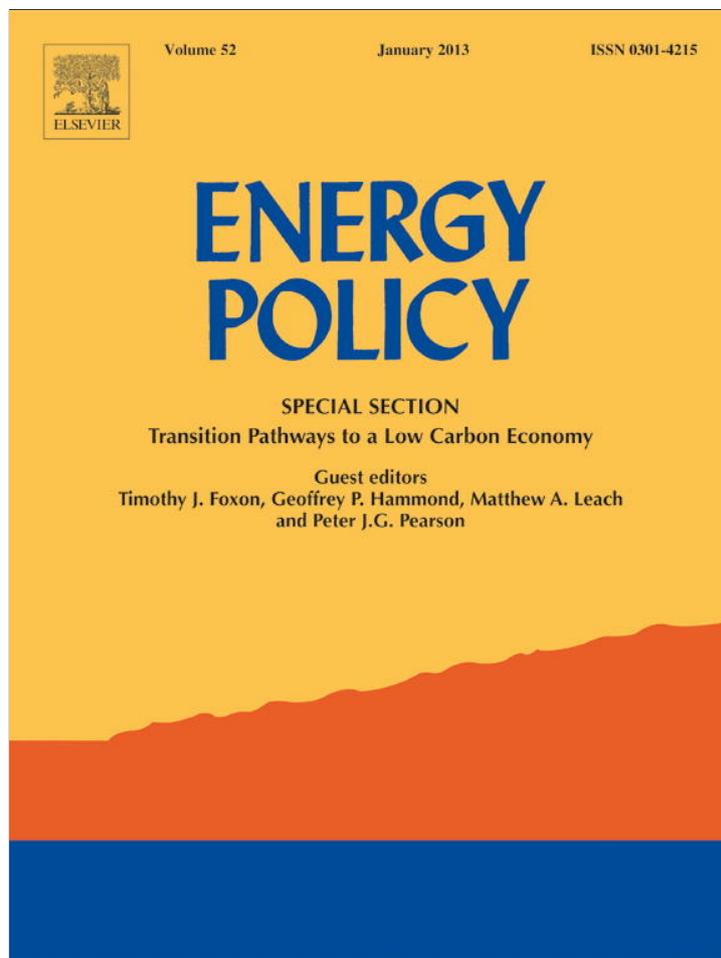


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## A review of the costs and benefits of demand response for electricity in the UK

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### H I G H L I G H T S

- ▶ The paper clearly articulates the range of benefits and costs from demand response.
- ▶ Estimates for benefits and costs are converted into a broadly comparable basis.
- ▶ It is found that a positive case exists for demand response in the UK.
- ▶ New quantitative modelling is provided for one UK benefit not found in the literature.
- ▶ Economic welfare gain is considered in assessment; other UK papers do not consider such effects.

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### A B S T R A C T

The recent policy discussion in the UK on the economic case for demand response (DR) calls for a reflection on available evidence regarding its costs and benefits. Existing studies tend to consider the size of investments and returns of certain forms of DR in isolation and do not consider economic welfare effects. From review of existing studies, policy documents, and some simple modelling of benefits of DR in providing reserve for unforeseen events, we demonstrate that the economic case for DR in UK electricity markets is positive. Consideration of economic welfare gains is provided.

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## 1. Introduction

For decades the assessment of the costs and benefits of Demand Response (DR) has been one of the focal points of energy economists' research. Recently UK policy-makers opened a discussion about the UK-specific costs and benefits of DR as part of the Electricity Market Reform (EMR). It has been pointed out that an appropriate regulatory framework is essential in order to optimise the benefits of storage and demand side management within the UK liberalised market (Strbac, 2008). For policy-makers to undertake the necessary regulatory changes required to accommodate DR in electricity markets, they must be confident about the economic case for DR.

This paper sets out to review the costs and benefits of DR for the UK electricity market. For this study, five of the most relevant papers and reports assessing potential current and future costs and benefits of DR in the UK are brought together and estimates

converted to a broadly comparable form in order to investigate the economic case for DR.

The main studies reviewed are as follows: DECC and Ofgem (2011a, 2011b), Ofgem (2010), Strbac et al. (2010), Strbac (2008) and Seebach et al. (2009). These illustrative analyses inform our survey of costs and benefits. Where possible, the concept of net welfare gain is used to distinguish between investment costs (e.g. installing smart meters) and DR programme returns (e.g. electricity aggregators' profits or consumer savings etc.) on the one hand, and societal costs (e.g. system level upgrades) and benefits (e.g. reductions in interruptions) on the other hand.

The paper aims to both classify the range of benefits and costs that can occur from DR and, where possible, to provide quantitative estimates of costs and benefits. The study then attempts to draw some broad insights and comparison of the order of magnitude differences in various costs and benefits for different forms of DR. Assumed customer participation and customer response rates of the studies are compared with various estimates in the literature in order to provide 'a reality check' to estimates.

The paper firstly provides background information about the implementation of DR in the UK electricity market and reviews the core benefits categories for DR (Section 2) identifies the main

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cost types relating to DR (Section 3); quantifies costs and benefits and CO<sub>2</sub> reductions (Section 4); Section 5 concludes with a discussion of policy implications.

## 2. Background

Demand side management (DSM) has evolved over the last three decades. Traditionally DSM has been applied and generally restricted to efficiency and conservation programmes.<sup>1</sup> When developing such programmes electricity prices were taken as a given; this is said to have hampered such programmes. More recently however, programmes that emphasise price responsiveness have arisen (Charles River Associates, 2005). The International Energy Agency (2003) seem to follow this line when defining DSM. They define demand side management as including wide ranging actions to reduce demand for electricity (or gas) and/or to shift demand from peak to off peak times. Such a definition can encompass programs emphasising price response as well as automated reductions in energy at peak times. When price responsiveness is considered in the literature, many authors refer to the latter as DR.<sup>2</sup>

Various definitions of DR exist.<sup>3</sup> In this study we apply the broad definition of Albadi and El-Saadany (2008, p. 1990) when reviewing the costs and benefits associated with demand side response.<sup>4</sup> The current study does not however, include energy efficiency improvements as a result of improved insulation etc. as a form of DR.

In order to investigate the costs and benefits of DR a theoretical framework was required to guide our analysis of benefits and costs for this paper and the earlier working paper (Bradley et al., 2011). In this study we draw on the framework used in a robustly developed report by the U.S. Department of Energy (2006). Using this framework requires information and assumptions on the following:

- DR options—e.g. tariff type, programme available or proposed to be used;
- *Customer participation*—the expected extent to which customers participate with programs;
- *Customer Response*—quantifying current structure of electricity usage by participants, and identifying how participants change their consumption patterns in response to price changes or incentives available;
- *Financial benefits*—quantifying (through various methods) the short-and long-term resource savings resulting from DR under varying market structures;
- *Other Benefits*—identifying and quantifying other benefits that can result from a given form of DR (e.g. benefits to functioning of the market or improved reliability); and
- *Cost*—estimating the costs required to attain a level of DR.

When assessing studies that estimate the benefits from DR, U.S. Department of Energy (2006) found a wide variation between illustrative studies and programme performance studies and

integrated resource planning studies of DR. Taking these findings on board, this study only looks at one form of study, illustrative studies (within which estimates and methods tend to be more consistent) in one country (the UK) with the same market structure and regulatory environment and often similar years and time frame.

Illustrative studies are said to estimate economic impacts (quantitatively) for DR within a given electricity market.

DR benefits assessment in such studies is based on assuming a level of DR and then estimating consequent benefits, therefore these forms of study are hypothetical and speculative (by U.S. Department for Energy (2006)). Whether these studies benefits estimates materialise, depends on how closely reality and actual circumstance match assumptions used in analysis. From limited analysis U.S. Department of Energy (2006) find that such studies tend to report high benefits, in part due to assuming DR penetration levels to be high, over a large base of participants and also because benefits tend to be assumed to be long term (they assume sustained participation for the period assessed).

Due to the importance of looking at these aspects for illustrative studies, an assessment of the extent to which assumptions on the level of DR compare with the most up to date information on participation and response in DR programs is conducted in Section 4. This study also looks at aspects of the UK context that may increase or decrease participation. This provides a 'reality check' to illustrative study estimates.<sup>5</sup> This study only uses published estimates of benefits and costs from DR as this increases the transparency of reporting (where modelling is conducted by the authors due to unavailable DR estimates, again published data is used).

Beyond attempting to find studies of a similar kind with similar methods, following recommendations by U.S. Department of Energy (2006) this study also attempts to avoid overlap between DR benefits categories. Where this is unavoidable the potential for double counting is identified.

This paper also identifies potential for welfare gains for different types of DR and their quantitative estimates. The latter contribution is important and it is rarely conducted for DR assessments. From all of the main UK studies reviewed, none seemed to identify whether benefits would result in net welfare gains. This is important as different forms of DR can vary in the extent to which they produce actual productivity and efficiency gains for the economy. In welfare economics: welfare is the sum of the producer and consumer surpluses. Welfare gain can be defined as the net increase in consumer and producer surplus without regard to the distribution of the gains (as seen in Boisvert and Neenan, 2003). Wealth transfers do not result in an increase in the sum of the consumer and producer surplus, only a change in distribution of the surplus between producers and consumers. See Boisvert and Neenan (2003) for more information about welfare gains and DR.

In the current study we attempt to identify whether DR benefits are likely to result in a welfare gain, assuming benefits outweigh costs (ABOC).<sup>6</sup> From Section 2.1 onwards the term welfare gain is termed a net welfare benefit in order to keep consistency and fluidity in our use of language.<sup>7</sup>

<sup>1</sup> For efficiency programmes, Spees and Lave (2007) report energy efficiency gains for nine studies, some of which include economic estimates.

<sup>2</sup> E.g. Torriti et al. (2010, p. 1) state that: "Demand Response (DR) refers to a wide range of actions which can be taken at the customer side of the electricity meter in response to particular conditions within the electricity system (such as peak period network congestion or high prices)."

