

# Behavioural responses to photovoltaic systems in the UK domestic sector

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## Abstract

Microgeneration — the generation of electricity and/or heat within the home — has recently become a notable addition to UK energy policy debates. Specifically research has suggested that, as well as providing renewable energy, these technologies might encourage changes in household energy consumption. The research presented here investigates this ‘double-dividend’ effect using PV households in the UK. It is shown that the installation of PV encouraged households to reduce their overall electricity consumption by approximately 6% and shift demand to times of peak generation. From a household perspective, system performance monitors had the most notable influence on these behavioural responses; however evolving industry arrangements for metering and microgeneration tariffs will be central in determining the future of microgeneration. The paper therefore concludes that the full benefits of microgeneration can only be realised if informed households are integrated within supportive industry and government frameworks.

*Key words:* microgeneration, photovoltaics, consumer behaviour, feedback

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## 1 Introduction

Energy policy has been traditionally dominated by supply-side issues. Helm (2002), for example, describes how successive UK governments sought to ensure the provision of sufficient secure and affordable supplies in order to keep the wheels of industry turning. However, while the recent UK energy review (DTI, 2006b) demonstrates that this is an on-going policy concern, the ‘predict and provide’ philosophy that has historically guided many energy policy decisions must now be tempered with a range of additional concerns such as environmental protection and fuel poverty. This can clearly be seen in the Prime Minister’s recent declaration that nuclear power was “back on the agenda with a vengeance” (BBC News, 2006), a statement advocating a supply-side solution to questions of both energy security and climate change. In this light, demand-side management might be seen as complementary but separate policy area. In the UK, for example, a supply-side shift to low-carbon technologies is promoted through the Department of Trade and Industry’s Renewables Obligation; on the demand side, the Department for Environment, Food and Rural Affairs has the Energy Efficiency Commitment.

In the domestic sector, the distinction between supply and demand is becoming increasingly blurred thanks to the introduction of small-scale generation technologies. Defined by §82 of the *Energy Act* 2004 as the generation of heat or electricity from renewable or co-generation sources with a electrical capacity of less than 50 kilowatts, microgeneration can play a vital role in meeting

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the goals of modern energy policy (e.g Boardman et al., 2005). Many groups have promoted microgeneration as a viable alternative to centralised generation on both environmental and economic grounds (e.g. Greenpeace, 2005; Willis, 2005), though other commentators believe that large-scale renewables are a better use of limited resources (Monbiot, 2006). Most notably though, it has been suggested that microgeneration creates opportunities for consumers to become more aware of their energy use and its impacts, thereby encouraging demand management (e.g. Haas et al., 1999; Dobbyn and Thomas, 2005; Bahaj and James, in press). Microgeneration might therefore be an example of a technology that bridges the divide between supply and demand.

This paper contributes to the microgeneration debate by presenting the results of a three-year investigation into the energy consumption behaviour of UK households with solar photovoltaics (PV). Specifically, the research considered whether microgeneration could provide a ‘double-dividend’ for energy policy by providing both renewable electricity supply and demand reduction. In Section 3, post-installation changes in household energy consumption are discussed using questionnaire and interview data from PV households; Section 4 examines the role of industry and government to understand how such changes might be promoted more widely. An introduction to the relevant literature and policy issues is presented first.

## **2 Background**

Microgeneration is a relatively new feature of the UK energy policy landscape and many of the relevant policy initiatives have been introduced since this research began in 2003. UK academic interest in consumer responses to mi-

crogeneration has grown in parallel but in countries such as Germany and Japan, where support for microgeneration has existed since the early 1990s (IEA-PVPS, 2005), some literature on this subject already exists. This section therefore provides a review of UK microgeneration policy and international experience before introducing the goals of the present study.

### *2.1 UK microgeneration policy*

UK microgeneration policy could be said to contain two elements: diffusion-oriented policies and use-oriented policies. On the diffusion side, grants have been the primary means of promoting microgeneration and this has helped to deliver over 82,000 microgeneration installations by 2005 (EST, 2005). Solar hot water systems account for 95% of these installations but as a heat-generating technology, they are less integrated with the wider energy system.<sup>1</sup> In contrast, electricity generating technologies can interact with the national grid introducing a range of use-oriented policy questions, for example, related to metering and tariffs. The EST study shows that solar photovoltaics (PV) are the most common electricity microgenerating technology in the UK, with twice as many installation as micro-wind; PV was therefore chosen as the focus of the study.

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<sup>1</sup> As part of the present research, a pilot study was conducted with 12 solar hot water households in the Oxford area. The results showed that these households tried to manage their hot water consumption using the storage capacity of the tank. Interactions with government and wider energy policy were considered only at the time of purchase, i.e. the availability of a grant.

### 2.1.1 Photovoltaics in the UK

While the UK may not be the most obvious location for solar energy, it does have a good solar resource ranging from 900 to 1300 kWh/m<sup>2</sup> per year (Jardine and Lane, 2003). Recognizing this, the government has promoted PV technology since the late 1990s and in 2001, a joint government-industry report recommended a £150 million 10-year programme to install PV on 70,000 roofs and 1400 larger non-domestic buildings. The intention was to create a PV-industry similar to that in Germany, Japan, and the US (Shanahan, 2003). Although this particular plan has not yet come to fruition, three other notable policies have existed. These include the PV field trials (2000-2002, approximately 1.5 MW<sub>p</sub> installed), the Major Photovoltaics Demonstration Programme (MDP) (2002-2006, approximately 6.7 MW<sub>p</sub> installed) and the Low Carbon Buildings Programme (LCBP) (since April 2006).

