The 'time' dimension of electricity, options for the householder, and implications for policy

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Abstract: Electricity has always had a 'time' dimension for suppliers, and the advent of variable renewable generation may make this dimension more obvious to consumers than it has been in the past. Variable generation increases the need for an 'active demand-side', in order to balance load and achieve security of supply, and various forms of smart grid are under consideration and trial, possible prototypes for the grids of the future. However, it is often not clear what the implications of an active demand side are for small-scale end-users, although their participation (or cooperation, at a minimum) is seen as essential. As utilities increasingly require the cooperation of their customers in managing distribution networks, so they need to persuade them to adopt new tariffs, technologies and customer-utility relationships. Four options are outlined and discussed, with the aim of developing a better understanding of the social and behavioural dimensions of distributed generation. The options are based on work carried out as part of the SUPERGEN HiDEF (Highly Distributed Energy Future) project in the UK. The focus is on householders, who have been used to a passive relationship with their energy retailers, along with simple tariffs. Policy questions revolve around how to encourage the cooperation of end-users – an 'active demand side' - and questions of control, equity and data privacy are significant factors in the embryonic public debate over smart grids.

Keywords: *household, electricity, dynamic demand, tariffs*

1. Introduction

Electricity has always had a 'time' dimension from the viewpoint of suppliers: it must be generated, transmitted and distributed in order to meet demand with as little wastage as possible. This has entailed careful planning so that generating plant is available when needed and, increasingly, a degree of planning so that demand from larger consumers is predictable and manageable. However, most residential and small business customers in most parts of the world have been used to a flow of electricity at any time, and at constant prices per unit.

With growing demand, especially growing peak demand, the time dimension has become more and more important to planners – hence the attention paid to demand-side management over the past few decades in parts of the world with sharp peaks, most commonly associated with high demand for air-conditioning on hot afternoons. In regions with a high proportion of nuclear generation, too, there have been adaptations to shift electricity demand in order to use the baseload available at night, such as storage heaters. Now, an increasing proportion of renewable generation increases the need to move from the old 'predict and provide' utility paradigm to one with a more 'active' demand side – where demand can be decreased *or* increased in order to match supply with demand.

Various forms of 'smart grid' are proposed in order to make this accurate matching possible. The term is used to mean many things, just as the term 'smart meter' has meant many things to many people [1]. In essence, though, a smart grid involves the merging of communication networks (fast-evolving technologies) with electricity grids and networks (not much changed in their basic structure since the time of Edison). The European Technology Platform defines the Smart Grid as:

– *an electricity network that can intelligently integrate the actions of all users connected to it -generators, consumers and those that do both –in order to efficiently deliver sustainable, economic and secure electricity supplies.* [2]

The intention is that smart grids will enable and/or require customer 'participation' , allowing for better control of generation, distribution and usage at all levels. But early pilot grids (such as those in Boulder, Colorado, and Amsterdam) are raising as many questions as they are answering. There are still fundamental questions to be asked about approaches to the smart grid. For example, should it be incremental and carefully costed and tested at each stage, or implemented comprehensively through massive infrastructure investments, in confidence that enough applications will emerge to justify those investments? If the latter, how are customers to be persuaded to fund the SG through their taxes and electricity charges? If the former, how much will consumer priorities influence SG development, and how much will the SG influence consumer practices?

While much attention has been paid to technical specifications for these grids, it not always clear what the implications are for small-scale end-users. While the grid itself is seen as an intelligent agent, it is often not clear how electricity customers may also be agents. They tend to be seen as passive elements in the system, communicating only through the billing system and the complaints system. The UK government has probably gone as far as any in its stated ambition for consumer/prosumer participation, in setting out a specification for smart meters that includes provision for microgeneration, customer feedback displays, ability to change supplier and tariff readily, and ability to control devices in the home; and in its statements on the nature of a smart grid. For example:

> A focus on the consumer's perspective must be at the heart of decision making at each stage under the programme; as well as the views of industry participants who will take on responsibility for delivery following changes to the regulatory framework [3].
>
> Consumers will need to be involved in the process of developing the electricity system… plans need to be developed in consultation with consumer interests… Clear rules and arrangements for the protection of consumer privacy will need to be a priority. First step: building increased smartness into homes, giving a clearer picture of energy use, greater choice and control [4].