<sup>3</sup> See Bradley et al. (2011) for a range of different definitions.

<sup>4</sup> Albadi and El-Saadany (2008, p. 1990) define demand response in a similar but slightly wider way to include energy savings that occur not just in response to network congestion or high prices: "DR includes all intentional electricity consumption pattern modifications by end-use customers that are intended to alter the timing, level of instantaneous demand, or total electricity consumption".

<sup>5</sup> The working paper from which the paper stems, also looks in details at methods of each study used. Some important points on methods of the various studies are also brought out in this paper where relevant.

<sup>6</sup> The project stops short of conducting a full welfare analysis due to time and resources required.

<sup>7</sup> A net welfare benefit is different from a net benefit which is any overall benefit that remains once reported costs (related to a demand side response investment e.g. smart metering) are deducted from benefits.

### 2.1. Benefits from DR

Strbac (2008) explains benefits in the most detailed way and provide good coverage for a range of benefits that can arise from DR. However, not all benefits are presented clearly and complexity remains.<sup>8</sup> This review attempted to clearly and where possible simply present what the benefits from DR actually are.

From reading this study and other literature, there seems to be eight core benefits possible from DR, these are displayed in Table 1.

A very clear summary of each of the eight core benefits from Table 1 is provided in Appendix A. Each benefit is also briefly discussed in this section.

### 2.2. Benefits from relative and absolute reductions in electricity demand

In order to look into benefits for electricity saving the current study reports estimated electricity savings (and consequent benefits) from the introduction of smart meters (from Department for Energy and Climate Change and Ofgem, 2011a, 2011b). Estimates of absolute reductions possible from the introduction of smart meters are provided later in the paper.

### 2.3. Benefits resulting from short run marginal cost savings from using DR to shift peak demand

To provide quantifiable indication and estimates of expected benefits from short run marginal cost savings from peak demand shifts, estimates from Ofgem (2010) and Department for Energy and Climate Change and Ofgem (2011a, 2011b) are discussed. If peaks in electricity demand can be regularly and reliably reduced, then essentially the requirement for extra generation, transmission and distribution capacity can also be reduced. Reduced generation capacity relates to the next benefit.

### 2.4. Benefits in terms of displacing new plant investment from using DR to shift peak demand

There appears to be two types of situation where DR can aid the displacement of new plant infrastructure; from DR via peak demand shifts<sup>9</sup> and from DR for emergencies and unforeseen events (described in the next section). To provide quantifiable indication and estimates from peak demand shifts, estimates from Department for Energy and Climate Change and Ofgem (2011a, 2011b) and Ofgem (2010) are applied.

### 2.5. Benefits of using DR in providing reserve for emergencies/unforeseen events

From literature reviewed it was not possible to provide an average annual estimate of value of DR to avoid the need for generation capacity to provide reserve for emergencies/unforeseen events; studies such as those of Strbac (2008) do however provide an indication of the likely value of benefits per kW. By not estimating this benefit, overlap (and double counting) with avoided generation from 2.4 is avoided. Beyond value to generators, there can also be benefit to households and businesses from reduced interruptions to service and avoided customer

minutes lost. The current authors employ new quantitative modelling described in Appendix B to estimate the potential value of this benefit, to customers (households and businesses).

### 2.6. Benefits of DR in providing standby reserve and balancing for wind

The value of storage and DR when providing standing reserve for balancing for wind can be calculated by analysis of the improvements in the system in terms of fuel cost and CO<sub>2</sub> emissions (Strbac 2008). In order to investigate this benefit for the UK, annual estimates from Seebach et al. (2009) are used.

### 2.7. Benefits of DR to distributed power systems

DR could facilitate connection of more distributed generation by providing greater flexibility in balancing the system (Strbac, 2008). No quantitative estimates for this benefit were found.

### 2.8. Benefits in terms of reduced transmission network investment by reducing congestion of the network and avoiding transmission network re-enforcement

Estimates of reduced transmission investment (from which annual values could be generated) as a result of a reduction in peak demand were available from Department for Energy and Climate Change and Ofgem (2011a, 2011b). These quantitative values are reported. No data to enable an annual estimate of the full value of reduced transmission network investment resulting from a move from preventative to a corrective electricity system management philosophy were found.

### 2.9. Benefits from using DR to improve distribution network investment efficiency and reduce losses

Similarly, with regards to improving distribution network investment efficiency through a change in philosophy using DR, Strbac (2008) identifies a range of potential benefits in his paper.<sup>10</sup> Quantitative estimates to enable an annual value of reduced distribution network investment resulting from a move from preventative to corrective electricity system management were found from Strbac et al. (2010). These are reported, as are values of reduced distribution network investment resulting from reductions in peak demand and avoided losses that result from both electricity saving and peak demand shift.

## 3. Costs of DR

In this section the costs associated with DR are firstly identified. A range of costs that can occur for DR are presented in Table 2.

Table 2 provides a concise overview of the various costs associated with DR. In the far right hand column, it can be seen that from this review it was not possible to find quantitative estimates for all costs, although a good number were quantified. Those that remain mainly un-quantified relate to participant costs. Qualitative discussion of such costs was reported in the literature, for example Ofgem (2010) provide good descriptions

<sup>8</sup> His study uses the term DSM, but the way the term is used by Strbac (2008) seems to generally fit with the definition of DR used in the current study.

<sup>9</sup> Sheffrin et al. (2008) identify that of the studies they reviewed, demand response in the range of 5–15 per cent of a system peak load can provide substantial benefits in decreasing need for additional resources and lowering real time electricity prices for all customers.

<sup>10</sup> "(i) Deferring new network investment, (ii) increasing the amount of distributed generation that can be connected to the existing distribution network infrastructure, (iii) relieving voltage-constrained power transfer problems, (iv) relieving congestion in distribution substations, (v) simplifying outage management and enhancing the quality and security of supply to critical-load customers, and (vi) providing corresponding carbon reduction." (Strbac, 2008, p. 4422).

**Table 1**

DR benefits identified from this literature review.

Sections	Benefit	Relevant studies	Quantification
2.2	Benefits from relative and absolute reductions in electricity demand	Department for Energy and Climate Change and Ofgem (2011a, 2011b)	Yes
2.3	Benefits resulting from short run marginal cost savings from using demand response to shift peak demand	Ofgem (2010) and Department for Energy and Climate Change and Ofgem (2011a, 2011b)	Yes
2.4	Benefits in terms of displacing new plant investment from using demand response to shift peak demand or respond to emergencies;	Ofgem (2010) and Department for Energy and Climate Change and Ofgem (2011a, 2011b)	Yes
2.5	Benefits of using demand response in providing reserve for emergencies/unforeseen events	Strbac (2008)	Partial
2.6	Benefits of demand response in providing standby reserve and balancing for wind	Strbac (2008), Department for Trade and Industry (2004), Department for Trade and Industry (2006) and Parliamentary Office of Science and Technology (2008), Seebach et al. (2009)	Yes
2.7	Benefits of DR to distributed power systems	Strbac (2008)	No
2.8	Benefits in terms of reduced transmission network investment by reducing congestion of the network and avoiding transmission network re-enforcement	Strbac (2008), Mott MacDonald (2007)	Yes
2.9	Benefits from using demand response to improve distribution network investment efficiency and reduce losses	Strbac (2008), Mott MacDonald (2007), Department for Energy and Climate Change and Ofgem (2011a, 2011b), Strbac et al. (2010).	Yes

**Table 2**

Different cost categories for implementation and operation of a DSM system (developed from U.S. Department of Energy, 2006, p. 23).

Type of cost	Cost	Quantification
<b>Participant costs</b>		
Initial costs	Enabling technology investment	Yes
	Establishing response plan or strategy	No
Event specific costs	Comfort/inconvenience costs	No
	Reduced amenity/lost business	No
	Rescheduling costs (e.g. overtime pay)	No
	Onsite generator fuel and maintenance costs	No
<b>System costs</b>		
Initial costs	Metering/communication system upgrades <sup>a</sup>	Yes
	Utility equipment or software costs, billing system upgrades	Partial
Ongoing programme costs <sup>b</sup>	Consumer education	Partial
	Programme administration/management	Partial
	Marketing/recruitment	Partial
	Payments to participating customers	Partial
	Programme evaluation	No
	Metering/communication	Yes

<sup>a</sup> Metering/communications costs can include dedicated wire or wireless lines leased from a third party telecommunications provider and costs to communicate pricing or curtailment information to customers or their energy service suppliers.

<sup>b</sup> Ongoing programme costs apply for incentive-based DR programs and optional price-based programs only. For default-service time-varying pricing, ongoing costs are equivalent to any other default-service tariff offering.

and discussion of such costs. U.S. Department of Energy (2006) find that of the studies they reviewed most do not report participant costs, but they report that it is possible to collect and report such information. Although this is so, they state that in practice customers estimate their costs and indicate acceptance when enrolling for voluntary DR programmes and that participant costs are most feasibly reflected by examining participation rates. So at the end of this section we provide an up to date review of participation as well as response rates for real time feedback and DR related programmes. This review also informs the robustness of participation assumptions applied by various studies and they inform discussions and conclusion. For most other costs, quantitative estimates were found. Appendices C and D provide detail relating to different cost categories.

With regards to enabling technology investments the current paper reports technology costs of smart meters from Department for Energy and Climate Change and Ofgem (2011a, 2011b). Although believed to fall into the category of “enabling technology investment” participant costs, suppliers will be required to procure and install smart meters as part of a mandatory smart meter roll out therefore these can be considered as system costs.

These cost however, are likely to be passed on to energy consumers. Quantitative estimates of technology costs from smart appliances are taken from Seebach et al. (2009) and these enable DR benefits relating to balancing for wind. U.S. Department of Energy refer to other enabling technologies as “smart thermostats, peak load controls, energy management control or information systems fully integrated into a business customers operations”. From review we only have annual UK estimates for smart metering and smart appliance technologies, but benefits also only directly relate to these, so there is no miss match.

