# Smart Metering and Electricity Demand: Technology, Economics and International Experience


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# Smart Metering and Electricity Demand: Technology, Economics and International Experience[2]


## Abstract

In recent years smart metering of electricity demand has attracted attention around the world. A number of countries and regions have started deploying new metering systems; and many others have set targets for deployment or are undertaking trials. Across the board advances in technology and international experience characterize the metering landscape as a fast-changing one. These changes are taking place at a time when increasing emphasis is being placed on the role of the demand-side in improving the efficiency of energy markets, enhancing security of supply and in unlocking the benefits of energy and carbon savings. Innovative forms of metering can be a useful tool in achieving an active demand-side and moving beyond a supply-focused sector. In this paper we focus in particular on smart metering in liberalized electricity markets. We firstly set the context for innovative electricity metering in terms of policy, the role and market structure for metering, and the potential for smart metering to increase demand-side participation. We then provide an overview of new metering technologies by examining international trends, the various components of smart metering systems, and the likely future developments. Next we assess the economics of smart meters focusing on the costs and benefits of smart metering and the distribution of these. We review the evidence in Europe, North America and Australia; we look at how countries and regions have differed in their approaches and how these differences have had an impact on policy making. We conclude by outlining the main challenges that remain, particularly in technology choice and its regulation, the methodology of analyzing costs and benefits and the role of uncertainty in investment and policy making.



Key words: Electricity demand, smart meters, energy saving, demand-side participation

JEL classification: L94, Q41, Q48



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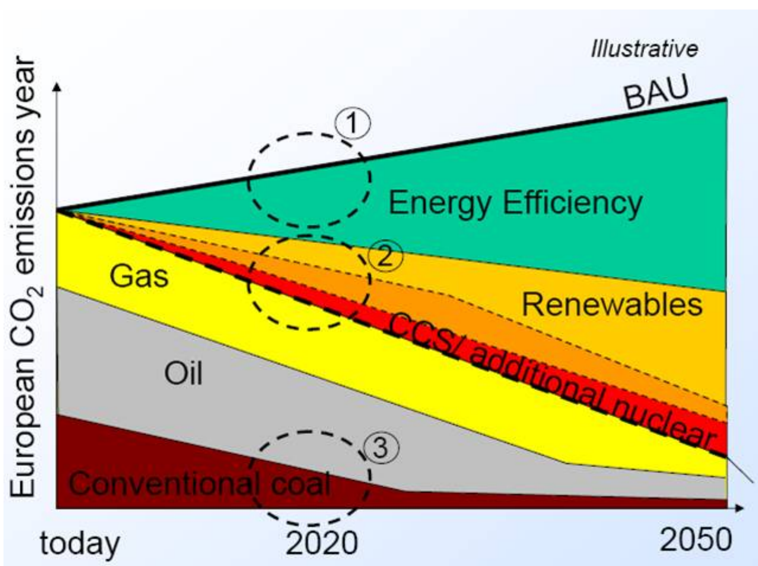
## 1. Introduction

The participation of the demand-side is essential in improving the overall efficiency of energy markets. In liberalised electricity markets, active participation by demand has been limited to date, although there is now increasing emphasis on its importance in contributing to a number of energy policy challenges (Bilton et al., 2008; Borenstein et al., 2002; Spees and Lave, 2007). Climate change, security of supply, and fuel poverty are the three main areas where a more active demand-side has the potential to have both significant and cost-effective impacts (Ofgem, 2006d).

Figure 1 illustrates the importance of (1) early investment in the demand-side; (2) the long-term role of renewables; and (3) the phasing out of conventional coal in moving from the business as usual (BAU) trajectory towards achieving European emissions targets (represented by the black dotted line).

Figure 1: Investors' perspective: strategic choices to achieve European $CO_2$ targets




*Source*: Neuhoff (2007)

The widespread recent interest in smart electricity metering can best be understood in the context of investing in demand-side participation. Innovative forms of metering allow for more detailed information to be collected on electricity consumption; communications technology facilitates greater interaction between the end-user and the rest of the electricity supply chain; and both information and interaction allow for end-users to become more actively involved in the electricity market by, for example, responding to price signals and information on consumption patterns.