If there is a sufficiently powerful combination of factors in implementing an active demand side, then the distribution of activity could change significantly. These factors would need to include:

(a) suppliers' and distributors' strong need to cultivate an 'active demand side' in order to manage the system;

(b) the ability and willingness of consumers to become prosumers, contributing to supply and storage as well as using it;

(c) regulatory support for distributed generation and equitable participation; and

(d) reliable and trusted technology.

It may be useful to break down the idea of 'activity' into aspects of control, investment decisions (e.g. network operators investing in substation equipment, or customers investing in efficient freezers or frequency-response-enabled appliances). It is unrealistic to imagine that all consumers will change from their relatively passive positions in the system to active , interested engagement, but there is potential for some change in most consumers [5].

As utilities increasingly need some cooperation from their customers in managing distribution networks, so they may need to 'teach' customers about the time dimension of electricity flows, in order to persuade them to adopt new tariffs and technologies more readily. An early example of this sort of practical education, conducted in the course of a trial of real-time pricing, is given in [6]. Technological and commercial drivers are moving in the direction of more sophisticated control and pricing arrangements, including real-time pricing, remote control of appliances by the utility, demand aggregation, and 'dynamic demand' through smart appliances. The purpose of this paper is to examine some of these options in order to move towards a better understanding of the social and behavioural dimensions of both 'active demand' and distributed generation.

2. Method

The material for this paper comes mostly from a literature review carried out as part of the SUPERGEN HiDEF (Highly Distributed Energy Future) project in the UK. The project is developing approaches, technologies and policies for an electricity system that provides sustainability, security and low carbon emissions through widespread deployment of distributed energy resources. It analyses possibilities for decentralising five features of electricity systems: resources, control, network infrastructure, participation (markets and commercial arrangements), and policy.

A number of possible types of customer-utility relationship arise from these possibilities. In this paper, four are selected and discussed with an eye to their policy implications. This of course means that other options are ignored – for example, demand aggregation and community energy services companies – but the aim is to open up the debate on active demand, not to give an exhaustive account of all that it might involve.

3. Themes in the active demand literature

The research literature on demand management does not always acknowledge or reflect the variety in electricity systems. This variety can be assessed on a number of scales, but three immediately come to mind: composition and timing of demand, type and scale of generation, and degree of regulation. For example, what are the current patterns of demand, and how much are they likely to alter in future, in what directions? Does the system have large-scale biddable centralized generation, a high proportion of nuclear (inflexible) generation, or a significant proportion of distributed and variable generation? How heavily regulated is the market?

The answers to these questions will affect what is seen as possible and desirable for the future. So will the technologies that are available, and the extent to which they are marketed around the world. Grid management that is suitable for a summer-peaking region with highly regulated utilities may not be applicable to a temperate region with liberalized markets, yet there will be an inevitable push to increase the market for technologies that have been designed for one set of circumstances into areas with other conditions. But as yet, there is not a great deal of experience in implementing demand response in parts of the world other than North America. A recent review of experience in the EU concludes that progress has been slow because of limited knowledge of demand response-related energy-saving capacities. The high estimated cost of necessary technologies and infrastructure, and the policy focus on market liberalisation [7]. Nor is there much on the relationship between demand response and demand reduction, in spite of its clear importance in terms of reducing the environmental impact of electricity more generally [8, 9]. And neither is there a great deal of research on what demand response means to consumers. Most of what there is comes from research carried out with customers who have opted into a programme, typically a very small proportion of the population to which they belong.

Therefore it is still useful to do some basic thinking about how we might best research demand response as seen from the standpoint of the end-user. As an exercise in this, four possible ways of encouraging an active demand side have been selected, to take an initial look at what they might mean to small-scale consumers or prosumers. They are outlined below.