Table 2 shows a range of system costs. For a good number of the categories (seven of the eight), estimates exist (from which annual figures can be derived) from Department for Energy and Climate Change and Ofgem's (2011a, 2011b) costs of roll out of smart metering. Appendix C identifies the specific system costs covered by the latter study.

Although many of the system costs are covered by the Department for Energy and Climate Change and Ofgem (2011a, 2011b) reports, for some costs coverage is believed to only be partial as indicated in Table 2 and discussed in Appendix C; most of these partial category costs relate to potential additional costs

**Table 3**  
Key findings from recent review studies on participation and levels of DR.

Review of response rates for DR			
Review study	Results		
Ehrhardt-Martinez et al. (2010)	<b>Likely aggregate level energy savings by feedback type (based on previous experience from studies and modelling)</b>		
	<b>Feedback type</b>	<b>Overall savings (given participation rates and average household values)</b>	
	Enhanced billing—opt out	2%	
	Real time feedback—opt out	4%	
Faruqui et al. (2010b)	<b>Feedback type</b>	<b>Average energy savings</b>	<b>Overall savings (given participation rates and average household values)</b>
	Real time feedback plus <sup>a</sup> —opt out	6%	
	Direct feedback by in home display (equiv. to real time feedback)	7%	–
	Direct feedback by in home display combined with prepayment (pay as you go type)	14%	–
VaasaETT (2011)	<b>Feedback type/form of pricing</b>	<b>Average energy savings</b>	<b>Overall savings (given participation rates and average household values)</b>
	Real time feedback plus <sup>a</sup> —opt out	6%	
	Direct feedback by in home display (equiv. to real time feedback)	8.7%	–
	Time-of-use	5%	–
Faruqui and Sergici (2010)	<b>Feedback type/form of pricing</b>	<b>Average energy savings</b>	<b>Overall savings (given participation rates and average household values)</b>
	Critical peak pricing	16%	–
	Direct feedback by in home display (equiv. to real time feedback)	8.7%	–
	Time-of-use	5%	–
Faruqui and Sergici (2010)	<b>Findings on drops in peak household demand from different tariff types</b>		
	<b>Tariff type</b>	<b>Drop in peak demand for those that participate</b>	
	Time-of-use	3–6%	
	Time-of-use + technology	21–30%	
	Critical peak pricing	13–20%	
	Critical peak pricing + technology	27–44%	

<sup>a</sup> Feedback plus translates to real-time information to the resolution of appliances (as opposed to overall electricity use).

associated with DR programmes other than time of use (TOU) programs that exist. Estimated benefit from studies do not relate to demand response programs beyond TOU, therefore there is not a mismatch between costs and benefits.

Although a few costs have not been fully captured, from review of cost estimates available for smart meters capital and installation costs dominate most other types of costs (see Appendix D). Based on this it can be said that system costs e.g. marketing etc. that are not fully captured are unlikely to dominate DR related costs.

### 3.1. Review of participation rates

A number of reviews have been conducted to look at the effect of energy feedback information and resulting response in energy use terms.<sup>11</sup> Ehrhardt-Martinez et al. (2010) cover 57 studies from 1974 to 2010. This is a very clear and comprehensive review and splits the conservation effects from feedback by study size, era, type of feedback and region. VaasaETT (2011) report for the European Smart Metering Industry Group the results from 100 DR pilot trials for different types of feedback and in some cases dynamic pricing. Additionally a study by Faruqui and Sergici (2010) looks only at household responses to dynamic pricing. The study reviews 15 dynamic pricing experiments, and prove that customers do respond to price. Most recently Faruqui et al. (2010b) cover 12 direct feedback trials using an In Home Display device between 1989 and 2009, including time of use and

prepayment trials. Table 3 summarises key results from these studies.

With regards to energy savings in Table 3, Ehrhardt-Martinez et al. (2010) identify that participation was generally over 75% (and typically 85%) for studies designed as 'opt out' (where all participants are included initially, but free to pull out of the study). For the UK context of implementing smart metering the feedback form is believed to be real time feedback with opt-out, therefore if implemented well the UK could expect a 4% energy reduction to result. Recent large scale UK trials suggest that household energy reduction of at least 3% is likely (AECOM, 2011). Faruqui et al. (2010b) find that if real time feedback via an in home display is combined with a system of pre-payment (pay as you go) as opposed to paying after consumption, household level energy savings appear to double—in order for this to translate into a doubling of national household savings would however require everyone to be on a pre-payment scheme. In the UK many people are not on such pre-payment (pay as you go) schemes. The effect of pre-payment schemes shows the importance of the context (in terms of payment structures) around which electricity is consumed.

With regards to shifting peak demand, Faruqui and Sergici (2010) show the drop in peak electricity demand is between 3 and 6% for those that use time-of-use type tariffs. Recent Irish trials indicate an overall 8% reduction for household participants, UK trials vary by group but suggest 10% can be possible (Commission for Energy Regulation, 2011; AECOM, 2011). In Faruqui and Sergici (2010) critical peak pricing (CPP) achieves a drop in peak demand of 13–20% without technology, this is much higher than TOU tariff structures without technology, this again shows the importance of structures used to incentivise DR.

When enabling technologies are used in conjunction with the time-of-use tariffs drops in peak demand can be far higher 21–30% (and 21–44% for CPP). This finding is an indicator of inconvenience, inhibiting effects of habit and bounded rationality

<sup>11</sup> Abrahamse et al. (2005) look at 38 peer-reviewed studies on different behavioural interventions related to energy use from 1977 to 2004. Darby (2006) conducts a review for Defra of 38 studies on gas and electricity from 1979 to 2005. Specific emphasis is placed on the divide between direct feedback, indirect feedback, and time of use studies. Fischer (2008) covers 21 trials from 1987 to 2005 as well as five other review papers that focused on a range of types of feedback.

(amongst other things). More directly, however it shows the very clear role and capability impact of enabling technologies in dramatically increasing levels of DR for electricity.<sup>12</sup> Estimates of enabling technology impacts from Faruqui et al. (2010b) were for households, comparable estimates for the non-domestic SME sector were not found, but a US study of DR enabling technology for small businesses by Martinez (2006) identifies that they could play a key role, especially for the significant proportion of SMEs towards the higher end of the energy use scale.

From their evidence based review Ehrhardt-Martinez et al. 2010 (and Darby, 2006) identify quite low overall energy savings that result from programs focused on peak load savings, the benefit focus by these authors seems to be the direct energy reduction (on the demand side). But the current authors believe that care needs to be taken not to under rate the supply side environmental and economic benefits, these must be identified and acknowledged to enable a fair comparison of benefits. This paper demonstrates this.

#### 4. Value of costs and benefits from DR

In this section a table is developed<sup>13</sup> (see Table 4) that identifies the main quantitative estimates from studies of various DR benefits and costs. The studies are described in detail and critiqued in the precursory working paper of Bradley et al. (2011).

The DECC and Ofgem impact assessments of the Smart meter rollout for the domestic (Department for Energy and Climate Change and Ofgem, 2011a) and small and medium non-domestic sector (Department for Energy and Climate Change and Ofgem, 2011b) provide quantitative estimates of the financial cost of implementation of smart metering technology as well as financial benefits from reductions in energy demand and peak demand shifting (as well as other non-DR benefits). Significant consultation was undertaken with the energy industry e.g. energy suppliers in relation to estimation of both costs and benefits (particularly non-DR related). Due to such consultation estimates must be considered in the light of this. An earlier discussion publication by Ofgem (2010) on DR provided significant detail on methods of estimating financial benefits associated with peak load shifting and different sensitivities for main assumptions, this work is used to discuss, contrast and compare estimates from Department for Energy and Climate Change and Ofgem (2011a, 2011b).

Seebach et al. (2009) model the costs and benefits of smart appliances in Europe. Specifically, Seebach et al. (2009) estimate the value of benefits in 2010 and 2025 from the use of smart appliances for network balancing of wind power. Benefits are assessed in terms of fuel cost savings, reduction in carbon emissions and reduction in wind curtailment, comparison is conducted with a standard scenario without DR.

<sup>12</sup> From Faruqui and Sergici (2010), enabling technology is believed to be defined as two way programmable communicating thermostats and always-on gate systems that allow multiple end uses to be controlled remotely. It should be noted that only a limited amount of the UK population have water and space heating that is electric and this should be accounted for when attempting to further investigate the impact of such technologies on DR in the UK. Although this is the case enabling technologies can be widely ranging and can have different impacts on DR.

<sup>13</sup> For Table 4, it should be noted that DR benefits relating to distributed power systems (Section 2.7) remain un-quantified as do a number of participant costs although the latter category were looked at from examination of participation rates. It was difficult to quantify benefits from avoided transmission network investment resulting from a different electricity system management philosophy, but values relating to peak demand shifts are provided. Ranking of these un-quantified benefits is not attempted, as without quantification this cannot be conducted with any confidence.

Strbac et al. (2010) look at the future financial benefits to the distribution network from a paradigm shift in the electricity system operation philosophy that could be enabled by technology in conjunction with DR. Benefits are estimated for avoided future distribution network re-enforcements costs. Strbac et al. (2010) consider a range of future development scenarios involving penetration of electric vehicles (EVs) and heat pumps (HPs) under two different network operation paradigms as follows:

1. A preventative business as usual (BaU) approach and;
2. A corrective smart meter enabled active control (AC) approach.

For the studies reviewed it was somewhat difficult to achieve consistency in measurement across units, timescales and treatment (e.g. discounting) for every single cost and benefit due to use of estimates from different studies. Although this was so, estimates were converted into as comparable form and basis as possible for most categories. Table 4 presents estimates, mainly as annual average values generated from present value estimates in most cases. It is useful to attempt to broadly compare various costs and benefits for broadly comparable categories.