Like the previous MDP, the current LCBP is a grant scheme that provides up to 50% of the cost of small-scale microgeneration systems ( $\leq 5$  kW<sub>p</sub>).<sup>2</sup> The programme also continues the MDP's accreditation system which aims to build consumer confidence through the certification of microgeneration installers and technologies. However there are several important differences between the two programmes. First, the MDP allocated approximately two-thirds of its funding to small-scale installations; the LCBP however plans to reduce funding for small installations over the first three years and then concentrate on larger developments. Secondly, applicants for a small-scale LCBP grant must demonstrate that they have taken steps to improve the energy-efficiency of their home (e.g. loft and cavity wall insulation, low-energy lighting, thermo-

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<sup>2</sup> Under the MDP, the average PV system size was 2.07 kW<sub>p</sub> (EST, 2003).

static and timed heating controls where applicable). Finally, the LCBP covers all microgeneration and energy-efficiency technologies, whereas the MDP was exclusively for PV.

By 2004, such programmes had successfully increased the installed capacity of PV in the UK to approximately 8.2 MW<sub>p</sub> (Figure 1). Consumer awareness of microgeneration has also increased; so much so that the government recently allocated a further £6.2 million for domestic installations following dramatic growth in consumer demand (EST, 2006b; ENDS Report, 2006). However given the LCBP's focus on a range of microgeneration technologies and larger developments, it is difficult to predict whether PV will remain a popular microgeneration technology; at nearly £6000 per installed kW<sub>p</sub>, photovoltaics are still too expensive for much of the general public (Faiers and Neame, 2006). Therefore while the present research provides a snapshot of the early adopters of PV (primarily MDP grant recipients), the wider applicability of the findings will depend on the success of the LCBP.

### *2.1.2 Microgeneration and the wider electricity system*

The introduction of microgeneration creates a range of policy challenges, many of which, such as efficient transmission and distributions systems, are technical in nature (e.g. Supergen Networks, 2006; ENSG, 2006). Although these issues affect the consumer experience (e.g. the work of the regulator Ofgem (Office of Gas and Electricity Markets) on improving the procedures for connecting microgeneration to the grid), the most relevant area of consumer policy pertains to the evolving arrangements to sell and meter microgenerated electricity.

The value of microgenerated electricity consists of three components: an export

value, a generation value and an (avoided) import value. For photovoltaics and other renewables, the generation value is particularly important as the government has an incentive to promote renewable electricity generation. Known as the Renewables Obligation, this scheme requires electricity companies to provide a portion of their supply from renewable sources (6.7% in 2006/7). Renewables Obligation Certificates, or ROCs, are awarded to generators for each renewable megawatt-hour produced and these can be sold to other suppliers who have not met their RO targets at a market price of about £40 per ROC. However the scheme was originally intended for large generators and microgenerators often find it difficult both to generate sufficient renewable electricity and to navigate the 27-page application form required to qualify for ROCs (Ofgem, 2005). Furthermore, in order for suppliers to pay customers for the ROC value, these certificates must be transferred to suppliers creating an administrative challenge. A recent review of the ROC mechanism suggested that ROC amalgamation agents might be created to simplify this process (DTI, 2006c) but the details of this initiative are still being resolved. Recent discussions have also been considering whether additional generation value might be awarded under the Energy Efficiency Commitment scheme (micro-CHP already qualifies for EEC credit) (Ofgem, 2006b).

In a non-microgenerating household, all electricity must be purchased from the grid, i.e. 'imported'. Since households are not required to have half-hourly meters, electricity suppliers estimate the consumption of each property using average demand profiles and use this information to purchase adequate supplies from the wholesale market (a process known as settlement). However in a microgeneration household, less electricity is likely to be purchased from the grid and consequently the accuracy of these estimates is affected

(particularly if larger numbers of microgeneration systems are installed). To avoid this problem, Ofgem allows suppliers to use modified settlement profiles ('P81' profiles) to account for the influence of microgeneration (Ofgem, 2002). In practice though, the cost of using P81 profiles typically outweighs the benefits (Ofgem, 2006b). This is because an additional meter register must be installed to measure exported electricity flows and there is uncertainty about how the cost of these devices might be recouped by electricity suppliers since UK consumers are allowed to change supply contracts within 28 days.

Accurate metering and settlement procedures are a significant part of the microgeneration debate (DTI, 2005b) and these arrangements influence the tariffs that consumers can be offered for their microgeneration output. Part of the difficulty is that numerous metering configurations are possible in microgeneration installations (Hughes and Bell, 2006). Owing to the settlement issues noted above, export meters are not a required feature of a microgeneration installation; instead the most common configuration for UK microgenerators is a standard import meter and a generation meter. (The generation meter is required by the grant programmes.) Consequently approximately 70% of microgenerators are paid for generated units or offered a nominal flat payment based on the performance of a typical system (Keirstead, 2007).

From a demand-side perspective, metering and tariff arrangements are important because each tariff provides different incentives to alter energy consumption. However the potential influence of the tariffs is likely to be dependent on their visibility to the consumer; for example, a trial is currently underway to evaluate the impact of monitoring display devices on domestic energy efficiency (Ofgem, 2006a). Such monitors are already a central feature of microgeneration installations, although they do not have a strong link to particular

tariffs.

The conclusion therefore is that microgeneration technologies such as PV are situated within a complex policy and technology environment. The use of monitoring devices and meters, the different rules for capturing the value of microgenerated electricity, and even the characteristics of PV generation itself are all likely to influence the way in which consumers respond to their microgeneration installation.

## *2.2 Previous studies of microgeneration and consumer behaviour*

To date, microgeneration studies have typically presented technical assessments of performance or offered summaries of national support policies (e.g. for photovoltaics, Kurokawa and Ikki, 2001; Pearsall, 2005). Where consumer behaviour has been considered, the focus has been primarily on the purchase decision (Labay and Kinnear, 1981; Jager, 2006). However recent literature has begun to suggest that the most interesting aspects of consumer behaviour occur once the technologies are installed within the home.

Post-purchase changes in energy consumption behaviour were first mentioned only in passing. A review of best practice with photovoltaics in Europe, for example, notes briefly that adopting households lowered their overall electricity demand (EC, 1997). Haas et al. (1999) suggest that Austrian PV households might either increase or decrease their electricity consumption depending on their pre-PV levels of consumption. It should be noted however that these studies referred to on-grid photovoltaic systems (like most UK PV installations). In the case of off-grid systems, a more consistent change in behaviour

has been seen with individuals and communities developing formal and informal methods of adapting their electricity consumption to the production of their PV systems (Schweizer-Reis et al., 2000; Jenny et al., 2006).