Smaller electricity users (domestic, small and medium sized enterprises (SME)) have been the focus of smart metering policy debate around the world as these users have traditionally not been given the appropriate incentives, means or the information to become active participants. In the European Union (EU), the 2006 Energy Services Directive (2006/32/EC) has given fresh impetus to energy efficiency policy making. As part of this drive, the Directive requires Member States to incorporate metering and billing policies into their National Energy Efficiency Action Plans. Providing information on actual consumption lies at the core of this requirement and has prompted a number of EU countries to explore the costs and benefits of implementing smart metering.

This paper presents an assessment of smart metering in liberalised electricity markets by investigating the technology, economics and international experience to date. By developing this framework, we shed light on the variations in international approaches and the challenges that remain in promoting smart metering as a tool for active demand. Section 2 sets the context for smart electricity metering. Section 3 reviews metering technology developments and explores international trends. Section 4 provides a framework for a social cost benefit analysis of smart metering. International experience in studying the costs and benefits is analysed in Section 5. Challenges and lessons from international experience are presented in Section 6 and finally, Section 7 concludes the paper.

## 2. The context for smart electricity metering

### *2.1. The policy context for smart metering*

One of the main policy drivers in Europe for considering more advanced forms of metering and more informative billing has been the 2006 EU Energy Services Directive (2006/32/EC). The directive places greater emphasis on the role of the demand-side in improving the efficiency of energy markets and in unlocking energy and carbon savings. Smart metering is increasingly seen as a tool in promoting more responsive demand in the market for electricity in the context of improving security of supply, reducing $CO_2$ emissions and tackling the growing problem of fuel poverty.

The directive requires member states to implement National Energy Efficiency Action Plans; Article 13 of the directive deals specifically with metering and billing. Member states are obliged to ensure that metering and billing of energy consumption for all customers reflect actual consumption and provide information on the time of use, as long as it is technically possible and cost-effective to do so (European Union, 2006). Understandably this has encouraged much debate and a number of consultations on the costs and benefits of implementing more advanced metering solutions. This has been the case particularly for small energy users, i.e. domestic and small business customers, where up until now very few have had meters installed that allow billing to be based on actual consumption.

The role of regulation in promoting smart metering has also been the subject of debate particularly in Great Britain where the regulator has decided that competition in metering is the best way of ensuring that smart metering delivers for customers. The UK government set out its expectation in the 2007 Energy White Paper that all gas and electricity customers would be given smart meters with separate displays over the next ten years (DTI, 2007). Furthermore, gas and electricity suppliers would be required to install smart meters in the SME sector above a certain energy threshold from 2008; and electricity suppliers would be required to provide real-time display units (a unit that displays actual consumption but does not replace the existing meter or communicate with the supplier) to all domestic customers who requested one and where meters were replaced or newly installed (DTI, 2007).

The most recent government response on metering and billing policies in April 2008 has confirmed that smart meters will be required by 2013 for the higher consumption end of the SME sector; the policy on real-time display units has been partially reversed and the government is working on a voluntary agreement with suppliers in its place; and further work will be conducted to finalise policy for domestic and small business users (BERR, 2008a). Questions, therefore, still remain and it is timely to examine developments and decision-making in other countries for insight. Firstly, however, we will take a closer look at metering in liberalised electricity markets and the role of demand response to establish the importance of evaluating new metering and billing policies.

### *2.2. Metering and liberalised electricity markets*

In its 2001 strategy for metering, Ofgem, the regulator for electricity and gas in Great Britain, set out the four key reasons for the importance of metering to electricity and gas customers as follows:

1. “Meter readings determine how much a customer is billed
2. The type of meter provided determines whether a customer pays for his energy on credit, or whether he pays before he consumes energy
3. Meters can provide information to the customer on how much gas or electricity they use in any particular time period; and
4. Metering costs contribute to the total bill paid by a customer” (Ofgem, 2001, p. 10).

Metering service consists of several activities that do not necessarily have to be carried out by a single party: (i) meter provision (supplying metering equipment); (ii) meter operation (installation, operation and maintenance); and (iii) meter reading and data processing.