##### 4.1. Value of benefits from relative and absolute reductions in electricity demand

In Table 4 it can be seen that from the Department for Energy and Climate Change and Ofgem (2011a, 2011b) work electricity savings generate the most significant DR related financial benefits, estimated to occur from a conservative assumption of a 2.8% reduction in the UK electricity use. DECC and Ofgem perform some sensitivities around this assumption, using alternative assumptions of 4% and 1.5% savings. When the 4% assumption is applied the value of electricity saved goes up from a value of £157m for the domestic sector to £237m. When the 1.5% assumption is applied the value reduces to £77m.<sup>14</sup> Therefore a very modest increase in electricity savings can have a significant effect on electricity saving benefits. A review by Ehrhardt-Martinez et al. (2010) acts as a 'reality check', they suggest that actually 4% is the likely aggregate level of electricity savings to be expected (from introduction of real time feedback in an opt out system such as the UK is believed will employ) based on experience of previous studies. Recent large scale trials for the UK identify that implementation of smart metering with real time display consistently resulted in at least a 3% reduction (AECOM, 2011). This is informative for what is likely in the UK context. The majority of the value of these electricity saving benefits are believed to be welfare transfers (from producer to consumer) and will not fall into the category of net welfare benefits,<sup>15</sup> as most of the reductions do not occur during peak times when inefficient generators are more likely to operate. Although this is the case, from a human welfare and equity point of view such transfers are highly desirable.<sup>16</sup> Also CO<sub>2</sub> emissions reductions (if valued), would fall into the category of a net welfare benefit to society, assuming economic benefits outweigh economic costs.

<sup>14</sup> For the small and medium non-domestic sector using figures, an assumption of a 1.5% reduction leads reduces annual average benefits from £34m to £17m, the 4% assumption increases benefits to £50m (based on Department for Energy and Climate Change and Ofgem, 2011b figures).

<sup>15</sup> ABOC.

<sup>16</sup> As they help consumers mitigate against rising energy prices and higher energy bills and can help ensure individuals energy security and reduce fuel poverty.

**Table 4**  
Summary table of potential costs and benefits of DR.

Form of DR benefit or cost		Benefit/cost	Units	Domestic/ non-domestic	Estimate of benefits/cost	Mt CO <sub>2</sub>	Potential contribution to net welfare benefits	Study
Reductions in energy demand (3.2)	Benefits	Reductions in electricity (energy savings)	Present value millions of £	Domestic	157	0.87	Low	Department for Energy and Climate Change and Ofgem (2011a) <sup>a</sup>
Peak demand shift (3.3, 3.4, 3.8 and 3.9)		Reductions in electricity (CO <sub>2</sub> savings)	Present value millions of £	Non-domestic	34	0.25	Yes	Department for Energy and Climate Change and Ofgem (2011b)
		Short run marginal cost savings (from shifting peak demand using TOU)	Present value millions of £	Domestic	19	0.25	Yes	Department for Energy and Climate Change and Ofgem (2011a)
				Non-domestic	4.2	0.25		Department for Energy and Climate Change and Ofgem (2011b)
				Domestic	6.1	n.v	Yes	Department for Energy and Climate Change and Ofgem (2011a)
				Non-domestic	1.4	n.v		Department for Energy and Climate Change and Ofgem (2011b)
		Displacing new plant investment (avoided investment from TOU)	Present value Millions of £	Domestic	33	n.v	Yes	Department for Energy and Climate Change and Ofgem (2011a)
		CO <sub>2</sub> reductions associated with TOU demand shifts	Present value millions of £	Non-domestic	1.0	n.v		Department for Energy and Climate Change and Ofgem (2011b)
		Reduced transmission and distribution network investment (avoided investment from TOU)	Present value millions of £	Domestic	2.4	n.v	Yes	Department for Energy and Climate Change and Ofgem (2011a)
				Non-domestic	0.9	n.v		Department for Energy and Climate Change and Ofgem (2011b)
				Domestic	1.5	n.v	Yes	Department for Energy and Climate Change and Ofgem (2011a)
Both of the above forms of DR		Reduced losses as a result of the introduction of smart meters (electricity and gas)	Present value Millions of £	Non-domestic	0.1	n.v		Department for Energy and Climate Change and Ofgem (2011b)
				Domestic	22	n.v	Yes	Department for Energy and Climate Change and Ofgem (2011a)
Not DR related		Other non-DR benefits resulting from smart metering (electricity and gas)	Present value millions of £	Non-domestic	5	n.v		Department for Energy and Climate Change and Ofgem (2011b)
		Estimated value of avoiding all customer interruptions and customer minutes lost for the UK	Millions of £ for the year	Both	Avoided customer interruptions minutes lost	n.a	Yes	Department for Energy and Climate Change and Ofgem (2011b)
				Domestic	445	n.a	Yes	Department for Energy and Climate Change and Ofgem (2011a)
				Non-domestic	26	n.a		Department for Energy and Climate Change and Ofgem (2011b)
Balancing for wind (3.6)		Benefits from balancing for wind (value of energy and CO <sub>2</sub> ) as a result of smart appliances	Value per unit in 2025 Euro/kW DSM	Domestic	Lower price scenario <sup>a</sup> 80	2	Yes	Seebach et al. (2009)
				Both	Upper price scenario <sup>a</sup> 130			
Balancing for a change in system management philosophy (3.9)		Reduced distribution network investment (from a change to a smart corrective smart electricity system)	Average annual (for the twenty years)	Both	25–500	n.v	Yes	Strbac et al. (2010)

Smart metering (electricity and gas)	System costs	Capital costs, installation costs, O&M costs, IT costs, the cost of capital, energy costs from smart meter consumed energy, meter reading costs, disposal costs, Legal, marketing and organisational costs	Average annual	Present value millions of £	Domestic	538	n.a	Department for Energy and Climate Change and Ofgem (2011a)
Smart appliances	Participant cost	Cost of the actual appliances and additional electricity use	Value per unit in 2025	Euro/kW DSM	Domestic	Lower scenario 10	Upper scenario 30	Department for Energy and Climate Change and Ofgem (2011b)
					Non-domestic	30	n.a	Seebach et al. (2009)

<sup>a</sup> D&O refers to DECC and Ofgem.

Department for Energy and Climate Change and Ofgem (2011a, 2011b) estimate an annual average financial value for these CO<sub>2</sub> savings as £23 million (domestic and non-domestic sector combined with the 2.8% assumption). The value however, does not reflect true benefit in terms of avoided damage costs of CO<sub>2</sub> which may be higher or lower depending on the impacts of climate change, but this is difficult to value.

#### 4.2. Value of benefits from shifting peak demand—Short run marginal cost savings, displacing of new plant investment, transmission and distribution benefits

As a result of the implementation of smart meters, additional DR benefits are expected to come forth relating to peak load shifting. Shifting electricity demands as a form of DR seems to produce large benefits (although less than electricity saving) for the domestic sector, but less for the small and medium non-domestic sector. The finding that benefits from demand shifts (although significant) are not the largest DR related benefits (from all categories of DR), contrasts with Spees and Lave (2007) assertion that decreasing peak load (and consequent benefits) is most important in evaluating DR.<sup>17</sup>

Of benefits relating to demand shifts (those associated with TOU tariffs) avoided investment in generation appears to be the largest benefit from Table 4, followed by short run marginal cost savings, the value of CO<sub>2</sub> reductions and then benefits in terms of avoided investment in the distribution and transmission and distribution network. This order of benefits (with avoidance of generation capacity being by far the largest benefit) is broadly consistent with findings of the Faruqui et al. (2010a) European analysis when looking at the effects of increasing adoption of dynamic tariffs in Europe.

Faruqui et al. (2010a) estimate that the benefits with high adoption rates (80% of customers reducing their demand at peak hours due to dynamic pricing, believed to translate into a 10% reduction in overall peak electricity use) could be higher than the costs of the advanced metering infrastructure required (including smart meters). If a low adoption of 20% (believed to translate into a 2% reduction in peak electricity use) is seen, then the value of benefits is well below (28% of) the cost of advanced smart metering infrastructure. Their study shows the importance of customer participation, for maximising benefits for shifting peak demand and that these benefits have the potential to be huge depending on the level of customer participation.

The Faruqui et al. (2010a) 10% reduction in overall peak energy use is a much more optimistic assumption than applied by Department for Energy and Climate Change and Ofgem (2011a, 2011b) for the TOU tariff (of 1.3%).<sup>18</sup> This is reflected in estimated results in Table 4, the value of UK (as opposed to Europe) benefits resulting from the TOU tariff is below 10% of the smart metering infrastructure cost. In the UK however, it is believed that a low 1.3% reduction in shifting peak demand would not break the smart metering investment as Faruqui et al. (2010a) indicate in their European analysis. This is due to other DR and non-DR related benefits shown in Table 4 and Appendix E.

<sup>17</sup> Spees and Lave (2007) however treat all energy efficiency as separate from demand response (the current study include short run energy savings as a form of DR, although excludes long run savings through investment in energy efficiency such as via installation of insulation).

<sup>18</sup> Their assessment is that in the short run 20% of current residential peak load is discretionary. They expect uptake of TOU tariffs to also be 20%. They assume that in the short run these customers will only shift their load for one in three times that they actually could. Taking their methods into account, the current authors estimate that this roughly equates to a 1.3% shift in peak domestic electricity demands  $(0.2 \times 0.2 \times 0.3333333) \times 100$ .

