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Demand Response in Smart Grids: Research Opportunities for the IS Discipline

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ABSTRACT

Information systems are going to play a key role in making today's electricity grids smarter and, in this way, will enable the energy turnaround from fossil to renewable energy sources. One of the approaches to cope with the intermittent feed-in of renewable energy is demand response, i.e. the *demand* side *responds* to requirements and price signals from the electricity grid. As yet, the supply side still largely responds to the demand by trying to generate the electricity that is currently needed. Since the huge coordination task of demand response in smart grids strictly requires information systems, this contribution analyzes existing information systems (IS) research contributions on this subject. Subsequently, we identify underrepresented areas by comparing our findings with the research of related disciplines and research projects funded by the European Union (EU). Finally, we discuss selected open issues and conclude by illustrating what the identified white spots mean for the smart grid's success and provide guidance for future IS research and development.

Keywords (Required)

Demand Response, Demand Side Management, Smart Grid, Integration of Renewables, Sustainability, IS for Green.

INTRODUCTION

California passed the so-called renewable energy standard in 2011. According to this law, all utilities in the state have to obtain at least 33 percent of their electricity from clean, renewable sources, such as wind or solar power, by 2020. Similarly, the European Union set the share of renewables to 20 percent (cp. 20-20-20 goals). Germany, as the largest member state, passed a law in 2011 mandating even 35 percent of renewables by 2020. As renewable energy sources are volatile per se, their integration into the electricity grid means a huge challenge for the stability of the grid in the coming years – not to mention the integration of e-vehicles and distributed energy generation sources such as solar roofs or cogeneration. Accurate measurement, better prognosis and close control of energy needs are seen as the key to cope with the growing share of renewables. Information systems are therefore going to play an important role by making grids smart: they are to master energy flows from production to consumption and vice versa in the distribution net. Intelligent grids will enable production to be adapted to demand and vice versa. This so-called Demand Response (DR) approach is a quick and effective means of coping with the increasing amount of intermittent power from renewable energy sources such as wind or solar: DR resources can be brought online within a matter of months, while it can take years to site and build a new power plant or new transmission lines. In the US, the forecasts of the nationwide demand response potential for reduction only in peak demand range from 38 GW to 188 GW by 2019 (FERC, 2009). For Europe, the estimates are quite similar depending – among others – on the imputed penetration rate of smart meters and the profile of commercial, industrial and residential resources available (SEDC, 2011).

It is only recently that information systems research has begun to deal with environmental sustainability topics to a significant degree (Funk et al., 2009). Works on so-called *Green IT* and *IS for Green* have particularly gained momentum (Melville, 2010) (Dedrick, 2010) (Watson et al., 2010) (Butler, 2011). Against the background of DR as an effective tool for the energy turnaround from fossil to renewable energy sources and the decisive role of information systems or the realization of a smarter electricity grid, this contribution intends to answer two questions: *What is the status quo of IS research on demand response? What are the correspondent research opportunities for the IS discipline?* Accordingly, we present the findings of a systematic literature review of the IS research contributions on demand response. Subsequently, we compare our results with (a) related disciplines and their focus of research and (b) areas addressed by EU-funded projects. We conclude by discussing what the identified white spots mean for the smart grid's success and provide guidance for future IS research. We start by defining demand response in the next section.

THE DEMAND RESPONSE APPROACH

Demand response has been conceptualized in a number of ways, with wider or narrower scope. The European Commission, for instance, has defined demand response as follows (Bertoldi, 2010): "*Demand response is a series of programs sponsored by the power grid, the most common of which pays companies (commercial DR) or end-users (residential) to be on call to reduce electricity usage when the grid is stressed to capacity."* While this definition largely limits the purpose of demand response to grid stabilization, the US Federal Energy Regulatory Commission (FERC, 2009) and the US Department of Energy have provided a broader definition: "*Changes in electric usage by end-use customers from their normal consumption patterns in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at times of high wholesale market prices or when system reliability is jeopardized."* Taking the market aspect of demand response into consideration, this definition goes beyond grid stabilization. Furthermore, end-user customers are not differentiated into commercial and residential groups. Other definitions by the UK electricity and gas regulator (Ofgem, 2010), the Demand Response Research Center of the Lawrence Berkeley National Lab (DRRC, 2011) or the business association Smart Energy Demand Coalition (SEDC, 2011) show additional differences in concepts and terms. However, whether one calls it demand side response (DSR), demand side management (DSM), demand response, or simply load management, all the approaches have a common denominator: They all aim at limiting peak electricity load or shifting peak loads to off-peak hours – even though for very different purposes.