3.1. Demand reduction via efficiency, rethinking energy services and lowering discretionary demand

Demand reduction is not always included in discussions of active demand, but I would argue that it is a central consideration. Managing a high-demand system is very different (and, mostly, more problematic) than managing a low-demand system. Climate change and energy security considerations mean that demand reduction is still normally a governmental policy objective, even if not necessarily a central objective for de-regulated utilities.

For demand reduction, the supplier-consumer relationship is normally voluntary/persuasive, sometimes assisted by technology. Although improved customer feedback from the supplier is useful, highly detailed data are not essential [10]. Some benefits are realised through changes in daily routines and practices, some through investment in improved technology, retrofits or efficiency measures, and some through rethinking the customer's approach to energy services – for example, car-sharing, turning down heating in unoccupied rooms, or line-drying laundry rather than using a mechanical tumble drier.

This would seem to be the simplest form of active demand, one that affects overall *and* peak demand. Truly 'active' customers minimise demand as a conscious exercise, often becoming more energy literate in the process. At the extremes, they may live in passive-standard homes and go off-grid. Much of this is likely to be beyond the control of suppliers, although there are structured and monitored forms of demand reduction in which suppliers are incentivised to invest in efficiency. An example is the Carbon Emissions Reduction Target in the UK, one of a number of initiatives introduced in the EU in response to concerns that market liberalisation would lead to increased consumption through lower prices. Under schemes such as this, although suppliers have no obvious reason to minimise demand in a competitive market, they do have an obligation to act in concert with their customers by funding efficiency measures and feedback/advice programmes (and, for CERT, some microgeneration), in order to be able to continue their business. Reference [11] gives an account of lessons learned in three EU countries from demand reduction obligations.

In demand reduction initiatives, control of usage normally rests with the customer. There may be equity considerations: who benefits most from subsidies, grants or demand reduction incentivizing tariffs? CERT has rules which address equity issues by defining priority groups and requiring suppliers to give minimum levels of assistance to them. Data privacy is rarely a problem, as benefits are likely to be estimated rather than measured, but even if they are measured, there is no need for high-resolution data. Evaluation of this type of active demand initiative can be a problem, though, when benefits are estimated.

3.2. 'Static' time-of-use pricing to minimise peak demand, through reduced discretionary demand and load-shifting

Static time-of-use (TOU) tariffs – static in that they stay the same over relatively long time periods of time, are often cited as the main reason for introducing smart metering. The customer-supplier relationship here is normally voluntary, with customers choosing to opt into TOU pricing, although there are moves in some parts of the world (e.g. Ontario) towards making it the default mode, especially for business customers. The tariffs rely on interval metering and an upgraded billing system, each of which is expensive and time-consuming to implement.

From the customer standpoint, adopting TOU tariffs need not mean any change in activity at all. Some will benefit in any case if they move away from a flat rate, depending on how the TOU tariff is structured and what their normal daily routines are. The TOU prices are dependable, and provided the customer has accurate information about when it is best to avoid high consumption, new habits of demand reduction and load-shifting can be formed.

The supplier continues to carry any risk associated with volatile electricity prices in the short term, even if that is likely to be passed to the customer in the longer term. There is a degree of supplier-customer engagement, and TOU pricing could be seen as a means of educating customers about the 'time' dimension of electricity, opening their eyes to the concepts of peak and trough demand. There is also scope for some automation, with a simple example being the programmable thermostat or washing machine, so that customers can cut down or cut out consumption at certain times of day; and scope for direct load control by the utility, to use consumer heat stores at certain times of day and reduce load at others.

