, do not only have different labels (consumers/pro-sumers/end-users) but are also assumed to behave differently from each other. Disregarding some ambiguousness and overlapping we arrived at the following user typology presented as attributes. The most prevalent type are the consumers, who are supposed to adapt/adopt to new developments in the energy system, such as smart grids. The prosumers are seen as users who consumer and (co-)produce energy, engage in various prosumer activities and are sometimes also seen as potential active players on energy markets in VPP's. Prosumers' most important attribute is their 'pro-activeness' inside the new energy system, which differs from passive consumers (who merely have to accept/adopt) to end-users which are responsive to DSM tariffs albeit relying more or lesser on the smart grids, towards the prosumer which is a knowledgeable, pro-active user, producer, trade partner in the new energy system.

Most studies lack a consistently used theoretical framework to study the (potential) roles of users. Most Applied theory is the social practice theory. Based on the social practice theory, the scholars often address the issue that users are not isolated 'atoms' but are tied do routinized behaviours which are not only depended on the household, but even on out-house institutionalized rules and norms (e.g. school/work time), and are therefore not easy to change.
Furthermore, based on the papers which focused upon user experiences (with a special attention to demand side management), it appeared that in most papers the issue of 'acceptance' of the smart grids widely discussed. It also appeared that few studies build on real life experiences based on smart grids projects, but most studies focus upon future scenarios and (online) surveys. The only two papers which build on real life experiences come to contradictory findings. Users' knowledge with regards to smart grids (such as an abundance of feedback information) is both shown to enhance acceptance and to create confusion, and in some contexts people prefer demand load control (the ability of energy suppliers to control user consumption) while they reject it in others.
The literature review has also shown that the future roles of stakeholders are foremost mentioned in policy reports. The future roles of the stakeholders are only discussed in some policy reports with a special focus on the role of the distribution system operators. From these reports, it seems that uncertainties still exist with regards to market structures (natural monopoly versus competition), task delegation, necessity of new (data handling) institutions etc. In the Dutch context, the distribution system operators also have a leading role in the smart grids pilots (Table 9). However, again, there very little knowledge with regards to the exact roles of the stakeholders inside smart grids pilot projects, and as facilitators of the renewable based de-centralized energy transition(s).
In Chapter 4 an overview of residential distributed energy resources provides information regarding the controllability and characteristics of the main distributed energy systems. Based on the individual technical parameters the eligibility of the system types can be evaluated for SEPS applications. Following the categories of controllability shown in Figure 11 at the beginning of this Chapter, the energy resources described in this section can be assigned in the order shown in Table 14. Regarding the characteristic of resources, Table 15 provides a summary of exemplary values for individual systems. The availability and activation duration of all the investigated systems is somehow limited either by technical parameters or by the needs or influence of customers. In terms of power supply or demand, most systems range with typical power connection values of households (~4kW). Depending on system configurations, EVs or PV systems may excel this value significantly. The two summary tables show, that the investigated systems at a residential level provide different potential for flexibility applications. Whilst existing systems like PVs, heat pumps or appliances provide limited controllability, especially the introduction of stationary BESS enables full flexibility for local optimization or ancillary services.
In Chapter 5 on literature about SEPS, definitions of SEPS are discussed, leading to the following descriptions of a product, service and product-service system which will be applied in the CESEPS project:

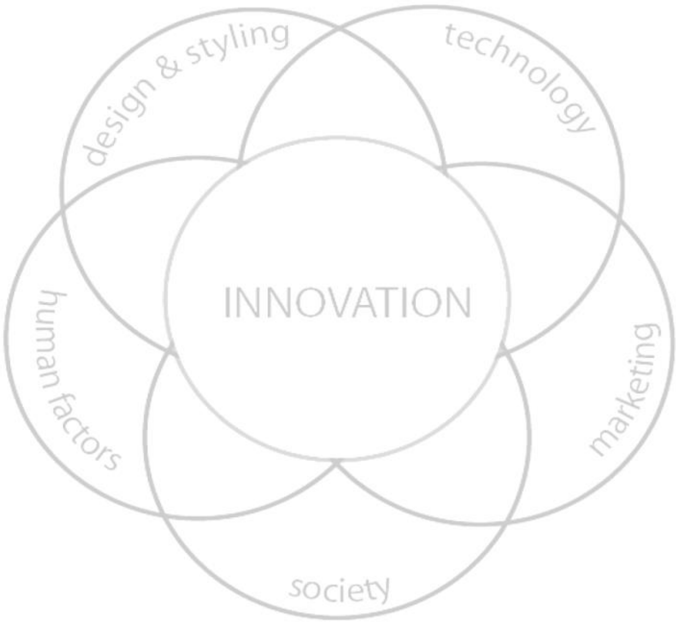
- A product is; a in series or in mass produced object that is created by men, which has a certain functionality, features, form giving and meaning.
- A service is an activity (work) done for others with an economic value and often done on a commercial basis.
- A product-service system comprises tangible products and intangible service designed and combined so that they jointly are capable of fulfilling final customer needs.

Further it is explored which SEPS are currently used in SG pilots, what sort of research activities have been taken place in SG pilots, which supporting methods have been used for the users' acceptance of SEPS, and when and why a 'design-driven approaches' has been used to develop SEPS.
Common SEPS are:

- distributed generation systems,
- smart appliances, smart meters,
- energy monitoring and control systems,
- user interfaces,
- time variable prices,
- contracts.

