Lappeenranta
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Salla Annala

HOUSEHOLDS' WILLINGNESS TO ENGAGE IN DEMAND RESPONSE IN THE FINNISH RETAIL ELECTRICITY MARKET: AN EMPIRICAL STUDY

Thesis for the degree of Doctor of Science (Technology) to be presented with due permission for public examination and criticism in the Auditorium 1382 at Lappeenranta University of Technology, Lappeenranta, Finland on the 2nd of October, 2015, at noon.

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ABSTRACT

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If electricity users adjusted their consumption patterns according to time-variable electricity prices or other signals about the state of the power system, generation and network assets could be used more efficiently, and matching intermittent renewable power generation with electricity demand would be facilitated. This kind of adjustment of electricity consumption, or demand response, may be based on consumers' decisions to shift or reduce electricity use in response to time-variable electricity prices or on the remote control of consumers' electric appliances. However, while demand response is suggested as a solution to many issues in power systems, actual experiences from demand response programs with residential customers are mainly limited to short pilots with a small number of voluntary participants, and information about what kinds of changes consumers are willing and able to make and what motivates these changes is scarce.

This doctoral dissertation contributes to the knowledge about what kinds of factors impact on residential consumers' willingness and ability to take part in demand response. Saving opportunities calculated with actual price data from the Finnish retail electricity market are compared with the occurred supplier switching to generate a first estimate about how large savings could trigger action also in the case of demand response. Residential consumers' motives to participate in demand response are also studied by a web-based survey with 2103 responses. Further, experiences of households with electricity consumption monitoring systems are discussed to increase knowledge about consumers' interest in getting more information on their electricity use and adjusting their behavior based on it. Impacts of information on willingness to participate in demand response programs are also approached by a survey for experts of their willingness to engage in demand response activities.

Residential customers seem ready to allow remote control of electric appliances that does not require changes in their everyday routines. Based on residents' own activity, the electricity consuming activities that are considered shiftable are very limited. In both cases, the savings in electricity costs required to allow remote control or to engage in demand response activities are relatively high. Nonmonetary incentives appeal to fewer households.

Keywords: demand response, electricity market, residential customer, load control, acceptability, supplier switching, consumption monitoring

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List of publications

This doctoral dissertation consists of an introductory section (Part I) and the publications listed below (Part II).

I Annala, S., Viljainen, S., and Tuunanen, J. (2013), Rationality of supplier switching in retail electricity markets, *International Journal of Energy Sector Management*, vol. 7, No. 4, pp. 459–477.

II Annala, S., Viljainen, S., and Tuunanen, J. (2012), Demand response from residential customers' perspective, in *EEM 12, 9th International Conference on the European Energy Market*, Florence, Italy.

III Annala, S., Viljainen, S., Pakkanen, M., and Hukki, K., Consumer preferences in engaging in a sustainable lifestyle, *International Journal of Innovation and Sustainable Development*, in press.

IV Annala, S., Viljainen, S., Tuunanen, J., and Honkapuro, S. (2014), Does knowledge contribute to the acceptance of demand response?, *Journal of Sustainable Development of Energy, Water and Environment Systems*, Vol. 2, No. 1, pp. 51–60.

Nomenclature

CPP	critical peak pricing
CPR	critical peak rebate
CPU	central processing unit
DLC	direct load control
DSM	demand-side management
DSO	distribution system operator
EU	European Union
IHD	in-home display
kWh	kilowatt-hour
LMP	locational marginal price
MW	megawatt
NO_x	nitrogen oxide
$PM_{2.5}$	particulate matter less than 2.5 micrometer in diameter
PTR	peak time rebate
PV	photovoltaic
RTP	real-time pricing
SGEM	Smart Grids and Energy Markets
SO_2	sulphur dioxide
TOU	time of use
TSO	transmission system operator
€ct	euro cent

PART I: OVERVIEW OF THE DISSERTATION

1 Introduction

Consumers are expected to take a larger role in the future power systems by adjusting their electricity consumption based on price signals and other incentives in order to facilitate efficient use of generation and network infrastructure and functioning of electricity markets. These expectations add to the increasing emphasis of consumers' role in the power system initiated by the opening of retail electricity markets. This doctoral dissertation aims to increase knowledge about the factors that promote residential electricity users' willingness and ability to modify the timing and level of their electricity consumption and about the factors that may act as barriers to such changes.

Traditionally, the electricity generation and network assets were scaled to meet the expected maximum demand, and the generation was controlled according to the fluctuating demand to keep the system in balance. Such planning and operation principles may lead to inefficiencies, if the system has to be sized to meet very short demand peaks. Further, increasing amounts of uncontrollable and intermittent generation such as wind and solar power are being connected to the power system. Demand response may both facilitate the efficient use of generation and network assets and help take advantage of renewable power generation. In the US, the Federal Energy Regulatory Commission (FERC 2012, p. 21) defines demand response as:

> "Changes in electric use by demand-side resources from their normal consumption patterns in response to changes in the price of electricity, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."

The European Commission (2013, p. 3) uses a similar definition:

> "voluntary changes by end-consumers of their usual electricity use patterns – in response to market signals (such as time-variable electricity prices or incentive payments) or following the acceptance of consumers' bids (on their own or through aggregation) to sell in organized energy electricity markets their will to change their demand for electricity at a given point in time."

Both the aforementioned definitions highlight the financial incentives as the motive for electricity users to adjust their consumption. Thus, participating customers may benefit by lower electricity bills. Additionally, if demand response results in a lower wholesale market price, also nonparticipants may enjoy lower electricity costs (U.S. Department of Energy 2006). Demand response reduces generators' opportunities to use market power in wholesale electricity markets if high prices lead to demand reductions (U.S. Department of Energy 2006). The power plants needed to cover the peak demand may be less efficient and more polluting than other power plants, and thus, reducing demand peaks may also reduce pollutant emissions. For example, Gilbraith and Powers (2013) modeled how residential demand response would decrease NO_x, $PM_{2.5}$, and SO_2 emissions in New York City. Another possible environmental benefit of demand response is that it could help match the often intermittent renewable energy sources such as wind and solar power with demand and reduce the costs of integrating renewable power to the power system. For example, Madaeni and Sioshansi (2013) modeled how demand response would reduce the costs of wind integration. In addition to the efficient resource use, avoided or deferred infrastructure investments (e.g. power plants and transmission and distribution lines) may lead to more efficient land use (Albadi 2007). Further, demand response may also contribute to the power system reliability by providing reserve and regulation (Kirby 2007). For a more comprehensive review about the benefits of demand response, see for instance O'Connell et al. (2014).

From an economic point of view, the value of demand response may be formed in several ways. Figure 1.1 illustrates the benefits and marketplaces of demand response from Finnish stakeholders' viewpoint.

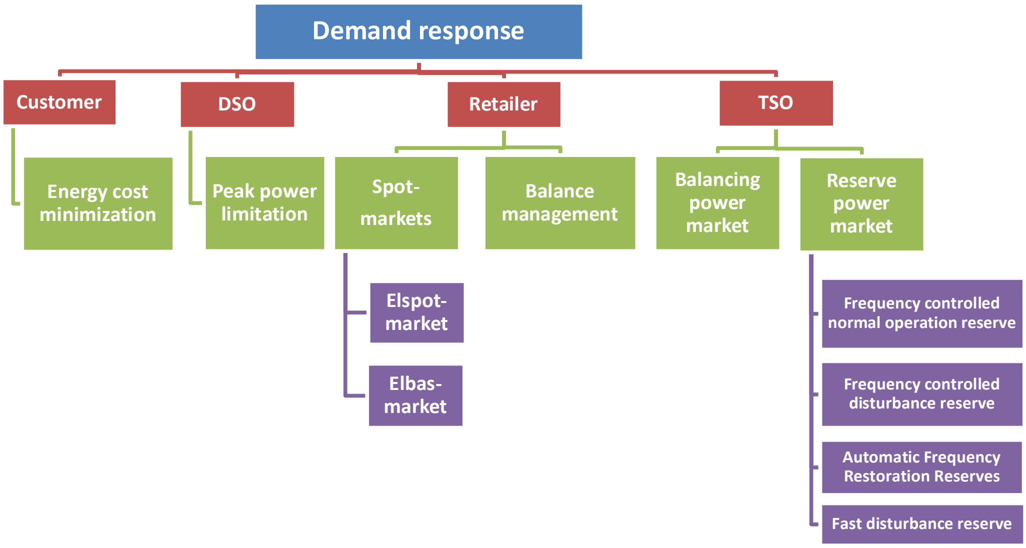

Figure 1.1 Benefits and marketplaces of demand response (Honkapuro et al. 2015)

In Finland, retail suppliers (and large end-users) can take demand response into account in their bids to the Nord Pool Spot Market. Further, they can apply demand response in their balance management. Additionally, flexible demand can be offered to the balancing power and reserve power markets maintained by the Finnish TSO Fingrid.

1.1 From demand-side management to demand response

Programs that aim to alter the timing and level of electricity consumption are not a new concept. Already in the 1980s almost half of the US electric utilities were engaged in some form of demand-side management (Gellings 1985). According to Gellings (1985), demand-side management (DSM) refers to the planning, implementation, and monitoring of activities that aim to change an utility's load shape (e.g. timing and magnitude) by influencing customers' electricity use. DSM programs aim to reduce electricity demand during peak times (peak clipping programs), to increase off-peak consumption (valley filling programs), or to change the time of use from high-cost periods to low-cost periods (load shifting programs) (Barakat & Chamberlin 1993). Additionally, DSM programs include programs to reduce (strategic conservation programs) or increase (strategic load growth programs) consumption year-round or seasonally (Barakat & Chamberlin 1993). The objectives of DSM programs encompass better reliability, lower costs and electricity bills, and a reduced need for generation investments (Barakat & Chamberlin 1993). The concepts of DSM and demand response are closely linked. DSM is, however, a wider concept and it can be said to cover both demand response and energy efficiency

(North American Electric Reliability Corporation 2007). Thus, measures to permanently reduce electricity consumption are not considered a part of demand response.

In open electricity markets, the use of demand response comes with a risk of conflict of interest between different parties. For example, controlling loads based on spot prices may lead to higher peak loads in networks (Belonogova et al. 2013, Honkapuro et al. 2015). On the other hand, for retail suppliers there is a risk of higher imbalance costs if other parties control the consumption of their customers (Honkapuro et al. 2015).