Most of the control of consumption (and generation) still normally rests with the customer, although a range of options exist. Still, the customer can normally choose how much control to hand over to a supplier or network operator, and whether to adopt any form of 'enabling technology'. Typically, customer participation in TOU programmes is very low, around 1%, if they are expected to opt into the programme. There is resistance to *compulsory* smart metering in several regions at the time of writing, on grounds of cost, invasion of privacy, and even the claimed damaging impact of radio waves from smart meters on health. Data privacy may be an issue for some customers, as individual load curves are being recorded and used for billing, and direct load control is certainly an extension of supplier power into the home, likely to be seen as a loss of privacy. Equity issues become more complex than they are for demand reduction: for example, why should a low consumer subsidise the installation of load-control technologies in the homes of high consumers? And the system can be somewhat inflexible, not offering any incentives for extra demand reduction at the times of greatest stress [12]. Evaluation of TOU pricing, though, can be fairly straightforward: what was the peak demand reduction in different weather conditions? Did consumer response persist? How many people participated? And who were the main gainers and losers from the new tariffs? (More difficult, this, but still possible to establish).

3.3. Dynamic (real time) pricing

One of the main features of real time pricing is the way in which it transfers some of the risk of price volatility to customers, by charging them the current spot price for electricity. It is mediated by smart metering and billing systems, and is likely to be of particular interest for microgenerators and/or for anyone interested in energy storage. There are few examples of real-time pricing (RTP) for small-scale end-users, beyond the trial stage. To date, the relationship between supplier and consumer/producer is normally voluntary, though contractual.

RTP requires a constant flow of information between supplier, consumer (and microgeneration technologies), so is heavily reliant on functioning ICT. Because of the unpredictable nature of local load balance at any point, response is best not left to the voluntary choice of the customer, but requires some automation. For example, the customer could set the upper boundary beyond which s/he will not pay for any more supply and the system must cap supply to the home; or the lower boundary beyond which s/he will not export any own-generation to the grid.

There is little experience with RTP for residential customers, and there is a great deal to be discovered about their response in terms of price elasticity and wider impacts on behavior patterns. A couple of early trials show some encouraging results when a relatively simple, robust scheme is put in place with well-informed customers [13, 14]. But we still know very little about how RTP might fit with microgeneration, storage generally, and new technologies such as heat pumps and electric vehicles. There are clearly both equity and data protection considerations, considering the potential complexity of RTP systems.

3.4. Dynamic demand – automated network balancing

Dynamic demand comes at the least 'active' end of the active demand spectrum. The relationship between network operator and customer is essentially one in which they co-manage the load in a locality through frequency response in smart appliances. The appliance responds to minute changes in frequency by cycling on or off according to the load on the network at any instant. Customers make the investment; it is not yet clear whether or how this type of arrangement might be formalised through contracts in which the customer payments are reduced in recognition for their contribution of ancillary services to the network operator. There is no householder intervention, other than choosing to buy the appliance, and even that may become a non-choice in time.

The four options are summarised in Table 1 overleaf.

4. Conclusions

The purpose of this paper was to examine some 'active demand' options for householders, in order to move towards a better understanding of social and behavioural dimensions of both 'active demand' and distributed generation. Involvement in active demand involves recognition of a dimension in electricity supply and usage – time – that is new to many consumers. However, 'active' can have many meanings, and an active demand side does not always mean that the people making the demand are consciously thinking about it. Indeed, they typically think about it very little and, for the more fine-tuned types of active demand, thinking is unnecessary: the function has to be automated.

Overall demand reduction – where conscious activity counts for most – tends to be relegated to the fringes of the debate on active demand. The debates on demand reduction and better load management are sometimes confused: achieving the latter does not necessarily mean that any progress is made on the former, although the former is, in the long term, the most important issue. Questions of control, equity and data privacy emerge as significant factors in the debates that are already taking place in California, Ontario, Victoria, and the Netherlands (to give a few examples) – debates that will spread to other regions before long.