In order to conduct a systematic literature review on IS research on DR, we will next structure these many aspects by clarifying how and where demand can be shifted and who wants to shift demand for what reasons.

How to Affect the Demand Side

As illustrated in Figure 1, three general options may be distinguished in order to affect electricity load. The first possibility is to give end-users a more detailed **feedback** on their electricity consumption in comparison to the status quo. Regardless of the various situations within the OECD member countries, residential and commercial customers usually receive their energy bill on a monthly or annual basis. The idea is that customers will alter how they use energy in response to knowing (a) the pure quantity of their consumption or (b) their consumed energy evaluated by changing electricity prices (NIST, 2012). Motivations on the customer side range from reducing electricity waste due to conservatism and for environmental reasons through to saving money. The second option is to give customers **monetary incentives** (or disprofits) in the form of flexible tariffs and dynamic pricing (e.g. critical peak pricing, time-of-use rates, real-time pricing etc.) to alter their consumption behavior. If customers offer to modify their energy consumption patterns due to a contractual or voluntary curtailment, they can also be financially compensated through either a discount on the supply price or a payment for the energy not used. Moreover, demand-bidding programs can allow consumers to specify their own reservation bid for a certain amount of load reduction. If the spot market-clearing price is at or above the reservation bid price, consumers would be required to reduce electricity demand by the specified amount in exchange for a payment for the reduction.[1] The third option for affecting electricity load is so-called **direct-load control**. End-users allow electricity market actors or third parties to remotely control all types of electricity consuming devices and machines (production machines, heating or cooling systems, thermostats, household appliances etc.). While the fixed-costs to install the communication infrastructure are significant, direct-load control implies decreasing marginal costs of communication – i.e. the more demand response transactions, the lower the costs for the average transaction. According to (Capgamini, 2008), a large body of empirical evidence shows that the effectiveness of the load control activity in itself is higher in comparison to giving feedback and offering monetary incentives to customers.

[1] http://www.rff.org/Documents/RFF-DP-04-19rev.pdf

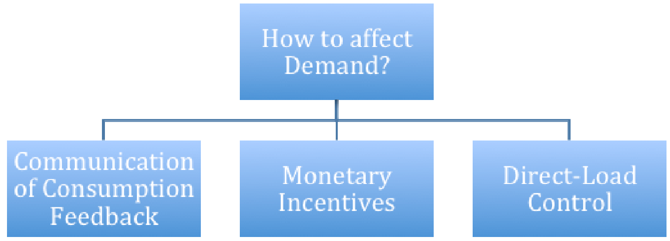

Figure 1: Affecting Electricity Load

All three options illustrated in Figure 1 require an ICT communication infrastructure in one way or another. Providing detailed energy bills, for instance, means reading interval values from the electricity meter. This data then has to be communicated to the utility's backend system in order to generate a bill. Subsequently, a utility can give customers access to this bill via its website or by sending an email. The more detailed the feedback is supposed to be - i.e. the more frequently the meter has to be read - the more financially attractive *automated* meter readings become. Utilities all over the world that were confronted with detailed energy bill mandates decided to create a so-called Advanced Metering Infrastructure (AMI) (e.g. Strueker et al., 2011). The AMI enables two-way communication between the utility's enterprise network and the smart meters installed at the customers. Besides mandated detailed energy bills, utilities in the EU and US are also required by law to offer customers dynamic pricing or time-of-use tariffs in the coming years. Overall, all kinds of monetary incentive programs with the purpose of altering electricity load essentially require the frequent reading of meters and the direct relaying of price updates or information about the required usage alteration (event notification) to the smart meter. Otherwise, customers do not know when to reduce or increase their electricity consumption. In the case of direct load control, either a smart meter infrastructure or the Internet is used as a communication network. Energy management providers such as EcoFactor (www.ecofactor.com) read a residential thermostat that is connected to the Internet in intervals close to seconds and send back control signals to manage the thermostat whenever necessary. Demand response aggregators increasingly work with commercial industrial facilities because the price of so-called machine-to-machine technology to realize direct load control mechanisms has steadily fallen (Vasseur and Dunkels, 2011). At the same time, the software required to effectively manage DR resources and events is becoming more advanced and the plethora of former proprietary communication standards has been reduced to only a few open and interoperable standards (e.g. ZigBee Smart Energy Profile as a HAN standard).