Traditionally, meters have been owned and metering activities have been undertaken by network operators. Even since the liberalisation of electricity markets this has continued to be the case in many European countries as can be seen from Table 1. Despite this trend, several countries have pursued competition in metering; the three main examples of this are Great Britain, Germany and the Netherlands. Two main models for metering have therefore emerged within the EU: (i) a regulated model where metering activities are treated as a regulated monopoly; and (ii) a liberalised model where some or all metering activities are open to competition.

Table 1: Ownership of electricity and gas meters in Europe

| **Ownership** | **Electricity** | **Gas** |
|---|---|---|
| Distribution Network Operator (DNO) | BE, DE, ES, IT, LT, LU, LV, NO, PL, PT, SE, SK, UK | BE, CZ, DE, ES, IT, LU, PL, SI, SE, SK, UK |
| Supplier | ES, UK | UK |
| Metering company | DE, UK | DE |
| Municipality | FR | CZ |
| Consumer | ES, PL, SI, UK | CZ, PL, SI, ES, UK |
| Ownership not regulated | DK | DK, LV |
| None of the above | BE, GR | - |

*Source:* ERGEG (2007)

**Country Key**: BE: Belgium; CZ: Czech Republic; DE: Germany; DK: Denmark; ES: Spain; FR: France; GR: Greece; IT: Italy; LT: Lithuania; LU: Luxembourg; LV: Latvia; NO; Norway; PL: Poland; PT: Portugal; SE; Sweden; SI: Slovenia; SK: Slovak Republic; UK; United Kingdom

In Great Britain, competition in metering is currently in a period of transition. When Public Electricity Suppliers in each region were required to separate their supply and distribution businesses in 2000, the DNOs took responsibility for all existing metering service. As incumbent meter service providers, they were obliged to provide metering services in their home areas if requested by suppliers. Prices for meter provision and operation offered by incumbents (separated from distribution charges) have since been regulated by Ofgem. Tables 2 and 3 show the price caps for domestic electricity meters and revenue caps for domestic electricity meter operation. Since this time, suppliers have also been given the right to choose alternative meter operators, data collectors or data aggregators (Ofgem, 2001).

Table 2: Price caps for annual domestic meter rental charges

| **Electricity meter type** | **Price cap - £ per year 2002/03 prices*** |
| --- | --- |
| Domestic credit | 1.12 |
| Prepayment (average cap for token, key and smartcard meters) | 9.75 |

*Note: These caps are indexed for inflation for subsequent years

*Source*: Adapted from Ofgem (2006b)

Table 3: Revenue caps for electricity meter operation

| **Chargeable activity** | **Revenue cap - £ per activity (2002/03 prices)*** |
| --- | --- |
| Single-phase meter appointment (domestic credit or PPM) | 21.37 |
| Poly-phase meter appointment (larger domestic and some non-domestic) | 34.91 |

*Note: Activity charges 2002/03 prices and are indexed for inflation for subsequent years

*Source*: Ofgem (2006b)

The regulated and commercial markets for metering have therefore coexisted in Great Britain. Although incumbents maintain a strong overall market share, competition is developing.[3] In the meter provision market, competitors are estimated to have obtained less than 1% of the market. In the market for meter operation it is estimated that competitors provide operation for around 20% of electricity meters and that 20% of new and replacement meters are being installed through competitive tenders (Ofgem, 2006b).

[3] Incumbent meter businesses are the Gas Transporters (National Grid Gas and the four independent distribution networks created in 2005) and electricity DNOs operating distribution networks in the 14 ex-PES regions (Scottish & Southern Energy, Scottish Power, United Utilities, Yorkshire Electricity Distribution Ltd., Northern Electricity Distribution Ltd., EON, EDF Energy and Western Power Distribution (Ofgem, 2006b).

The main example of this is Centrica. In 2003 Centrica appointed alternative metering businesses for both electricity and gas on a regional basis with three separate businesses (Onstream, United Utilities and Siemens/Capital Meters) via competitively-sourced contracts. Due to retail competition, churn contracts need to be negotiated between competitive metering businesses and other suppliers to set out the terms for continued meter rental if the customer chooses to switch supplier. In addition, other suppliers are attempting to provide for some or all of their metering service in-house. In gas, most suppliers have signed up for long-term metering contracts with National Grid (Ofgem, 2006a). Ofgem investigated these contracts under the Competition Act and in March 2008 announced a £41 million fine on the basis that the contracts blocked the introduction of smart gas meters. National Grid has appealed the decision to the Competition Appeal Tribunal (Power UK, 2008).