These categories of SEPS have been described and discussed to develop a general framework for the CESEPS project.

It is noticed that the current research efforts in the evaluations of SG performance are mainly based on technological perspectives, market perspectives, and in a very limited extent on end-user perspectives. Furthermore, there exists general consensus on the need to engage the end-users for the successful development of smart grids. Several reports exist which focus on how to engage them. However, end-users of actual SG pilots often reported on lack of empowerment, limited insights into the HEMS, and high complexity of SEPS. On the basis of this information, a research gap can be observed between endeavours to actively involve end-users and the design process of smart energy products and services. That is the case for the evaluation of smart energy products and services from a design-driven perspective as well as regarding end-user perceptions.
In Chapter 5 it is suggested that design approaches could at the same time reduce the complexity of SEPS for end-users and increase the acceptance of these new energy technologies by end-users. Several examples of designs using SEPS are shown in combination with the design methods applied. In general, it can be concluded that the design of a successful product is one which takes into account the five aspects of the so-called innovation flower. Those aspects are technologies, finance, society, human factors, and design and styling.



LITERATURE

Ackermann T., G. Andersson and L. Soder. Distributed generation: a definition. Electric Power Systems Research, 57, 195-204, 2001.
AEP-OHIO. gridSMART Demonstration Project -Final Technical Report. Americal Electric Power, 2014.
Aghaei J. and M.-I. Alizadeh. Demand response in smart electricity grids equipped with renewable energy sources: A review. Renewable and Sustainable Energy Reviews, 18, 64-72, 2013.
AHAM and ACEEE. Joint Petition to Energy Star to Adopt Joint Stakeholder Agreement as it Relates to Smart Appliances, 2011.
Akhil A.A., G. Huff, A.B. Currier, et al. DOE/EPRI Electricity Storage Handbook in Collaboration with NRECA. Sandia National Laboratories, 2015.
Alter L. "Thermostats are getting smarter, but it is still a dumb answer to the problem of saving energy." Retrieved 26/01/2017, 2017, from http://www.treehugger.com/sustainable-product-design/thermostats-are-getting-smarter-it-still-dumb-answer-problem-saving-energy.html.
Altshuller G. and L. Shulyak. And Suddenly the Inventor Appeared: TRIZ, the Theory of Inventive Problem Solving. Worcester, Technical Innovation Center, 1996.
Ashby M.F. and K. Johnson. Materials and Design: The Art and Science of Material Selection in Product Design. New York, Elsevier Science, 2013.
Badami V.V. and N.W. Chbat. Home appliances get smart. IEEE Spectrum, 35, 36-43, 1998.
Baines T.S., H.W. Lightfoot, S. Evans, et al. State-of-the-art in product-service systems. Proceedings of the Institution of Mechanical Engineers, Part B: Journal of Engineering Manufacture, 221, 1543-1552, 2007.
Bajpai P. and S.N. Singh. Electricity trading in competitive power market : An overview and key issues. International Conference on Power Systems, Kathmandu, Nepal, 2004.
Ballo I.F. Imagining energy futures: Sociotechnical imaginaries of the future Smart Grid in Norway. Energy Research & Social Science, 9, 9-20, 2015.
Balta-Ozkan N., B. Boteler and O. Amerighi. European smart home market development: Public views on technical and economic aspects across the United Kingdom, Germany and Italy. Energy Research & Social Science, 3, 65-77, 2014.
Barbero S. and A. Pereno. Systemic energy grids: A qualitative approach to smart grids. Sustainability, 6, 220-226, 2013.
Barnicoat G. and M. Danson. The ageing population and smart metering: A field study of householders' attitudes and behaviours towards energy use in Scotland. Energy Research & Social Science, 9, 107-115, 2015.
Behrangrad M. A review of demand side management business models in the electricity market. Renewable and Sustainable Energy Reviews, 47, 270-283, 2015.
Benzi F., N. Anglani, E. Bassi, et al. Electricity smart meters interfacing the households. IEEE Transactions on Industrial Electronics, 58, 4487-4494, 2011.
Bigerna S., C.A. Bollino and S. Micheli. Socio-economic acceptability for smart grid development – a comprehensive review. Journal of Cleaner Production, 131, 399-409, 2016.
Blessing L.T.M. and A. Chakrabarti. DRM, a Design Research Methodology. London, Springer-Verlag, 2009.
Bliek F., A. van de Noord, B. Roossien, et al. PowerMatching City, a living lab smart grid demonstration. IEEE ISGT Europe. Gothenburg, Sweden, 2010.
Boughnim N. and B. Yannou. Using blueprinting method for developing product-service systems. International Conference of Engineering Design (ICED). Melbourne, Australia, 2005.
Broman Toft M., G. Schuitema and J. Thøgersen. The importance of framing for consumer acceptance of the Smart Grid: A comparative study of Denmark, Norway and Switzerland. Energy Research & Social Science, 3, 113-123, 2014.
Buchanan K., N. Banks, I. Preston, et al. The British public's perception of the UK smart metering initiative: Threats and opportunities. Energy Policy, 91, 87-97, 2016.
Buijs J. Modelling product innovation processes, from linear logic to circular chaos. Creativity and Innovation Management, 12, 76-93, 2003.
Büscher C.H. and P. Sumpf. "Trust" and "confidence" as socio-technical problems in the transformation of energy systems. Energy, Sustainability and Society, 5, 1-13, 2015.

