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Approaches to induce behavioral changes with respect to electricity consumption

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Abstract Facilitating behavioral changes is indispensable for reducing energy demand and ultimately achieving a sustainable society. However, individual methods by which to induce such behavioral changes have been considered in specific fields and disciplines. In the present study, we carried out an intensive review of academic journal articles and reports related to approaches, instruments, and practices of demand control in electricity and relevant behavioral changes across various fields and disciplines, such as engineering, economics, policy research, and psychology. Our goal is to discuss the effectiveness of these approaches and instruments and to discuss the relevant conditions for effective policy design to induce behavioral changes in a comprehensive manner. We selected and reviewed 110 papers published between 1978 and 2015 covering the practices in 17 countries that appear to be the most relevant to our research purposes. In general, empirical studies show that demand control approaches such as dynamic pricing and information feedback either shift the peak load or reduce electricity consumption. In addition, the effectiveness of an instrument depends on the characteristics of the location, the household, the industry, and the climate. We found only a small amount of literature on the life cycle impact on energy consumption and life cycle costs, although these studies are essential for better policy design for realizing energy savings and a sustainable society.

Keywords Energy visualization · Demand response (DR) · Feedback · Advanced metering infrastructure (AMI) · Smart meter · Behavioral change

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Introduction

Ensuring balance between energy supply and energy demand is crucial in dealing with energy challenges. On the supply side, efforts have been made to improve efficiency and to realize sustainability by shifting to renewable energy sources such as biomass-based electricity generation, utilization of waste heat, and small hydropower, and by introducing distributed energy sources, including co-generation systems (Bayod-Rújula 2009; Bazmi and Zahedi 2011). Despite these attempts on the supply side, increasing energy demand at the global level has been overwhelming such efforts. Indeed, global energy demand is expected to grow by 37 % by 2040, under the central scenarios, although growth in global demand will slow from more than 2 % per year over the next two decades to 1% per year after 2025 due to both price and policy efforts, as well as structural shifts in the global economy toward less energy-intensive industries (International Energy Agency (IEA)/Organisation for Economic Co-Operation and Development (OECD) (2014)). This makes effectively controlling energy demand imperative.

Meanwhile, various practices have been implemented on the demand side. These include, but are not limited to, pricing as an economic instrument and the application of various advanced technologies. For example, demand response balances the supply and demand for electricity by adjusting the demand (Capgemini 2008). A smart grid that attempts to optimize electricity flow using computer-based remote control, and automation has also been tested (Zhou et al. 2010; Mah et al. 2012). Such systems have become feasible as a result of technological advancements. These systems differ from the conventional system, which basically attempts to adjust the supply to meet the demand.

Indeed, a variety of theoretical and practical studies have investigated various methods by which to facilitate consumers' behavioral changes in order to reduce energy demand and to find the best instruments, including pricing and visualizations of electricity information, to effectively control demand. In fact, there are review articles that summarize various types of relevant instruments and approaches published in various fields and academic disciplines. These include, but are not limited to, theories on peak-load pricing in the field of regulatory economics (Crew et al. 1995), methods to induce environmentally friendly behaviors (Dwyer et al. 1993), interventions to promote energy savings at the household level in the field of environmental psychology (Abrahamse et al. 2005), demand responses in electricity markets in the field of electricity system research (Albadi and El-Saadany 2008), and feedback systems for electricity consumption at the household level from the viewpoint of energy efficiency (Fischer 2008).

However, to the best of our knowledge, very few studies have attempted to summarize the approaches, instruments, and practices related to demand control and behavioral changes of consumers across all fields and disciplines in a comprehensive manner, despite the strong need to integrate the knowledge in these disparate fields. The present study attempts to provide just such a comprehensive review. We surveyed academic journal articles and reports related to approaches, instruments, and demand control practices and relevant behavioral changes across various disciplines, such as engineering, economics, policy research, and psychology. In the present paper, we discuss how the process of information feedback in various forms to consumers can lead them to change their behavior. Such a process involves economic incentives and consumption information as feedback.

Through this literature review, we first summarize how crucial factors related to energy demand controls are presented in the selected literature. We then address some essential findings from the literature, such as the effectiveness of feedback, visualization of electricity information, and price adjustment, in inducing behavioral changes in consumers, and various conditions that influence the effectiveness of these tools. By doing so, we attempt to gain insight into the effective design of relevant policies and measures to control demand in order to achieve energy savings on the demand side.

Methods and overview of the reviewed paper

We searched the relevant literature in academic journals and on the Internet using the keywords "energy" and "visualization." We then narrowed the search candidates by looking at the references included in the literature in the first screening and using keywords such as "feedback" and "smart meters." We focused on academic journals with high citation records. The journals we selected include *Energy Policy*, *Energy and Buildings*, *Applied Energy*, *The Journal of Consumer Research*, *The Journal of Regulatory Economics*, *Automation in Construction*, *Energy*, *The Journal of Econometrics*, *The Journal of Environmental Psychology*, and *The Rand Journal of Economics*. Next, we reviewed report-type literature that also appeared to be relevant to the scope of our study. Furthermore, while taking the geographical distribution of case study areas into account, we added papers focused on regions of Asia, because the literature on practices in these regions was relatively scant. Through these screenings, we ultimately selected 110 papers that appeared to be relevant to our purposes. These papers cover various practices in 17 countries between 1978 and 2015. Tables 1 and 2 present the details of the literature organized by country and by type of literature (names and types of journals), respectively. We first summarize the manner in which crucial factors involved in energy demand control are demonstrated in the literature and then address some essential findings based on our literature review.