**Table 5**  
Estimated benefits from peak demand shifts from Ofgem (2010).

Study	Benefits/cost	Time period	Units (not present value)	Estimate of benefits/costs		Mt CO <sub>2</sub> (electricity)	
Ofgem (2010)	<b>Benefits</b> —short run marginal cost savings from shifting peak demand	Range for two winter and one autumn day	Millions of £ unless otherwise stated	5% shift 0.4–0.8	10% shift 0.7–1.7	5% shift 560–1350 t	10% shift 800–2650 t
Ofgem (2010)	<b>Benefits</b> —displacing new plant investment from shifting peak demand	Annual estimate	Millions of £	£129–£261	£265–£536	n.a	n.a
Ofgem (2010)	<b>Benefits</b> —improved distribution network investment efficiency	Annual estimate	Millions of £	£14	£28	n.a	n.a

The Department for Energy and Climate Change and Ofgem (2011a, 2011b) estimates are also conservative compared to Ofgem (2010). For each type of DR<sup>19</sup> (short run marginal cost savings, generation and transmission related benefits) associated with peak demand shifting in Table 4, estimated benefits of Department for Energy and Climate Change and Ofgem (2011a, 2011b) appear to be substantially lower than those of Ofgem (2010). Table 5 shows estimates from Ofgem (2010).

One has to ask why the benefits from the Department for Energy and Climate Change and Ofgem (2011a, 2011b) work are generally much lower? As a starting point, the Ofgem (2010) estimate includes estimation for larger commercial and industrial consumers. Also, the assumptions about how much electricity is shifted by Department for Energy and Climate Change and Ofgem (2011a, 2011b) are much more conservative and these are very important in determining benefits. Even with Department for Energy and Climate Change and Ofgem's (2011a) high benefits scenario, using TOU tariffs they only assume roughly a 2.7% shift in demand. This compares with the 5% and 10% shifts estimated by Ofgem (2010) which are much more optimistic. Also the Department for Energy and Climate Change and Ofgem's (2011a, 2011b) values are discounted at 3.5%, the daily estimates of Ofgem (2010) are not. It is clear from Ofgem (2010) that benefits have the potential to be very high (also indicated by Faruqi et al., 2010a).

The review table on participation and response (Table 3) shows that the drop in peak demand for time-of-use type tariffs was between 3 and 6% (for time of use customers) for the range of experiments studied by Faruqi and Sergici (2010), but when enabling technologies are used in conjunction with the time-of-use tariffs drops in peak demand can be far higher (21–30%). Recent trials in Ireland and the UK suggest reductions of 8.8% with TOU tariffs and up to 10% in some cases for UK participants without technology. Department for Energy and Climate Change and Ofgem (2011a, 2011b) assume a 20% uptake of TOU tariff, Faruqi et al. (2010a) identify that experience of the UK shows that roughly 15% of customers are on TOU type tariffs.

With this information on the UK level of participation and knowledge of drops in peak demand for TOU tariff customers from Faruqi and Sergici (2010) and recent UK trials, this would translate into an overall 0.45% reduction in peak demand (with 3% reduction from TOU customers) or a 1.5% reduction (with 10% reduction from TOU customers).<sup>20</sup> Clearly the 1.5% reduction is fairly close to the assumed reduction of 1.3% by Department for Energy and Climate Change and Ofgem (2011a, 2011b). This is quite sobering and shows that the Department for Energy and Climate Change and Ofgem (2011a, 2011b) assumptions are quite realistic given the current situation but conservative with regards to the future, the Ofgem (2010) and Faruqi et al. (2010a)

assumptions are on the optimistic side. If however enabling technologies are used in conjunction with TOU then more optimistic assumptions of demand shifts may be possible. Increasing current levels of participation with TOU (or other tariffs or incentives) would increase overall levels of peak shifts. Additionally, a move towards different structures such as critical peak pricing to engage participation (as well as or instead of TOU) could significantly increase response and therefore benefits achieved from peak shifting.

Much of the short run marginal cost saving benefits associated with reducing peak electricity demand would fall into the category of net welfare benefits<sup>21</sup> as during peak times less efficient generators are more likely to be run. Daily CO<sub>2</sub> reductions that can result from shifting peak demand can be very high; the DECC and Ofgem publications do not identify physical CO<sub>2</sub> benefits resulting from demand shifts of electricity, but Ofgem (2010) do, as seen in Table 5. If valued, these CO<sub>2</sub> reductions would fall into the category of net welfare benefits.<sup>22</sup> Avoided generation and distribution investment related benefits could also be classed as net welfare benefits assuming benefits outweigh costs<sup>23</sup> as they could ensure the electricity provision with less need for such infrastructure (and its cost). These findings underlie the importance of accounting for supply side environmental and economy benefits from peak load shifting as a form of DR.

Other benefits such as reduced losses in Table 4 that result from peak shifting and electricity savings are also significant. The value however contains value from benefits for electricity and gas; it was the only DR related benefit from Department for Energy and Climate Change and Ofgem (2011a, 2011b) that could not be attained in disaggregated form for electricity.

#### 4.3. Summary of DR costs and benefits relating to electricity savings and shifting peak demand

In total the conservative Department for Energy and Climate Change and Ofgem (2011a, 2011b) electricity<sup>24</sup> DR benefits directly resulting from the introduction of smart metering presented in Table 4 amount to an average annual (derived from present value figures) estimate of £286 million per year. This compares with an average annual cost (derived from present value figures) for smart metering (for electricity and gas) of £567 million.<sup>25</sup>

The value of other (non-DR) benefits is £472m (electricity and gas related). Most of these other non-DR benefits result for

<sup>21</sup> ABOC.

<sup>22</sup> ABOC.

<sup>23</sup> With regards to benefits from peak demand shifts relating to improved distribution network efficiency, Department for Energy and Climate Change and Ofgem (2011a) are said to actually use the Ofgem (2010) annual estimate of £14 million.

<sup>24</sup> A small amount of DR benefit (gas related) is present in the values of benefits from reduced losses.

<sup>25</sup> Appendix D provides a disaggregated breakdown of costs for smart metering.

<sup>19</sup> Excluding benefits to the distribution network which are said to use the same values.

<sup>20</sup>  $0.15 \times 3$  or  $0.15 \times 6$ .

suppliers as a result of the roll out, see [Appendix E](#). Added together with electricity DR benefits, average annual benefits associated with the introduction of smart metering (electricity DR related<sup>26</sup> and electricity and gas non-DR related) are £758 million compared with average annual costs for electricity and gas smart metering at £567 million.<sup>27</sup> It should be noted that UK energy suppliers were heavily involved in consultation on cost estimates (much of which will be passed onto consumers) and that a large amount of the benefits from smart metering will reside with them. Based on this analysis however, the economic case for DR looks to be reasonably positive for the categories of DR so far considered.<sup>28</sup> This is particularly the case if one accounts for the conservative DR electricity (savings) related assumptions (for central estimates) by [Department for Energy and Climate Change and Ofgem \(2011a, 2011b\)](#). With regards to peak demand shifting, the literature suggests that the (conservative) central energy shift assumptions of [Department for Energy and Climate Change and Ofgem \(2011a, 2011b\)](#) is broadly quite achievable, but that enabling higher levels of shift are likely to require higher participation rates (than current) with TOU tariffs and, or a move to alternative structures such as CPP. It is clear that certain enabling technologies can play a key role and substantially increase peak shifting of electricity.

This analysis of the economic case for electricity DR so far only considers DR directly associated with the introduction of smart metering (e.g. electricity savings and those related to peak demand shifts). Beyond these there are other DR benefits e.g. balancing for wind generation and those relating to a change in electricity system operating philosophy, enabled as a result of changes in the structure of demand (from technologies such as electric vehicles, heat pumps and smart appliances) and electricity generation (wind generation). This is in addition to benefits of DR in providing reserve for emergencies/unforeseen events. Therefore we now look at the latter category of benefits, followed by DR for balancing wind, enabled as a result of the introduction of smart appliances and then benefits for distribution from a change in electricity system management philosophy.

#### 4.4. Value of benefits from using DR in providing reserve for emergencies/unforeseen events

In [Table 4](#) it can be seen that the maximum potential value from using DR to avoid all customer interruptions in 2008–2009 is estimated to be £160 million and £275 million for avoiding all customer minutes lost for the UK. The undiscounted values of benefit for one year are based on modelling using Ofgem financial penalties and rewards for customer interruptions and customer minutes lost (see [Appendix B](#) for the detailed methods). In reality it is unlikely that all interruptions and customer minutes lost would be completely avoidable for a year, additionally the method assumes that the benefit gained from avoiding interruptions and customer minutes lost is the same across customer interruptions and customer minutes lost, e.g. whether the first interruption or minute lost in a year or the 30th. Therefore the value is an indicator of potential maximum value attainable from avoiding interruptions and minutes lost. The estimate does

however illustrate that if DR could be used (with minimal costs) to avoid customer interruptions and customer minutes lost, then significant benefits exist for customers in the UK. Because it is an annual undiscounted benefit and an estimate it is difficult to draw clear comparisons with discounted benefits. These benefits could contribute to creation of net welfare benefit as avoiding loss of electricity supply to businesses and households can avoid decreases in productivity resulting from electricity loss and interruption.

#### 4.5. Costs and benefits of DR in providing standby reserve and balancing for wind

The introduction and penetration of smart appliances in the UK will bring forth opportunities for DR that will enable improved ability to perform balancing for wind generation. In their method, appliance penetration rates were estimated by appliance type based on analysis for 2010 and 2025, they then estimate capacity that can be shifted by smart appliances in each country, the method is summarised in [Bradley et al. \(2011\)](#). Estimates of costs and benefits of smart appliances for balancing are only generated for two specific years, so no discounting of cost and benefits occurs for these studies. Ideally one would have discounted costs and benefits over a number of years as occurred for [Department for Energy and Climate Change and Ofgem \(2011a, 2011b\)](#).