Cagan J. Creating Breakthrough Products: Innovation from Product Planning to Program Approval. Upper Saddle River, FT Press, 2002.
Cambini C., A. Meletiou, E. Bompard, et al. Market and regulatory factors influencing smart-grid investment in Europe: Evidence from pilot projects and implications for reform. Utilities Policy, *40, 36-47, 2016.*
CCMC. SG-CG/M490/L_Flexibility Management: Overview of the main concepts of flexibility management CEN-CENELEC-ETSI Smart Grid Coordination Group, 2014.
Cheng M., J. Wu, S. Galsworthy, et al. Availability of load to provide frequency response in the great Britain power system. Power Systems Computation Conference (PSCC), Wrocław, Poland, 2014.
Choudhury A., H. Chandra and A. Arora. Application of solid oxide fuel cell technology for power generation - A review. Renewable and Sustainable Energy Reviews, *20, 430-442, 2013.*
Connolly D., Mathiesen, B. V. A technical and economic analysis of one potential pathway to a 100% renewable energy system. International Journal of Sustainable Energy Planning and Management 1, 7-28, 2014.
Cooper S.J.G., G. Hammond and M. McManus. Performance implications of heat pumps and micro-cogenerators participating in demand side management. 3rd International Conference in Microgeneration and Related Technologies in Buildings: Microgen 3, Naples, Italy, 2013.
Covrig C.F., M. Ardelean, J. Vasiljevska, et al. Smart Grid Projects Outlook 2014. Joint Research Centre
Institute for Energy and Transpor, 2014.
Dalvi S.D., D. Chandrababu and V. Kumar. Design and development of smart electricity meter – the path towards sustainable globe. International Journal of Ambient Energy, *37, 348-353, 2016.*
de Groot R.J.W., F. van Overbeeke, A.J.M. Schouwenaar, et al. Smart storage in the Enexis LV distribution grid. 22nd International Conference on Electricity Distribution (CIRED2013), Stockholm, Sweden, 2013.
Debe M.K. Advanced Cathode Catalysts and Supports for PEM Fuel Cells. DOE Annual Merit Review Proceedings, 2012.
Desmet P.M.A. Designing Emotions. PhD Thesis, Delft University of Technology, Delft, 2002.
Deuten J.J., A. Rip and J. Jelsma. Societal embedding and product creation management. Technology Analysis & Strategic Management, *9, 131-148, 1997.*
DeWaters J.E. and S.E. Powers. Energy literacy of secondary students in New York State (USA): A measure of knowledge, affect, and behavior. Energy Policy, *39, 1699-1710, 2011.*
DNV-GL. Living and doing business in the energy world of tomorrow, pp 24, 2015.
DNV-KEMA. PowerMatching City: a living Smart Grid demonstration, 2013.
Döbelt S., M. Jung, M. Busch, et al. Consumers' privacy concerns and implications for a privacy preserving Smart Grid architecture—Results of an Austrian study. Energy Research & Social Science, *9, 137-145, 2015.*
e.onEnergy. "On Site Generation : Learn more about our onsite renewable energy generation technologies." from https://www.eonenergy.com/for-your-business/large-energy-users/manage-energy/on-site-generation.
EC. Technology Roadmap, 2010.
EC. Communication from the Commission to the European Parliament, the Council, the European Eco-nomic and Social Committee and the Committee of the Regions: Smart Grids: from innovation to deployment. European Commission, 2011a.
EC. Energy 2020 — A Strategy for Competitive, Sustainable and Secure Energy. European Commission, 2011b.
EC. Delivering a new deal for energy consumers. European Commission, 2015.
EC. Impact assessment support study on: "Policies for DSOs, Distribution Tariffs and Data Handling". European Commission, 2016.
ECME. The Functioning of Retail Electricity Markets for Consumers in the European Union: Final Report. Brussels. Directorate-General for Health & Consumers, 2009.
Ecorys. The role of DSOs in a Smart Grid environment. Netherlands. EU, 2014.
EG&G. Fuel Cell Handbook. Morgantown, U.S. Department of Energy, 2000.
Eger A., M. Bonneman, D. Lutters, et al. Productontwerpen, Lemma, 2004.
Eggink W. (2013). The Design and Styling of Future things. The Power of Design.
Eid C., E. Koliou, M. Valles, et al. Time-based pricing and electricity demand response: Existing barriers and next steps. Utilities Policy, *40, 15-25, 2016.*
ELIMA. Environmental Life Cycle Information Management and Acquisition for Consumer products. ELIMA, 2005.