Since consumer behaviour was not the main focus of most of these studies, little explanation of the mechanisms that might drive these changes in consumption has been offered. In the past two years however, new research has begun to examine this question in greater detail. One of the most notable studies is Dobbyn and Thomas (2005), which considered the behavioural responses of both those who chose to install microgeneration and those who happened to live in microgenerating homes but were not actively involved in the purchase decision (e.g. social housing). The key finding of the research was that the latter group of ‘passive’ adopters underwent a significant increase in their awareness of electricity use, encouraging changes in behaviour. Although the sample size of the study was small and the results based on interviews, the overall conclusion — that microgeneration “provides a tangible hook to engage households emotionally with the issues of energy use” (p.7) — is intriguing. Similarly, a second study monitored the energy consumption and generation of nine PV-equipped social housing units and found that load-shifting behaviour had occurred (i.e. switching demand to times of generation). The incentives for these behaviours, such as payment schemes for microgenerated electricity, were also discussed reinforcing the importance of the policy context in which these consumers act (Bahaj and James, in press).

These previous studies are summarized in Table 1.

### *2.3 Study aims and methodology*

The growth of microgeneration in the UK (specifically photovoltaics) raises questions about the relationship between consumers and the existing electricity system. With the ability to generate electricity and sell it back to the grid, households are no longer restricted to being passive recipients of electricity. Indeed the literature cited above has suggested that microgenerating households might become actively engaged in the dynamics of electricity production and consumption. However these studies have provided only a general introduction to this process and its implications for policy; further research is needed to understand the behaviour of PV households in detail, not as passive users of a new technology, but as potentially active participants within a wider socio-technical network (e.g Shove, 1998).

The paper therefore has two aims. The first is to describe post-installation changes in the energy consumption behaviour of PV households and offer some explanation for why these shifts have occurred; in other words, to determine whether PV offers a ‘double-dividend’ for energy policy by providing renewable electricity as well as encouraging more efficient energy use. Secondly, the role of industry and government needs to be examined to see how behavioural responses to PV are influenced by the broader socio-technical system.

To answer these questions, it was initially hoped that the research would pair two types of data: detailed monitoring data (measuring the generation and demand of PV households for at least one year before and after the installation of PV) and social surveys (describing the attitudes and behaviour of the monitored households on a similar time-scale). However after exploring

several potential data sources, this approach was deemed infeasible due to difficulties in acquiring both system performance data (e.g. commercial sensitivity constraints on data access and limited resources for independent system monitoring) and parallel access for social surveying (e.g. privacy concerns). These two types of PV household data were therefore separated, with detailed questionnaires and interviews (conducted by the author) providing the results discussed here; supplementary system performance data from a different set of PV households (courtesy of the Northumbria Photovoltaics Application Centre) provided interpretive context for these results. For a policy perspective on the issues raised by these surveys, semi-structured interviews were then conducted with key industry and government stakeholders.

A full discussion of the methodology and results can be found in Keirstead (2006).

### **3 Does PV yield a double-dividend?**

The research began with the design and distribution of closed-format questionnaires to 118 UK PV households in November 2004 (approximately 1/6 of the domestic installations at the time); a response rate of 77% was achieved through the use of self-addressed stamped return envelopes, the offer of a gift certificate prize, and a letter of introduction. As part of the questionnaire, respondents were asked if they were willing to participate in follow-up interviews and 63 such interviews were conducted in Winter 2005. This section considers the results of both surveys.

### 3.1 Demographic and attitudinal profiles of the respondents

The questionnaire began by examining the demographic and attitudinal characteristics of the respondents. First, the sample was checked to see if it was representative of both UK households at large and UK PV households specifically. Using the results of a previous survey of UK PV households (EST, 2004), it was found that the sample was representative of most PV households in terms of their age, income, household size and environmental concern. However when compared with the national population (represented by ONS, 2004), the respondents were significantly ( $p < 0.001$ ):

- older (92% of PV households were older than 45);
- wealthier (40% had annual household incomes greater than £50,000);
- better-educated (77% had degree-level qualifications vs. 30% nationally);
- and
- more likely to own their own home (97% versus 71% nationally)

Using these demographic attributes, the respondents were clustered into two descriptive groups: ‘families’ (45–64, annual income of £50,000–100,000, 3 household occupants, 10–20 years residency) and ‘retirees’ (over 65, annual income of £35,000–50,000, 2 occupants, more than 20 years residency). The analysis found that there were very few significant differences between these groups on subsequent energy consumption questions.

Data were also collected to identify the respondents’ psychological characteristics. These factors included knowledge (of energy use and climate change), self-identity (as a ‘home energy-saver’, measured using Callero’s methodology (1992)), worldview (from Dunlap et al. (2000)) and values (using a modified

version of Rokeach (1973)). For the knowledge and worldview constructs, comparison with national datasets (Park et al., 2001) was possible and showed significantly higher awareness and concern about energy, climate change and environmental issues than the general public ( $p < 0.001$ ). Using the other instruments, it was found that the respondents generally saw themselves as ‘home energy-savers’ (defined by an interest in energy bills and do-it-yourself repairs) and felt that altruistic values were more important than selfish values (i.e. expressing a preference for social equality and helping the environment over social recognition).

In their critique of energy intervention studies, Abrahamse et al. (2005) observed that many studies fail to describe the underlying mechanisms that shape consumer behaviour. The interviews therefore explored these characteristics further to understand how households arrived at the decision to purchase of PV and whether this might influence subsequent energy use behaviour. It was found that the respondents’ interest in energy and environment issues encouraged them to seek information on PV technology, for example by attending exhibitions or contacting an installer. Similarly the final purchase decision seems to have been closely linked with the values of the respondents; that is, PV provided concerned individuals with a way to take responsibility for the environmental impact of their lifestyles:

“We’ve always been environmentally-concerned and so we thought ‘Okay, like everybody else we use cars and we use planes so what can we do to help?’ So when we heard that this sort of system [PV] was available... that was in a way, an easy way to compensate for being modern, wanting to use electricity and cars.”