Ofgem’s price controls on electricity meter operation and on the provision of new/replacement meters by distributors fell away on 31 March 2007. Price controls remain in place for the provision of legacy meters installed before this date. It is anticipated that bringing an end to price controls will encourage more suppliers to seek alternative service providers (Ofgem, 2006c).

As suppliers in Great Britain are now responsible for purchasing metering services on behalf of their customers, any decisions about whether to invest in more advanced metering solutions are also up to them. Competition among suppliers is relied upon to foster innovation in metering and to prevent lock-in to one specific type of metering technology. Furthermore, although metering makes up a small proportion of a customer’s final bill, it is central to the provision of good customer service (Ofgem, 2006 c). Ofgem considers that suppliers are best placed to manage the risks associated with investing in metering because they have access to the best information about their customers’ needs and will base their decisions on this information (Ofgem 2006d).

### *2.3. Electricity metering and active demand*

*Characteristics of electricity and electricity demand* The participation of the demand-side in setting prices and clearing the market for electricity is limited even in liberalised electricity markets. Most customers are not given the opportunity to respond to fluctuations in the cost of delivering electricity to them. Electricity has a marginal cost of production that fluctuates rapidly due to two of its main characteristics. Firstly, because electricity must be consumed as it is produced its cost of production is sensitive to the time when it is used. Secondly, it is the only product that is consumed continuously by almost all customers; its real-time demand determined by retail customers physically taking power from the grid rather than agreeing by contract with the generator in advance. The cost of delivering electricity to the customer also fluctuates rapidly and depends on the amount of electricity all customers are demanding at any given time (Stoft, 2002).

Although wholesale prices tend to vary hour by hour, retail prices are adjusted only a few times each year. Residential customers in particular are rarely exposed to price fluctuations and typically pay a per-kWh electricity charge independent of the time of use. In the UK, this alone accounts for approximately 34 percent of total consumption that is unresponsive to changes in wholesale price.[4] Large electricity customers in the UK on the other hand, — all those with a peak load above 100kW — are equipped with more advanced metering facilities that allow for half-hourly measurement of electricity consumption and automatic communication of this information to the supplier.

Residential demand tends to fluctuate more than commercial and industrial demands and residential consumers tend to have more peaky loads at times of system load factor when generation prices are high (Littlechild, 2003). Because of this, there are broad implications for the rest of the market and electricity system from the lack of responsiveness of the residential load. Technically demand is inelastic but the real problem is that there is a lack of pricing. For instance, it is often not possible for suppliers to differentiate between peak and off-peak electricity prices for users who are metered on a non-half hourly basis.

During hours of peak demand, peak-load generators with relatively low ramping costs must be dispatched in addition to baseload generators to meet additional power requirements. Costs of production are higher during peak hours than at other times of the day when levels of demand can be satisfied by baseload generation alone. The inability to signal short-run changes in the costs of generation at different times of the day and year means that consumers are not given any price incentive to use power when it is cheapest to produce, or to stop or reduce consumption when it is more expensive. This in turn has an effect on the reliability of the system and on future peak-load capacity investment decisions, as significant investment is required to ensure that supply meets the daily, seasonal and annual variations in load.

[4] Based on electricity consumption figures from DUKES (2006).

*Active demand* Up until now, the focus of improving efficiency in liberalized electricity markets has been very much on the supply-side, as in the case of the UK. As a natural progression of liberalization, the focus is now shifting to explore the potential efficiencies that greater participation of end-users in the market can bring. The main barriers to increasing participation are (i) inelasticity of demand; and (ii) information asymmetry (Bilton et al., 2008).

The literature on demand-side participation in the context of metering can be divided into two main strands directly related to these barriers

1. Pricing: demand elasticity and the responsiveness of customers to various forms of pricing;
2. Information: the effects of improving the information that is available to customers on their energy consumption.

The first category is often referred to as demand response and is the most recent stage in the evolution of demand-side management programmes. Pricing is central to demand response strategies and the overall aim is to increase the elasticity of electricity demand by giving customers price signals that are more cost-reflective. More advanced forms of pricing require more advanced metering solutions. Technological advances have made this possible, however they are also more costly to implement. Deciding how advanced a metering infrastructure should be depends in part on the magnitude of response that advanced pricing structures can elicit.