Ellabban O. and H. Abu-Rub. Smart grid customers' acceptance and engagement: An overview. Renewable and Sustainable Energy Reviews, 65, 1285-1298, 2016.
ENEXIS. "Installatie Tesla Powerwalls gestart voor pilot Jouw Energie Moment 2.0 ". from https://www.enexis.nl/over-enexis/nieuws/Installatie-Tesla-Powerwalls-gestart-voor-pilot-Jouw-Energie-Moment-2-0.
EPEXSPOT. EPEX SPOT reaches in 2015 the highest spot power exchange volume ever. Press Release, 2016. https://www.apxgroup.com/wp-content/uploads/2016-01-08_EPEX-SPOT_2015_Annual-Press-Release-EN.pdf.
Esterl T., S. Kaser and A. Zani. Harmonization issues for cross-border balancing markets: Regulatory and economic analysis. International Conference on the European Energy Market, EEM, 2016-July, 2016.
ETP. Strategic Deployment Document for Europe's Electricity Networks of the Future. European Technology Platform Smart Grids 2010.
Fabrizio E., V. Branciforti, A. Costantino, et al. Monitoring and managing of a micro-smart grid for renewable sources exploitation in an agro-industrial site. Sustainable Cities and Society, 28, 88-100, 2017.
Faruqui A., D. Harris and R. Hledik. Unlocking the €53 billion savings from smart meters in the EU: How increasing the adoption of dynamic tariffs could make or break the EU's smart grid investment. Energy Policy, 38, 6222-6231, 2010.
Fell M.J., D. Shipworth, G.M. Huebner, et al. Public acceptability of domestic demand-side response in Great Britain: The role of automation and direct load control. Energy Research & Social Science, 9, 72-84, 2015.
Fernandes A., T. Woudstra, A. van Wijk, et al. Fuel cell electric vehicle as a power plant and SOFC as a natural gas reformer: An exergy analysis of different system designs. Applied Energy, 173, 13-28, 2016.
Friis F. and T. Haunstrup Christensen. The challenge of time shifting energy demand practices: Insights from Denmark. Energy Research & Social Science, 19, 124-133, 2016.
Galus M.D. Agent-based modeling and simulation of large scale electric mobility in power systems. Doctoral Thesis, ETH, Zürich, 2012.
Galus M.D. and G. Andersson. Balancing renewable energy source with vehicle to grid services from a large fleet of plug-in hybrid electric vehicles controlled in a metropolitan area distribution network. ELECTRA, 262, 4-11, 2012.
Galus M.D., S. Koch and G. Andersson. Provision of load frequency control by PHEVs, controllable loads, and a cogeneration unit. IEEE Transactions on Industrial Electronics, 58, 4568-4582, 2011.
Galus M.D., M.G. Vayá, T. Krause, et al. The role of electric vehicles in smart grids. Wiley Interdisciplinary Reviews: Energy and Environment, 2, 384-400, 2013.
Gangale F., A. Mengolini and I. Onyeji. Consumer engagement: An insight from smart grid projects in Europe. Energy Policy, 60, 621-628, 2013.
Garnier E. and R. Madlener. Day-Ahead Versus Intraday Valuation of Demand-Side Flexibility for Photovoltaic and Wind Power Systems. Aachen. RWTH Aachen University, 2014.
Geelen D. Empowering end-users in the energy transition: An exploration of products and services to support changes in household energy management. TUDelft, 2014.
Geelen D., A. Reinders and D. Keyson. Empowering the end-user in smart grids: Recommendations for the design of products and services. Energy Policy, 61, 151-161, 2013a.
Geelen D., A. Scheepens, C. Kobus, et al. Smart energy households' pilot projects in The Netherlands with a design-driven approach. IEEE PES ISGT Europe 2013, Copenhagen, IEEE, 2013b.
Geelen D., M. Vos-Vlamings, F. Filippidou, et al. An end-user perspective on smart home energy systems in the PowerMatching City demonstration project. IEEE PES ISGT Europe 2013, Copenhagen, IEEE, 2013c.
Geum Y. and Y. Park. Designing the sustainable product-service integration: a product-service blueprint approach. Journal of Cleaner Production, 19, 1601-1614, 2011.
Giordano V., F. Gangale, G. Fulli, et al. Smart Grid Projects in Europe - Lessons Learned and Current Developments. Luxembourg. European Commission, 2011.
Goedkoop M.J., C.J.G. van Halen, t.R.H. R.M., et al. Product Service systems, Ecological and Economic Basics, 1999.
Goulden M., B. Bedwell, S. Rennick-Egglestone, et al. Smart grids, smart users? The role of the user in demand side management. Energy Research & Social Science, 2, 21-29, 2014.
Green B. (2002). Pleasure with Products Beyond Usability - Introduction. Pleasure with Products Beyond Usability. W. S. G. a. P. W. Jordan. London, Taylor and Francis.