Who Wants to Affect Whose Demand (kW) and Consumption (kWh) for What Reason

Traditionally, load management programs aim at directly stabilizing the grid. All OECD member states have installed reserve mechanisms in the form of markets for balancing energy and/or reliability programs. DR resources can be used to reduce peak demand within a system operator's territory and to provide services such as spinning or balancing reserves. These types of DR programs, which are under the direct control of the system operator, usually take place at factories, offices and commercial buildings. Consumer-focused demand response has long been under development though. The US DR market, for instance, is currently deemed to have a value of USD 6 billion annually through direct payments and avoided investment costs, which the Smart Energy Demand Coalition (SEDC, 2011) reckons could equate to €3.5 billion annual new revenues in Europe.

The renewable energy sources of wind and solar with their erratic generation profiles will, in principle, increase the demand for balancing energy. At the same time, the market for balancing energy is already very attractive today. In Germany, for instance, so-called *secondary* or *minute reserve* is compensated many times over the current spot market price and twice as high as the guaranteed feed-in tariff for renewable energy. Consequently, it is likely that more and more DR providers will enter the market and will pool many small loads to create a large virtual energy storage facility that provides energy for balancing generation and consumption in the power grid. Due to the high prices, they will pursue selling their balancing energy into the balancing markets. Besides control energy, there is a more direct market-based option to balance demand and supply in smart grids: Making better use of existing distribution grid capacity through more sophisticated DR applications could considerably contribute to prevent the need for balancing energy from occurring in the first place. As more intermittent resources like wind and solar come into the system, the electricity price at the spot market is going to be very volatile. This price dispersion also gives strong incentives to DR providers to aggregate the load reducing or shifting capacities of individual customers in the residential, commercial or industrial sector into larger amounts. Dependent on the market regime, DR aggregators can sell to electricity retailers (reducing risk exposure of retailers), DSOs (helping DSOs to dispatch the system), distribution network companies, other balancing responsible parties or owners of non-controllable generation.

Moreover, the DR provider can also directly sell load flexibilities on the electricity market (cp. SDEC, 2011 and EU funded project ADDRESS).

While traditional load management programs usually targeted a specific end-user application (e.g. air conditioning), required a full facility shutdown or were limited to very large enterprises, utilities can now work with third party DR providers. The vertically integrated utility PG&E in California, for example, now cooperates with a couple of DR aggregators.[2] As these intermediaries are highly specialized and have the necessary "behind the meter" expertise, the processes at their customers' facilities can vary widely and the curtailment strategies are much more customized (e.g. automated or manual depending on the sensitivity of the process and customer comfort). If a third party provider can aggregate sufficient DR resources within a utility's service territory, he is then able to mitigate the risk of a given customer's non-performance during a DR event. The best case scenario would mean that this portfolio approach enables the aggregator to even guarantee demand reductions, i.e. to give service-level agreements.

Today's advanced metering and control technology allows utilities and retailers to have visibility into the performance of residential resources on a near real-time basis. However, the integration of domestic consumers is challenging. As opposed to large industrial consumers, they are less motivated by purely economic concerns (minimal gains – dependent on price dispersion). Moreover, residential customers are generally unable to make precise predictions on their available load flexibilities; therefore it is difficult for them to 'offer' services in the classical sense. Instead, the idea is for their services to be made available at the market's 'request', i.e. through price and/ or volume signal mechanisms, and for the provision of services to be on a voluntary and contractual basis.

LITERATURE REVIEW AND METHODOLOGY

We structured the literature review following (Webster and Watson, 2002). Accordingly, we performed a title, subject and abstract search in pertinent journal databases, namely Business Source Premier, MLA International Bibliography, EconLit, ScienceDirect and ACM Digital Library. In this way, our search has included the following IS journals from 2005 to the end of January of 2012: Academy of Management Review, ACM Transactions on Information Systems, Communications of the ACM, European Journal of Information Systems, Information Systems Journal, Information Systems Research, Journal of Management Information Systems, Journal of the AIS, Management Science, MIS Quarterly and Business & Information Systems Engineering.