Table 1: Summary of four 'active demand' options, from the end-user standpoint

Options for householders in a 'new dimension' world	**Main objectives**	**Householder activity**	**Comments**
Demand reduction	Better-informed energy management; retrofits and investment in energy efficiency.	Question routines and practices, change practices, invest in efficiency measures, develop energy literacy.	The most conscious and obviously 'active' option. Enabling technology or measures can be very simple or non-existent.
Static time-of-use tariffs	System management to reduce peak load and need for expensive 'peaking plant'	Choice of tariff and possible direct load control by utility; possible changes in routines / investment in enabling technology.	Must have interval metering. Raises some equity and data management issues. May have application for microgenerators, to optimise generation in home over time.
Real-time pricing	Load management to reduce peaks *and* utilize variable generation efficiently	Choice of tariff/ contract, and technologies.	More complexity and risk than TOUP, but more flexibility – necessary for less predictable supply. Relatively untried, but central to the idea of the smart grid.
Dynamic demand, smart appliances	Network management to maintain grid frequency	Choice of appliances and possible contract with network operator.	Least problematic of all options, and compatible with any of them. But requires highly reliable, robust technology.

There are likely to be tensions between approaches that aim to inform and involve householders (leaving them with considerable control), and those that encourage them to adopt technologies that will lessen their control and/or transfer it to the utility. Consumers and prosumers vary in their willingness to pay attention to their energy use, let alone to manage it. There is scope for a suite of approaches, in order to involve as many of the population as necessary in system management; however, there is a strong case for incentivising active consumer involvement in the first instance.

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References

[1] Darby, S. (2008) Why, what, when, how, where and who? Developing UK policy on metering, billing and energy display devices. Proceedings of ACEEE Summer Study on Energy Efficiency in Buildings, Asilomar, CA. August 17-22, 2008.

[2] European Technology Platform, http://www.smartgrids.eu/?q=node/163

[3] DECC (2009) *Towards a smarter future: government responses to the consultation on electricity and gas smart metering.* Department of Energy and Climate Change, London. http://www.decc.gov.uk/assets/decc/Consultations/Smart%20Metering%20for%20Electricity%20and%20Gas/1_20091202094543_e_@@_ResponseElectricityGasConsultation.pdf

[4] DECC (2009) *Smarter Grids: the opportunity.* Department of Energy and Climate Change, London. http://www.decc.gov.uk/assets/decc/what%20we%20do/uk%20energy%20supply/futureelectricitynetworks/1_20091203163757_e_@@_smartergridsopportunity.pdf

[5] Valocchi M, Schurr A, Juliano J and Nelson E (2009) *Plugging in the consumer: innovating utility business models for the future.* IBM report, http://www-05.ibm.com/de/energy/pdf/plugging-in-the-consumer.pdf

[6] Isaacson M, Kotewa L, Star A and Ozog M (2006) *Changing how people think about energy*. Proceedings, ACEEE, 7-124 - 7-139

[7] Torriti J, Hassan MG and Leach M (2010) Demand response experience in Europe: policies, programmes and implementation. *Energy* **35**, 1575-1583

[8] York D and Kushler M (2005) Exploring the relationship between demand response and energy efficiency: a review of experience and discussion of key issues. American Council for an Energy-Efficient Economy research report, http://www.aceee.org/research-report/u052

[9] Shaw R, Attree M, Jackson T and Kay M (2009) The value of reducing distribution losses by domestic load-shifting; a network perspective. *Energy Policy* **37**, 3159-3167

[10] Ehrhardt-Martinez K, Donelly KA and Laitner JA (2010) Advanced metering inititatives and residential feedback programs: a meta-review for household electicity-saving opportunities. American Council for an Energy-Efficient Economy research report, http://www.aceee.org/research-report/e105

[11] Eyre N, Pavan M and Bodineau L (2009) *Energy company obligations to save energy in Italy, the UK and France: what have we learnt?* Proceedings, ECEEE 2009 Summer Study.

[12] Herter K (2007) Residential implementation of critical-peak pricing of electricity. *Energy Policy* **35**, 2121-2130

[13] PNNL (2007) *Pacific Northwest GridWise Testbed demonstration projects. Part 1. Olympic Peninsula project.* Pacific Northwest National Laboratory. http://gridwise.pnl.gov/docs/op_project_final_report_pnnl17167.pdf

[14] Star A, Evans A, Isaacson M and Kotewa L (2008) *Making waves in the heartland: how Illinois' experience with residential real-time pricing can be a national model*. Proceedings, American Council for an Energy-Efficient Economy summer study, 2,281-2,291. ACEEE