– *D.P.*

However despite their environmental concern and high incomes, the interviews found that the cost of PV was still an obstacle to many respondents. Of course, the grant did encourage a purchase decision — as one respondent noted, “no grant, no PV” (D.R.) — but it was found that other ‘catalytic’ factors were often also involved. In some cases, these convenient coincidences made the installation process less disruptive (e.g. the roof was being replaced anyway). The main effect though was to lower the net cost of PV even further:

“So I thought ‘we’ll have those [PV]’ and as luck would have it, I’ve got a lump sum from a pension fund. So when I turned 50 and I thought, well the government will pay half the price, I’ll get the rest of it, get it done and I’ve not really regretted it ever since.”

– *J.W.*

The results therefore suggest that the post-PV energy consumption of these ‘active’ adopters (after Dobbyn and Thomas, 2005) is likely to be influenced by two factors. On the one hand, the demographic and psychological profile of these households suggests that PV is part of a personally-motivated environmentally-aware lifestyle. However, the role of the grant and other catalytic factors illustrates that consumer decisions are not taken in isolation. Any subsequent changes in energy consumption are therefore also likely to be the product of both internal and external factors.

### *3.2 Changes in overall electricity demand*

The study’s main goal was to describe any changes in energy use encouraged by the adoption of PV. However, as noted above, it was not possible to gather

detailed consumption data from periods before and after the installation of PV. Instead, the questionnaire focused on forms of energy consumption which were better suited to a closed-format survey, such as the installation of insulation measures, the efficiency of appliances, and the use of efficient lighting.

Haas et al. (1999) suggested that the purchase of PV may be part of a ‘conservation chain’, i.e. a series of energy-saving investments, and evidence was found to support this hypothesis. When asked about their pre-PV energy efficiency actions, respondents were found to have had significantly higher rates of loft and cavity-wall insulation (loft: 97% vs. 88% national,  $p = 0.001$ ; cavity wall: 43% vs. 25% national,  $p \ll 0.001$ ) and efficient lighting (49% of lighting points pre-PV vs. 6.4% nationally,  $p \ll 0.001$ ) compared to national figures (ODPM, 2001; MTP, 2005). After the installation of PV, significant differences to the respondents’ pre-PV situation were found in only two measures: the use of a green electricity tariff (up from 50% to 76% of respondents, largely acting on the installer’s advice,  $p \ll 0.001$ ) and the use of efficient lighting (up from 49% to 58% of lighting points,  $p < 0.05$ ). Significant changes in appliance efficiency were not seen, arguably because of the slow turnover in these stocks (75% of respondents had owned their systems for less than 2 years).

The closed-format of the questionnaire could not include all possible sources of energy consumption, but respondents were asked to estimate their overall electricity saving since the installation of PV, as well as their certainty in this change. A self-assessed overall saving of 5.6% was found when weighting the responses by certainty (Figure 2). When asked to elaborate on this change, those who reported a saving claimed to be significantly more aware of electricity generation and consumption issues than non-savers ( $p \ll 0.001$ ). These initial responses were confirmed in the follow-up interviews; for ex-

ample, many respondents reported being more aware of leaving lights and appliances switched on unnecessarily. By combining the questionnaire and interview results, the respondents were divided into three saving groups (Table 2).

The reported overall savings are comparable with the conclusions of previous literature on feedback and domestic energy saving (Darby, 2006). However it is difficult to determine whether these are lasting changes in consumption behaviour. For example, one respondent lamented that “modern lifestyle has moved on quite rapidly in terms of energy use” (D.S.) and their electricity use continued to rise after installing PV, largely due to the proliferation of consumer electronics. These findings therefore represent a snapshot of the double-dividend effect and further research would be valuable both to measure the changes more precisely and to determine their durability.

### *3.3 Changes in consumption patterns and the role of monitoring*

The reliability of self-estimates of electricity use is largely dependent on the information environment of households and how energy consumption is assessed (Kempton and Layne, 1994). One respondent, for example, believed that she had saved electricity because her monthly direct debit payment had gone down; however the questionnaires and interviews found that many respondents were very energy literate and took regular meter readings in kilowatt-hours. The energy information environment of PV households however is not only determined by the traditional import meter. Indeed the research found that 86% of respondents had a monitoring device which, unlike a meter, is primarily intended to display generation (and occasionally consumption) information

to the household.

To explore the role of monitors, questions were asked about their use within the home: specifically, the visibility of the device, how frequently it was viewed, which metrics were used and how. The results showed that 61% of monitors were installed in visible areas such as kitchens or living rooms but in older systems (> 2 years), the monitor was often installed in a hidden location (e.g. with the inverter in an attic or metering cupboard). 51% of respondents viewed their monitors at least once a day and those with ‘visible’ monitors viewed them significantly more frequently ( $p < 0.05$ ).

The most common monitor, owned by 56% of respondents, was a Leiderdorp LI-12 (Figure 3). This device displays a PV system’s instantaneous output, as well as the cumulative generation and kilograms of carbon dioxide saved since installation or a system reset. Instantaneous and cumulative generation are commonly found on other devices as well and regardless of the specific monitor model, the most popular metric was instantaneous output (favoured by 62% of respondents). This information was primarily used to ensure that the system was working and it also provided a sense of satisfaction to the owners:

“There’s a nice kudos feeling because when you notice that you’re producing a couple of kilowatts, you feel good. You think to yourself, ‘oh I’m doing well today, it’s exporting some, I’m doing okay’.”