Grogan A. Smart appliances. Engineering & Technology, 7, 2, 2012.
Günther D., J. Wapler and M. Miara. Simulation and analysis of demand side management effects on operating behavior and efficiency of heat pump systems. 11th IEA Heat Pump Conference, Montréal (Québec), 2014.
Gupta R.B. Hydrogen Fuel: Production, Transport and Storage. 611, 2009.
Hara T., T. Arai, Y. Shimomura, et al. Service CAD system to integrate product and human activity for total value. CIRP Journal of Manufacturing Science and Technology, 1, 262-271, 2009.
Hargreaves T., M. Nye and J. Burgess. Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term. Energy Policy, 52, 126-134, 2013.
Hargreavesn T., M. Nye and J. Burgess. Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors. Energy Policy, 38, 9, 2010.
Hatley D.D., R.J. Meador, S. Katipamula, et al. Energy Management and Control System: Desired Capabilities and Functionality. Pacific Northwest National Laboratory, 2005.
He X., L. Hancher, I. Azevedo, et al. THINK Final Report: Shift, Not Drift: Towards Active Demand Response and Beyond. European University Institute, 2013.
Hiroux C. and M. Saguan. Large-scale wind power in European electricity markets: Time for revisiting support schemes and market designs? Energy Policy, 38, 3135-3145, 2010.
Hogan W.W. Time-of-Use Rates and Real-TimePrices, Harvard Kennedy School, 2014.
Honebein P.C., R.F. Cammarano and C. Boice. Building a Social Roadmap for the Smart Grid. The Electricity Journal, 24, 78-85, 2011.
Horne C., B. Darras, E. Bean, et al. Privacy, technology, and norms: the case of Smart Meters. Soc Sci Res, 51, 64-76, 2015a.
Horne C., B. Darras, E. Bean, et al. Privacy, technology, and norms: The case of Smart Meters. Social Science Research, 51, 64-76, 2015b.
Ida T., K. Murakami and M. Tanaka. A stated preference analysis of smart meters, photovoltaic generation, and electric vehicles in Japan: Implications for penetration and GHG reduction. Energy Research & Social Science, 2, 75-89, 2014.
IEA. Technology Roadmaps: Smart Grids. Paris. International Energy Agency, 2011.
IEA. World Energy Outlook. Paris. International Energy Agency, 2012.
IEC. IEC TR 61850-1:2003. Communication networks and systems in substations - Part 1: Introduction and overview 2003. https://webstore.iec.ch/publication/20071.
ISO. ISO 15118-3:2015. Road vehicles -- Vehicle to grid communication interface -- Part 3: Physical and data link layer requirements, 2015. http://www.iso.org/iso/catalogue_detail.htm?csnumber=59675.
IVT. "IVT PremiumLine HQ Bergvärmepump." from http://www.ivt.se/produkter/berg-jord-sjovarme/ivt-premiumline-hq/oversikt/.
Jacobsen R.H. and S.A. Mikkelsen. Infrastructure for intelligent automation services in the smart grid. Wireless Personal Communications, 76, 23, 2014.
Joo J. and L. Kim. Strategic Guidelines for the Diffusion of Smart Grid Technologies Through a Korean Testbed. Information Technology for Development, 22, 503-524, 2016.
Joore P. (2013). A Multilevel Design Model CLarifying the Mutual Relationship between New Products and Societal Change Processes. The Power of design. A. Reinders, J. C. Diehl and H. Brezet, Wiley.
Kessels K., C. Kraan, L. Karg, et al. Fostering Residential Demand Response through Dynamic Pricing Schemes: A Behavioural Review of Smart Grid Pilots in Europe. Sustainability, 8, 929, 2016.
Khan A.A., S. Razzaq, A. Khan, et al. HEMSs and enabled demand response in electricity market: An overview. Renewable and Sustainable Energy Reviews, 42, 13, 2015.
Khan A.R., A. Mahmood, A. Safdar, et al. Load forecasting, dynamic pricing and DSM in smart grid: A review. Renewable and Sustainable Energy Reviews, 54, 1311-1322, 2016.
Klaassen E.A.M., C.B.A. Kobus, J. Frunt, et al. Responsiveness of residential electricity demand to dynamic tariffs: Experiences from a large field test in the Netherlands. Applied Energy, 183, 1065-1074, 2016.
Kobus C.B.A., R. Mugge and J.P.L. Schoormans. Washing when the sun is shining! How users interact with a household energy management system. Ergonomics, 56, 451-462, 2013.
Kok J.K., B. Roossien, P.A. MacDougall, et al. Dynamic pricing by scalable energy management systems - Field experiences and simulation results using PowerMatcher. IEEE Power and Energy Society General Meeting 2012, San Diego (California), 2012.
Koliou E., C. Bartusch, A. Picciariello, et al. Quantifying distribution-system operators' economic incentives to promote residential demand response. Utilities Policy, 35, 28-40, 2015.
Koliou E., C. Eid, J.P. Chaves-Ávila, et al. Demand response in liberalized electricity markets: Analysis of aggregated load participation in the German balancing mechanism. Energy, 71, 245-254, 2014.