1.2 Smart meters

For now, a majority of small electricity users buy electricity under flat tariffs that do not provide them with incentives to adjust their electricity consumption according to the fluctuating wholesale power prices, availability of renewable generation, or congestion in electricity networks. However, the roll-out of smart meters that is under consideration or implementation in many countries (and already implemented in some countries including Finland) enables to provide more sophisticated tariff structures also to smaller customers such as households.

Inside the European Union (EU), Directive 2009/72/EC concerning common rules for the internal market in electricity required the member states to conduct a cost-benefit analysis of the implementation of smart metering systems by 3 September 2012. If the outcome of the analysis was positive, 80% of consumers should be equipped with smart meters by 2020. Based on the cost-benefit analyses, large-scale roll-out of smart electricity meters will be implemented (or has already been implemented) in 16 Member States by 2020 (European Commission 2014a). Smart meters are expected to help households reduce their energy consumption and to allow them to adjust their electricity consumption according to market price fluctuations that may reduce their energy costs (European Commission 2012). According to the European Commission (2011, p. 2), smart meters are an essential part of smart grids, which in turn are described as “the backbone of the future decarbonized power system.” Directive 2009/72/EC does not define the concept of smart meter. However, Directive 2012/27/EU on energy efficiency that elaborates on the requirements related to smart meters defines a smart metering system as

> “an electronic system that can measure energy consumption, providing more information than a conventional meter, and can transmit and receive data using a form of electronic communication.”

In addition, meters installed based on Directive 2009/72/EC must provide end-users with information on actual time of use (Directive 2012/27/EU).

1.3 Demand response and energy policies

Directive 2012/27/EU (p. 7) describes demand response as “an important instrument for improving energy efficiency” and as “a mechanism to reduce or shift consumption, resulting in energy savings in both final consumption and, through the more optimal use of networks and generation assets, in energy generation, transmission, and distribution.” The directive requires the EU Member States to ensure that electricity transmission and distribution tariffs do not include incentives that could hinder demand response resources from participating in balancing and ancillary services markets and that demand response providers are not discriminated in these markets. Network tariffs must enable improvement of consumer participation in system efficiency. Additionally, participation of demand response in the wholesale and retail markets and the system services markets (e.g. balancing, reserve) must be encouraged. The directive thus facilitates participation of demand response resources in the electricity markets but does not set specific demand response targets. Such goals are not set in other EU legislation either.

However, demand response could be an important tool in helping the EU to reach its climate and energy targets. In 2007, the European Council agreed to reduce greenhouse gas emissions by at least 20% compared with the 1990 level by 2020, to reduce energy consumption by 20% compared with the estimations of 2020 consumption, and to cover 20% of energy consumption with renewable energies by 2020 (European Council 2007). In October 2014, the Council set more rigorous targets for 2030. According to the Council, in 2030 the greenhouse gas emissions should be 40% lower than in 1990, the proportion of renewable energy of the EU energy consumption should be at least 27%, and energy consumption should be reduced by at least 27% compared with 2030 projections (European Council 2014). Additionally, a communication from the European Commission (2014b) stated that in the electricity sector the share of renewables should be at least 45% in 2030.

Further, according to the European Commission (2013), better use of the currently underexploited demand response potential can help save tens of billions of euros by 2020 as a result of avoided generation investments to cover the peak demand, lower network capacity requirements, and lower electricity bills for customers. Additionally, demand response is described as “an integral part of a consumer-centric retail market vision in the energy sector” (European Commission 2013,

p. 4). Demand response and time-variable electricity pricing are seen as part of consumer empowerment and broadening of consumer choice in the internal energy market (European Commission 2012, 2013).

Unlike in the EU, where demand response is not a goal per se but a tool to reach other goals, in the US, some states have set specific goals for peak demand reduction and demand response (see Gogte et al. 2013). For example, the California Public Utilities Commission set in 2003 a goal to meet five percent of system peak demand by 2007 through demand response (the amount achieved through emergency programs not included) (California Public Utilities Commission, 2003). However, in 2007, less than half of the targeted price-responsive demand response had been achieved (California Energy Commission, 2007). The participation in the price-responsive demand response has remained below the target level, and according to the California Energy Commission (2013, p. 63), most of the large commercial and industrial customers that were defaulted to critical peak pricing have opted out whereas for residential customers time-variable prices are “optional and largely undersubscribed.”

1.4 Outline of the work

This doctoral dissertation consists of an introductory part (Part I) and four scientific publications (Part II). This dissertation focuses on demand response from the residential consumers’ point of view. Thus, the literature reviewed in Part I of this dissertation and the scientific publications comprising Part II present the views of residential consumers and do not necessarily reflect the views of larger electricity users. Furthermore, the dissertation considers demand response incentives included in electricity tariffs but not any possible inconsistent or conflicting incentives in suppliers’ and DSOs’ tariffs.

The introductory part is organized as follows. Chapter 2 discusses the objectives of electricity retail market opening and experiences from open electricity markets. Chapter 3 presents different demand response program types. Examples about how time-variable pricing has affected residential electricity demand are also given. Further, previous studies on consumers’ views on time-variable pricing and willingness and ability to shift electricity consumption are reviewed. Chapter 4 describes the research questions and design. Chapter 5 gives an overview of the publications included in Part II of this dissertation. Chapter 6 concludes the dissertation. Next, the function of the scientific publications that form Part II is introduced in brief.

Publication 1 *Rationality of supplier switching in retail electricity markets (2013)*
Publication 1 aims to enhance understanding on saving opportunities required to trigger electricity supplier switching and on other factors that affect switching activity in the electricity market. The publication demonstrates by calculations how much residential customers could have saved in their electricity costs if they had switched away from their incumbent supplier in 2007–2010. The saving opportunities are then compared with the occurred switching rates to form a preliminary estimate about how large monetary incentives could trigger action also in the case of demand response. The present author analyzed the price data and wrote most of the article. The coauthors provided comments on the manuscript.

Publication 2 *Demand response from residential customers' perspective (2012)*
Publication 2 presents the results of a web-based survey that concerned residential customers' willingness to allow remote control of their electric appliances. The objective of the publication is to increase knowledge about the triggers and barriers of residential demand response. Required monetary incentives are discussed as well as other motives to participate in demand response. The present author analyzed the survey responses and wrote most of the article. The author planned the survey together with the coauthors and Vantaa Energy. The coauthors provided comments on the manuscript.

Publication 3 *Consumer preferences in engaging in a sustainable lifestyle (in press)*
Publication 3 aims to increase knowledge about how residential consumers interact with consumption monitoring systems and other solutions that aim to increase sustainability of living. It canvasses residents' experiences from an apartment house with several ecological features (e.g. consumption monitoring systems for electricity and water use, solar panels, shared-use electric vehicle). Residential consumers' interaction with ecological technologies and other sustainable solutions and willingness to monitor and adjust their consumption based on increased awareness of their consumption are discussed. The present author wrote most of the article and reflected on the experiences of the residents against behavior theories. The coauthors provided comments on the manuscript.

Publication 4 *Does knowledge contribute to the acceptance of demand response? (2014)*
Publication 4 further elaborates on the impact of increased knowledge on willingness to participate in demand response activities. The publication is based on an expert survey conducted in a workshop of the research program Smart Grids and Energy Markets (SGEM). Its objective

is to consider whether people well aware of the concept and benefits of demand response are willing to engage in demand response activities and what motivates them to participate. The present author analyzed the survey responses and wrote most of the article. The author planned the survey together with the coauthors. The coauthors provided comments on the manuscript.

2 Electricity retail market opening

In traditional power systems, electricity was sold to end-users by vertically integrated utilities that held geographic monopolies on supply and distribution of electricity. These utilities were typically owned by states or municipalities. Alternatively, they were private and their prices and entry to the market were regulated (Joskow 2006).

The performance of the electricity sector varied across countries and within countries (Joskow 2006). Large differences in electricity prices were seen as a proof of the failure of regulation in delivering low prices (Beato and Fuente 1999, Rothwell and Gómez 2003), and for example in the US, the interest in reforming the electricity sector started from the states with the highest retail electricity prices and the largest gaps between the wholesale and retail prices (Joskow 2003). Regardless of the pre-market opening price level, an overarching goal across the different countries and regions that have restructured their electricity sector has been to improve the efficiency of the sector and lower electricity prices for the consumers (see e.g. Rothwell and Gómez 2003, Crow 2001, Joskow 2006). While competition was believed to boost efficiency in electricity generation and supply, such benefits were not believed to occur in the networks, and therefore, electricity networks were kept as regulated monopolies. The approaches to the regulation of retail prices after market opening have varied. In some countries, the retail tariffs were not regulated at any point after market opening, in some they were regulated until the level of competition was considered adequate, and finally, in many countries retail prices are still regulated years after market opening. The regulated prices are often considered a barrier to competition in electricity markets and also to the provision of demand response incentives to consumers.

In addition to providing consumers with low-cost electricity, retail competition was expected to stimulate development of new retail products, innovative technologies, and differentiation of service quality to meet consumers' individual preferences (Joskow 2006, Anderson 2009). Competing retail suppliers were also expected to contribute to the increase in competition in the wholesale market (Joskow 2006). Other aims of market opening have included reduction of cross-subsidization between different types of customers and a need to attract private investments to the sector (Beato and Fuente 1999, Crow 2001, Rothwell and Gómez 2003). Further, the electricity sector restructuring and market opening were in some countries related to a wider tendency towards privatization and reduction of government's role in the national economy

(Crow 2001). In the EU Member States, the market opening was also related to the target of the EU internal market.

Larger customers have typically more actively taken their opportunity to switch electricity supplier than households. Some electricity market specialists have questioned the benefits of retail competition for small customers. For example according to Joskow (2006, p. 26), “it is far from obvious” that households and small commercial customers are better off under retail competition than they would be in a regime where the distribution company would buy them electricity by compiling a portfolio of short-term forward contracts in the wholesale market as there is no evidence that retail suppliers would have provided customers with significant value-added services.

2.1 EU Member States

In the EU Member States, the first electricity market directive 96/92/EC imposed the right to choose electricity supplier to large electricity end-users. The directive described electricity market opening as “an important step towards completion of the internal energy market”, which was related to a wider goal of an EU internal market with free movement of goods, services, capital, and people. The internal electricity market was expected to increase the efficiency of electricity generation, transmission, and distribution and to reinforce the security of supply and competitiveness of the European economy.

The subsequent electricity market directive 2003/54/EC required that from 1 July 2004 all nonresidential customers and from 1 July 2007 all customers had to be able to freely choose their electricity supplier as “the freedoms which the Treaty guarantees European citizens – free movement of goods, freedom to provide services and freedom of establishment – are only possible in a fully open market, which enables all consumers freely to choose their suppliers and all suppliers freely to deliver to their customers.”