As to presentation style, we found that tables (U.S. Depertment of Energy 2006) and tree type figures (Albadi and El-Saadany 2008) have been historically used to sort the definitions and classifications of demand response measures. Other styles of presentation include analytical frameworks in which the relationships between measures (options), effectiveness, and benefits to the demand side (consumers) are clarified (Olmos et al. 2010), and the mapping of feedback options in the fourth quadrant on two axes, immediacy (immediate/

Table 1 Details of the literature organized by country

Region	Country
America (49)	USA (45), Canada (4)
Europe (46)	Europe (6), UK (17), The Netherlands (6), Sweden (4), Finland (3), Norway (2), Germany (2), Switzerland (1), Italy (1), Hungary (1), France (1), Denmark (1), Austria (1)
Asia (15)	Korea (5), Japan (7), China (3)

Note: CIS (formerly the Soviet Union), the Middle East, Africa, and Oceania are not included

Table 2 Details of the literature organized by type of literature

Type	Names of academic journals (top 10) and proceedings
Journal article (63)	Energy Policy (11)
	Energy and Buildings (7)
	Applied Energy (5)
	Journal of Consumer Research (5)
	Journal of Regulatory Economics (3)
	Automation in Construction (2)
	Energy (2)
	Journal of Econometrics (2)
	Journal of Environmental Psychology (2)
	Rand Journal of Economics (2)
Report (31)	–
Conference proceeding (16)	ECEEE Summer Study (9)
	ACEEE Summer Study (2)
	International Conference on Energy Efficiency in Household Appliances and Lighting (1)
	International Conference on Computer Application and System Modeling (1)
	IEEE Transmission & Distribution Conference & Exposition (1)
	Proceedings of the IEEE (1)
	SCP cases in the field of Food, Mobility and Housing (1)

Note: The breakdown of report-type papers is omitted from the table

frequent or single events), and control (user-directed or other-directed) (Darby 2001). One literature source also used systemic flows of information on price signals and remote meter management and analyzed the technical aspects of using information technologies (European Regulator's Group for Electricity and Gas 2007). The present paper looks into the interface between consumers and overall information networks and relevant technologies.

Some of the review-type studies list essential information, such as measures, effects, and associated literature (Abrahamse et al. 2005; Darby 2006a; Fischer 2007), while others list information on companies that have implemented demand responses (Barbose et al. 2004). Both methods turn out to be useful when comparing individual studies and practices from various viewpoints. However, the practicality of such comparisons of multiple studies is limited because it requires a standardized presentation of fields and scales, making comprehensive discussion across fields and disciplines difficult.

Several approaches and methods present designs for and configurations of meter systems. These studies often use tree type figures, which include information on the requirements for design and configuration, especially from technical, physical, and communication viewpoints (Depuru et al. 2011), and display tables that summarize design components, and the functions necessary to incorporate them (Jain et al. 2012). Karjalainen (2011) also illustrate the relationships between various options for presenting feedback on household electricity consumption.

Furthermore, various types of models have been proposed for obtaining the relationship between the implementation of measures and changes in consumers' behavior. For example, Fischer (2008) showed that feedback on electricity consumption effectively explains reduced electricity consumption, citing heuristic models of relevant environmental behavior. Other studies considered four steps to energy self-efficacy (The Hub Research Consultants 2005), factors determining consumer interest in energy savings (Nielsen 1993), and energy data flow (Kempton and Layne 1994). Studies in the field of environmental psychology illustrate hypothesized factors influencing household energy consumption (Benders et al. 2006).

Findings

In explaining how energy is conceptualized (Sheldrick and Macgill 1988), it must be stressed that energy studies cover a wide variety of fields. In the literature selected, we sorted information about relevant instruments or measures, the conditions that are applied, and the effectiveness of measures to control demand and induce behavioral changes. For example, we summarized information from the perspective of how and to what extent such measures as visualization and price adjustments could be effective in controlling demand and spurring consumers' behavioral changes under certain conditions. Figure 1 illustrates how the process of information feedback in

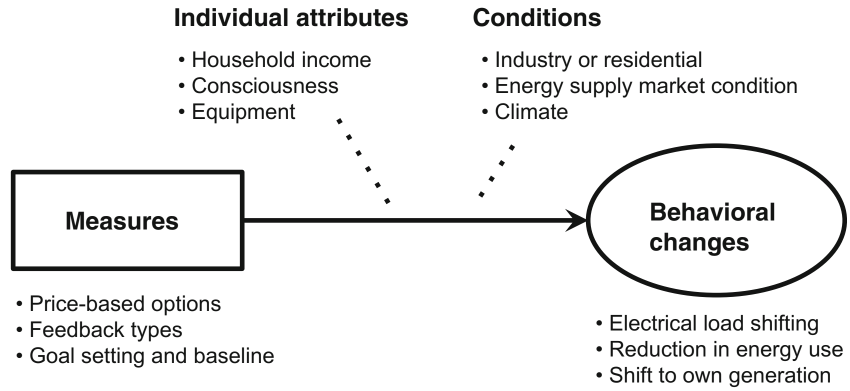

Fig. 1 The process of information feedback

various forms to consumers can lead them to changes in their behavior. Specifically, the process involves economic incentives and consumption information as feedback. Moreover, the figure shows some factors that determine the degree to which feedback influences consumers' behavior.