Krippendorff K. On the Essential Contexts of Artifacts or on the Proposition That "Design Is Making Sense (Of Things). Design Issues, *5, 9-39, 1989.*
Krishnamurti T., D. Schwartz, A. Davis, et al. Preparing for smart grid technologies: A behavioral decision research approach to understanding consumer expectations about smart meters. Energy Policy, *41, 790-797, 2012.*
Laitinen T., L. Penttinen, H. Sæle, et al. From Smart Meters to Smart Consumers. SmartRegions – Promoting best practices in innovative smart metering services to the European regions, 2013.
Lawrence T.M., M.-C. Boudreau, L. Helsen, et al. Ten questions concerning integrating smart buildings into the smart grid. Building and Environment, *108, 273-283, 2016.*
Lewis P.E., C. Dromacque, S. Brennan, et al. EMPOWER DEMAND 2. Energy Efficiency through Information and Communication Technology – Best Practice Examples and Guidance. VaasaETT Global Energy Think Tank, 2012.
Lilliestam J. and S. Ellenbeck. Energy security and renewable electricity trade—Will Desertec make Europe vulnerable to the "energy weapon"? Energy Policy, *39, 3380-3391, 2011.*
Lin K.-Y. and H.-P. Lu. Why people use social networking sites: An empirical study integrating network externalities and motivation theory. Computers in Human Behavior, *27, 10, 2011.*
Livieratos S.N., V.E. Vogiatzaki and P.G. Cottis. A generic framework for the evaluation of the benefits expected from the smart grid. Energies, *6, 988-1008, 2013.*
Lobaccaro G., S. Carlucci and E. Löfström. A review of systems and technologies for smart homes and smart grids. Energies, *9, 2016.*
Lombardi M., S. De Francisci, L. Pizzoferro, et al. Enel Info+ project: A demo to evaluate the impact of the consciousness on the customer energy consumptions. 22 International Conference on Electricity Distribution. Stockholm, 2013.
LomboXnet. "Smart Solar Charging. LomboXnet, met de snelheid van het licht en de kracht van de zon,." from http://www.lomboxnet.nl/smart-solar-charging*.*
Lopes M.A.R., C. Henggeler Antunes, K.B. Janda, et al. The potential of energy behaviours in a smart(er) grid: Policy implications from a Portuguese exploratory study. Energy Policy, *90, 233-245, 2016.*
Lucia U. Overview on fuel cells. Renewable and Sustainable Energy Reviews, *30, 164-169, 2014.*
Lund H., A.N. Andersen, P.A. Østergaard, et al. From electricity smart grids to smart energy systems – A market operation based approach and understanding. Energy, *42, 96-102, 2012.*
Lund P.D., J. Lindgren, J. Mikkola, et al. Review of energy system flexibility measures to enable high levels of variable renewable electricity. Renewable and Sustainable Energy Reviews, *45, 785-807, 2015.*
Machidon O.M. Societal Implications of Current and Emerging "Smart" Technologies. International Journal of Technoethics, *6, 60-70, 2015.*
Mah D.N.-y., J.M. van der Vleuten, P. Hills, et al. Consumer perceptions of smart grid development: Results of a Hong Kong survey and policy implications. Energy Policy, *49, 204-216, 2012.*
Mathiesen B.V., H.B. Lund, D. Connolly, et al. Smart Energy Systems for coherent 100% renewable energy and transport solutions. Applied Energy, *145, 6, 2015.*
McKenna E., I. Richardson and M. Thomson. Smart meter data: Balancing consumer privacy concerns with legitimate applications. Energy Policy, *41, 807-814, 2012.*
McLean A., H. Bulkeley and M. Crang. Negotiating the urban smart grid: Socio-technical experimentation in the city of Austin. Urban Studies, *53, 18, 2016.*
Melaina M.W., O. Antonia and M. Penev. Blending Hydrogen into Natural Gas Pipeline Networks: A Review of Key Issues. U.S. Department of Energy, Office of Energy Efficiency & Renewable Energy, 2013.
Michaels L. and Y. Parag. Motivations and barriers to integrating 'prosuming' services into the future decentralized electricity grid: Findings from Israel. Energy Research & Social Science, *21, 70-83, 2016.*
Moliner R., M.J. Lázaro and I. Suelves. Analysis of the strategies for bridging the gap towards the Hydrogen Economy. International Journal of Hydrogen Energy, *41, 19500-19508, 2016.*
Mont O.K. Clarifying the concept of product–service system. Journal of Cleaner Production, *10, 237-245, 2002.*
Moretti M., S.N. Djomo, H. Azadi, et al. A systematic review of environmental and economic impacts of smart grids. Renewable and Sustainable Energy Reviews, 2016.
Nagasawa K., C.R. Upshaw, J.D. Rhodes, et al. Data management for a large-scale smart grid demonstration project in Austin, Texas. ASME 2012 6th International Conference on Energy Sustainability. San Diego, 2012.

Naus J., G. Spaargaren, B.J.M. van Vliet, et al. Smart grids, information flows and emerging domestic energy practices. Energy Policy, 68, 436-446, 2014.
Naus J., B.J.M. van Vliet and A. Hendriksen. Households as change agents in a Dutch smart energy transition: On power, privacy and participation. Energy Research & Social Science, 9, 125-136, 2015.
Neuhoff K., J. Barquin, J.W. Bialek, et al. Renewable electric energy integration: Quantifying the value of design of markets for international transmission capacity. Energy Economics, 40, 760-772, 2013.
Niaz S., T. Manzoor and A.H. Pandith. Hydrogen storage: Materials, methods and perspectives. Renewable and Sustainable Energy Reviews, 50, 457-469, 2015.
Nicholls L. and Y. Strengers. Peak demand and the 'family peak' period in Australia: Understanding practice (in)flexibility in households with children. Energy Research & Social Science, 9, 116-124, 2015.
Niesten E. and F. Alkemade. How is value created and captured in smart grids? A review of the literature and an analysis of pilot projects. Renewable and Sustainable Energy Reviews, 53, 629-638, 2016.
Nikolaidis P. and A. Poullikkas. A comparative overview of hydrogen production processes. Renewable and Sustainable Energy Reviews, 67, 597-611, 2017.
Obinna U., P. Joore and e. al. Sustainable Development of Energy Products for Smart Grid Households. 1st South East European Conference on Sustainable development of Energy, Water and Environment Systems – SEE SDEWES. Ohrid, 2014.
Obinna U., P. Joore, L. Wauben, et al. Insights from stakeholders of five residential smart grid pilot projects in the Netherlands. Smart Grid and Renewable Energy, 7, 1-15, 2016.
Obinna U., P. Joore, L. Wauben, et al. Comparison of two residential Smart Grid pilots in the Netherlands and in the USA, focusing on energy performance and user experiences. Applied Energy, 191, 264-275, 2017.
OCHSNER. "SmartGrid: OCHSNER Wärmepumpen." from http://www.ochsner.com/de-de/die-waermepumpe/ochsner-technik/.
OCPP. Open Charge Point Protocol 1.6 (OCPP 1.6) 2016. http://www.openchargealliance.org/protocols/ocpp/ocpp-16/.
Ogunjuyigbe A.S.O., C.G. Monyei and T.R. Ayodele. Price based demand side management: A persuasive smart energy management system for low/medium income earners. Sustainable Cities and Society, 17, 80-94, 2015.
Orillaza J.R.C., L.B. Orillaza and A.L.J. Barra. Consumer acceptance of prepaid metering and consumer preferences. IEEE PES Asia-Pacific Power and Energy Engineering Conference (APPEEC), 2014.
Pahl G., W. Beitz, J. Feldhusen, et al. Engineering Design: A Systematic Approach, Springer London, 2007.
Palensky P., G. Zucker, F. Judex, et al. Demand response with functional buildings using simplified process models. IECON 2011 - 37th Annual Conference on IEEE Industrial Electronics Society, Melbourne, 2011.
Park C.-K., H.-J. Kim and Y.-S. Kim. A study of factors enhancing smart grid consumer engagement. Energy Policy, 72, 211-218, 2014.
Powells G., H. Bulkeley, S. Bell, et al. Peak electricity demand and the flexibility of everyday life. Geoforum, 55, 43-52, 2014.
PowerMatchingCity. "PowerMatchingcity: Resultaten fase 2." from http://www.powermatchingcity.nl/site/pagina.php?id=34.
PSP. Final Technology Performance Report. Pecan Street Smart Grid Demonstration Program, 2015.
Raimi K.T. and A.R. Carrico. Understanding and beliefs about smart energy technology. Energy Research & Social Science, 12, 68-74, 2016.
Rathnayaka A.J.D., V.M. Potdar, T. Dillon, et al. Goal-Oriented Prosumer Community Groups for the Smart Grid. IEEE Technology and Society Magazine, 33, 41-48, 2014.
Rathnayaka A.J.D., V.M. Potdar and S.J. Kuruppu. An innovative approach to manage prosumers in smart grid. 2011 World Congress on Sustainable Technologies, WCST 2011. London, pp 141-146, 2011.
Rawlings J., P. Coker, J. Doak, et al. Do smart grids offer a new incentive for SME carbon reduction? Sustainable Cities and Society, 10, 245-250, 2014.
Rebours Y. A Comprehensive Assessment of Markets for Frequency and Voltage Control Ancillary Services. Doctoral thesis, University of Manchester, Manchester, 2008.
Reinders A., J.C. Diehl and H. Brezet. The Power of Design: Product Innovation in Sustainable Energy Technologies, Wiley, 2013.