For example Great Britain, Finland, and Sweden had implemented full electricity market opening already in the 1990s, as had also Norway (which is not a member of the EU). However, many of the EU Member States opened their markets in full only in 2007. In 2013, the average switching rate for residential electricity customers in the EU Member States was slightly less than 6% (ACER and CEER 2014). The switching rates exceeded 10% in Portugal, Belgium, the Netherlands, Spain, Great Britain, Ireland, Sweden, and Norway (ACER and CEER 2014).

Table 2.1 presents the timetable of full market opening in the EU Member States. The table also shows the switching rates of residential customers in 2013 and whether the retail prices for residential customers were regulated in 2014. Further, the table presents whether a decision about a large-scale (at least 80% of customers) roll-out of smart meters by 2020 was made by July 2013.

Table 2.1 Market opening, switching, and regulation of prices and smart metering in EU28 and Norway

Country	Full market opening[a]	Switching rates for residential customers in 2013[b]	Residential retail price regulation in 2014[c]	Smart meter roll-out by 2020[d]
Austria	2001	2%	No	Yes
Belgium	2007	15%	No	No
Bulgaria	Households and small businesses not yet eligible		Yes	No decision yet
Croatia	2008	0%	Yes	
Cyprus	Formally 1st of January 2014, only one retail supplier		Yes	No decision yet
Czech Republic	2006	6%	No	No
Denmark	2003	6%	Yes	Yes
Estonia	2013	0%	Yes	Yes
Finland	1997	7%	No	Yes
France	2007	2%	Yes	Yes
Germany	1998	6%	No	Selective
Great Britain	1999	12%	No	Yes
Greece	2007	0%	No	Yes
Hungary	2007	0%	Yes	No decision yet
Ireland	2005	11%	No	Yes
Italy	2007	8%	No	Yes
Latvia	2007	0%	Yes	Selective
Lithuania	2007	0%	Yes	No
Luxembourg	2007	0%	No	Yes
Malta	Market opening requirement not applied to Malta		Yes	Yes
Netherlands	2004	13%	No	Yes

Country	Full market opening[a]	Switching rates for residential customers in 2013[b]	Residential retail price regulation in 2014[c]	Smart meter roll-out by 2020[d]
Norway	1995	15%	No	Yes
Poland	2007	1%	Yes	Yes – Official decision pending
Portugal	2006	27%		No
Romania	2007	0%	Yes	Yes – Official decision pending
Slovakia	2007	4%	Yes	Selective
Slovenia	2007	4%	No	No decision yet
Spain	2003	13%	Yes	Yes
Sweden	1999	11%	No	Yes

[a] E-Control 2005, CREG 2008, SEWRC 2014, Croatian Energy Regulatory Agency 2008, European Commission 2014c, ERO 2007, Estonian Competition Authority 2014, Bundesministerium für Wirtschaft und Arbeit et al. 2005, RAE 2008, Hungarian Energy Office 2008, CER 2005, Autorità per l'energia elettrica e il gas 2008, Public Utilities Commission 2008, National Control Commission for Prices and Energy 2008, ILR 2011, Malta Resources Authority 2014, DTe 2005, Energy Regulatory Office of Poland 2008, Romanian Energy Regulatory Authority 2008, Entidade Reguladora Dos Serviços Energéticos 2008, URSO 2008, Annala and Viljainen 2008

[b] ACER and CEER 2014

[c] European Commission 2014c

[d] European Commission 2014d, Norwegian Water Resources and Energy Directorate 2014

The figures in the third column (switching rates) were estimated from a graph, thus small deviations (+/- 1 percentage point at the most) are possible.

2.2 Other open electricity markets

In the US, policies concerning retail electricity markets vary between states. By autumn 2013, 23 states and the District of Columbia had opened their residential electricity markets to competition (U.S. Energy Information Administration 2013). Texas has a mandatory retail choice program and thereby the highest proportion of customers among retail choice in the US (U.S. Energy Information Administration 2013). In 2012, the states with the highest participation in voluntary residential retail choice programs were Connecticut, Ohio, and Pennsylvania (U.S. Energy Information Administration 2013).

Further, the retail energy markets in New Zealand and Australia are among the most active in the world (VaasaETT 2013). In New Zealand, households have been able to switch electricity supplier since 1999 (Electricity Authority 2013). In Australia, Victoria, New South Wales, South Australia, and the Australian Capital Territory achieved full retail contestability in 2003 and Queensland in 2007 (Australian Energy Regulator 2009). In Tasmania, full retail contestability was introduced in July 2014 (Australian Energy Regulator 2014).

2.3 Finnish retail electricity market

Market opening

The opening of the Finnish electricity market was enacted in the first Electricity Market Act 386/1995 and the Electricity Market Decree 518/1995. The Government proposal 138/1994 for the Electricity Market Act stated that the objective of the act is to improve the functioning of the electricity market and to secure that the well-functioning power system (generation, transmission, distribution) in Finland will be efficient and competitive also in the future (Hallituksen esitys Eduskunnalle sähkömarkkinalaiksi HE 138/1994). Further, the sector would be prepared for the merging of the Nordic and European markets. The reform would decrease barriers to competition and remove unnecessary regulation from the parts of the market where competition is possible (power generation, foreign trade, supply). According to the proposal, competition and deregulation would facilitate efficient use of resources in the electricity sector and bring cost savings for electricity users and the national economy. Additionally, clear rules would be set for monopoly businesses, that is, electricity networks.

Customers of at least 500 kW became eligible to switch supplier in November 1995 and smaller customers in January 1997. Initially, it was required that all customers that switch away from their local incumbent supplier must be equipped with meters that register their hourly electricity consumption. This requirement was removed from households and other small customers (main fuse 3 x 63 A at the most) in the autumn 1998, which enabled switching free of charge. The energy part of the electricity bill has not been regulated at any point after the market opening. However, the retail supplier with the largest market share within a distribution system operator’s

(DSO's) area of responsibility is obliged to supply electricity to households and other small end-users (main fuse 3 x 63 A at the most or annual consumption 100 000 kWh at the most) with reasonable and public prices (obligation to deliver) (Electricity Market Act 588/2013).

Retail market structure and competition

Before the deregulation, about 120 companies supplied electricity at the retail level (Lewis et al. 2004). In 2014, 72 retail suppliers operated in the Finnish electricity market (Energy Authority 2015a). Six of them did not have obligation to deliver in any DSO's area and 45 offered contracts to the whole country (Energy Authority 2015a). Thus, a considerable share of the suppliers focus on supplying customers in their traditional area only as noticed also in Publication 1. A vast majority of the retail suppliers belong to a parent company that also owns a distribution system operator (Energy Authority 2015a). Over the recent years, however, some of the largest energy companies in Finland have forgone electricity distribution network business. Fortum sold its electricity distribution network in Finland to Finnish and international investors in 2014 (Fortum 2014), and Vattenfall completed the sale of its electricity distribution business in 2012 (Vattenfall 2013).

In 2014, about 10% of the Finnish electricity customers switched supplier (Energy Authority 2015a). Table 2.2 shows the proportion of households that switched their electricity supplier between 2006 and 2014 divided according to the switchers' annual electricity consumption as the consumption of different types of households varies considerably. In 2012, an average Finnish household used 8577 kWh of electricity (World Energy Council 2015). This is over twice as much as the European average of 3956 kWh (World Energy Council 2015). In addition to the size of the household, the electricity consumption of Finnish households depends on the heating method. About 22% of the Finnish households had electric space heating in 2008 (Ministry of Employment and the Economy 2008). The annual electricity consumption of an apartment not equipped with a sauna stove is about 2000 kWh per year, the consumption of a detached house with a sauna stove but no electric space heating about 5000 kWh whereas the consumption of a detached house with direct electric heating is about 18 000 kWh (Ministry of Employment and the Economy 2008).

Table 2.2 Households and other permanent dwellings that switched supplier (Energy Authority 2015a)

Year	Annual consumption < 10000 kWh	Annual consumption > 10000 kWh
2006	3.1%	7.7%
2007	3.0%	6.8%
2008	3.4%	5.6%
2009	7.2%	10.9%
2010	8.0%	10.5%
2011	7.0%	11.7%
2012	6.6%	9.6%
2013	10.2%	12.7%
2014	11.8%	11.2%

Data about the proportion of customers on market contracts and on contracts under obligation to deliver are not available. However, several references suggest that a majority of residential customers buy electricity from their local supplier with prices under obligation to deliver ("list prices"). In 2007, Lewis et al. (2007) estimated that about 70% of households would buy electricity at list prices. In 2012, Ariu et al. (2012) estimated that the proportion of such households would be 65%. Further, in a survey made in September 2014 with a sample (1002 persons) representative of the Finnish population (age, gender, place of residence), 59% of the respondents said that they get one bill for electricity that covers both electricity supply and network service and 37% said that they get separate bills (YouGov Finland 2014). In most cases, residential customers that buy electricity from the supplier that has the obligation to deliver get one electricity bill whereas customers that buy electricity from other suppliers are billed separately by the supplier and the DSO.

Typically, both suppliers' and DSOs' tariffs consist of a fixed component (€/month) and a consumption-based component (€ct/kWh). However, suppliers, in particular, may also offer tariffs without a fixed component, whereas in the DSOs' tariffs, the proportion of the fixed component has increased over the past years (see Energy Market Authority 2013). DSOs also collect an electricity tax. In 2015, the electricity tax for nonindustrial customers is 2.253 €ct/kWh (or about 2.79 €ct/kWh including VAT) (Laki sähkön ja eräiden polttoaineiden valmisteverosta 1260/1996).

Figure 2.1 shows the average total electricity price and the proportion of price components in 1 August 2015 for residential customers that buy electricity from the supplier under obligation to deliver (annual consumption 2000, 5000, 18 000 and 20 000 kWh). The taxes include electricity tax and VAT. The price data were obtained from Energy Authority (2015b).