We searched the listed databases for papers that mentioned demand response systems and closely related terms. That is, we constructed search strings that follow the pattern {demand response} AND ({dynamic pricing} OR {provider} OR {revenue model} OR {…}) and the subsequent sets of keywords they represent:

- {demand response systems}:= {demand response, demand side management, demand response curtailment, demand response aggregator, load-shifting, demand response applications, capacity-based demand response, demand response capacity forecasting, demand side bidding},
- {provider}:= {utility, transmission network operator, transmission service operator, distribution network operator, distribution service operator, independent service operator, electricity retailer, electricity supplier, smart meter operator, third party provider as an intermediary}
- {purpose}:= {load balancing, grid stabilization, cost-savings by shifting demand, spinning reserve, capacity market}
- {revenue model}:= {selling demand capacity to transmission service operators, selling demand capacity to distribution network operator, selling demand to distribution service operator, over the counter (OTC)}
- {dynamic pricing}:= dynamic pricing, flexible tariffs, critical peak pricing, CPP, time of use, TOU, real-time pricing, RTP, peak-time rebates}
- {direct control management}:= {direct load control, automated load control, automated end-to-end interaction, vehicle to grid, PHEV smart chargers, batteries, rooftop solar panel, programmable commuting thermostats, smart appliances, home energy controller, lighting, electric heating, home automation, network operating center, NOC}
- {feedback to customers}:= {informative billing, real time usage via website or in-house displays}
- {automated data exchange}:= {smart meter data exchange, meter data management, meter data repository, centralized data repository, DataCommsCon, online portal, texas web portal, smart meter data pool, smart meter data hub}

[2] http://www.pge.com/mybusiness/energysavingsrebates/demandresponse/amp/

- {sector}:= {residential, commercial, industrial}
- {market regime}:= {deregulated market, regulated market, liberalized market, existence of capacity markets}
- {introduction and adoption barriers}:= {IT-security risks, privacy concerns, smart meter roll-out, regulation barriers}
- {precondition electricity price dispersion}:= {range of prices, the percentage difference of highest and lowest price, the standard deviation of the price distribution, the variance of the price distribution, the coefficient of variation of the price distribution}

The findings of our literature search were, however, sobering. As there were hardly any search results for our queries, we went on by merely using the search string {demand response systems}. With these keywords, we found 627 matches. Out of these 627 hits, 391 did not satisfy the criterion of a direct connection to the electricity topic. None of the remaining 226 articles, however, matched with the above listed IS journals. Finally, we searched the IEEE Xplore database that includes engineering and economics journals in the area of energy. By searching only for {demand response} OR {demand side management} under the title of research contribution we got 449 hits.[3] Based on an analysis of the titles, 70 per cent of the papers addressed engineering questions and 30 per cent were on financial aspects of demand response.

The lack of IS research on demand response is a surprise, as we found numerous contributions from engineering and economics at the same time. However, it is striking to see that nearly all articles we found appeared in energy journals such as 'Electric Power Systems Research', 'Applied Energy', 'Electricity Journal', 'Energy Economics', 'Energy', 'Energy Policy', 'Energy Conservation and Management', 'IEEE Transactions on Power Systems', 'Renewable Energy: An International Journal', 'IEEE Transactions on Smart Grids' etc. One could conclude that DR in smart grids raises no research questions beyond the traditional engineering and economics/financial perspective. Accordingly, other disciplines were unable to contribute due to their lack of domain-specific knowledge. However, it appears unreasonable to assume that no IS research is required in a research area at the intersection of IT, electricity and human interaction. Consequently, we review research projects on DR and try to determine the nature of the addressed research questions in the next section.

ANALYSIS OF EU-FUNDED DR RESEARCH PROJECTS

In order to better understand the identified IS research desideratum, we concluded an analysis of 219 smart grid research projects funded by the European Union. Based on (JRC-IE, 2011) and the supporting online accessible project information, we identified 45 (28 completed and 16 running) research projects focusing on or addressing DR aspects according to our structure presented in the previous sections. The selected 45 projects are listed in Table 1 and Table 2. The project abstracts convey a cross-section of Demand Response research in Europe today and give an idea of the spectrum of addressed DR challenges.

In (JRC-IE, 2011), the authors assigned all 219 EU-funded smart grid projects to the categories of 'Integrated System', 'Smart Meter and AMI', 'Home application – Customer behavior', 'Grid automation distribution', 'Grid automation transmission' or 'Specific Storage Technology Demonstration'. Although multiple assignments were possible, the resultant categorization is not very helpful for two reasons. First, the categorizations are not consistently applied and lead to incorrect assignments. In the project E-price, for instance, smart meters and customer behavior play an important role. However, the only assigned categorizations to this project are 'Grid automation distribution' and 'Grid automation transmission'. Second, the categorizations show large overlaps and, consequently, are often confusing. The categorization "Integrated system" characterizes projects that are developing ICT infrastructure and systems in general to share information, price and control signals among distributed users (e.g. projects E-telligences, Web2Energy,). For most of the DR projects, however, smart meters and the Advanced Metering Infrastructure (AMI) are key components in order to exchange information between the smart grid users.