Reinders A., M.d. Respinis, J.v. Loon, et al. Co-evolution of smart energy products and services: A novel approach towards smart grids. 2016 Asian Conference on Energy, Power and Transportation Electrification (ACEPT), Singapore, 2016.
Rekik M., Z. Chtourou, N. Mitton, et al. Geographic routing protocol for the deployment of virtual power plant within the smart grid. Sustainable Cities and Society, *25, 39-48, 2016.*
Rhodes J.D., C.R. Upshaw, C.B. Harris, et al. Experimental and data collection methods for a large-scale smart grid deployment: Methods and first results. Energy, *65, 462-471, 2014.*
RVO. Your Energy Moment. Smart Grid with Consumer Participation. Netherlands Enterprise Agency, 2015.
Scharff R. Design of Electricity Markets for Efficient Balancing of Wind Power Generation. Doctoral thesis, KTH, Stockholm, 2015.
Schick L. and C. Gad. Flexible and inflexible energy engagements—A study of the Danish Smart Grid Strategy. Energy Research & Social Science, *9, 51-59, 2015.*
Schifferstein H.N.J. and P. Hekkert. Product Experience. Amsterdam, Elsevier, 2008.
Shaheen S., D. Sperling and C. Wagner. Carsharing in Europe and North American: Past, Present, and Future, 1998.
Silva V., L. Glorieux, C. Kieny, et al. Estimation of innovative operational processes and grid management for the integration of EV 2011.
Skjølsvold T.M. Back to the futures: Retrospecting the prospects of smart grid technology. Futures, *63, 26-36, 2014.*
Sonnenschein M., O. Lünsdorf, J. Bremer, et al. Decentralized control of units in smart grids for the support of renewable energy supply. Environmental Impact Assessment Review, *52, 40-52, 2015.*
Souchkov V. (2013). Technology Roadmapping. The Power of Design. A. Reinders, J. C. Diehl and H. Brezet, Wiley.
Stadler M., G. Cardoso, S. Mashayekh, et al. Value streams in microgrids: A literature review. Applied Energy, *162, 980-989, 2016.*
Stedin. "Hoog Dalem an all-electric wijk." from https://www.stedin.net/over-stedin/projecten/hoog-dalem.
Stephens J., E. Wilson, T. Peterson, et al. Getting Smart? Climate Change and the Electric Grid. Challenges, *4, 201, 2013.*
Stifter M., R. Kamphuis, M. Galus, et al. IEA DSM Task 17: Roles and Potentials of Flexible Consumers and Prosumers. IEA DSM 2016.
Stifter M. and S. Ubermasser. Dynamic simulation of power system interaction with large electric vehicle fleet activities. PowerTech (POWERTECH), 2013 IEEE Grenoble, 2013.
Stragier J., J. Derboven, L. Laporte, et al. Kilowhat? A multidisciplinary approach on the development of a home energy management system. Behaviour & Information Technology, *32, 1086-1104, 2013.*
Stragier J., L. Hauttekeete and L. De Marez. Introducing smart grids in residential contexts: Consumers' perception of smart household appliances. Innovative Technologies for an Efficient and Reliable Electricity Supply (CITRES), Boston, 2010.
Swaminathan S. and T. Ting. Customer Focused Approach to Implementing Smart Grid Applications for Publicly Owned Utilities. The Electricity Journal, *26, 79-83, 2013.*
Tukker A. and U. Tischner. New Business for Old Europe. Product-Service Development, Competitiveness and Sustainability, Greenleaf Publishing Ltd, 2006.
Ubermasser S. and M. Stifter. A multi-agent based approach for simulating G2V and V2G charging strategies for large electric vehicle fleets. CIRED 2013. 22nd International Conference and Exhibition on Electricity Distribution, Stockholm, 2013.
UCTE. P1 – Policy 1: Load-Frequency Control and Performance [C]. Union for the Coordination of the Transmission of Electricity, pp 18, 2009.
Ueno T., F. Sano, O. Saeki, et al. Effectiveness of an energy-consumption information system on energy savings in residential houses based on monitored data. Applied Energy, *83, 18, 2005.*
USDE. Benefits of demand response in electricity markets and recommendations for achieving them. U.S. Department of Energy, 2006.
USEF. USEF: The Framework Explained, 2015.
van Dam S. Smart Energy Management for Households. A practical guide for designers, HEMS developers, energy providers, and the building industry. Delft, CreateSpace Independent Publishing Platform, 2013.
van Dam S.S., C.A. Bakker and J.D.M. van Hal. Home energy monitors: impact over the medium-term. Building Research & Information, *38, 458-469, 2010.*