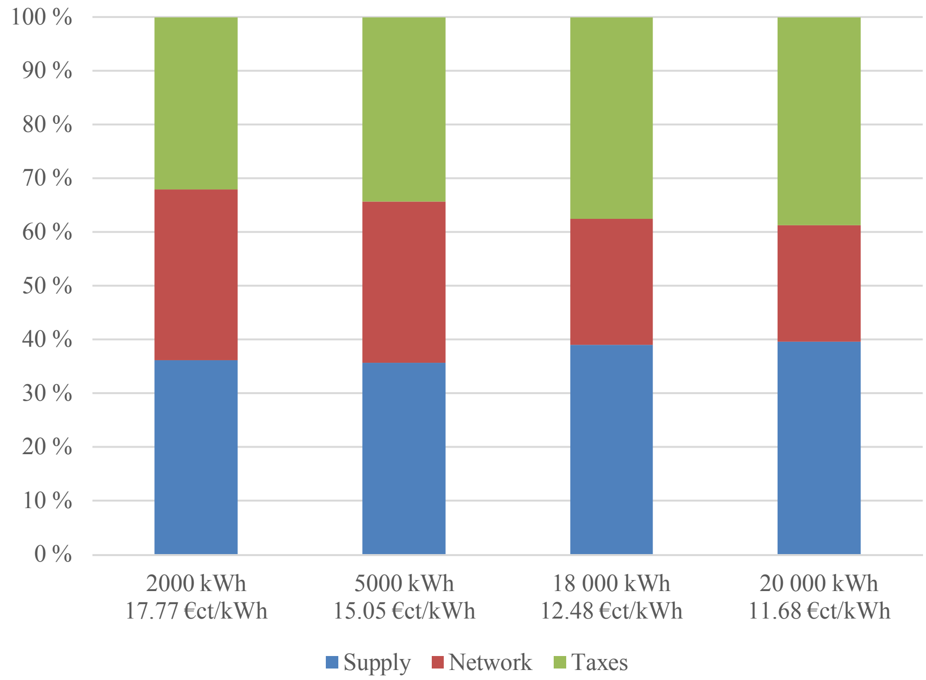

Figure 2.1 Formation of electricity price for residential customers

Typically, both suppliers and DSOs offer tariffs in which the consumption-based component is flat (same price regardless of when electricity is consumed) or applies two price levels (e.g. a higher price during day, lower during night-time). Additionally, some suppliers offer tariffs where the consumption-based component follows the hourly prices (or their monthly average) in the Nord Pool Spot market.

Smart metering and demand response in Finland

In 2007, the Finnish Ministry of Trade and Industry (the majority of duties transferred to the new Ministry of Employment and the Economy in 2008, when ministries were reorganized) appointed a working group to canvass the opportunities related to demand response and smart meters in the electricity market (Ministry of Employment and the Economy 2008). The closing report of the working group stated that hourly registering meters and hourly balance settlement are prerequisites for the demand response by small electricity users and suggested a gradual transition to hourly metering by the year 2014. This suggestion was implemented in the Decree of the

Council of State concerning balance settlement and measurement 66/2009 that requires that the measurement of electricity consumption and small-scale power generation must be based on hourly metering and remote reading (Valtioneuvoston asetus sähköntoimitusten selvityksestä ja mittauksesta 66/2009). The changes to the metering systems had to be carried out by the end of 2013. Distribution network operators (that are responsible for metering in Finland) were given the opportunity to deviate from the requirement in 20% of the electricity consumption places at the most if 1) the main fuse of the consumption place is 3 x 25 A at the most or 2) if the annual consumption does not exceed 5000 kWh and the customer buys electricity under obligation to deliver. However, at the beginning of 2014, smart meters had been installed to about 93% of consumption places (Energy Authority 2014). Based on a questionnaire sent to all Finnish DSOs in 2014, Järventausta et al. (2015) estimated that about 1 800 MW of loads (mainly electric heating in detached houses) could be controlled by smart meters. However, retail suppliers' opportunities to use the meters for load control were found limited as in most cases DSOs are not able to transmit suppliers' control signals or at least it would require manual work.

Further, the working group stated that the day/night tariff system should be maintained as the Finnish transmission system operator Fingrid has estimated that if the tariff was waived and the electricity currently used at night-time was consumed evenly around the day, the Finnish peak demand would rise by at least 300 MW (Ministry of Employment and the Economy 2008). The group, however, stated that turning on the night loads should be staggered better. Additionally, the group stated that the products offered in the retail market should include tariffs based on the hourly wholesale price and products with demand response opportunities. However, residential users' willingness to execute demand response activities without automation or external control of appliances was questioned as the financial incentive was considered small.

Currently, demand response can be offered to the balancing power market and the reserve power market. Requirements for these loads are listed in Table 2.3. Because of the minimum sizes of offers to these markets, only large end-users can participate directly. Smaller loads can, however, be aggregated.

Table 2.3 Fingrid's marketplaces for demand response (Fingrid 2015)

Market place	**Type of contract**	**Minimum size**	**Activation time**	**How many times activated**
Frequency controlled normal operation reserve	Yearly and hourly markets	0.1 MW	3 minutes	Constantly
Frequency controlled disturbance reserve	Yearly and hourly markets	1 MW	5 s / 50%, 30 s / 100%, when f under 49.9 Hz OR 30 s, when f under 49.7 Hz and 5 s, when f under 49.5 Hz	Several times per day
Frequency controlled disturbance reserve (on-off-model)	Long-term contract	10 MW	Instantly, when f under 49.5 Hz	About once a year
FRR-A	Hourly market	5 MW	Must begin within 30 s of the signal's reception, must be fully activated in 2 minutes	Several times a day
Balancing power market	Hourly market	10 MW	15 minutes	According to the bids, several times per day
Fast disturbance reserve	Long-term contract	10 MW	15 minutes	About once a year

3 Residential demand response

Demand response may be motivated by time-variable electricity pricing or by other types of incentives not linked to the retail price of electricity. When consumers pay time-variable prices that reflect the cost of electricity in different times, they are encouraged to use less in high-price periods (U.S. Department of Energy 2006). Typical time-variable pricing structures are introduced in Section 3.1. Consumers may also be paid for reducing their load upon request when grid reliability is jeopardized or when electricity prices are high (U.S. Department of Energy 2006). This is often the case in direct load control programs introduced in Section 3.2. Section 3.3 reviews impacts of both time-variable electricity pricing and direct load control on residential electricity demand. Section 3.4 presents previous studies about consumers' willingness to participate in demand response.

3.1 Price incentives

In most markets, the majority of small customers buy electricity at flat tariffs. For example Borenstein (2013) estimated that over 99% of residential customers in the US buy electricity at time-insensitive rates. Flat tariffs are, however, criticized as inefficient because if customers were exposed to the changing wholesale price, they would buy less when the prices are high thereby reducing investments in peaking generators (Spees and Lave 2008). Further, they are seen as inequitable because customers with a flat (or counter-cyclical) consumption curve subsidize the ones with high coincident peak consumption (Spees and Lave 2008). The following subsections discuss the most typical forms of time-variable electricity pricing: time of use pricing, real-time pricing, critical peak pricing, and peak time rebate. These four tariffs are also mentioned in Directive 2012/27/EU as possible network and retail supply tariffs to support demand response measures by final customers.

3.1.1 Time of use

Time of use (TOU) tariffs are the most traditional form of time-variable electricity pricing. TOU tariffs apply higher prices for consumption during peak hours and lower prices for off-peak consumption. Other price levels (e.g. shoulder/mid peak) are also possible. The timing of the different price levels is fixed, and the prices are typically set for a long time. TOU prices have been offered to residential customers for decades in many countries. For example, in France residential TOU tariffs were introduced in 1965 (Aubin et al. 1995) and in Finland in the early

1970s (Helynen et al. 2007). In Finland, the estimated penetration of TOU tariffs was 17% of all households in 2012 and 85% of residential customers with electric heating (Ariu et al. 2012). In France, about a third of residential customers were on TOU tariffs (Ariu et al. 2012).

Typically, TOU tariffs have been recommended to residential customers who use a certain amount of electricity at night-time (Ariu et al. 2012). However, In Italy, all households on default tariffs (who have not actively chosen a market offer) have been gradually moved to two-tier TOU prices (peak price 8 AM to 7 PM on working days, off-peak 7 PM to 8 AM on working days and all Saturdays and Sundays) since July 2010 (Autorità per l'energia elettrica e il gas 2010). Further, Ontario has made a three-level TOU the default tariff for residential customers that buy electricity from their local distribution company (i.e., who have not chosen a competitive retailer) (Faruqui et al. 2013). The Irish energy regulator CER has decided to make TOU the default tariff for all households after the smart meter roll-out that is planned to start in 2018 (CER 2014a, 2014b).

3.1.2 Real-time pricing

Real-time electricity pricing (RTP) refers to a pricing structure in which prices change hourly (or more often) based on the wholesale market prices. RTP participants are typically informed about the hourly prices on a day-ahead or hour-ahead (only largest customers) basis (Faruqui and Sergici 2013). Real-time pricing programs and pilots have mainly focused on larger customers. However, in Illinois, the electric utilities with over 100,000 customers are required to offer RTP tariffs to residential customers (Public Utilities Act 220 ILCS 5/Art. XVI).

In Finland, over 90% of electricity consumption places are equipped with smart meters (Energy Authority 2014). Some of the retail suppliers in Finland offer contracts based on the hourly prices of the Nord Pool Spot market to residential customers (see e.g. Fortum 2015, Helen 2015, Vattenfall 2015). However, statistics about how popular contracts of this kind are among residential customers are not publicly available. In December 2013, spot-price-based electricity contracts were not offered to residential customers in EU capitals outside the Nordic countries (ACER and CEER 2014).

3.1.3 Critical peak pricing

Critical peak pricing (CPP) rates typically apply TOU as their base rate, but on a limited number of event days, a predetermined higher price is applied during peak hours. Participants are typically informed about a "critical peak event" on a day-ahead basis but when enabling technologies are used, also shorter notification periods are possible (Faruqui and Sergici 2013).

Massachusetts Department of Public Utilities (2014) has ordered that after smart meter deployment, the basic service customers (customers that have not chosen a competitive supplier and buy electricity from distribution companies) will be defaulted to a TOU rate with a CPP component with an option to opt-out to a flat rate with a peak time rebate component.

3.1.4 Peak time rebate

Peak time rebate (PTR) pricing, also referred to as critical peak rebate (CPR), is related to CPP, but instead of applying high prices for all consumption during events, participants are rebated if they reduce their electricity use compared with a baseline during the event (FERC 2012). Whereas CPP has been described as a "carrot-and-stick" option, PTR can be experienced as a "carrot-only" option because if PTR customers do not reduce their use during events, their bills remain the same but if they do, they get lower bills (George 2007). According to George (2007), it is likely that because of the absence of risk, more customers will take advantage of the PTR than opt-in to CPP programs.