In the following, we explain the most important findings from our literature review based on Fig. 1. The first group of literature deals with economic incentives. Consumers generally respond well to energy price changes, which are therefore effective in controlling demand. Higher prices generally reduce energy consumption (Caves et al. 1984; Chao and Wilson 1987; Borenstein 2002; Taylor et al. 2005; Herter et al. 2007; Summit Blue Consulting 2007; Reiss and White 2008; Faruqui and Sergici 2009). Hence, price mechanisms, including dynamic pricing, real-time pricing (Aubin et al. 1995), time-of-use (TOU) pricing (Faruqui and Malko 1983), and peak-load pricing (Chao 1983; Matsukawa 2001), can reduce or shift energy consumption during peak times (Hausman and Trimble 1984; Borenstein et al. 2002; Borenstein 2005; Faruqui et al. 2005, 2009; Rocky Mountain Institute 2006; Herter et al. 2007; Hydro One Networks Inc 2008). For example, Herter et al. (2007) examined individual households' consumption data and showed that introducing peak-load pricing to the residential sector reduced electricity consumption by 13 % in California. Faruqui and Sergici (2009) also reported that dynamic pricing reduced electricity consumption in California. Likewise, in the industrial sector, Taylor et al. (2005) found that the price-based elasticity of energy demand is larger during peak-demand times than during off-peak times, confirming the effectiveness of pricing approaches.

Secondly, technological advancement facilitates the introduction of demand control systems, such as smart meters and computerized interactive tools (Abrahamse et al. 2005; Wilhite et al. 1999), through increased availability and reduced implementation costs. Indeed, applying information technology facilitates the reduction of energy demand (Goldman et al. 1997; Matsukawa 2004; Ueno et al. 2006a). One example is the advanced metering infrastructure (AMI), which includes automatic electric meter reading using communication equipment called smart meters and real-time visualization of information on the amount of electricity being used and prices associated with that use (Barbose et al. 2004; Owen and Ward 2006). Optimizing the electricity supply by connecting to home appliances over networks is also being tested (Farhangi 2010; Güngör et al. 2011). Additional technologies have been developed that allow consumers to control home appliances remotely when they are not present (Han et al. 2011). Smart meters have been introduced in numerous countries and regions, including the USA and EU countries (Office of Gas and Electricity Markets (OFGEM) 2006; Owen and Ward 2006; European Regulator's Group for Electricity and Gas 2007; Owen and Ward 2007; U.S. Demand Response Corrdinating Committee 2008; European Regulator's Group for Electricity and Gas 2009; Faruqui et al. 2009; Depuru et al. 2011). In the USA, where electrical power production is separate from power distribution and transmission, electric power companies are attempting to introduce demand responses that balance the purchase price with demand under the assumption that wholesale prices will change when electric power companies purchase electricity from power generation companies and sell to consumers (demand side) (U.S. Department of Energy 2006; Federal Energy Regulatory Commission 2008; U.S. Demand Response Coordinating Committee 2008). Countries in Asia, such as China and Korea, have also been seeking to introduce smart meters and smart grids. In Korea, such a possibility is being discussed at different levels of implementation, including in-house displays in homes, in relatively large buildings, and in large-scale urban design (Choi et al. 2009; Ah et al. 2012; Yeo et al. 2013; Ryu et al. 2014). In China, studies and practices are advancing toward the introduction of home energy management systems (HEMS), ultimately reducing energy consumption within cities (Feng et al. 2013; Zhang et al. 2013). In Japan, where conventional electrical power production is not separate from power distribution and transmission, the liberalization of retail electricity sales will be launched in April 2016 (Agency of Natural Resources and Energy of Japan 2014). In line with this movement, electric power companies are already testing smart meters, predicting that the introduction of distributed renewable energy will grow in coming years. In fact, the adjustment of supply-demand balance is imperative in the distributed energy system. Smart meters are expected to play an important role in grasping such information on a real-time basis and in helping to adjust the supply-demand balance. One study notes the significance of standardization of technology for widespread technology dissemination (European Regulator's Group for Electricity and Gas 2009).

Thirdly, feedback-type mechanisms, another approach to demand control, provide explicit information on energy consumption and energy bills (Dobson and Griffin 1992; Wilhite and Ling 1995; Iyer et al. 1998; Wilhite et al. 1999; Roberts and Baker 2003; Roberts 2004; Ueno et al. 2006b). The key aspects of this approach are visualization (how to provide information) and frequency (how often information is delivered to consumers) (Winett et al. 1979; Arvola et al. 1993; Brandon and Lewis 1999; Darby 1999; Benders et al. 2006; Iyer et al. 2006; Ueno et al. 2006a; European Regulator's Group for Electricity and Gas 2007; Fischer 2007; Owen and Ward 2007). A key condition is that it is important for consumers to understand their current consumption status (Sheldrick and Macgill 1988; Wilhite and Ling 1995; Haakana et al. 1997; Egan 1999; Bonino et al. 2012). For example, providing a baseline level of consumption as a reference is effective. The frequency of providing information also matters: the more frequently the information is provided, the better the consumers respond (showing energy savings) (Seligman et al. 1978; van Houwelingen and van Raaij 1989; Nexus Energy and Opinion Dynamics Corporation 2005; Mountain 2006; Alahmad et al. 2012). Van Houwelingen reported that providing consumption information on a daily basis resulted in a 12 % gas consumption reduction, as compared to monthly feedback (van Houwelingen and van Raaij 1989), illustrating the effects of providing frequent information. Basically, energy conservation awareness can be better maintained if consumers are exposed to relevant information. Finally, the visualization of energy consumption alone, which communicates energy consumption levels on a regular base, may not affect energy consumption (Hausman and Trimble 1984) or may have a limited impact. However, the visualization of energy consumption alone can reinforce energy consumption reduction (Hydro One Networks Inc 2008).