— *M.B.*

Importantly though, only three of the 78 respondents with monitors reported owning a device that could display consumption information. There was however a demand for this information and 73% of respondents said that their ideal monitoring device should have a metric to compare generation and con-

sumption. As Darby's (2006) review of feedback literature makes clear, one of the requirements of effective feedback is that it must be relevant; therefore without information on consumption, it can be difficult to compare demand patterns with the output of the PV system and respond, e.g. by matching consumption with generation over various timescales. Nevertheless 43% of respondents reported some form of load-shifting activity primarily in response to the generation profile of their PV system; this occurred mainly in households where technology or the occupants' lifestyle facilitated the load-shift (e.g. those who had timers for appliances or where at home during the day):

“...like today, it's a lovely sunny day so I'll use the washing machine now because I know that it'll be on solar energy. And if I was going to do any baking, I tend to wait until it's a sunny day and then do enough baking to last me for a bit.”

— *C.H.*

In addition to these specific changes, monitors also created a general awareness of the nature of PV-generated electricity: as one respondent astutely noted, “[PV] doesn't operate at the times when in a sense you need it most, which is when it's dark or when it's winter.” (J.R.). This awareness of the link between generation and consumption could also be seen when households were asked which energy saving actions (if any) they might take in future. The installation of further microgeneration technologies (e.g. micro-CHP or micro-wind) was the preferred action of 18% of respondents and they indicated that their experience with PV had made them slightly more likely to act ( $p < 0.1$ ); however respondents claimed that PV had a greater influence on encouraging them to undertake improvements in the efficiency of lights and appliances ( $p < 0.05$ ).

Although monitors are clearly an important element of a microgeneration installation, it is the meters that are used to establish microgeneration tariffs. The survey found that only 48% of PV installations had export meters installed and the majority of these had been installed before 2003. Consequently only 29% of respondents were paid for their exported units; most received a flat payment or one based on generated output instead. While some respondents were happy with this arrangement, others felt that they were being “ripped off” (T.M.) without more accurate metering and compensation. Respondents also indicated that the existing level of tariffs was not high enough to influence their consumption behaviour.

### *3.4 Summary*

The results of the questionnaire and follow-up interviews revealed that a double-dividend from PV does exist. Respondents reported an estimated 6% reduction in overall electricity use and evidence was seen of an increase in general energy awareness and the use of efficient lighting. Changes were also seen in the time of electricity use, prompted primarily by the information provided by monitoring devices. However the potential of post-PV energy-saving may have been partially limited by the extensive measures taken by these households before installing PV. Although many of the behavioural responses discussed here appear to have been personally motivated (i.e. the tariffs seem to have had little effect on behaviour), the role of industry and government is now examined for a more complete understanding of these findings.

## 4 The role of industry and government

Consumers interact with stakeholders from the microgeneration industry at two key moments. First, at the time of purchase, households wishing to adopt PV must negotiate the process of selecting an installer, securing grant funding, and connecting the system to the grid. Once the system has been commissioned, households wishing to sell their PV electricity must then establish a relationship with an electricity supplier. At both of these stages, the practices of these wider stakeholders could have an influence on the household's perception of PV and their resulting energy consumption. The research therefore sought to complement the household-level data with the perspectives of key industry and government groups. This was accomplished through semi-structured interviews with 25 representatives from major government departments, electricity suppliers, PV installers, metering and monitoring firms, and industry trade associations in late 2005. While the results revealed the complex position of photovoltaics and microgeneration in UK energy policy more generally (Keirstead, 2007), this paper considers only the influence of these industry actors on consumers.

### *4.1 Purchasing PV*

As noted by Boczkowski (2004), the diffusion of a technology and the experiences of its early users represent “two sides of the same innovation coin” (p. 255). Through their interpretation of the intended use of a new product, early adopters can shape a technology's evolving design and function (e.g. Ornetzeder, 2001; Wüstenhagen et al., 2003). Therefore it is important to ex-

plore the interactions of those promoting PV (and related technologies) and the early-adopting households interviewed above, in order to gain a better understanding of how behavioural responses to PV might be encouraged.

The first point of contact between these groups is the purchase decision and the interviews found that the UK PV industry's primary concern at this stage was the diffusion of PV, i.e. increasing the number of installations. This was because the installation industry is largely dependent on grants, especially to encourage the small private household installations which are "the lifeblood of many companies in the PV industry" (Hacker, 2005). When the interviews were conducted, the industry had recently been through a series of extensions to the MDP and the details of the LCBP had not yet been announced. Consequently there was a sense of uncertainty about whether sufficient grant funding would be available in future and hence installers remained focused on encouraging consumers to adopt PV. For example, one installer emphasised that the grant "legitimizes a new technology, it reduces the cost so it makes it more affordable for people to do it and also it provides some quality assurance to people." Similar arguments were seen in lobbying efforts as well, with the Renewable Energy Association also working to ensure that a viable grant programme would remain.

However, PV households often saw the installers as more than implementers of a government grant. Many households commented on the convenience of having a central contact coordinate the various workers required to install a PV system (e.g. scaffolders, electricians etc.) and valued the advice that installers provided on selecting an electricity supplier or seeking planning permission for their system. Most importantly, consumers noted that installers could play a role in encouraging further behavioural change:

“The guy that installed it said to me ‘you will find that you will suddenly become far more conscious of leaving lights on’, and doing this and doing that and so on and he was right.”

– *L.S.*

Similar results were found in Dobbyn and Thomas (2005), where ‘passive’ adopting households, i.e. those without a great deal of initial energy awareness, exhibited the greatest changes in energy consumption when they were provided with information about the system’s operation at the time of installation. Consequently the installers’ focus on the adoption decision suggests that they might not be fully aware of the influence they could have on subsequent energy consumption behaviour.

#### *4.2 Living with PV: electricity tariffs, meters, and monitors*

One of the main attractions of purchasing a PV system is the ability to sell excess electricity production to the grid. However although a number of payment options are available (e.g. generation, export, profile as above), respondents noted that selecting a tariff was a difficult and confusing process. This was primarily because the tariffs were not prominently advertised in the media or on corporate websites; in some cases, staff working on telephone inquiry lines were not even aware that their firms offered such tariffs. Most households therefore selected the tariff plan recommended by their PV installer and did not explore further options. While many consumers were satisfied with this arrangement, others believed that they were not getting a fair deal:

“Well I got a letter saying my cost of using electricity was going to go up, and

I phoned them up and said ‘well am I going to get more for my electricity that I generate?’ and they just said ‘well that’s a separate system.’ Really if they’re going to put their prices up, they need to give my element of what I’m charging, that has to go up at the same percentage.”