3.2 Direct load control

Direct control (DLC) of consumers' electric appliances (e.g. air conditioners, electric space and water heaters) has been applied in many time-based rate programs to facilitate response to the changing prices. There are also DLC programs in which the participant allows remote control (shutdown or cycling) of electric appliances in exchange for incentives not tied to the market price of electricity or to a fixed timetable. The incentive for participating in a DLC program may be a bill credit (e.g. $10 upon enroll and additional $10 for each summer or $5 for monthly bills in July–August), a bill discount (e.g. a 3% discount on summer bills), or a fixed compensation per event (e.g. $3 per event) (Roseville Electric 2015, Idaho Power 2015, City of Columbia 2015, Pennsylvania Peak Saver 2015).

DLC has long traditions as a load management tool. For example, Detroit Edison has been switching off electric water heaters during peak load periods since 1934 (Hastings 1980). Initially, the water heaters were switched off for a four-hour period each day using timers. In 1968, radio signals replaced the timers. ClearlyEnergy (2014) has summarized DLC programs currently offered in the US. The motivation behind the majority of the programs is to reduce peak demand in summertime. Thus, the control is typically applied to air conditioners. Other appliances mentioned include electric water heaters, central heating, pool pumps, heat pumps, and hot tubs. In 2012, a vast majority of the reported peak reduction potential of residential customers in the US came from direct load control programs (FERC 2012).

3.3 Experiences from demand response pilots

TOU

The impacts of the Italian default TOU have been examined by Torriti (2012) and Maggiore et al. (2013). Torriti (2012) analyzed consumption of 1446 households in July 2009 to June 2010 (flat tariff) and in July 2010 to June 2011 (the first year of the TOU tariff) and noticed that the morning peak that occurred between 8 AM and 8.30 AM in the first year was replaced by an earlier and lower peak between 6.45 AM and 7.15 AM during the first TOU year. Further, the evening peak was delayed to after 9 PM but occurred higher than under the flat tariff, and therefore, TOU's usefulness in mitigating peak issues was questioned. Maggiore et al. (2013) used consumption data of 8,427 customers (average consumption 2,124 kWh per year) for January–June 2010 (flat tariff), January–June 2011 (transitional TOU tariff, a limited difference between peak and off-peak prices), and January-June 2012 (final TOU tariff with a larger price difference). On average, customers shifted 0.9% of their monthly consumption in 2011 and 2012 from peak to off-peak hours compared with their consumption in 2010. In both 2011 and 2012, the highest shifting, about 2.9%, occurred in January.

Faruqui et al. (2013) analyzed the consumption of the customers of four local distribution companies in Ontario (about half of Ontario's population) in their first year with TOU rates. Depending on the distribution company, the peak period reductions varied between 2.6% and 5.7% during summer and between 1.6% and 3.2% during winter.

The decision to make TOU default tariff in Ireland was preceded by a smart metering customer behavior trial (test period January 1–December 31, 2010, opt-in recruitment) that tested the impact of five TOU tariffs (four with a similar schedule but different prices, one with a different schedule) and four demand-side management (DSM) stimuli on households' energy consumption behavior (CER 2011). Each of the tested TOU tariffs consisted of three price levels and applied the peak price between 5 PM and 7 PM on weekdays. Along with the bill, all participants were sent an energy usage statement with information about how much it costs to run some appliances at different times of the day and how the participants' energy use has changed compared with the previous bill. To one group, the bill and the statement were sent every month, and to the three other groups every other month. Additionally, the households in one of the bimonthly billed groups were given electricity monitors while the households in another group received an "overall load reduction incentive" based on their previous usage (reward of 20 € if they managed to save 10%). On average, the pilot participants reduced their overall electricity consumption by 2.5% and the peak time consumption by 8.8% compared with a control group that was kept on a flat tariff and not provided with DSM stimuli. The median of the reductions made by individual households was lower because the households with a higher consumption also made larger percentage reductions. Of the tested DSM stimuli, an electricity monitor combined with bimonthly bills and energy usage statements was found the most effective in reducing peak time consumption when the impacts on all pilot participants were examined (not divided according to tariffs).

RTP

The RTP program of an Illinois-based electric utility Commonwealth Edison (ComEd) has been reviewed by at least Allcott (2011), Navigant Consulting (2011), and Horowitz (2012). All the participants have voluntarily opted in to the program. Allcott (2011) analyzed the hourly consumption of residential customers from May to December 2003 and concluded that the residential RTP should maybe be seen as a peak energy conservation program rather than a mechanism to shift consumption as households reduced their consumption during peak hours without equivalent increases in consumption during other parts of the day. Horowitz (2012) used data from 2005. His analysis did not show a systematic reduction in electricity use when the price rose. Navigant Consulting (2011) analyzed the medium-run (response to differences in the average hourly price) and short-run (response when the hourly prices deviate from hourly means) elasticities of demand of the program participants. In the medium run, participants responded strongest to the prices in summer weekdays. In weekends, the price elasticities were lower and in winter not statistically significant (or customers responded by increasing the electricity use during high prices). In the short run, participants reduced their use on high price alert days, but there was not much evidence about shifting of consumption.

CPP

The California Statewide Pricing Pilot (July 2003–December 2004) tested two versions of CPP (Faruqui and George 2005). In CPP-F, the critical peak period was fixed and the participants were notified day-ahead. In CPP-V, the length of the peak period varied and the participants were notified on the event day. On average, residential CPP-F participants reduced their summer peak period electricity use by 13.1% on critical weekdays and by 4.7% on normal weekdays. The reductions varied across the four climate zones included in the pilot. In the coolest zone (that also had the lowest central air conditioning saturation, 7%), the households' peak-period reduction was on average 7.6% on critical weekdays and 2.2% on normal weekdays. In the hottest zone (with 73% central air conditioner saturation), the reductions were 15.8% and 6.5%, respectively. In winter, the reductions in the peak-period use were lower. The CPP-V sample consisted of customers whose average summer use was more than 600 kWh/month (air conditioner saturation about 80%) and of customers that had volunteered for a previous smart thermostat pilot (all equipped with smart thermostats and central air conditioning). The first group was also offered demand-response-enabling technologies installed for free, and about two thirds took the option. The average reductions in the peak time use on critical weekdays were 15.8% for the first group and 27.2% for the latter group. According to Faruqui and George (2005), about two thirds of the reduction of the latter group stemmed from the smart thermostat. The California Statewide Pricing Pilot used opt-in recruitment (Herter 2007).

Fenrick et al. (2014) estimated the demand impact of a CPP pilot that ran in the summer of 2011 in Minnesota and South Dakota and included both opt-in and opt-out samples. The elements that contributed to the reductions during CPP events were also assessed based on survey questions about participants' green attitudes and other attributes. Fenrick et al. (2014) found that in general, the CPP events led to demand reductions and that green attitude was the most significant driver of reduction. Central air conditioning also contributed to the reductions but to a lesser degree. Further, participants that had opted in to the pilot made much larger reductions during events (farm rural participants 28%, residential participants 26%) than the opt-out sample (farm rural 3%, residential 11%). The opt-out group, however, enjoyed bill protection. Also participants who were not on CPP tariffs but received information about the events through IHDs made reductions (farm rural 1%, residential 7%).

DLC

In Northern Europe, the demand peaks typically occur during cold winter days. Therefore, the focus of many DLC pilots has been on heating. Koponen (2012) reviews a DLC pilot carried out in Northern Finland in winter 1996–1997. In the pilot, electric heating of almost 7000 small houses and resort apartments that had voluntarily joined a load control program in exchange for reduction in their electricity tariff was controlled. The participants were assigned to different groups based on the estimated heat storage and heat loss properties of their house. A majority of the participants did not notice the control events. Complaints were made by less than 0.1% of the participants. In these cases, the heat losses of the houses were typically higher than estimated and these participants were thus assigned to a wrong group. Lindskoug (2006) presents a Swedish pilot in which direct electric heating and water heaters of 50 households were controlled in winter 2003–2004. The households were given a compensation of 300 SEK per year for allowing the control. The pilot tested whether direct electric heating could be controlled for a continuous two-hour period without noticeably reducing comfort. The heating load was reduced by 67% on five cold weekdays between 8 and 10 AM. The pilot found that between -10 and +15°C, the controllable electric heating load was on average 4–5 kW per household. None of the households complained about the control.

3.4 Consumers' willingness to participate

The success of demand response programs depends on consumers' willingness to participate and abilities to react to price signals or other incentives. Over the recent years, these aspects have attracted increasing interest.

What kind of consumption is considered shiftable

Scala et al. (2010) studied households' willingness to shift the usage of appliances from afternoon to late evening or early morning hours. The appliances included in the study made in the US were: washing machine, dryer, dishwasher, microwave, vacuum cleaner, water heater, furnace fan, CPU and monitor, laptop, and central and window air conditioners. Microwave, CPU, and laptop were the appliances that the respondents (147) were least willing to shift (58.5%, 59.2%, and 67.3%, respectively, stated they would not be willing to shift the use of these appliances). For all other appliances, the proportion of respondents not willing to shift use regardless of savings was below 20%. However, for vacuum cleaner, water heater, central and window air conditioners, and furnace fans, over 20% of respondents would require savings of over $2 per appliance cycle in order to shift. The calculations by Scala et al. (2010) also show that because of the small power consumption or the short assumed cycle type, achieving savings of 10–50 cents per cycle by shifting laptop and microwave use would require a difference of over 1000 $/MWh in on-peak and off-peak prices. Scala et al. (2010) concluded that under their current understanding of prices, energy customers are not very willing to shift consumption without large savings per appliance cycle. Their calculations also showed that the required savings may be unrealistic because of the corresponding difference in on-peak and off-peak LMPs.

Broberg et al. (2014) carried out a choice experiment about consumers' preferences regarding remote control of heating and household electricity. The sample consisted of 918 randomly recruited people in Sweden. The choices presented to the respondents included contracts in which heating would be controlled 1) between 7 AM and 10 AM on weekdays, 2) between 5 PM and 8 PM on weekdays, or 3) never. Further, the same choices were used for the inhibition of use of certain household appliances (dishwasher, washing machine, tumble dryer/drying cabinet, electrically heated towel rails, comfort underfloor heating). The alternatives presented for annual compensation were SEK 300, 750, 1500, or 2500. The analysis of the responses revealed that a larger compensation was required for the control of household electricity than for the control of heating. In the morning, the required compensation for the control of heating did not differ significantly from zero. In the evening, the compensation requirement was SEK 630. Further, the compensation required for the control of household electricity was considerably larger in the evening (SEK 1435) than in the morning (SEK 829).