Overall, the analysis of the abstracts reveals that most projects are not limited to a single technological or economic research goal, such as finding an optimal DR algorithm for grid stability or learning about price elasticities of demand. Unlike Swiss2G and Kybernet, many projects address engineering, economic, computer science and societal aspects at the same time (e.g. E-Energy Project 'MeRegio' or Grid4EU). In contrast to the results of the literature search, the research projects clearly show that DR in smart grids raises new questions – also on IS topics, or at least seems to require a more holistic or alternative view.

[3] A detailed list may be requested from the authors.

	Project name	Project description
1	Automation systems for Demand Response, ForskEL (2006-2009)	More than 500 households with electric heating participated in a demonstration project about demand response. Participants paid for electricity based on spot prices.
2	BeyWatch (2008-2011)	BeyWatch will develop an energy-aware and user-centric solution, able to provide intelligent energy monitoring/control and power demand balancing at home/building & neighborhood level.
3	Consumer web (2010-2011)	Make consumption data available to consumers in a way that helps them to understand their own consumption, their consumption pattern and energy consumption in general; motivates them to optimize their consumption; and enables them to achieve energy savings.
4	Control and regulation of distribution system, ForskEL (2006-2010)	The project's objective is to study the effects of load management systems and online real time electricity pricing systems in modern distribution systems.
5	Demand response medium-sized industry consumers (2009-2011)	To investigate the possibility of introducing flexible electricity demand and regulation power in Danish Industry consumers via a price- and control signal from the supplier of electricity.
6	Dynamic tariffs (2010)	To investigate the opportunities for and effects of changed tariffs for electricity with the special objective of better integration of renewable energy from ever-increasing wind power production.
7	EcoGrid Denmark, ForskEL (2007-2009)	To develop new long term technologies and market solutions for power systems with increased share of distributed generation and renewable energy sources while maintaining the reliability of supply.
8	EDISON (2009-2011)	The project will assess the introduction of electrical vehicles in the Danish electricity system and develop frameworks and technical solutions that enable a more wide-scale demonstration. The solutions must allow the electrical vehicles to be charged intelligently in terms of system stability.
9	Demand as frequency controlled reserves, ForskEL (2006-2008)	The project developed technology for demand frequency controlled reserve (DFR) implementation, a system that automatically stops or starts electricity consumption in response to system frequency variations.
10	Energy @ home (2009-2011)	"Energy@Home" project aims to develop a system in which "smart appliances" can manage themselves by adjusting power consumption depending on power supply and prices, or in order to avoid overloads within the home.
11	Fieldtrail Mobile Smart Grid (2010-2011)	Demonstrate an earlier tested proof-of-concept (PoC) for demand response with one EV on multiple EVs and charge spots in one location based on individual driver demands.
12	From wind power to heat pumps (2009-2011)	To control 300 intelligent heat pumps as if they were one big energy storage facility capable of storing electricity as heat.
13	GAD (2007-2010)	The first aim of the GAD Demand Side Management Project is to optimize electrical energy consumption and its associated costs at domestic level.
14	Harz.EE-Mobility (2009-2011)	The Harz.EE-mobility project aims to harness as much of this renewable energy as possible to enhance passenger mobility. By doing so, the project also aims to ensure the stability of energy networks, to boost economic performance, and to foster energy security and climate protection.
15	Intelligent Remote Control for Heat Pumps, ForskEL (2010-2011)	The project will develop and demonstrate an intelligent remote control system for individual heating pumps, enabling the balance responsible party to plan consumption and deliver regulatory power, internal balancing and possibly primary reserves.
16	Interactive meters, activating price flexible power consumption, ForskEL (2006-2009)	It is technically possible to manage and activate the potential for flexible electricity consumption in the segment of large office blocks and public buildings.
17	Kybernet (2009-2011)	The project objective is the development of a system prototype for control of industrial loads and dispersed electrical power plants on a distribution electrical grid.
18	LASTBEG - Large Scale Tool for Power Balancing in Electric Grid (2009)	This project will demonstrate an optimization of renewable energy supplies (RES), primarily wind energy sourced onshore and offshore, with an existing pumped storage power plant (PSPP). It will integrate smart meters with power demand and supply forecasting to enable consistency of power supply in a small European country (Lithuania).
19	Market Based Demand Response (2005-2008)	The main objectives of the pilot study were to achieve daily load shifting and to explore customer acceptance and load curve impacts of hourly based tariffs and automatic load control schemes.
20	Address (2008-2012)	ADDRESS investigates how to effectively activate participation of domestic and small commercial customers in power system markets and in the provision of services to the different power system participants.
21	Advanced Systems of Efficient Use of Electrical Energy – SURE (2011-2014)	The main purpose of the project is to build active network concepts based on new technological solutions and to test these solutions in actual power networks.
22	CET2001 Customer Led Network Revolution (2011-2013)	This project will explore how new tariffs can alter customer behavior, enable networks to respond more flexibly to customers by using advanced voltage control devices.
23	Consumer to Grid (C2G) (2010-2012)	This study investigates the way in which information about potential energy savings is best presented to the consumer in order to reduce energy consumption in the smart-grid
24	NET-ELAN (2008-2011)	This project aims to answer the question of whether and how it can be in terms of a multi-sector system solution, a number of vehicles with electrified drive components used both useful as a distributed energy storage in the electric network and the consumer side demand management.
25	Price elastic electricity consumption as reserve power - a demonstration project in the horticultural sector (2006-2010)	The project objective is charting the scale of the realizable potential for price-elastic electricity consumption within the horticultural sector, and demonstration of the technical opportunities and the financial incentive for the individual market gardens to participate in the markets for regulated and reserve power via price-elastic electricity consumption.
26	Project "Intelligent home" (2009-2011)	The aim is to achieve energy saving behavior change by making visible the biggest energy consumers.
27	Smart Grid (2008-2011)	SEAS NVE decided to deploy the NES system for all of its nearly 400,000 customers to assist with a goal toward energy independence. The system will help them to communicate bi-directionally with their customers in order to better manage supply and demand.
28	ESB Smart Meter Projects (2009-2011)	The project aims at: - assessing the impact of Time of Use pricing and billing/information stimuli on the Customer Behavior; - assessing the available technologies for AMI roll out in an Irish context.