In the case of this form of DR, [Seebach et al. \(2009\)](#) estimate that benefits outweigh costs in 2025. Benefits are only estimated to be above costs in 2025 due to costs being predicted to be lower by this year (as a result of the expected large markets for smart appliances) and also due to the prediction of more intermittent and inflexible generation in future (which increases expected benefits). Annual value of benefits was reported to be 256 million euro (value of energy and CO<sub>2</sub> benefits) for the low price scenario in 2025. Given the lower price scenario for [Seebach et al. \(2009\)](#) as in [Table 4](#), benefits can be seen to be approximately eight times greater than costs. Applying this benefit to cost ratio to the annual value of benefits, this would imply that costs are 32 million euro (lower price scenario). Therefore the economic case for using smart appliances to provide DR for balancing appears to be positive for the UK in 2025. This is in line with [Seebach et al.'s \(2009\)](#) finding that of countries assessed, the UK was one of the countries where expected net benefits in 2025 were predicted to be highest. This signals that there is a good prospect for DR to play a role in electricity system balancing (for wind) in UK. It should be noted that the scale of these net benefits are over 200 million euro (for a year).

It should also be realised that estimated annual CO<sub>2</sub> reductions resulting from the balancing of wind (shown in [Table 4](#)) are greater than all other quantified values of CO<sub>2</sub> reduction. This is a result of avoided fossil fuel generation (gas) as a result of an increase in capture of wind generation enabled by balancing from DR. This is an interesting finding for environmental policy with regards to strategies to reduce the CO<sub>2</sub> emissions associated with electricity consumption and production in the UK. It also again illustrates the importance of looking at economic and environmental benefits on the supply side (balancing for wind) that result from DR, especially for the UK.

In [Bradley et al. \(2011\)](#), the authors flag up a number of method related concerns and assumptions relating to the estimates of [Seebach et al. \(2009\)](#), and for these reasons the annual 2025 costs and benefits presented by [Seebach et al. \(2009\)](#) may be a bit more 'rosy' than in reality. Although this is so, estimated benefits were said by [Seebach et al. \(2009\)](#) to be conservative and the reported benefits are much higher than reported costs, so one may expect net benefits as reported by [Seebach et al. \(2009\)](#) for 2025 based on their analysis. The extent of future net benefits

<sup>26</sup> Excluding reduced losses, DR benefits associated with gas are not included.

<sup>27</sup> It was difficult to separate out costs individually for electricity and gas from [Department for Energy and Climate Change and Ofgem \(2011a, 2011b\)](#).

<sup>28</sup> The economic case for electricity related demand response in small and medium non-domestic sector is very clear, a strongly positive net present value should be expected given that the value of electricity savings on their own (one DR related benefit) are greater than the value of smart metering costs (electric and gas). A caveat with regards to this finding is that some costs that are shared for the domestic sector and non small and medium non-domestic sector role out were reported in domestic sector costs.

for the UK however, will rely on whether additional costs of smart appliances can be kept low (which depends on the development of large markets amongst other things such as acceptability to consumers) and whether the UK does in fact see the sort of generation system development that is predicted e.g. a combination of high amounts of intermittent and inflexible generation (as this effect benefits estimates).

For these DR benefits reported, much of the value could fall into the category of being net welfare benefits<sup>29</sup> (as opposed to transfers) as Seebach et al. (2009) state that benefits represent avoided fuel costs by reducing wind spillage and so replacing conventional energy on the one hand and increasing the efficiency of part loaded plants through providing additional balancing capacity by smart appliances.

#### 4.6. Benefits to the distribution network from a change in electricity system management philosophy

Strbac et al. (2010) estimate the order of magnitude of benefits to the distribution network that would result from a change in electricity system management philosophy, enabled by DR in conjunction with use of various technologies such as electric vehicles (EVs), heat pumps (HPs) and smart appliances in conjunction with smart metering technology. Table 4 shows that average annual benefits (developed from present value estimates over a 20 year period) are in the range of between £25 and £500 million per year assuming that avoided costs of distribution network reinforcement can be spread over 20 years. Estimated benefits result from avoided or postponed distribution network reinforcement costs. Clearly, these benefits are very significant and have the potential to be as large or even larger than any other DR related benefit (from those quantified). The extent to which higher end predicted benefits will materialise is dependent on the penetration of EVs and HPs, and decisions on distribution network reinforcement e.g. whether like for like reinforcement occurs or whether a strategy is taken to insert new distribution substations. A range of scenario penetration rates were modelled by Strbac et al. (2010) e.g. low to high penetration assumptions for EVs and HPs etc. As with benefits values of Department for Energy and Climate Change and Ofgem (2011a, 2011b) these benefits were discounted at 3.5% and the time frame is very similar to Department for Energy and Climate Change and Ofgem (2011a, 2011b).

These benefits could be classed as net welfare benefits<sup>30</sup> because they reduce the need for costly distribution infrastructure when ensuring electricity provision and enable higher utilisation rates for infrastructure. There is also no overlap between benefits reported for balancing for wind generation as these relate to avoided fossil fuel generation. Benefits depend on changing the current paradigm of management of the electricity supply system from the current business as usual preventative approach to a corrective active control approach and philosophy. The current author foresees that such a change in electricity system management may entail organisational (and perhaps other) costs beyond those reported so far in the current review. Such cost considerations should be investigated when further considering the economic case for such a change in electricity system management philosophy.<sup>31</sup> Although this is so, Strbac

et al. (2010) clearly show that the rewards from such a change enabled by DR could be great and larger than any other DR related benefit even without quantification of additional benefits to the transmissions system from such an approach.

Identification of the economic case for various types of electricity DR has now been reviewed for those areas of DR for which it was possible (based on quantified estimates).

## 5. Conclusions

This paper presents a synthesis of the costs and benefits of DR and highlights environmental gains where possible. Uncertainties exist, but studies were all of a consistent category (illustrative studies) for the same region and electricity system and over approximately the same time period. For all but two of the quantitative benefits estimates, the current authors were able to convert estimates into a common comparable basis. Therefore the study illustrates the relative scale of different costs and benefits (given assumptions) and allow the economic case for different types of DR to be explored.

In summary, from quantitative estimates available, there appears to be a reasonable economic case for DR for electricity. It should however be realised that the actual economic case for DR for electricity will ultimately depend on ensuring participation in DR. Given inconvenience costs and that expected savings for individuals can sometimes be low (from just savings from reducing electricity), there may be low incentives (monetary) to participate in DR for many electricity consumers. This means that sharing of benefits (from supply side) along the wider supply chain to consumers is likely to be important in increasing the financial reward (e.g. through reduced billing costs) for participation and hence achieving the higher levels of DR and resulting financial and environmental benefits, tariff structures and appropriate institutional arrangements will be important in achieving this. Non-financial motivations relating to pro-environmental behaviour are also important as is a good consumer engagement and support strategy in implementing programs and feedback as UK evidence from AECOM (2011) shows.

Although benefits can be low for some individuals, the benefits for the UK as a whole are clearly very significant as demonstrated in this paper. Importantly the level of DR does not have to be huge in order to realise many of the estimated benefits of this paper (e.g. 2.8% reduction in overall electricity use and a 1.3% shift in peak demand). The evidence from the literature suggests that such reductions are achievable and that there is actually potential for electricity reductions and shifts to be much greater given the right environment, and that likewise resulting benefits would be much greater.

The key to unlocking these benefits is then the lowering of participant costs to and for consumers to take part in DR and appropriate sharing of benefits along the supply chain as discussed. In future technologies such as smart appliances and electric vehicles (beyond smart metering) could play a strong role in reducing costs for participants, maximising benefits and therefore helping to enable the required level of consumer participation.

Smart metering is a necessary condition for several types of DR and an important cost. It is concluded that to maximise benefits from DR, it must be ensured that implementation of smart metering and other technologies is done in such a way as to ensure trust, maximum customer acceptability and satisfaction as well as education along with implementation, as if it is not, participation with the technology will be lower and the investments may not be used (therefore reducing DR benefits) and will have been costly. The actual costs of the infrastructure are also affected by customer engagement and trust, for example if customers are not educated on why smart metering is needed

<sup>29</sup> ABOC.

<sup>30</sup> ABOC.

<sup>31</sup> Strbac et al. (2010) state that real time network control that incorporates DR will have significant implications on the UK regulatory and commercial arrangements, as maintaining the present structure where supply and network businesses act independently of one another will lead to inefficient network investment.

(and benefits to them) and engaged and have trust in those implementing the infrastructure, it may be more difficult to organise and implement the delivery of the smart meters into homes and businesses (therefore increasing costs of the roll out). The issue of trust is particularly important in the UK context where there is currently low trust in suppliers generally, this raises the issue of what is the best way to ensure trust in the delivery of the infrastructure, data collected and its use. This issue will be important in ensuring participation and securing benefits from DR whilst keeping costs on the lower side.

The regulatory environment is also likely to be important in ensuring a positive economic case for DR, for example by ensuring that services come forward from suppliers that offer a share of the benefits of DR to consumers (whether through various tariff structures or incentives). If the right structures are not in place to engage participation, response of consumers is likely to be more difficult and troubling with knock on effects to benefits that can result.

Given that a huge investment in smart metering has been mandated by government in the UK and that consumer participation is central to maximising benefits, the regulatory framework (including current Electricity Market Reforms) must ensure that barriers to consumer participation with DR (directly or indirectly) are removed and that the system actively encourages DR so that benefits from DR are maximised.<sup>32</sup> This will help ensure that electricity consumers, and others see a fair return on the smart metering and other DR related investments (via benefits directly gained from their DR). This is particularly the case given the large benefits that suppliers will see from the smart metering investment which generally will not require DR—electricity consumers must also see benefits, this will incentivise their participation and reduce electricity consumption (and electricity shifting) that can reduce electricity bills and CO<sub>2</sub>, and help ensure energy security and wider economic benefits to the UK demonstrated in this paper. Ensuring these wider society benefits is particularly important considering that costs (e.g. smart metering infrastructure etc.) are ultimately likely to be passed on to household and business customers from suppliers. Additionally, one of the key justifications for the smart metering infrastructure was to aid reductions (and shifts) in energy consumption and provide benefits to the consumer and society (Department for Energy and Climate Change and Ofgem, 2011a, 2011b).