Meanwhile, individual attributes such as consumption patterns (Kasulis et al. 1981), income, and environmental consciousness determine consumers' degree of response to price changes (Filippini 1995), particularly in the residential sector. For example, with regard to lifestyles and consumers' behavioral patterns (demand side), one study analyzed the relationship between behavioral patterns at home and electricity consumption (Ellegård and Palm 2011), while other studies discussed electricity consumption by devices and home appliances (Mansouri and Newborough 1999; Wood and Newborough 2003; Bonino et al. 2012; Krishnamurti et al. 2013). Generally, high-income households and households who have air-conditioning equipment or a water-heating system (i.e., households whose energy consumption is relatively high) tend to reduce their energy consumption more for a given level of energy price increase (Ham et al. 1997; Matsukawa 2004; Herter et al. 2007; Herter 2007). The business sector generally responds better to price increases, either shifting demand or reducing consumption (Borenstein et al. 2002). These observations suggest that shifting energy consumption times may bring larger benefits for consumers with high consumption levels.

However, whether these mechanisms reduce the total energy demand depends on the pricing patterns during non-peak-demand times and under other conditions (Sexton et al. 1987). The most relevant studies did not examine the total demand reduction, although some studies reported a slight decrease in total energy demand. For example, Owen and Ward (2007) examined the case of the UK and found that introducing smart meters led to an electricity consumption reduction in the UK. As of yet, no studies have revealed the long-term impacts of pricing approaches.

Attempts such as the use of graphical representations and the comparison of an individual consumer's consumption level with the average consumption level are also important in encouraging consumers to exhibit more energy-saving behavior (Lord et al. 1996; Soós and Ürge-Vorsatz 2003; Primen 2004; Quesnelle 2004; Owen and Ward 2010; Karjalainen 2011; Jain et al. 2012; Krishnamurti et al. 2013). Graphical presentations facilitate consumers' perception of their current energy consumption (Jain et al. 2012), whereas more detailed information on energy consumption allows the consumer to understand how to save energy (Karjalainen 2011; Krishnamurti et al. 2013). These approaches have become more available at the household level, and their effects have also been confirmed (Lord et al. 1996; Soós and Ürge-Vorsatz 2003; Primen 2004; Quesnelle 2004; Reusswig et al. 2007; Owen and Ward 2010). Finally, regarding feedback-type mechanisms, we note that another approach to demand control is the introduction of goal setting (with a penalty when violated) and consulting (van Houwelingen and van Raaij 1989; McCalley and Midden 2002). The effects of these mechanisms appear to depend on the context. Goal setting, for example, can increase environmental consciousness (Winett and Kagel 1984; Bonino et al. 2012). Therefore, together with other demand control mechanisms, goal setting can bring about additional energy saving behavior.

The review revealed that it is significant for consumers to understand how they can effectively reduce energy consumption. Providing information or consulting services for energy consumption by individual pieces of equipment can possibly create a substantial reduction in energy demand (Fischer 2008). Individual attributes again determine the extent to which these mechanisms lead to energy savings. Specifically, the enhancement of energy saving consciousness is important in driving low-income households to change their behavior through these mechanisms (Dwyer et al. 1993; Henryson 2000; Darby 2006b; Vassileva et al. 2013; Vassileva and Campillo 2014). Likewise, it is important to understand the characteristics of the market into which demand control mechanisms are to be introduced (Kempton and Layne 1994; Faruqui and George 2002). Geography, climate, income, education, and community characteristics are factors to be considered (New Perspectives and NFO Utilities 2003; Uwasu et al. 2014). As mentioned earlier, few studies have examined the long-term energy-saving effects of these feedback mechanisms. However, these studies imply that the visualization of energy consumption patterns increases consumer knowledge of energy consumption behavior (Hutton et al. 1986; Darby 2001, 2006a; Lynham et al. 2016). In other words, increasing consumer knowledge has the potential to change consumer behavior (Lynham et al. 2016).

Discussion

Our literature review provides structure to the results of individual studies. When consumers/customers are elastic with respect to energy prices, dynamic pricing is effective for shifting demand times or reducing energy demand. Individual attributes such as income and possession of energy-consuming equipment determine the degree of response to price changes and direct energy consumption behavior. For example, better educated people are more environmentally conscious, and thus non-economic measures such as information feedback alone can work for demand control. However, indirect measures, such as campaigns and goal setting, may enhance peoples' awareness of energy savings, positively affecting the impact of demand-control measures. Hence, these observations imply that policy-makers need to at least understand consumers' attributes so that they can choose proper demand-control measures by combining different measures when necessary (Hara et al. 2015) and might better consider the consequences of new policies. In what follows, we analyze the literature in order to derive further insight into policy design for energy demand control.