— *R.B.*

During the industry interviews however, electricity suppliers noted that the tariffs offered to microgenerators were primarily ‘aspirational’ products. In other words, given the difficulties of claiming ROC and settlement values from a “handful” of microgeneration customers, the financial benefits were negligible and the tariffs were essentially a strategic offering:

“I think we’re at the very early stages of something that could potentially be very large so we need to be in the party now as it were, understanding what’s going on out there so we’re ready when things really do start progressing.”

– *Electricity supplier*

Similar comments were made by representatives of the metering industry. They observed that although the technologies needed for microgeneration metering were readily available (e.g. export meters), regulatory obstacles, such as the 28-day rule for changing domestic supply contracts, made it difficult to justify an investment: in the words of trade association representative, “it’s the system and the bureaucracy that go behind it that will cause the problem rather than the meters themselves.” The use of more advanced metering technologies (e.g. automated meter reading) has also been linked with microgeneration but evidence from the literature suggests that the potential benefits in the UK are relatively minor (e.g. for the reduction of peak demand) (Owen and Ward, 2006). This is certainly true for PV systems, which do not generate during the

UK's peak demand on dark winter evenings.

Finally, it was hypothesised that the makers of the monitoring devices might wish to be actively engaged with PV households as a way to develop and promote their products. However the interviews found that although the initial device designs did benefit from the input of PV households, the small size of these firms made it difficult to identify consumer demands and introduce further innovations on a continual basis. This is because the sales of monitoring devices are strongly linked with the existence of support programmes for PV itself. Therefore until the market grows significantly, respondents felt that it would be too expensive to add consumption information to monitoring devices.

#### *4.3 The role of government*

The interviews therefore found that most of the industry stakeholders with which PV households interact have little interest in the behaviour of the households once PV is installed. This suggests that central government (the Department of Trade and Industry (DTI), regulator Ofgem, and others) may have a role to play in promoting the benefits of consumer responses to micro-generation. At first glance, it appears that consumer behaviour is a concern of central government: for example, the DTI's microgeneration strategy expresses an interest in researching consumer behaviour "in particular, what drives early-adopter purchase decisions" (DTI, 2006a). However not only does this emphasise the purchase decision again, but industry lobbyists also noted that consumer research was often one of the first elements of government funding to be cut. Furthermore although the regulator Ofgem has a mandate to protect consumer interests, their ability to intervene in the market is limited.

A more detailed discussion of the government issues surrounding microgeneration can be found in Keirstead (2007).

#### *4.4 Summary*

The results appear to confirm that microgeneration households are not considered as full-fledged ‘citizens’ of the electricity system (Devine-Wright and Devine-Wright, 2005). Instead the efforts of industry and government are focused on distributing microgeneration technology, with less consideration for how households respond once the technology is in place. Unfortunately there is a danger that if behavioural responses to microgeneration technologies are not considered now, when consumer technologies and protocols are still being developed, then the industry could find that households become locked into behaviours that may be undesirable in the longer term. At the very least, the full benefits of the double-dividend are unlikely to be achieved.

## **5 Discussion**

The research found evidence of a ‘double-dividend’ from photovoltaics, indicating that the value of microgeneration technologies comes not only from the green electricity they produce, but also from their ability to influence subsequent electricity consumption behaviour. However if the full potential of this effect is to be realised, policy and industry stakeholders will need to ensure that a supportive socio-technical system is in place. This section therefore considers how the double-dividend could be promoted through improvements to the regulatory environment and the introduction of certain practical measures.

### *5.1 Improving the institutional framework*

During the interviews, a spokesperson for the electricity regulator Ofgem noted that their role was “to give a bit of leadership to the industry.” Certainly Ofgem has encouraged the integration of microgeneration into the main electricity system by clarifying connection procedures and the use of modified settlement profiles. However the results showed that electricity suppliers still find it difficult to claim the full value of microgeneration and arguably this affects their willingness to engage with consumers and promote further energy saving. The following suggestions therefore seek to address some of the regulatory and commercial barriers to achieving the full potential of microgeneration.

The first challenge arises from the way in which consumer responses to microgeneration are treated within the regulatory environment. This is an area of policy that is still evolving but at present, it could be argued that Ofgem is pursuing an ‘additive’ regulatory approach. Under such a system, a microgeneration household would be able to claim ROC credit for the renewable electricity they generate and energy efficiency commitment or similar credits would be available for the feedback benefits of a monitoring device; however the interaction of microgeneration and monitoring, e.g. load shifting as discussed here, would not be considered. The preference for an additive approach can be seen in a recent Ofgem call for pilot projects to quantify the demand reduction potential of monitoring and smart metering (Ofgem, 2006a). The tender document makes no mention of microgeneration, suggesting that the interactive value of microgeneration and monitoring for encouraging load-shifting might be lost. While details of the pilot studies have not yet been released,

the results of this study suggest that at least some comparison should be made of the effects of monitoring devices in import-only and microgeneration households. Furthermore, recalling that respondents expressed an interest in monitors that could present both generation and consumption data, these trials could be used to quantify the benefits of such devices, consider how they might be integrated with billing and metering arrangements, and consider how they might be financed.

The question of an ‘additive’ approach to regulation is simply one example of how institutional frameworks are evolving. The development of ROC amalgamation agents, for example, also shows that there is still potential to incorporate microgeneration households into the wider electricity system. However, this is not only a question of post-installation use-oriented regulation. The diffusion of microgeneration technology, which is the focus of so much industry activity, also provides an opportunity to reshape the system. Recent research has highlighted how alternative diffusion models might redefine the relationship between consumers and suppliers, encouraging both higher rates of adoption and greater long-term benefits. However the report laments that “current policy is too focused on incremental changes. It misses opportunities to support micro-generation as part of a broader shift towards demand reduction and consumer behaviour change.” (Watson et al., 2006, p.2). The findings of this research support this conclusion, specifically noting that installers may be unaware of their potential contribution to these goals. Clearly then, both industry and government have a role to play in engaging with households and ensuring that the full benefits of microgeneration are realised.