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## Appendix A. Benefits

### A.1. Benefits from relative and absolute reductions in electricity demand

Reductions in electricity demand can result in reduced costs (through electricity savings) to consumers and reductions in CO<sub>2</sub> emissions as well as reduced consumption of resources which has

<sup>32</sup> It may also be useful for the electricity market reforms to make similar considerations to ensure that regulatory barriers (direct or indirect) will not in future result for DR for balancing (with the introduction of smart appliances and other technologies) and for the evolution towards a more preventative, smart active control electricity system management structure as future financial and particularly CO<sub>2</sub> reduction benefits are substantial.

the potential to impact on resource scarcity (and the economy) when finite resources are used for electricity generation. Electricity demand reductions are defined as relative or absolute.<sup>33</sup>

In this paper long term benefits such as reduction in generation, distribution and transmission infrastructure that can result from absolute electricity reductions are not assessed. We only look at these benefits for peak shifting, as this is where quantification of such benefits were found in the literature. This avoids any double counting issues between the two forms of DR but may underestimate benefits.

### A.2. Benefits resulting from short run marginal cost savings from using DR to shift peak demand

The nature of electricity demand is that it does not remain constant throughout the day, there is variability and peaks in demand occur on a daily basis. When very high (peak) demands are made on the electricity system, supply is also needed to respond in real time. What complicates the issue is that electricity cannot be stored cheaply or in great quantities Ofgem (2010).

In practice, the most efficient generators are likely to be running much of the time, but as demands on the system increase additional and sometimes less efficient (in terms of economy and environment) generators are required. This is a key factor in why the price of electricity per unit (kWh) increases during peak time. The high cost of generation to meet peak demand is ultimately passed onto the consumer. Shifting some demands to outside of peak hours reduces the extent to which inefficient generation capacity is required, therefore reducing cost of electricity per kWh.

### A.3. Benefits in terms of displacing new plant investment from using DR to shift peak demand

This electricity generation related benefit first relates to displacement of the extent of generation capacity required to meet peak demands. In this situation DR techniques are used to persuade some customers to ensure that peak demands are regularly and reliably lower than the peak would naturally be without DR.

### A.4. Benefits of using DR in providing reserve for emergencies/unforeseen events

This benefit relates to identifying and persuading some customers to forgo consumption relatively infrequently but at short notice, to provide the ability to the system to reduce demand quickly in an emergency. These customers would effectively be 'on line' to surrender some of their demands to the network.<sup>34</sup> Using DR in this way would enable displacement of the need for infrequently used long term reserve generation capacity (see Strbac, 2008 for more detail). There are also benefits to customers as described in the main paper.

<sup>33</sup> Relative is defined as on site (business) electricity reductions which result in decreasing electricity consumption per unit of gross value added (business). For households, a relative reduction in energy consumption is equivalent to a decrease in electricity use per unit of household income. In the latter situation overall usage of electricity could still increase. When absolute reductions in electricity result, there is an overall decrease in on site electricity demand (over a period of time) for a household or an organisation. These definitions similarly follow discussions on relative and absolute decoupling at an economy level as seen in Jackson (2009).

<sup>34</sup> In this study we define this as 'reserve for emergencies/unforeseen events'. Strbac (2008) terms it as stand by reserve. The reason we define this differently is in order to separate out benefits more clearly and to avoid the term stand by as readers may be familiar with this term being applied to their end use consumption.

#### A.5. Benefits of DR in providing standby reserve and balancing for wind

Balancing electricity demand and supply will become increasingly difficult as the UK increases intermittent renewable generation such as wind and (possibly) inflexible generation capacity such as nuclear. With increasing intermittent supply, Strbac (2008) discusses losses in efficiency that result from using flexible generation such as gas fired power for providing synchronised reserve and standing reserve for balancing (avoided if DR is used). A summary is provided in Bradley et al. (2011).

DR can perform the role of standing reserve as opposed to having flexible generation capacity on standby. Strbac (2008) notes that DR could provide a way of increasing the amount of wind power that the system can absorb as fewer generating units are scheduled to operate. It is noted that this is particularly relevant in conditions of high wind and low demand. By increasing the amount of wind energy absorbed, this would allow a decrease in the amount of fuel bunt.

#### A.6. Benefits of DR to distributed power systems

Similarly as for large scale wind, DR can bring benefits in the form of enabling greater use of distributed power generation. Benefits of DR in this context again relate to balancing, as achieving balance of demand and supply in a distributed supply system comprising different forms of renewable generation and different forms of combined heat and power (CHP) will be difficult because it is not easy or desirable to modulate output of renewable or heat-led plants to follow a particular electricity load shape (Strbac, 2008).

#### A.7. Benefits in terms of reduced transmission network investment by reducing congestion of the network and avoiding transmission network re-enforcement

Strbac (2008) identifies that the advantage of the current UK operating philosophy (preventive, dominantly based around providing enough infrastructure to ensure security and minimising the chance of black outs for all times of the day) is simplicity of operation, but that this property emerges at the expense of increased operating costs and low utilisation of generation and network capacity with use of generation being at about 50%, and use of network capacity even below this. The author notes that recent advances in ICT could enable a change in the operating system philosophy from preventative to corrective. The alternative approach identified by Strbac (2008) is to operate the system at a lower operating cost including reduced network and generation capacity (therefore with higher utilisation), this is as long as overloads occurring after outages of circuits and generators, can be effectively eliminated by conducting suitable corrective actions, e.g. curtailing some loads at appropriate locations. It is said that DR programmes would be a core strategy in ensuring appropriate actions be taken. This active approach would allow transmission network investment to vary while ensuring security of the system (Strbac, 2008). Benefits to the transmission network can also result from sustained peak load shifting.

#### A.8. Benefits from using DR to improve distribution network investment efficiency and reduce losses

Similarly, with regards to improving distribution network investment efficiency through a change in philosophy using

DR, Strbac (2008) identifies a range of potential benefits in his paper.<sup>35</sup>

Again it should be noted that regular reductions in peak demand can result in reduced distribution investment needs, without having to change the electricity system management philosophy.

### Appendix B. Method of modelling the value of customer service interruptions and customer minutes lost

The Electricity Distribution Quality of Service Report 2008/09 on page 14 provide a table (Table B.1) of Distribution Network Operator (DNO) interruptions performance to date (2005/06–2008/09) and financial impact.

DNO companies receive penalties or rewards for performance against targets for both customer interruptions and customer minutes lost (penalties and rewards are given separately for each). We use these penalties/rewards (for under or overachievement of targets) as a proxy to estimate the total value that may be attained (the benefits to customers) from preventing customer interruptions and customer minutes lost. This is because avoidance of interruptions and customer minutes lost can potentially occur via corrective actions from DR.

We now outline the steps that are taken to derive an annual estimate of the UK value of avoiding interruptions and customer minutes lost. We describe eight steps to enable the estimation.

*Step 1:* Firstly values in Table B.1 for customer interruptions were converted from customer interruptions per 100 customers into actual customer interruptions by multiplying the values in the table by customer numbers for each company (for each relevant year in terms of hundreds of customers)<sup>36</sup>.

Similarly, values in Table B.1 for customer minutes lost were converted from customer minutes lost per customer into actual customer minutes lost by multiplying the values in the table by customer numbers for each company (for each relevant year).

*Step 2:* Once values, whether targets or performance were expressed in terms of actual customer interruptions and customer minutes lost, performance was subtracted against the target (*performance minus target*) for each year for each company. In some instances this led to negative values (extent to which performance was below the target – over achievement of target) and some positive values (where performance was above the required target – target missed). This was done for each year for each company.

*Step 3:* An estimate of target achieved or better over four years for each company was then estimated by adding *performance minus target* values—negative values (over achievement of target). Similarly an estimate of target missed over the four years for each company was then generated by adding *performance minus target* values—positive values (target missed). Two separate columns of numbers were therefore generated, with numbers given by each company.

*Step 4:* The two above estimates are added together: Over achievement of target over four years (negative value)+under achievement of target over four years (positive value). This gives overall performance over the four years by each company.

<sup>35</sup> (i) Deferring new network investment, (ii) increasing the amount of distributed generation that can be connected to the existing distribution network infrastructure, (iii) relieving voltage-constrained power transfer problems, (iv) relieving congestion in distribution substations, (v) simplifying outage management and enhancing the quality and security of supply to critical-load customers, and (vi) providing corresponding carbon reduction." (Strbac, 2008, p. 4422).

<sup>36</sup> Customer numbers by year and company are from Ofgem Distribution network operator information (Available at: <<http://www.ofgem.gov.uk/Pages/MoreInformation.aspx?docid=539&refer=Networks/ElecDist/PriceCtrls/DPCR5>>).

**Table B.1**

DNO interruptions performance to date (2005/06–2008/09) and financial impact (Ofgem, 2010, p. 14).