We first discuss the impact of demand control on consumers. Literature on demand control exclusively examines the mechanism of energy consumption, focusing on energy-consumption reduction. As these analyses are based on economic models that assume the achieved consumption level is Pareto efficient, the analyses are not immediately able to judge whether a consumer's utility level has been improved. However, literature on consumer satisfaction and technological aspects suggests that dynamic pricing and appropriate energy consumption can increase customer satisfaction and increase prudent energy use by eliminating wasteful energy consumption (Green 2008). At the same time, the negative impact of demand control can be larger for low-income households and small enterprises because energy bills tend to account for a larger share of low-income households' and small enterprises' expenditures. However, empirical studies on income distribution are scant.

Life cycle impacts and fiscal aspects should also be investigated (Keirstead 2005). Indeed, the life cycle or economy-wide impacts of demand control are also significant in the context of policy design, but few empirical analyses have been conducted (Van Dam et al. 2013). Specifically, the concept of rebounding energy demand, arguing that energy savings of one type can result in increased energy consumption of another type, has been reported in the economics literature (Berkhout et al. 2000). One approach to demand control requires additional energy consumption or triggers different energy consumption. For example, substitutability between energy sources, such as in switching from air conditioners to heaters, which decreases electricity consumption but increases oil consumption. This type of rebound can occur when the target energy type is highly substitutable with other energy sources. Another example is the production of new equipment for introducing demand-control measures. Computational general equilibrium (CGE) models, in which interlinkages between production sectors and households are simultaneously taken into account, are an effective approach to examining rebound effects. CGE models have been used to examine the impact of environmental taxes on the overall economy (e.g., Turner 2009). However, to the best of our knowledge, no studies with CGE models have addressed the current practices of demand control.

Conclusions

In the present paper, we presented a comprehensive review of academic journal articles and reports related to the approaches, instruments, and practices used to control demand and spur relevant behavioral changes across various fields and disciplines. Our literature review examined various approaches by which to induce behavioral changes in consumers and revealed that interdisciplinary discussion is indispensable.

We demonstrated the importance of integrating research in various fields. For example, economic research focuses on the role of price in controlling demand, whereas research in the fields of engineering and social sciences, such as psychology, has revealed the significance of how and to what extent information feedback affects consumers' behavior. Thus, integrating such knowledge across fields and disciplines will lead to more effective energy-demand control.

Specifically, we found that individual approaches, including demand control through price changes, generally reduce or shift energy consumption during a particular time period. The introduction of information or visualization technologies and goal setting facilitates further reductions in energy consumption. Whether these approaches are effective in reducing energy consumption depends on the attributes of the consumer, market characteristics, and geographical conditions. Some research areas remain to be investigated.

AMI advanced metering infrastructure, *CGE* computational general equilibrium, *DR* demand response, *EU* European Union, *HEMS* home energy management system, *TOU* time-of-use

References

Abrahamse W, Steg L, Vlek C, Rothengatter T (2005) A review of intervention studies aimed at household energy conservation. J Environ Psychol 25:273–291. doi:10.1016/j.jenvp.2005.08.002

Agency of Natural Resources and Energy of Japan (2014) Strategic Energy Plan

Ah S, Shin D, Choe Y et al (2012) Integrated energy monitoring and visualization system for smart green city development: designing a spatial information integrated energy monitoring model in the context of massive data management on a web based platform. Autom Constr 22:51–59. doi:10.1016/j.autcon.2011.07.004

Alahmad MA, Wheeler PG, Schwer A et al (2012) A comparative study of three feedback devices for residential real-time energy monitoring. IEEE Trans Ind Electron 59:2002–2013

Albadi MH, El-Saadany EF (2008) A summary of demand response in electricity markets. Electr Power Syst Res 78:1989–1996. doi:10.1016/j.epsr.2008.04.002

Arvola A, Uutela A, Anttila U (1993) Billing feedback as means to encourage household electricity conservation: A field experiment in Helsinki. In: ECEEE 1993 Summer Study. pp 11–21

Aubin C, Fougere D, Husson E, Ivaldi M (1995) Real-time pricing of electricity for residential customers: econometric analysis of an experiment. J Appl Econ 10:S171–S191. doi:10.1002/jae.3950100510

Barbose G, Goldman C, Neenan B (2004) A Survey of Utility Experience with Real Time Pricing

Bayod-Rújula AA (2009) Future development of the electricity systems with distributed generation. Energy 34:377–383. doi:10.1016/j.energy.2008.12.008

Bazmi AA, Zahedi G (2011) Sustainable energy systems: role of optimization modeling techniques in power generation and supply—a review. Renew Sustain Energy Rev 15:3480–3500. doi:10.1016/j.rser.2011.05.003

Benders RMJ, Kok R, Moll HC et al (2006) New approaches for household energy conservation—in search of personal household energy budgets and energy reduction options. Energy Policy 34:3612–3622. doi:10.1016/j.enpol.2005.08.005

Berkhout PHG, Muskens JC, Velthuijsen JW (2000) Defining the rebound effect. Energy Policy 28:425–432. doi:10.1016/S0301-4215(00)00022-7

Bonino D, Corno F, De Russis L (2012) Home energy consumption feedback: a user survey. Energy Build 47:383–393. doi:10.1016/j.enbuild.2011.12.017

Borenstein S (2002) The trouble with electricity markets: understanding California's restructuring disaster. J Econ Perspect 16:191–211

Borenstein S (2005) The long-run efficiency of real-time electricity pricing. Energy J 26:93–116