Impact of pricing structure and control of appliances on the acceptability of demand response

Leijten et al. (2014) studied how the adjustment type (autonomous: households adjust usage manually to match the demand with supply; convenience technology: technological devices adjust the demand to match supply), production level (household, community of households, central), and price (stable, an increase by 25%) affect the acceptance of future energy systems. The questionnaire study made in the Netherlands (139 responses) showed that price (followed by the adjustment type) was the most important factor explaining system acceptability. The respondents preferred a stable price and autonomous adjustment of their consumption. Production level was the least determining factor (in this attribute, central production was preferred).

Dütschke and Paetz (2013) studied the acceptability of dynamic electricity pricing by a web-based survey conducted in Germany (160 responses). Their study measured the impact of three attributes: dynamics (static: TOU with three price levels; dynamic: hourly RTP with three price levels; variable: RTP with prices varying freely within a given range), price spread, or a cost difference between price zones (low: 15–25 €ct/kWh, high: 10–35 €ct/kWh) and the means of demand response (manual control of appliances by the resident or smart appliances that react to price information). The study showed a preference for a static tariff with a low price spread and an automated response to prices. The price dynamics had the highest impact on the overall evaluation of a program.

Attitudes towards consumer's role in the smart grid scenarios

Goulden et al. (2014) considered people's likely engagement in two contrasting visions of the smart grid. The first vision 'centralized demand-side management' (CDSM) was based on the traditional arrangements of energy systems (centralized generators). The CDSM entailed increased monitoring of consumption, provision of accurate consumption information to end-users, dynamic electricity pricing, and remote control of consumer appliances. In the alternative vision, the market actors were not exclusively divided into generators and end-users, and the latter were more independent through microgeneration. According to Goulden et al. (2014, p. 24), the participants (in total 72 persons) of the focus group discussions conducted in the UK deployed two different personas, energy consumer ("for whom energy is simply a good to be expended in pursuit of personal goals") and energy citizen (that "engages with energy as a meaningful part of their practices") that characterized their orientation to the energy system. Goulden et al. (2014) argue that the concept of energy consumer and CDSM result from the same paradigm but nevertheless, the goals of the CDSM are undermined in the energy consumer frame. According to Goulden et al. (2014), the focus group discussions suggested that targeting the energy consumer might induce only the kinds of behavior changes that enable convenience or are convenience-neutral, or that bring significant financial benefits. CDSM was associated with losing home autonomy. Participants with experience of community or personal generation better acknowledged the role of energy in their practices and were more open to the smart grid schemes. Thus, the importance of active user engagement and energy citizen frame was highlighted.

Rodden et al. (2013) also studied UK consumers' attitudes towards future smart energy systems. Animated sketches about what future energy infrastructure may look like were used as a basis for focus group discussions (in total 17 participants). According to Rodden et al. (2013) users feel obligated to do something about energy but do not have sufficient motivation and know-how to concern themselves with the complex details of a smart infrastructure. For example, the focus group participants questioned their willingness and ability to shift electricity consumption ("I think if a machine tried to tell me when to put the washing machine on I'd probably break it", "if you got a routine it is almost certainly there for a reason not just because you like doing things at certain times") (Rodden et al. 2013, pp. 1178–1179). Further, consumers' lack of trust in energy companies was highlighted and energy tariffs were considered complex already.

Consumers with own generation

McKenna (2013) investigated the behavior of 130 UK residential consumers with grid-connected PV (photovoltaic) systems to estimate consumers' possible responses to dynamic electricity pricing in future power systems with high penetration of renewables. McKenna's analysis showed that on an average day, the PV households' electricity demand between 9 A.M. and 5 P.M. was about 8% higher than their average daily demand. The PV households' daytime demand was also higher than the demand of a control group without PV, whereas the PV households' evening demand was lower. Further, the PV households consumed more on high irradiance days. McKenna points out that the large proportion of social housing in the PV sample (and thus possibly different day-time dwelling occupancy than that of the general population) and their low energy consumption (compared with the UK national average) must be kept in mind when generalizing the results. To gain knowledge about how and why PV households shift demand, McKenna also analyzed an internet discussion forum for households with PV. According to McKenna, wealthy families, owner-occupiers, retirees, and people interested in demand response to save on energy bills were probably overrepresented in the discussion forum group. Of the studied 105 discussion forum participants, 45 mentioned performing behavior that counts as demand response. Washing machines and dishwashers were the most commonly mentioned appliances used in such behavior.

Opt-in vs. opt-out

To boost participation rates in demand response programs, also opt-out solutions have been discussed (for discussion about default time-variable rates, see (Faruqui et al. 2014)), and some countries have already implemented or made a decision about implementing default time-variable prices. According to Alexander (2010), moving residential customers en masse to time-variable electricity prices could cause customer revolt against smart grids. Alexander (2010) also emphasizes electricity as a necessity and the adverse effects that the lack of electricity and sufficient heat and cooling have on health. According to her, CPP and TOU rates would send a "punitive and potentially harmful signal" to households that must maintain indoor temperatures low enough on hot summer days. Furthermore, the impact of high cooling and heating costs to food insecurity, support for stable and fixed electricity prices by advocates for residential customers, and the lack of popularity of both mandatory and voluntary TOU (and RTP) rates among residential customers are highlighted. According to Alexander (2010), pilot studies have also shown that low-income customers are less price elastic (because of their average usage profiles and improbability of buying new appliances or other devices to automate response to high-price periods) than higher-income customers. Further, for lower-use customers, the bill savings could be offset by higher prices to pay for the costs of implementing dynamic rates (e.g. metering) (Alexander, 2010).

Savings from RTP

At least Prüggler (2013), Vesterberg et al. (2014), and Valtonen et al. (2015) have estimated benefits of shifting consumption based on time-variable electricity prices (RTP). In Prüggler (2013), cost savings from shifting residential consumption were estimated using Austrian spot prices in 2011 and three residential load profiles (annual consumption 5772 kWh, 3236 kWh, 3985 kWh) and one measured heat pump profile used in a single family home. The benefits were calculated in a case where part of the load (2, 5, 15, or 50%) from the highest price hour would be shifted to the lowest price hour, part of the load from the second highest price hour to the second lowest price hour, and so on. Based on the three load profiles used, shifting 2% of the load from the 12 highest price hours to the 12 lowest price hours would have led to yearly cost savings of less than 1 €. The annual saving from shifting 5% of the load from the highest price hours would have been up to 2.2 €. Shifting of 15% would have saved up to 6.5 € per year and shifting of 50% 21.6 € per year. Shifting of heat pump load would have led to higher annual savings: 4.4 € for 2% shift, 11 € for 5% shift, 32.9 € for 15% shift, and 110 € for 50%. Further, Prüggler (2013, p. 497) states that shifting of 15% or 50% of the load are more realistic for a heat pump load than for other household loads and concludes that shifting the use of conventional household appliances (e.g. washing machines, dishwashers) is “not reasonable at all.”

Vesterberg et al. (2014), estimated residential load curves based on consumption data of 200 Swedish detached houses not on RTP contracts during the measurement period. The load curves were then used to calculate economic benefits of shifting consumption based on Nord Pool Spot prices for price area Sweden 3 in February working days (average and maximum prices between 2005 and 2008). The benefits were calculated assuming that the load curve was kept intact but moved one to seven hours ahead. Even if the whole consumption was moved seven hours ahead (thus moving the demand peak to the lowest hourly prices), the daily cost saving for a median household would be only 2.15% (about 0.38 SEK) when calculated with average prices. When maximum prices were used in the calculation, the benefit of shifting consumption seven hours ahead would have been 5.56% (1.05 SEK). According to Vesterberg et al. (2014), the savings were surprisingly small, and in reality, such load shifting is probably unfeasible. They consider shifting all consumption ahead by three hours, or more highly unlikely, because it would require a complete change of household's habits, which in turn would cause disutility for the households.

Valtonen et al. (2015) analyze the economic potential of the control of electric heating based on hourly consumption data of 1388 Finnish households and the Nord Pool Spot prices for Finland in 2011. In the analysis, heating load is shifted from a high-price hour to the next hour (duration of load disconnection one hour). At the most, five controls are executed per day, and after each control there is at least a two-hour period when new controls are not enforced. In 2011, the savings per customer would have been on average only 2.5 € per year. However, Valtonen et al. (2015) noted that the economic potential for the load control is many times higher in the balancing market.

4 Research design

4.1 Research gap and research questions

Demand response is suggested to be an important tool in reaching the targets to use power generation and networks more efficiently and to enhance the functioning of the electricity markets. Currently, most households buy electricity under flat tariffs that do not encourage demand response. Previous pricing pilots have given encouraging results about households' response to time-variable electricity pricing (see e.g. a review by Faruqui and Sergici (2010)). However, often the pilot participants have voluntarily opted in to the pilot, and their response may, therefore, not be similar to what the response of the wider population would be as people who find shifting consumption easy and believe that they will benefit from the program are more likely to participate. The possible overoptimistic results given by pilots with the opt-in recruitment are also highlighted by Alexander (2010), Schnittger and Beare (2012), and Goulden et al. (2014). Alexander (2010) notes that the pilots may be short and include "extensive education and hand holding" for a small number of voluntary participants. Thus, it is not clear either whether the changes made in consumption are persistent. Further, information about what kinds of changes in electricity consumption residential consumers are willing and able to make and what motivates these changes is still scarce, as noticed also by Breukers and Mourik (2013). Finnish retail suppliers have also indicated the lack of motivation among customers as a barrier to the implementation of demand response (Honkapuro et al. 2015). This doctoral dissertation contributes to the knowledge about what kinds of factors impact on residential consumers' willingness and ability to take part in demand response. The research gap is approached by the following research questions:

RQ1: Which kinds of incentives trigger consumer action in electricity markets?
RQ2: Under what conditions would consumers change their behavior?
RQ3: In which way would consumers change their behavior?
RQ4: What do experts value in engaging in timely energy usage?

These questions are addressed in four scientific publications:

P1: Rationality of supplier switching in retail electricity markets
P2: Demand response from residential customers' perspective

P3: Consumer preferences in engaging in a sustainable lifestyle

P4: Does knowledge contribute to the acceptance of demand response?

The relationships between the research questions and the publications are presented in Fig. 4.1.