DNO	2005/2006		2006/2007		2007/2008		2008/2009		Total 4 year penalties and reward (£million)
	Target	Performance	Target	Performance	Target	Performance	Target	Performance	
<b>Customer interruptions (CI)</b>									
CN West	109.4	107.8	107.8	119.3	106.2	116.9	104.6	92.8	–1.07
CN East	77.9	71	77.5	83.3	77.1	79.4	76.7	68.5	1.21
ENW	57.2	49.8	57.1	54.4	57.1	50.7	57.1	48.3	5.41
CE NEDL	74.5	65.7	74.5	74	74.5	66.3	74.5	64.2	3.23
CE YEDL	68.7	67.2	68.6	84.8	68.5	75.7	68.5	76.4	–4.82
WPD S Wales	99.7	81.3	98.2	83.4	96.8	77.7	95.3	66.1	6.28
WPD S West	84.5	72.1	84.5	80.3	84.5	76.4	84.5	58.4	5.35
EDFE LPN	36.2	32	36.2	36.9	36.2	31.5	36.2	28.7	5.57
EDFE SPN	90.5	77.8	88.5	85.9	86.5	90.1	84.5	82.7	1.43
EDFE EPN	90.3	66.2	88.8	77.2	87.2	73.1	85.7	84.8	8.7
SP Distribution	60.9	57.6	60.8	64.9	60.8	58.6	60.8	55.7	1.78
SP Manweb	46.7	42.7	46.7	46.1	46.7	43.1	46.7	49.3	1.14
SSE Hydro	96.2	77.9	95.8	78.6	95.5	69.2	95.2	75.8	7.63
SSE Southern	91	78.2	90.1	75.3	89.2	65.7	88.3	64.3	15.48
<b>Customer minutes lost (CML)</b>									
CN West	102.3	83.6	98.5	110.7	94.7	101.5	91	79.3	1.99
CN East	80.1	62.6	76.7	80.8	73.4	70.4	70	58.4	6.33
ENW	59.8	47.5	58.1	57.7	56.4	48.1	54.7	50.8	6.53
CE NEDL	71.4	64.4	70.4	78.2	69.4	70.5	68.4	76.3	–1.62
CE YEDL	68.5	67.4	66.8	81.7	65.1	75	63.4	73	–7.08
WPD S Wales	72.2	42.2	72.2	47.6	72.2	41.9	72.2	36.8	11.92
WPD S West	62.2	43.5	62.2	50.1	62.2	50	62.2	43.9	12.14
EDFE LPN	40.2	34.4	40.1	43	40.1	42.6	40.1	44.2	–1.59
EDFE SPN	81.4	72.5	77	88.7	72.6	102.6	68.2	99.8	–7.65
EDFE EPN	73.7	57.1	72.2	68.4	70.6	73.8	69.1	88.3	–1.27
SP Distribution	64.9	66.7	61.2	77.5	57.6	60.6	54	48.5	–4.62
SP Manweb	51.8	57.4	49.9	62.7	48	54.7	46.1	54.8	–8.45
SSE Hydro	95.9	64.7	94.9	76.8	93.9	71.6	93	75.1	10.91
SSE Southern	82	68.7	80.5	70.9	78.9	66.2	77.4	65.6	14.02

Customer interruptions then correspond to the 4 yr period in Table B.1 for which penalties and incentives information are provided in Table B.1. The same procedure is applied to ensure that customer minutes lost apply to the 4 yr period for each company.

This process helps lead to a value being placed per interruption or per customer minute lost.

The level of financial reward or penalty per no. of interruptions or per customer minutes lost (below or above the target) is believed to be broadly the same, and they are treated as such.

Step 5: The next step is to estimate the total number of customer interruptions for which a penalty or incentive was placed for all companies (as opposed to an individual company) for the four years—the procedure is also followed for customer minutes lost;

Step 6: A similar totalling procedure is conducted for the incentive or reward: Total overall penalty or incentive for interruptions above or below targets for all companies are added together (over the four years)—the procedure is also followed for customer minutes lost.

To produce an estimate of value per interruption (or alternatively per customer minutes lost) over the four years, the following procedure is applied:

Step 7: The total financial value (+ve incentives and –ve penalties added together) is divided by the total customer interruptions (–ve below target values and +ve over target values) to provide an estimate of average value per interruption for all companies (based on the four years data). This procedure is also conducted in the same way for customer minutes lost to estimate average value per customer minute lost.

Step 8: The final step is to approximate the total potential value for avoiding customer interruptions for the UK in a year. To

do this we identified the maximum UK customer interruptions that may have been avoidable for 2009 and multiply this by the average value per interruption to give an approximate estimate of overall potential value possible from avoiding all interruptions for that year.

For customer minutes lost we estimated maximum UK customer minutes lost that could be avoidable for the UK for the most recent year (2009 in data) and multiplied this by the average value per customer minute lost to give an approximate estimate of overall potential value possible from avoiding all customer minutes lost.

Assumptions of the method:

- In step 6, it is assumed that financial penalties and rewards levied per interruption (above or under target) are the same value (either positive or negative). Similarly it is assumed that financial penalties and rewards levied per customer minute (above or under target) are the same value (either positive or negative). This is however believed to be the case in reality.<sup>37</sup>
- In step 7 it is assumed that the four years worth of data (from penalties and rewards as well as interruptions and customer minute lost) across companies can be used to provide a reliable average value per interruption and average value per customer minute lost.
- It is then assumed that this average value (based on the four years) can be applied in step 8 to estimate overall value of interruptions (or customer minutes lost) for the UK in 2009.

<sup>37</sup> <http://www.ofgem.gov.uk/Networks/ElecDist/QualofServ/QoSIncent/Documents1/Ofgems%20Audits%20of%20Electricity%20DNOs%20Interruption%20Reporting%20and%20Audits%20of%20One-off%20Exceptional%20Events-Terms%20of%20Reference.pdf>.

Beyond procedural assumptions, two intrinsic assumptions are embedded in the method:

- The method assumes that the penalties/rewards per interruption or minutes lost is a reasonable proxy for value lost or gained by customers.
- It is assumed that benefit gained from avoiding interruptions and customer minutes lost are the same across customer interruptions and customer minutes lost (e.g. whether the first interruption or minute lost in a year or the 30th). In reality this may not be the case, there may be decreasing marginal benefit. The estimation method also estimates value from all interruptions and customer minutes lost, in reality it is unlikely that all would be completely avoidable for a year. Based on these two latter assumptions, the estimate should be seen as an indicator of potential maximum value attainable from avoiding interruptions and minutes lost and not actual.

### Appendix C. Costs

Specific system costs relating to smart meters (electricity and gas—as further disaggregation was not possible) for the domestic sector in Department for Energy and Climate Change and Ofgem (2011a) are reasonably comprehensive and include such things as: capital costs (display and meter, communications and infrastructure), installation costs, operating and maintenance (O&M) costs, IT costs, the cost of capital (10% per annum), electricity costs from smart meter consumed electricity (the latter is actually a participant cost), meter reading costs, disposal costs, legal, marketing and organisational costs (which include: marketing and consumer support costs, legal costs and other costs). Other costs include: data protection, ongoing regulation, assurance, accreditation, tendering, programme delivery, trials and testing (Department for Energy and Climate Change and Ofgem, 2011a).

For costs described by Department for Energy and Climate Change and Ofgem (2011b) for smart meter roll out for the small and medium non-domestic sector, total costs include: asset costs (advanced meter and smart meter costs, retrofit advanced costs, and display costs), cost of capital, installation and maintenance costs and communication infrastructure (including a modem) costs are also included. Costs reported for the domestic sector but not the non-domestic sector in Department for Energy and Climate Change and Ofgem (2011a, 2011b), are costs that occur for both the domestic and small and medium sized non-domestic.<sup>38</sup>

With regards to system costs in Table 2 in the main paper, the category “Utility equipment or software costs, billing system upgrades”, DECC and Ofgem do include tendering costs, but it is unclear whether this actually includes billing and settlement system costs. Similarly with regards to consumer education,<sup>39</sup> consumer engagement costs are included in the DECC and Ofgem reports but are believed to relate directly to engagement with smart metering and not necessarily specific DR programmes run by energy companies, although on the benefits side we only look at benefits associated with existing tariffs such as TOU, this avoids a mismatch or comparing “apples with oranges”. Department for Energy and Climate Change and Ofgem (2011a) note that they are reviewing their cost estimate in light of conducting consumer engagement on a coordinated basis and the development of a

<sup>38</sup> Lienert (2011) stated that when costs are shared between the domestic sector and small and medium non-domestic sector, then these costs are generally just reported for the domestic sector.

<sup>39</sup> For example costs of educating about the time-varying nature of electricity costs, potential load response strategies and choice of tariffs for or of demand response programmes available (U.S. Department of Energy, 2006).

consumer engagement strategy. With regards to the category “Programme administration/management” these are believed to be captured for the role out of smart meters but are not believed to be captured for specific DR programmes (although as stated, tariffs such as TOU and their management already exist and relevant value of benefits described later only relate to these). The same issue is thought to exist for the quantified costs for the category “Marketing/recruitment”; these are not necessarily captured for specific DR programmes but are for the role out of smart meters.

### Appendix D. Disaggregated breakdown of costs for smart metering

See Table D.1.

Table D.1

Breakdown of quantified costs for smart metering for gas and electric—domestic and small and medium non-domestic sector from Department for Energy and Climate Change and Ofgem (2011a, 2011b).

Cost type	Domestic costs 2011	SME costs 2011 (option 2)
<b>Costs of smart metering in Department for Energy and Climate Change and Ofgem (2011a, 2011b) (£million)</b>		
Capital	4005	265
Installation	1596	96
O&M	692	39
Comms upfront	792	58
Comms O&M	1314	93
Energy	731	28
Disposal	15	3
Pavement reading inefficiency	238	8
Supplier IT	510	
Central IT	362	
Industry IT	154	
Industry set-up	198	
Marketing	85	
Integrate early meter into DCC	65	
<b>Total cost</b>	<b>10757</b>	<b>590</b>

Table E.1

Breakdown of benefits in the other category (put together from the Department for Energy and Climate Change and Ofgem, 2011a, 2011b).

Type	Category	Average annual value (developed from present values)
<b>Other non-DR benefits</b>		
Customer	Micro generation	2
Supplier	Avoided site visit	159
	Inbound inquirers	53
	Customer service overheads	9
	Debt handling	54
	Avoided PPM COS premium	50
	Remote (dis) connexion	12
	Reduced theft	12
	Customer switching	80
Network	Reduction in customer minutes lost	2
benefits	Operational savings from fault fixing	4
	Better informed enforcement investment decisions	6
	Avoided investigation of voltage complaints	2
	Reduced outage notification calls	1
<b>Total</b>		<b>446</b>

## Appendix E. Full list of benefits in the other (non-demand response related) category

See Table E.1.

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