Borenstein S, Jaske M, Rosenfeld A (2002) Dynamic pricing, advanced metering, and demand response in electricity markets

Brandon G, Lewis A (1999) Reducing household energy consumption: a qualitative and quantitative field study. J Environ Psychol 19:75–85

Capgemini (2008) Demand response: a decisive breakthrough for Europe: how Europe could save gigawatts, billions of Euros and millions of tons of CO2

Caves DW, Christensen LR, Herriges JA (1984) Consistency of residential customer response in time-of-use electricity pricing experiments. J Econ 26:179–203

Chao H-P (1983) Peak load pricing and capacity planning with demand and supply uncertainty. Bell J Econ 14:179–190

Chao H-P, Wilson R (1987) Priority service: pricing, investment, and market organization. Am Econ Rev 77:899–916

Choi T, Ko K, Park S, et al. (2009) Analysis of energy savings using smart metering system and IHD (In-home display). In: IEEE Transmission & Distribution Conference & Exposition: Asia and Pacific. pp 1–4

Crew MA, Fernando CS, Kelendorfer PR (1995) The theory of peak-load pricing: a survey. J Regul Econ 8:215–248

Darby S (1999) Energy advice—what is it worth? In: ECEEE 1999 Summer Study. pp Panel III, 05, 1–13

Darby S (2001) Making it obvious: designing feedback into energy consumption. In: Bertoldi P, Ricci A, Almeida A De (eds) 2nd International Conference on Energy Efficiency in Household Appliances and Lighting. Italian Association of Energy Economists/ EC-SAVE programme, pp 685–696

Darby S (2006a) Social learning and public policy: Lessons from an energy-conscious village. Energy Policy 34:2929–2940. doi:10.1016/j.enpol.2005.04.013

Darby S (2006a) The effectiveness of feedback on energy consumption: a review for DEFRA of the literature on metering, billing and direct displays

Depuru S, Wang L, Devabhaktuni V (2011) Smart meters for power grid: challenges, issues, advantages and status. Renew Sustain Energy Rev 15:2736–2742. doi:10.1016/j.rser.2011.02.039

Dobson JK, Griffin JDA (1992) Conservation effect of immediate electricity cost feedback on residential consumption behaviour. In: 1992 ACEEE Summer Study on Energy Efficiency in Buildings. pp 33–35

Dwyer WO, Leeming FC, Cobern MK et al (1993) Critical review of behavioral interventions to preserve the environment: research since 1980. Environ Behav 25:275–321

Egan C (1999) Graphical display and comparative energy information: what do people understand and prefer? In: ECEEE 1999 Summer Study. pp Panel II, 13, 1–13

Ellegård K, Palm J (2011) Visualizing energy consumption activities as a tool for making everyday life more sustainable. Appl Energy 88:1920–1926. doi:10.1016/j.apenergy.2010.11.019

European Regulator's Group for Electricity and Gas (2007) Smart Metering with a Focus on Electricity Regulation

European Regulator's Group for Electricity and Gas (2009) Status Review on Regulatory Aspects of Smart Metering (Electricity and Gas) as of May 2009

Farhangi H (2010) The path of the smart grid. IEEE Power Energ Mag 8:18–28. doi:10.1109/MPE.2009.934876

Faruqui A, George S (2002) The value of dynamic pricing in mass markets. Electr J 15:45–55. doi:10.1016/S1040-6190(02)00330-5

Faruqui A, Malko JR (1983) The residential demand for electricity by time-of-use: a survey of twelve experiments with peak load pricing. Energy 8:781–795

Faruqui A, Sergici S (2009) Household response to dynamic pricing of electricity: a survey of the experimental evidence

Faruqui A, George S, Winfield J (2005) Quantifying customer response to dynamic pricing. Electr J 18:53–63. doi:10.1016/j.tej.2005.04.005