Table 1: *Completed* EU-funded Research Projects in the Area of Demand Response, based on (JRC-IE, 2011)

	Project name	Project description
29	Decentralized customer-level under frequency load shedding in Switzerland (2010-2012)	The project focuses on a smart demand side management of household consumers. Modern communication technology enables the management of large groups of distributed loads under a single innovative control schemes to use the flexibility of electrical loads for power system purposes
30	DLC+VIT4IP (2010-2013)	DLC+VIT4IP will develop, verify and test a high-speed narrow-band power line communications infrastructure which is capable of supporting applications such as demand side management.
31	EcoGrid EU (2011-2014)	To build and demonstrate a complete prototype of the future power system with more than 50% renewable energy. The primary focus is on market integration and inclusion of electricity customers.
32	Electricity demand as frequency controlled reserves, ENS (2009-2012)	Through 11 work packages, including hardware, design, development, laboratory test, practical implementation, data analyses, etc., a technology will be developed in which the electricity consumption will be used as a frequency controlled reserve (DFR).
33	E-price (2010-2013)	This project proposes an advanced ICT and control framework for ancillary services (reserve capacity) The demand side management is being made possible by the large scale introduction of smart meters.
34	E-telligence (2009-2012)	The idea behind e-Telligence is the intelligent system integration of electricity generation and consumption. To this aim, the project will develop and field-test: • a regional market place for electricity; • feedback systems, tariffs and incentive programs; • power generation and demand side control systems; • modern ICT and international standards
35	Grid4EU (2011-2015)	Grid4EU focuses on how DSOs can dynamically manage electricity supply and demand, which is crucial for integration of large amounts of renewable energy, and empowers consumers to become active participants in their energy choices.
36	Heat Pumps as an active tool in the energy supply system, ForskEL (2010-2012)	Heat pumps will provide flexibility due to the possibility to either increase, decrease or interrupt the power consumption. The project will deal with the ability of heat pumps to operate in so-called Virtual Power Plants, to deliver regulating power and to react on spot-market electricity prices.
37	Introduction of emergency Demand Side Response (DSR) (2011-2012)	The main goal of the pilot project is to gain practical experience of the functioning of emergency DSR programs in a smart grid/smart meters environment. This experience will be used to develop the target DSR programs.
38	Large-scale demonstration of charging of electric vehicles, ForskEL (2011-2013)	Developing of ChoosCOM for intelligent charging and communication with electric cars and test it by 2400 families in 300 EVs. Main investigation is whether it is possible to move the charge of EVs to a more production and environmental friendly time – and whether the EV owner is interested in it.
39	Micro-Request-Based Aggregation, Forecasting and Scheduling of Energy Demand, Supply and Distribution (MIRACLE) (2010-2013)	The project's main goal is to develop a concept for flex-offers that specify electricity demand and supply which is flexible in time and amount and an infrastructural approach to process lots of these flex-offers issued by small consumers and producers in near real-time.
40	Plug n' play-concept for intelligent indeklimastyring, ForskEL (2011-2013)	A concept for energy efficient control of air-air heat pumps and electric storage water heaters with focus on indoor climate, energy savings and demand response is developed.
41	Smart neighboring heat supply based on ground heat pumps, ForskEL (2011-2012)	The project is to develop and demonstrate the concept of 'neighboring heating' based on smart control of a heat pump in a combination with a hot water storage, where the possibilities of 'tapping' cheap electricity from the grid or/ and high wind production are demonstrated.
42	Swiss2G (2010-2013)	The goal of the project is the development of an algorithm which allows a grid connected device to identify the status of the (distribution) grid and to make appropriate actions to stabilize its behavior.
43	Tertiary reserve power with zero CO2 emission (2011-2014)	Demand side management and renewable producers will be integrated in TSO's ancillary services as additional tertiary reserve power for load frequency control.
44	E-Energy Project "MeRegio" (2008-2012)	The Project MeRegio aims to demonstrate that a shift from the present day power supply system to "minimum emission regions" is possible by intelligently combining technical energy management and innovative ICT.