## *5.2 Practical measures for promoting the double-dividend*

While re-orienting the institutional framework for greater consumer engagement may be a long-term task, a number of practical measures can be taken now to encourage the double-dividend. For example, a pre-requisite for consumer responses to microgeneration is an understanding of the technology itself. As the interviews showed, early-adopting MDP households typically had a well-developed awareness of the technology resulting from their decision process. However as the LCBP grants seek to promote the spread of microgeneration to a wider mix of households, there is a risk that new adopters might not have this background knowledge. This issue was seen in Dobbyn and Thomas (2005) and, together with the results of this study, it suggests that ‘introduction packs’ could be used to establish this base knowledge. Provided at the time of installation, these packs would provide information about the system’s operation (e.g. what to do in case of system failure), a description of the monitoring device and its various metrics, and a list of available microgeneration tariffs. Most importantly, the packs should also describe the experiences of other microgeneration households, providing an introduction to further possible reductions in energy consumption. The grant administrator already has such case studies available on their website (EST, 2006a) and therefore compiling the information and distributing the packs to successful grant recipients (especially large-scale developers) may be a very cost-effective way to engage microgeneration households. Alternatively installers could implement this initiative, potentially allowing a firm to distinguish itself from its competitors in an increasingly crowded microgeneration market.

One of the benefits of the introduction packs would be to inform consumers

about the characteristics of their specific generation technology. For example, while solar photovoltaics generate their electricity in the daytime, micro-CHP units will be generating largely in the evening (i.e. when heat is more likely to be required), creating different opportunities for load-shifting and demand reduction. The introduction packs can start to establish this awareness but the main way to promote the link between generation and demand is through the use of effective monitoring devices. Currently the grant programme does not require that such devices be fitted to new microgeneration installations (though it does recommend it) so one option would be to require all grant recipients to install a monitor. However linking monitors to the grant process is not ideal as the industry hopes that microgeneration technologies will eventually be able to thrive without grant support. Fortunately there is likely to be a continuing role for the accreditation system, as a tool for ensuring consumer confidence, and this might be a better option for promoting monitors. Currently operated by the grant administrator, this registry of approved technologies and installers could be expanded to include the role of monitors. In accordance with the principles of effective feedback, monitors would ideally only be approved if they displayed both generation and consumption data on comparable timescales; similarly approved installers would be those who used such monitors as standard practice. Alternatively differentiated ‘approved’ and ‘recommended’ designations could be introduced to encourage a wider range of devices. Regardless of it is achieved though, monitoring devices should be considered as a standard feature of a modern microgeneration installation.

## 6 Conclusion and further research

In recent years, there has been increased interest in the role of microgeneration in energy policy. Although diffusion-oriented policies primarily position microgeneration as an alternative supply technology, international experience has suggested that there may also be benefits on the demand side. This research represents a major attempt to describe and explain these changes in energy consumption behaviour. By examining UK PV households, it was shown that a ‘double-dividend’ from microgeneration does exist with PV producing renewable electricity as well as stimulating changes in consumer behaviour. Two notable changes were seen: a 6% saving in the overall amount of electricity used and load-shifting to times of peak PV generation. Furthermore it was shown that monitoring devices, which display the output of the PV system to households in real time or cumulatively, can facilitate these changes by increasing energy awareness — even for the households studied here, who had high levels of energy awareness before installing PV.

However behavioural responses to microgeneration are not simply the result of technologies installed within the home or the disposition of the occupants. Industry and government interviews showed that the wider socio-technical system — notably key features such as regulation, electricity tariffs, and metering technology — influence how microgeneration households are incorporated into the electricity system. At present, these arrangements appear to do little to encourage post-purchase energy efficiency in adopting households. However it was noted that the role of microgeneration consumers within the electricity system is still evolving and behavioural responses to microgeneration might yet be encouraged. Specifically it was suggested that the institutional frame-

work should capture fully the benefits of microgeneration (e.g. by using an integrated, not additive, regulatory approach) and that consumers should be provided with a supportive information environment (through the use of generation/consumption monitors and introductory information packs).

While these results indicate that it would be naïve to think of microgeneration simply as another generation technology, further research will be needed to broaden our understanding of these effects and establish a basis for rigorous regulation. Specific questions that might be asked include:

- What are the behavioural responses to other kinds of microgeneration technologies (e.g. micro-CHP, micro-wind, heat pumps)?
- How do behavioural responses to microgeneration vary between different demographic and attitudinal groups? (i.e. beyond the early adopters considered here)
- What is the influence of monitors that display both generation and consumption information, compared with the present monitors that primarily feature generation information only?
- Where a behavioural response to microgeneration is seen, how long does the effect last? In other words, what sort of rebound effect might be seen?

It seems that ultimately a study is needed to measure the electricity consumption and generation profiles of microgeneration households in detail, thereby providing a firmer base of evidence. While this was not feasible in the present research, the results will hopefully still encourage researchers and policy makers to view microgeneration as a potentially valuable link between energy supply and demand.