Faruqui A, Harris D, Hledik R (2009) Unlocking the €53 billion savings from smart meters in the EU: how increasing the adoption of dynamic tariffs could make or break the EU's smart grid investment
Federal Energy Regulatory Commission (2008) Assessment of Demand Response & Advanced Metering
Feng YY, Chen SQ, Zhang LX (2013) System dynamics modeling for urban energy consumption and CO2 emissions: a case study of Beijing, China. Ecol Model 252:44–52. doi:10.1016/j.ecolmodel.2012.09.008
Filippini M (1995) Swiss residential demand for electricity by time-of-use. Resour Energy Econ 17:281–290
Fischer C (2007) Influencing electricity consumption via consumer feedback: a review of experience. In: ECEEE 2007 Summer Study. pp 1873–1884
Fischer C (2008) Feedback on household electricity consumption: a tool for saving energy? Energy Effic 1:79–104. doi:10.1007/s12053-008-9009-7
Goldman CA, Kempton W, Eide A, et al. (1997) Information and telecommunication technologies: the next generation of residential DSM and beyond
Green A (2008) Potential of In-Home Displays in the PG&E Service Territory
Güngör VC, Sahin D, Kocak T et al (2011) Smart grid technologies: communication technologies and standards. IEEE Trans Ind Inf 7: 529–539. doi:10.1109/TII.2011.2166794
Haakana M, Sillanpää L, Talsi M (1997) The effect of feedback and focused advice on household energy consumption. In: ECEEE 1997 Summer Study. pp Panel IIII, ID38, 1–11
Ham JC, Mountain DC, Chan MWL (1997) Time-of-use prices and electricity demand: allowing for selection bias in experimental data. Rand J Econ 28:S113–S141. doi:10.2307/3087458
Han J, Choi C, Lee I (2011) More efficient home energy management system based on ZigBee communication and infrared remote controls. IEEE Trans Consum Electron 57:85–89. doi:10.1109/TCE.2011.5735485
Hara K, Uwasu M, Kishita Y, Takeda H (2015) Determinant factors of residential consumption and perception of energy conservation: time-series analysis by large-scale questionnaire in Suita, Japan. Energy Policy 87:240–249. doi:10.1016/j.enpol.2015.09.016
Hausman JA, Trimble J (1984) Appliance purchase and usage adaptation to a permanent time-of-day electricity rate schedule. J Econ 26:115–139
Henryson J (2000) Energy efficiency in buildings through information—Swedish perspective. Energy Policy 28:169–180. doi:10.1016/S0301-4215(00)00004-5
Herter K (2007) Residential implementation of critical-peak pricing of electricity. Energy Policy 35:2121–2130. doi:10.1016/j.enpol.2006.06.019
Herter K, McAuliffe P, Rosenfeld A (2007) An exploratory analysis of California residential customer response to critical peak pricing of electricity. Energy 32:25–34. doi:10.1016/j.energy.2006.01.014
Hutton RB, Mauser GA, Filiatrault P, Ahtola OT (1986) Effects of cost-related feedback on consumer knowledge and consumption behavior: a field experimental approach. J Consum Res 13:327–336
Hydro One Networks Inc. (2008) Time-of-Use Pricing Pilot Project Results
International Energy Agency (IEA) / Organisation for Economic Co-Operation and Development (OECD) (2014) World Energy Outlook 2014
Iyer M, Kempton W, Payne C (1998) Comparison Groups as a Tool for Evaluating Energy Efficiency Programs: An Analysis of Energy Star Billing Comparison Groups
Iyer M, Kempton W, Payne C (2006) Comparison groups on bills: automated, personalized energy information. Energy Build 38:988–996. doi:10.1016/j.enbuild.2005.11.009
Jain RK, Taylor JE, Peschiera G (2012) Assessing eco-feedback interface usage and design to drive energy efficiency in buildings. Energy Build 48:8–17. doi:10.1016/j.enbuild.2011.12.033
Karjalainen S (2011) Consumer preferences for feedback on household electricity consumption. Energy Build 43:458–467. doi:10.1016/j.enbuild.2010.10.010
Kasulis JJ, Huettner DA, Dikeman NJ (1981) The feasibility of changing electricity consumption patterns. J Consum Res 8:279–290
Keirstead J (2005) Photovoltaics in the UK domestic sector: a double-dividend? In: ECEEE 2005 Summer Study. pp 1249–1258
Kempton W, Layne LL (1994) The consumer's energy analysis environment. Energy Policy 22:857–866. doi:10.1016/0301-4215(94)90145-7
Krishnamurti T, Davis AL, Wong-parodi G et al (2013) Creating an in-home display: experimental evidence and guidelines for design. Appl Energy 108:448–458. doi:10.1016/j.apenergy.2013.03.048
Lord D, Kempton W, Rashkin S et al. (1996) Energy Star Billing: Innovative Billing Options for the Residential Sector. In: Proceedings of The IEEE. pp 2, 137–143
Lynham J, Nitta K, Saijo T, Tarui N (2016) Why does real-time information reduce energy consumption? Energy Econ 54:173–181
Mah DN, van der Vleuten JM, Ip JC, Hills PR (2012) Governing the transition of socio-technical systems: a case study of the development of smart grids in Korea. Energy Policy 45:133–141. doi:10.1016/j.enpol.2012.02.005
Mansouri I, Newborough M (1999) Dynamics of energy use in UK households: end-use monitoring of electric cookers. In: ECEEE 1999 Summer Study. pp Panel III, 08, 1–10
Matsukawa I (2001) Household response to optional peak-load pricing of electricity. J Regul Econ 20:249–267
Matsukawa I (2004) The effects of information on residential demand for electricity. Energy J 25:1–17
McCalley LT, Midden CJH (2002) Energy conservation through product-integrated feedback: the roles of goal-setting and social orientation. J Econ Psychol 23:589–603
Mountain D (2006) The impact of real-time feedback on residential electricity consumption: the hydro one pilot
New Perspectives, NFO Utilities (2003) Energy matters: home energy resource its effets on energy efficiency in the home
Nexus Energy Software, Opinion Dynamics Corporation, Primen (2005) Information Display Pilot: California Statewide Pricing Pilot (Final Report)
Nielsen L (1993) How to get the birds in the bush into your hand: Results from a Danish research project on electricity savings. Energy Policy 21:1133–1144
Office of Gas and Electricity Markets (ofgem) (2006) Domestic Metering Innovation
Olmos L, Ruester S, Liong S-J, Glachant J-M (2010) Energy efficiency actions related to the rollout of smart meters for small consumers
Owen G, Ward J (2006) Smart meters: commercial, policy and regulatory drivers
Owen G, Ward J (2007) Smart meters in Great Britain: the next steps ?
Owen G, Ward J (2010) Smart Tariffs and Household Demand Response for Great Britain
Primen (2004) California Information Display Pilot Technology Assessment (Final Report)
Quesnelle K (2004) Pay-As-You-Go-Power Treating Electricity as a Commodity
Reiss PC, White MW (2008) What changes energy consumption? Prices and public pressures. Rand J Econ 39:636–663
Reusswig F, Lorek S, Fuchs D (2007) Initiating the sustainability transition of the German electricity system: time lags between citizen and consumer action. In: SCP cases in the field of Food, Mobility and Housing. pp 479–502
Roberts S (2004) Consumer Preferences for Improving Energy Consumption Feedback