Table 2: *Running* EU-funded Research Projects in the Area of Demand Response, based on (JRC-IE, 2011)

GUIDANCE FOR FUTURE IS RESEARCH

Engineering has set the technical groundwork for smart grids. As such, it is to be clearly stated that demand response can be realized. As we have shown in our literature review, much research has been performed on demand response systems and smart grid components. However, the analysis of the EU-funded DR research projects illustrates that technical equipment in itself is not sufficient to make demand response a success. As discussed earlier, there are currently different approaches to demand response. All have in common that they require automated information exchange and that it is necessary to influence end customers' behavior based on common economic and legal mechanisms. Therefore, a technical solution alone will not be sufficient to establish DR.

The question of whether or not DR will be realized depends to a great part on individual's economic situation and assessment of the benefits, as well as on human behavior and attitude regarding the technology and own habits. The coordination of a number of such decentralized resources implies transaction costs. IT is known as a measure to decrease transaction costs and it is necessary for the coordination process from a technical perspective. From an economic point of view the realization of DR is dependent on both, each individual's investment decision (whether or not the installation of DR is beneficial) as well as on macro-economic efficiency. Individual's investment decisions depend on the overall regulative regime and economic framework. As displayed in Figure 2, we summarize these considerations in four additional factors which have to be studied: (1) Information Technology, (2) Economics, (3) Law and Regulation, and (4) Human Behavior. To bring together these four research fields, Information Systems Research as an interdisciplinary research field can play a crucial role.

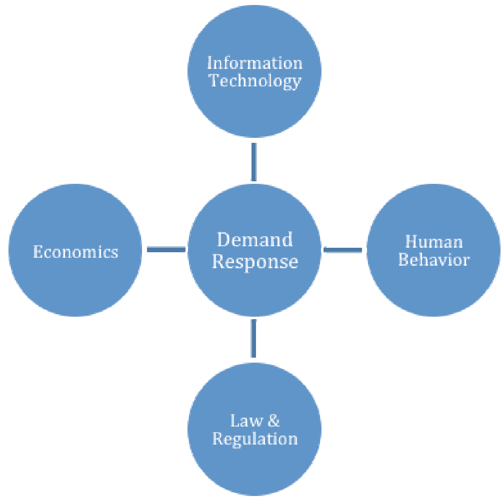

Figure 2: Disciplines involved in DR research

Although, each of the mentioned areas is worth being studied on its own, it is the interrelation between them which make IS approaches appealing. In the following paragraphs, we discuss some evident research questions in relation to the mentioned four research perspectives.

In order to make the demand responsive, it is necessary to establish communication technology. As such, humans as well as devices are able to communicate with each other and coordinate demand in critical situations. One prerequisite is a secure communication that protects each commercial, industrial and residential customer's data. With regard to individual's privacy, however, privacy law might be necessary to adapt. At the same time, it is also necessary to properly design the system to ensure these issues without neglecting cost and economic utility. Consequently, interdisciplinary research on the areas of law & regulation and IT is needed. In the case of DR, technical possibilities might not be in line with legal situations, e.g. the more detailed consumers' consumption data is, the better grid stabilization can be performed by the DNO. But on the other hand, more detailed consumption data might be in conflict with data privacy law. Additionally, in deregulated electricity markets, the exchange of smart meter data and market communication between the various electricity market participants entitled to this data are a challenging and complex task (Strüker et al. 2011). Moreover, if utilities in both regulated and deregulated markets have to protect their customers' energy data, while at the same time letting third parties (non-electricity market actors, such as DR aggregators or energy management providers) access that data (cp. California[4]), the situation will become even more complex.