van Dam S.S., C.A. Bakker and J.D.M. Van Hal. Insights into the design, use and implementation of home energy management systems. Journal of Design Research, *10, 86-101, 2012.*
Van Vliet B., E. Shove and H. Chappells. Infrastructures of Consumption: Environmental Innovation in the Utility Industries, Taylor & Francis, 2012.
van Wijk A. Welcome to the green village. 2013.
van Wijk A. and L. Verhoef. Our Car as Power Plant. Stand Alone107, 2014.
Ventosa M., P. Linares and I.J. Pérez-Arriaga. Power System Economics. Power Systems, *61, 47-123, 2013.*
Verbong G.P.J., S. Beemsterboer and F. Sengers. Smart grids or smart users? Involving users in developing a low carbon electricity economy. Energy Policy, *52, 117-125, 2013.*
Vesnic-Alujevic L., M. Breitegger and Â.G. Pereira. What smart grids tell about innovation narratives in the European Union: Hopes, imaginaries and policy. Energy Research & Social Science, *12, 16-26, 2016.*
Wang Q., C. Zhang, Y. Ding, et al. Review of real-time electricity markets for integrating Distributed Energy Resources and Demand Response. Applied Energy, *138, 695-706, 2015.*
Watson J. Co-provision in sustainable energy systems: The case of micro-generation. Energy Policy, *32, 1981-1990, 2004.*
Weck M.H.J., J. van Hooff and W.G.J.H.M. van Sark. Review of barriers to the introduction of residential demand response : a case study in the Netherlands. International Journal of Energy Research., 2016.
Wijbenga J.P., P. MacDougall, R. Kamphuis, et al. Multi-goal optimization in PowerMatching city: A smart living lab. IEEE PES Innovative Smart Grid Technologies Conference Europe. Istanbul, IEEE Computer Society, 2015.
Wilkenfeld G. Appliances Get Smart: But how and when? CLASP, 2014.
Wimmer R., M.J. Kang, U. Tischner, et al. Erfolgsstrategien für Produkt-Dienstleistungssysteme Vienna. Berichte aus Energie- und Umweltforschung, 2008.
Wind J. Hydrogen-fueled road automobiles – Passenger cars and buses. Compendium of Hydrogen Energy. M. Ball, A. Basile and T. N. Veziroglu, Elsevier Ltd. 4, 2016.
Wissner M. The Smart Grid – A saucerful of secrets? Applied Energy, *88, 2509-2518, 2011.*
Wolsink M. 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, 2012.*
Wu Y.J., P. Li, J.G. Yu, et al. Progress on sorption-enhanced reaction process for hydrogen production. Reviews in Chemical Engineering, *32, 271-303, 2016.*
Yunus A.R., F. Abu, J. Jabar, et al. Empowering smart customer to participate in electricity supply system. Australian Journal of Basic and Applied Sciences, *9, 85-94, 2015.*
Zakeri B. and S. Syri. Electrical energy storage systems: A comparative life cycle cost analysis. Renewable and Sustainable Energy Reviews, *42, 569-596, 2015.*
Zhang F., P. Zhao, M. Niu, et al. The survey of key technologies in hydrogen energy storage. International Journal of Hydrogen Energy, *41, 14535-14552, 2016.*
Zhang X., S.H. Chan, H.K. Ho, et al. Towards a smart energy network: The roles of fuel/electrolysis cells and technological perspectives. International Journal of Hydrogen Energy, *40, 6866-6919, 2015.*
Zhou B., W. Li, K.W. Chan, et al. Smart home energy management systems: Concept, configurations, and scheduling strategies. Renewable and Sustainable Energy Reviews, *61, 11, 2016.*
Zottl A. and H. Huber. Analyse Anlagenplanung/Monitoring erdreichgekoppelter Wärmepumpenanlagen mit Erdwärmesonden. 10. Internationales Anwenderforum Oberflächennahe Geothermie - Erdgekoppelte Wärmepumpen und unterirdische thermische Energiespeicher, Regensburg, 2009.

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