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## Tables

Study	Location (sample size)	Key findings
<i>Grid-connected</i>		
EC (1997)	France (21)	“Increased awareness of the value of electricity generated has led system owners to take other energy savings measures in their homes.” (p. 5)
Haas et al. (1999)	Austria (21)	High-consumers (> 3500 kWh per year) reduce overall demand after installation of PV, low consumers increased demand; PV is “the last part in a chain of energy conservation investments” (p.189)
Erge et al. (2001)	Germany (68)	Consumption of PV households was “not different” from that of non-PV households (p. 483)
Dobbyn and Thomas (2005)	United Kingdom (29)	Found changes in behaviour (e.g. turning off lights, shifting loads, investigating additional generation capacity) especially in ‘passive’ adopting households (e.g. social housing)
Bahaj and James (in press)	United Kingdom (9)	Detailed monitoring of consumption found that “increased energy awareness can lead to changes in the way energy is used, reducing overall consumption but ‘education’ must be sustained to ensure long-term energy reductions” (p. 1)
<i>Off-grid</i>		
Schweizer-Reis et al. (2000)	Germany and Spain (> 300)	Evidence that respondents “happy with this limitation [of electricity production]; it makes us feel responsible for our energy consumption” (p. 8). Load shifting and conservation behaviours seen in response to monitoring devices
Jenny et al. (2006)	Cuba (49)	Residents “developed rules and agreements for coordination of their energy use that have led to good adaptation to the dynamics of energy production.” (p. 1)

Table 1  
Existing research on PV and household behavioural responses

### **No saving**

- No saving or an increase in electricity consumption
- 36 interviewees, a mix of age and income categories, largely two-person households
- 4.3% more CFLs, no change to appliance ownership, some improvements to insulation and double-glazing
- No increase in awareness of electricity generation or consumption
- Sample quote: *“No I’ve tried not to [change the overall amount of energy used] really, I’ve just tried to carry on as normal . . . I mean I was always very careful anyway, I didn’t need to be educated on that score.”* – K.D.

### **Small saving**

- Average self-assessed saving of –9% (weighted by certainty)
- 22 interviewees, mainly ‘families’ (i.e. >2 occupants) with high incomes
- 13.6% more CFLs, some improvements in appliance efficiency, some improvements to insulation and double-glazing
- Slight increase in awareness of electricity generation and consumption
- Sample quote: *“I think we’ve probably been a bit more sensitive to when to consume and probably a little more disciplined with general little things like leaving lights on in unoccupied rooms and things like that, yeah, we’re just a little more aware.”* – M. N.

### **Large saving**

- Average self-assessed saving of –35% (weighted by certainty)
- 5 interviewees, mainly low-income single-occupant retired households
- 24% more CFLs, some changes in appliance ownership, some improvements to double-glazing and draught-proofing
- Notable increase in awareness of electricity generation and consumption
- Sample quote: *“The panels themselves have led to a lot of further energy measures saving because it’s made me particularly, much more aware of how much energy I was using.”* – D. E.

Table 2

Post-installation electricity saving groups

## **Illustrations**

See overleaf

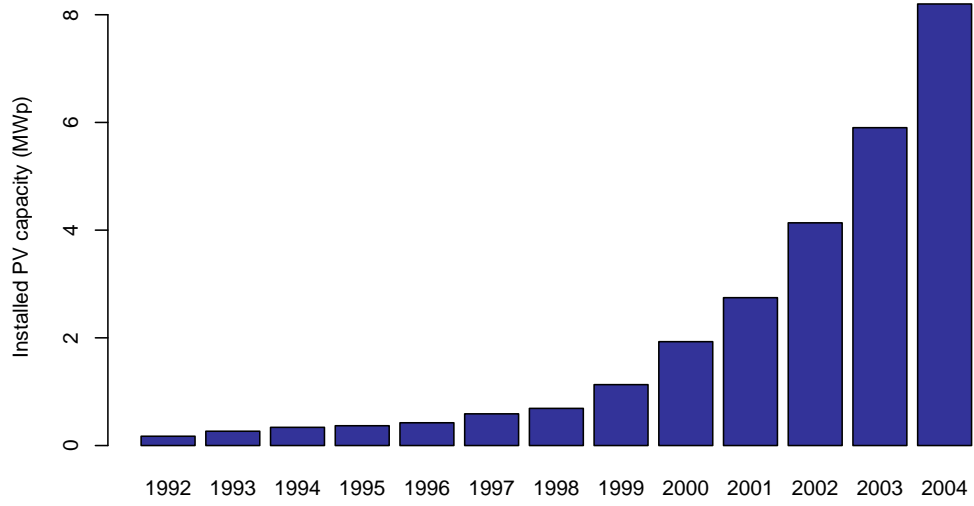


Fig. 1. Installed PV capacity in the UK as of 2004 (IEA-PVPS, 2005; DTI, 2005a)

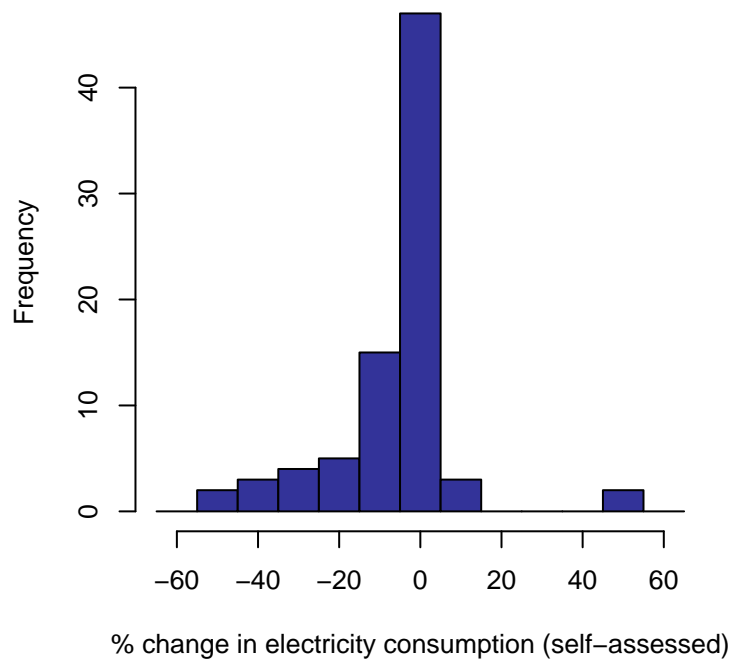


Fig. 2. Post-installation electricity savings,  $\mu = -5.6\%$ ,  $n = 91$



Fig. 3. Leiderdorp LI-12 PV monitor