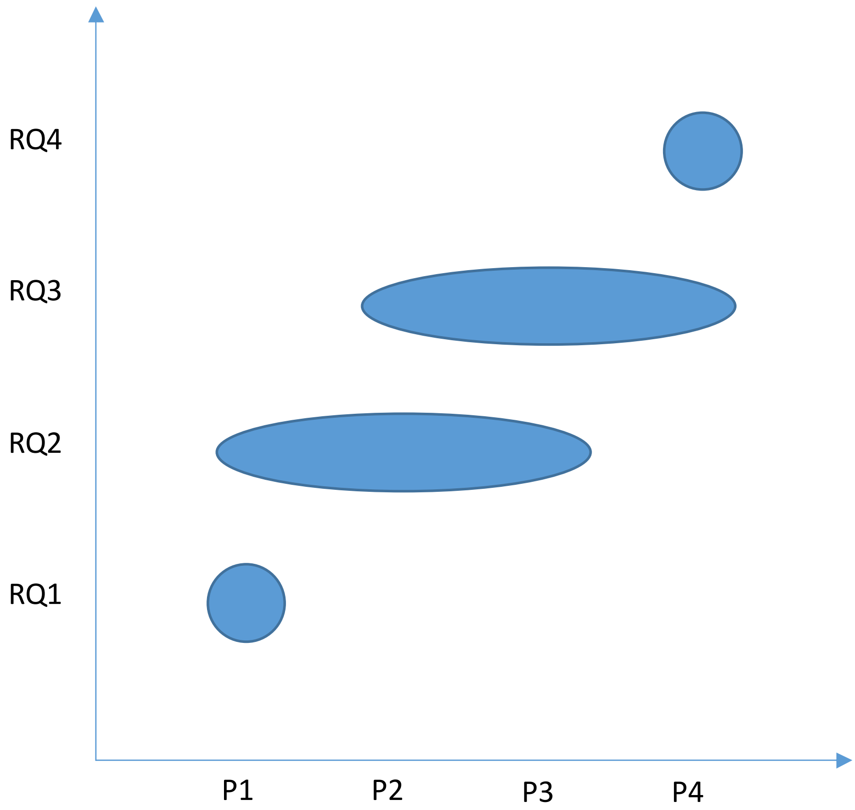

Figure 4.1 Relationships of the publications and the research questions.

4.2 Research approach

The four scientific publications included in this doctoral dissertation apply both quantitative and qualitative data. Publication 1 calculates the possible savings from supplier switching in the Finnish residential electricity market. The publication uses actual price data in 2007–2010 obtained from the database of the Finnish Energy Authority. This database contains the offer prices and prices under obligation to deliver of all Finnish electricity retail suppliers. The calculated saving potential is then compared with the switching activity in the Finnish retail market to discuss what kinds of monetary incentives trigger action in the electricity markets. This is then used as a first estimate about how large monetary incentives could trigger action also in the case of demand response.

Publication 2 approaches households' willingness to allow remote control of their electric appliances. The publication is based on a web-based survey with 2103 responses conducted in cooperation with Vantaa Energy. The survey consisted of both closed- and open-ended questions and gathered thus both quantitative and qualitative data.

Publication 3 reviews how residential consumers interact with information and technical solutions designed to increase sustainability of living and energy use. The publication uses interview- and web-based survey data of residents of an apartment house with features to improve energy efficiency, for example in home displays (IHDs) and a web-based system to monitor electricity and water consumption. The publication presents views of people with real-life experience about these technologies. Further, the people had not chosen to have these technologies installed and thus, the impact of opt-in bias is limited.

Publication 4 adds to the discussion on consumers' willingness to participate in demand response addressed in Publication 2 and to the literature on the impacts of information on behavior reviewed in Publication 3. The web-based survey used in Publication 2 was used as a basis for a survey conducted in a workshop of a research program "Smart Grids and Energy Markets". The majority of the participants of the workshop were specialized in electricity markets and power systems and represented universities, other research organizations, and the power industry (e.g. distribution network companies). The survey addressed the willingness of people well aware of the benefits of demand flexibility to engage in demand response activities.

4.3 Research limitations

Publication 1 used actual price data from the Finnish retail electricity market and compared them with the level of switching in Finland. The saving opportunities were calculated separately for customers of all suppliers with obligation to deliver. However, regional switching data were not available and, therefore, the switching rates used concerned customers in the whole of Finland. Because the saving opportunities, which were calculated as the difference between the obligation to deliver prices and the offer prices, varied from region to region, a more accurate estimate of what kind of savings trigger switching could be formed by comparing what kind of contracts customers in each area have chosen with the switching activity in the area.

Publication 2 applied data obtained from a web-based survey conducted in cooperation with Vantaa Energy that was interested in customers' viewpoints in demand response and preferred information channels about electricity consumption and electricity prices. The survey could be accessed on Vantaa Energy's web page. The topic and the opportunity to participate in the survey were also addressed in Vantaa Energy's customer magazine. The survey was open to everyone interested in participating, and not limited to the customers of Vantaa Energy. However, the sample was not representative of the Finnish population because the aim was mainly to learn about the potential for demand response within the municipality of Vantaa. Representative data would enable more detailed analyses about the willingness and motives of different types of consumers to take part in demand response. Further, the differences in the preferred information channel on electricity consumption and prices could be analyzed. Finally, because of the survey method, it is possible that the respondents were more interested in energy issues than average residential consumers. The survey is thus susceptible to the same self-selection bias identified in other surveys and pilots about demand response or energy issues in general.

Publication 3 was based on residents' views on the different ecological features of an apartment house where they had lived for one summer. The information was gathered by interviewing the residents and by conducting a web-based survey. However, no metered data were available to analyze the actual consumption of the residents. In addition, because the house was new and included ecological features right from the start, analyses about how the metered consumption changed in response to these features (e.g. the energy consumption monitoring system) could not be made. Follow-up studies could also provide information about how the energy monitoring system affects the choices related to space heating. Further, the persistence of behavioral changes and interest in the monitoring of consumption could be analyzed.

Publication 4 used data from a survey conducted in a workshop of a research program "Smart Grids and Energy Markets." The majority of the participants had background in engineering. As the topic of demand response is gaining increasing interest also in other fields of science, surveys with experts with different educational backgrounds could provide further insights. Additionally, testing different types of informational approaches with nonexperts would provide information about what kinds of approaches are most effective in increasing willingness to participate and what kinds of barriers to demand response can be reduced with enhanced provision of information.

5 Review of the publications

This section summarizes the publications that constitute Part II of this doctoral dissertation. An overview of the publications is presented in Table 5.1.

Table 5.1 Overview of the publications

	Objective	Method	Findings
P1	To examine saving opportunities from supplier switching in residential electricity markets and enhance understanding on other factors that influence switching activity	Analysis of price data (obligation to deliver prices and offer prices of all Finnish suppliers) Literature review	During the examined four-year period, 70% of customers would have found a contract cheaper than the contract under obligation to deliver on all examined days (first day of each month in 2007–2010) and 90% of customers on at least 90% of days. Support for the role of the limits of perfect rationality described in the theory of bounded rationality in switching behavior was found from the literature.
P2	To investigate what would motivate residential consumers to allow remote control of their electric appliances	Web-based survey	74% of survey respondents would allow remote control of their electric appliances in return for savings in electricity costs. The required savings were relatively high; 66% of respondents who consume 2000–4999 kWh per year would require savings of over 50 € whereas of those who consume 15,000–25,000 kWh 65% require savings higher than 100 € per year. An option to reduce emissions would motivate less than a third of the respondents. The major concern was whether the control system functions always in the agreed manner.
P3	To increase knowledge about how residential end-users interact with energy monitoring systems and other technologies and efforts that aim to reduce energy use	Interviews and web-based survey data of residents of an apartment house with several ecological features	All ecological features of the house were considered useful by the majority of respondents. For almost half of them, the most important feature was that the building itself is energy efficient. It was followed by the consumption monitoring system (18%). The use of the monitoring system was motivated by efforts to save in energy costs. Easy access to consumption data was valued. A majority of respondents chose the shared-use electric vehicle as the least important ecological feature of the house.
P4	To explore the willingness of people who are well aware of the concept and benefits of demand response to engage in demand response programs	Survey conducted in a workshop of the research program Smart Grids and Energy Markets	The knowledge about benefits of demand response to the power system had a surprisingly small impact on the willingness to engage in demand response activities. Experts also required relatively high savings in order to participate and short payback times for demand-response-enabling investments.

The following sections 5.1–5.4 discuss the publications and their contribution in more detail.

5.1 Rationality of supplier switching in retail electricity markets

In many of the open electricity markets, the supplier switching activity of residential customers, in particular, has been relatively low. Nevertheless, also households are expected to take an active role in the future smart grid environment. Publication 1 calculates whether the low switching activity is explained by low savings available from switching electricity supplier (case Finland) and reviews previous literature about why consumers decide to stay with their incumbent supplier.

The calculation is based on price data obtained from the database of the Finnish Energy Authority that covers both the prices under obligation to deliver and the offer prices of all electricity suppliers operating in Finland. The price data for 2007–2010 are used to calculate the saving opportunities of small (apartments without electric heating) and large (detached houses with electric space heating) residential consumers. The difference between the price under obligation to deliver and the lowest offer price is used as the basis of the calculation as several references have estimated that a majority of the Finnish households buy electricity on prices under obligation to deliver. For example Lewis et al. (2007) estimated in 2007 that about 70% of residential customers would buy electricity on such prices.

During the examined period (first day of each month in 2007–2010), about 70% of residential customers would have been better off with competitive contracts (compared with contracts under obligation to deliver) all the time and about 90% of customers on at least 90% of the examined days. For an average small customer, the offer prices were over 10% lower than the prices under obligation to deliver on all examined days. For the larger residential customers, the percentual saving opportunities were not quite as high, but because of their large consumption, the monetary saving opportunities were considerable especially in the two latter years of the comparison (over 250 €/year for an average customer). Despite the saving opportunities, the switching rates of residential customers that consume less than 10,000 kWh per year varied between 3 and 8% per year during the examined period and the switching rates of larger residential customers between 5.6 and 10.9% per year. During the latter two years of the analysis, the saving opportunities were higher than during the first two years, and also the switching activity rose. Compared with the saving opportunities, the switching rates were, however, moderate.

Further, the review of previous literature suggest that the limits of perfect rationality (incomplete information about available alternatives, uncertainty about their outcomes and the difficulty of calculating the best course of action) as described in the theory of bounded rationality (Simon 1972) may contribute to the decision to stay with the incumbent electricity supplier.