Roberts S, Baker W (2003) Toward effective energy information: improving consumer feedback on energy consumption
Rockey Mountain Institute (2006) Automated demand response system pilot (Final Report: Volume1). Boulder, Colorado
Ryu J-H, Hong W-H, Seo Y-K (2014) Characteristic analysis of peak load in electricity on large scale hotels considering the energy efficiency. Int J Smart House 8:207–222
Seligman C, Darley J, Becker L (1978) Behavioral approaches to residential energy conservation. Energy Build 1:325–337. doi:10.1016/0378-7788(78)90012-9
Sexton RJ, Johnson NB, Konakayama A (1987) Consumer response to continuous-display electricity-use monitors in a time-of-use pricing experiment. J Consum Res 14:55–62
Sheldrick B, Macgill S (1988) Local energy conservation initiatives in the UK: their nature and achievements. Energy Policy 16:562–578. doi:10.1016/0301-4215(88)90210-8
Soós R, Ürge-Vorsatz D (2003) Turning down demand through electricity disclosure: are consumers ready? A survey of Hungarian residences and businesses. In: ECEEE 2003 Summer Study. pp 1261–1272
Summit Blue Consulting (2007) Evaluation of the 2006 Energy-Smart Pricing Plan (Final Report)
Taylor TN, Schwarz PM, Cochell JE (2005) 24/7 hourly response to electricity real-time pricing with up to eight summers of experience. J Regul Econ 27:235–262. doi:10.1007/s11149-005-6623-6
The Hub Research Consultants (2005) Seeing the light: the impact of micro-generation on the way we use energy (Qualitative research findings)
Turner K (2009) Negative rebound and disinvestment effects in response to an improvement in energy efficiency in the UK economy. Energy Econ 31:648–666. doi:10.1016/j.eneco.2009.01.008
U.S. Demand Response Corrdinating Committee (2008) Demand Response and Smart Metering Policy Actions Since the Energy Policy Act of 2005: A Summary for State Officials
U.S. Depertment of Energy (2006) Benefits of demand response in electricity markets and recommendations for achieving them
Ueno T, Sano F, Saeki O, Tsuji K (2006a) Effectiveness of an energy-consumption information system on energy savings in residential houses based on monitored data. Appl Energy 83:166–183. doi:10.1016/j.apenergy.2005.02.002
Ueno T, Tsuji K, Nakano Y (2006b) Effectiveness of displaying energy consumption data in residential buildings: To know is to change. In: 2006 ACEEE Summer Study on Energy Efficiency in Buildings. pp 264–277
Uwasu M, Hara K, Kobayashi H (2014) Analysis of energy consumption patterns and climate effects using panel data. Int J Autom Technol 8:626–633
Van Dam SS, Bakker CA, Buiter JC (2013) Do home energy management systems make sense? Assessing their overall lifecycle impact. Energy Policy 63:398–407. doi:10.1016/j.enpol.2013.09.041
van Houwelingen JH, van Raaij WF (1989) The Effect of goal-setting and daily electronic feedback on in-home energy use. J Consum Res 16:98–105
Vassileva I, Campillo J (2014) Increasing energy efficiency in low-income households through targeting awareness and behavioral change. Renew Energy 67:59–63. doi:10.1016/j.renene.2013.11.046
Vassileva I, Dahlquist E, Wallin F, Campillo J (2013) Energy consumption feedback devices' impact evaluation on domestic energy use. Appl Energy 106:314–320. doi:10.1016/j.apenergy.2013.01.059
Wilhite H, Ling R (1995) Measured energy savings from a more informative energy bill. Energy Build 22:145–155
Wilhite H, Høivik A, Olsen J-G (1999) Advances in the use of consumption feedback information in energy billing: the experiences of a Norwegian energy utility. In: ECEEE 1999 Summer Study. European Council for an Energy Efficient Economy, pp Panel III, 02, 1–14
Winett RA, Kagel JH (1984) Effects of information presentation format on resource use in field studies. J Consum Res 11:655–667
Winett RA, Neale MS, Grier HC (1979) Effects of self-monitoring and feedback on residential electricity consumption. J Appl Behav Anal 12:173–184
Wood G, Newborough M (2003) Dynamic energy-consumption indicators for domestic appliances: environment, behaviour and design. Energy Build 35:821–841. doi:10.1016/S0378-7788(02)00241-4
Yeo I, Yoon S, Yee J (2013) Development of an Environment and energy Geographical Information System (E-GIS) construction model to support environmentally friendly urban planning. Appl Energy 104:723–739. doi:10.1016/j.apenergy.2012.11.053
Zhang S, Liu J, Zhang S, Cao J (2013) Interaction research on the smart power consumption. Energy Power Eng 5:824–827. doi:10.4236/epe.2013.54B158
Zhou X, Cui L, Ma Y (2010) Research on Smart Grid Technology. In: 2010 International Conference on Computer Application and System Modeling (ICCASM 2010). pp V3, 599–603