It is also necessary to come up with new economic models taking into account the system's restrictions as well as regulatory issues. The electricity grid is a natural monopoly, and as such, subject to regulation. This fact cannot be neglected while designing economic models for the smart grid and demand response. The first main question is, what is considered to be part of the network (and as such part of the natural monopoly)? The second main question is how to regulate the natural monopoly that is an essential precondition for developing a market of new products and services (like DR). Under current regulation in many countries, distribution network operators might have no incentive to invest in the ICT infrastructure for DR. How can these investments be factored-in to receive regulatory support? From a regulatory perspective there might be comparable approaches in other industries, e.g. telecommunications (sharing costs and benefits and avoiding free-rider effects). Nevertheless, a 1:1 transferability is certainly not given.

[4] The California Public Utilities Commission has adopted a policy that utilities must give access to energy consumption data to individual consumers and their appointed third-party providers by the end of 2010 and then provide the data in a somewhat real-time manner by the end of 2011.

Currently, there is much discussion amongst industry managers, researchers and regulation officers on how to make demand response a success. One critical issue is the investment cost for demand response systems and how to set economic incentives to invest. To address this question, researchers from economics, IT as well as from law have to work together.

Demand response is a result of humans' preferences and choices. Today, demand for electricity is very inelastic in the short term and still inelastic in the long term. While expecting dynamic prices and growing daily price spreads for peak and off-peak prices in the future, it is imaginable that humans will adapt their behavior and respond to hourly changing electricity prices. It is even more likely that intelligent devices will respond to price changes automatically, given that the customers' preferences are represented correctly by these devices. Will customers be willing to delegate economic decisions to smart devices? These examples show that there are numerous questions that comprise research areas of human behavior as well as of IT.

Our purpose is not to provide a comprehensive list of open questions. However, we want to sketch a research agenda for DR that incorporates the different viewpoints as mentioned earlier. We suggest that IS can bridge the gap between the different disciplines since it has a long tradition in interdisciplinary research. Still open issues (just to name a few) are:

(1) IT Security and Data Privacy in deregulated markets

(2) Smart Meter Data Exchange Infrastructures

(3) Revenue models and marketization: capacity markets

(4) DR beyond the smart meter interface and the utility industry

(5) Regulation and the smart grid: what alternatives exist to stimulate investments?

(6) How do customers accept such new technology, what are their main concerns and what are the key drivers?

(7) Economic models for the network effect of demand response

(8) How large is the economic value of demand response and who benefits most?

IS researchers have addressed similar questions in the past and they possess a large set of methodological approaches and tools. Technology acceptance models, innovation diffusion and empirical research (e.g. surveys, experimental economics) could be applied to some of the issues raised. Existing economic models, e.g. from the telecommunication industry, other networked industries, or information economics can be transferred and adapted to smart grid economics. Thus, IS research could significantly contribute to the young research field of demand response in smart grids.

CONCLUSION

Demand response is a critical and urgent aspect of our future energy landscape. Many technical aspects have been solved so far, but a number of open issues remain – especially in the intersection of different scientific research disciplines. Since human interaction with information systems is one of the main topics in Information Systems Research, the aim of this article is to provide an overview on both, DR research in general and IS research on DR in particular. Therefore, we first described our understanding of DR in order to raise two questions along which we structured our literature research, namely, what is the status quo of IS research on demand response and what are the correspondent research opportunities for the IS discipline? Six scientific databases were searched and we found 627 articles, of which 226 were relevant. The distribution of articles on research disciplines shows a clear majority of 70% of publications in engineering compared to 30% in economics/financial issues. We did not find one article according to our search criteria in any of the major IS journals.

We therefore examined the research focus of different research projects and found that they often also studied IS topics, and moreover, the research approach was interdisciplinary. Thus, we were able to conclude that a focus only on technical and financial aspects is not sufficient for making DR a success. It is also important to take IS, Economics, Human Behavior and legal/regulatory issues into account. Along these research aspects, we discussed the most evident open questions and and provide a research agenda for future IS research on DR and Smart Grid Economics.

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