5.2 Demand response from residential customers' perspective

Previous studies have shown that demand-response-enabling technologies, for example remote control of consumer appliances, boost the impact of time-variable pricing on electricity demand. Publication 2 focuses on the acceptability of the direct control of electric appliances from residential electricity users' perspective. It studies on what grounds household customers would accept control of their electric appliances and whether the remote control raises some concerns in them. As savings in electricity costs are expected to be an important reason to participate in demand response, also the magnitude of required savings is approached. Additionally, the preferred information channels about electricity consumption and price data are discussed. The publication is based on an online survey conducted in December 2011 in cooperation with Vantaa Energy, an energy company active in retail supply, distribution, and generation of electricity. The survey including both closed- and open-ended questions was accessible on Vantaa Energy's web page for two and half weeks. It received 2103 responses.

Generally, the respondents were open to the direct control of the electric appliances, and only 14% stated that they would not allow it for any reason. Savings were clearly the most important motive to allow the remote control as 74% of respondents stated that they would allow control of their appliances if it led to savings in their electricity costs. The required savings were, however, relatively high compared with the electricity prices in Finland. For example, 64% of customers that consume between 2000 and 4999 kWh in a year would require a compensation of over 50 €/year to allow control of their appliances. Environmental reasons (29%) and having the opportunity to remote control appliances oneself (32%) would also motivate some respondents.

A majority of the respondents had some concerns related to the remote control and only 13% of the respondents stated that nothing would worry them if their appliances were remotely controlled. The possible concerns that the respondents were asked about were mainly related to electric space heating (drop in the room temperature, adequacy of hot water, freezing of water pipes). More than those, the respondents were, however, concerned about whether the control system always functions in the agreed manner. In addition to alternatives listed in the questionnaire, the respondents could also freely name other concerns they had. Outside the given alternatives, many respondents stated they want to retain full control of their own appliances and were worried about whether the system would adapt to changes in customers' needs. Respondents also worried how it would be secured that only authorized parties could access the consumption data and the control system and how the controls would affect their electricity costs.

Web service seemed to be the preferred information channel about issues related to electricity consumption and prices. The result may be partially explained by the research method (online survey) but it may also indicate that households appreciate the availability of information but do not want to be constantly bombarded with it as SMS was the least favored option (options included in the study: SMS, email, web service, IHD, letter).

5.3 Consumer preferences in engaging in a sustainable lifestyle

Ecological aspects, for example efforts to reduce energy use, are increasingly being taken account when planning new residential areas and buildings. For example, the apartment house Espoon Adjutantti has many features that aim to improve the sustainability of living. Its apartments are equipped with energy monitoring systems (both a web service and an IHD) and a home/away switch to control electric appliances and heating. Additionally, rooftop solar panels produce part of the electricity used in the house, there are charging points for electric vehicles, and for the first year, the residents were provided with a shared-use electric vehicle for free. The publication aims to increase knowledge about how residential consumers interact with energy consumption monitoring systems and how they perceive technologies and other efforts that aim to enhance the sustainability of living.

The publication is based on interviews of residents from ten households in Adjutantti and a web-based survey sent to all the households. Eleven residents participated in the interviews whereas the web-based survey attracted responses from 28 households. In addition, previous efforts to improve the ecological sustainability of living and the energy consumption of residential customers are reviewed.

The interviews and the web-based survey show that the residents appreciated the environmental features but mainly because of financial reasons: they were thought to help save money and maintain the value of the apartment in the longer run. All features were found useful by the majority of respondents (varied between 71–96% of respondents). The home/away switch was found useful by 96% of respondents, and it was used daily by 67%. Interestingly, 89% found solar panels useful although less than half believed they would help save money. The shared-use electric vehicle was considered the least important ecological feature of the house, which is not that surprising as previous literature has shown that environmental concern impacts behavior mainly if the costs of the behavior (including inconvenience) are low. For almost half of the respondents (46%), the most important ecological feature was that the building itself was good and energy efficient. The consumption monitoring system was considered most important by 18%. The majority of the respondents used mainly the IHD although the web service contained more data. The monitoring system was considered inspiring, useful and a way to reify energy consumption. Some of the interviewed residents said that the system had affected their consumption habits (water use, turning off lights and TV). Many, however, thought that the monitoring did not affect their consumption because it was moderate already. Further, after the initial enthusiasm, the interviewees had reduced the monitoring of consumption significantly.

5.4 Does knowledge contribute to the acceptance of demand response?

Publication 4 studies the willingness of people well aware of the concept and benefits of demand response to engage in demand response. Further, it studies whether the main purpose of the program (environmental/reliability) affects the willingness to participate.

Based on the web survey used in Publication 2, a questionnaire aimed to demand response experts was developed. The expert survey was conducted in a workshop of a research program Smart Grids and Energy Markets (SGEM) in September 2012. The workshop participants represented both industry and research institutes, and most were specialized in electricity networks and markets. Responses were received from 32 persons.

Most expert respondents (only one said no, 30 yes) would be willing to participate in a demand response program if they benefited financially. The median saving required to participate was 100 € per year. In some of the price-based programs, it may be difficult or even impossible (in the case of RTP) to calculate the impact on one’s electricity costs beforehand. Half of the experts were willing to take part in a demand response program even if they could not calculate the outcome for them and half were not. Further, most respondents would be ready to invest in demand-response-enabling technologies. The expected payback times were, however, relatively short (median two years). The expert respondents were more likely to allow remote control of their electric appliances for power system reliability reasons than if it was done to facilitate sustainability of power generation. However, a majority also required financial compensation for controls made for reliability reasons.

6 Discussion and concluding remarks

Demand response has the potential to facilitate efficient use of the electricity network and generation infrastructure, to help match renewable generation with demand, and to increase the security of supply. It could be an important tool in helping the EU reach its energy and climate targets for 2020 and 2030. Additionally, it is considered a part of consumer empowerment and promotion of consumer choice in the EU internal energy market.

This doctoral dissertation has discussed demand response from the residential electricity consumers' viewpoint. The publications included in the dissertation approach residential consumers' willingness and ability to participate in demand response through their behavior in liberalized electricity markets and based on their interest in monitoring and adjusting their own electricity consumption. Additionally, the expected benefits for allowing remote control of household appliances and the impact of information and different kinds of motives to adjust the electricity consumption behavior are discussed based on survey data.

Because the empirical data concerns residential consumers, the conclusions drawn should not be generalized across larger electricity users. Other types of electricity customers may have better knowledge about their consumption, better abilities to adjust it, and a higher economic potential.

Next, the contributions of this dissertation are discussed. Finally, suggestions for future research are made.

6.1 Contributions of this study

Which kinds of incentives trigger consumer action in electricity markets?

Switching rates and saving opportunities are interconnected. The savings required to trigger switching are, however, relatively high. In 2009–2010, offer prices for small households were most of the time well over 20% lower than prices under obligation to deliver. Yet, the annual switching rates for households that consume less than 10,000 kWh per year remained below 10%. For larger households, the percentual saving opportunities were lower but because of the large consumption, the annual saving opportunity exceeded 200 €, and about 11% of the larger residential users switched supplier.

The savings required to trigger electricity supplier switching may be used as the first estimate about how large savings residential consumers would require in order to take part in demand response programs. However, as consumers have already been somewhat passive in choosing the lowest priced contract for them out of relatively simple pricing structures, it can be expected that getting consumers to choose electricity contracts with demand response incentives (which may make the comparison of contracts more difficult) will be at least equally challenging.

Under what conditions would consumers change their behavior?

Savings in electricity costs are the main motive to take part in demand response programs or to try to reduce electricity consumption. However, the required savings may be problematically high as previous literature (Prüggler 2013, Vesterberg et al. 2014, Valtonen 2015) has shown that for residential customers, the benefits of shifting consumption based on electricity wholesale market prices are low. Environmental aspects, willingness to contribute to reliability, and gaining access to remote control system also appeal to some, although a much smaller group of end-users. Further, in general, environmental attitudes have been relatively weak predictors of proenvironmental behavior (see e.g. Ungar 1994). However, in the CPP pilot studied in Fenrick et al. (2014), green attitude was found to be the most significant driver for reduction during critical peak hours. Therefore, it is important to also inform consumers about the nonmonetary benefits of participating in demand response programs.

Consumers are not prepared to continuously keep updated on prices and their consumption. Thus, an automated response may be a better option (willingness to allow remote control, however, depends on what appliances are concerned). If the response relies on consumers' active decisions, the pricing structures have to be simple and stable enough so that consumers are able to act accordingly without checking the prices all the time and it is possible to form new habits to take advantage of the new pricing. Consumers' preference for static tariff structures is also reported in Dütschke and Paetz (2013). However, static tariffs would naturally limit the scope of the program's helpfulness in matching demand with renewable generation or in sudden reliability problems. Furthermore, consumption and price data must be available with minimum effort.

The acceptability is likely to increase if the demand response products are flexible also from the consumers' point of view so that consumers are given the opportunity to bypass the external control, and they do not have to commit themselves to the program for a long time.

In which way would consumers change their behavior?

Residential consumers seem ready to allow remote control of electric appliances that do not require changes in their everyday routines or significant interaction by the user. Such appliances include for example electric space and water heaters and air conditioners. The acceptance of remote control is important as in previous pilots (e.g. California Statewide Pricing Pilot reviewed in Faruqui and George (2005)), demand-response-enabling technologies have contributed significantly to the reductions made in response to time-variable electricity prices.

Based on residents' own activity, the consumption that is considered shiftable is typically limited to the use of dishwasher, washing machine, and tumble drier. However, also such consumption may be considered nonnegotiable. In response to increasing information about own consumption (e.g. data provided by IHDs), consumers mainly focus on consumption that they consider wasteful regardless of how significant it is in relation to the household's overall consumption. Changes triggered may include for example turning off unused appliances and switching off lights when leaving a room.

What do experts value in engaging in timely energy usage?

Information about the concept and benefits of demand response have a surprisingly low impact on willingness to participate in demand response programs. Experts also require relatively high financial incentives in order to engage in demand response. This may imply that informational measures have a limited scope in increasing the interest in demand response. However, the main purpose of the program may have an impact on the willingness to participate and savings required.

6.2 Future research

The willingness to participate in demand response and interest in monitoring one's electricity consumption may differ among different groups of residential users depending for instance on age, education, environmental attitudes, interest in technology, apartment type (detached house/terraced house/apartment house), and space heating method. With representative data, it could be analyzed what kinds of triggers appeal to different types of customers and how different types of information channels about consumption and prices are valued among different types of consumers. Further, measurement data of consumers on time-variable tariffs combined with qualitative data (e.g. interviews) would enable comparisons of measured shift/reduction of consumption with the amount of effort the consumers felt they spent. Such studies could help plan more effective incentive schemes for demand response and enable targeted marketing and provision of information to different types of customers.

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PART II: PUBLICATIONS

ACTA UNIVERSITATIS LAPPEENRANTAENSIS

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