The concepts of *time-of-use pricing* (TOU), *real-time pricing* (RTP) and *critical peak pricing* (CPP) are not new, however their application in the past has been very limited particularly in the domestic and small business sectors. Most recent studies of the price elasticity of electricity have included analysis of *time-of-use pricing* (Ballard et al., 2001). This form of pricing is static, i.e. the variation in retail price is determined in advance according to different blocks of time and is adjusted infrequently. An early example of such a study in the residential sector is a series of *time-of-use pricing* experiments funded by the US Department of Energy beginning in 1975. Atkinson’s 1981 study compares the results of two of these experiments and concludes that time-of-use prices are the most significant variables explaining time-of-use demand; and that time-of-use elasticities can lead to a significant reduction in the level of peak demand and an overall levelling of residential and system load curves (Atkinson, 1981).

Gallant and Koenker (1984) address the question of residential *time-of-use pricing* around the same time based on data from another US experiment, in North Carolina. In their study they ask whether the efficiency gains from residential *time-of-use pricing* exceed the metering costs necessitated by the more complex rate structures. Their findings suggest that the costs of metering at that time outweigh the net welfare gain to households. Filippini (1995) studies the elasticities of peak and off-peak residential electricity consumption using data on 220 households in 19 Swiss cities. He finds that demand for both peak and off-peak electricity is elastic and that peak and off-peak electricity are substitutes.

Studies have also focused on more dynamic forms of pricing particularly in recent years. Real-time and *critical peak pricing* are both forms of dynamic pricing; *real-time pricing* being the most dynamic with different retail electricity prices for different hours of the day and different days of the week. The aim of this pricing system is to expose the demand-side to the price fluctuations in the wholesale market. *Critical peak pricing* (CPP) is a combination of time-of-use and real-time pricing. Critical peak pricing structures are usually based on a time-of-use structure to begin with and this structure is then supplemented with a separate rate that applies to the critical peak hours. These hours take place on days of the year when the system is under pressure and can be called at short notice. There is usually a limit to the number of hours that can be called during the year, typically between 50 and 100 (Borenstein et al., 2002).

One of the most recent pricing pilots to include a critical peak pricing structure is the California Statewide Pricing Pilot conducted in 2003/2004. Herter (2007) analyses the results from the pilot with a view to informing policy makers who are considering implementation of CPP rates in the residential sector. Findings show that while high-use customers respond significantly more in terms of kW reduction than low-use customers; in terms of percentage reduction of annual electricity bills low-use customers save significantly more. This would suggest that full-scale implementation of CPP may be a suitable strategy rather than targeting high-end users only, depending on the distribution of costs.

Although there are strong theoretical arguments in favour of *real-time pricing* of electricity, implementation has been lacking and restricted mainly to industrial applications. Technology has played a role in this as the cost of time-of-use metering until recently was substantially less than real-time metering. However, cost reductions have made real-time metering more affordable in the last decade. Furthermore, technological advances have made it possible to combine real-time pricing with more sophisticated forms of automated demand response technology so that responding to frequent price changes does not always require customer intervention (Borenstein et al, 2002).

The responsiveness of demand to various pricing structures can also manifest itself in long-run changes to consumer behaviour such as increased participation through microgeneration – the generation of electricity or heat within the home. Cost-reflective pricing may encourage customers to rely on self-supply when prices are high or to invest in microgeneration to supply to the grid at times of scarcity (i.e. high prices). Additional meter functionality is required to differentiate between exports and imports of electricity. Recent research by Keirstead (2007) has suggested that microgeneration can encourage further changes in household consumption. The study shows that among households with PV installed in the UK, electricity consumption has been reduced by approximately 6% and demand has shifted to times of peak generation. Table 4 provides a summary of these pricing-based studies and their results.

Innovation in and analyses of electricity pricing programmes have typically occurred in regions where summer and winter peaks are of prime importance to the electricity system. Encouraging demand response in order to reduce or shift peak consumption from to off-peak periods have been the main goals. The effects of improving the available information on customer energy consumption, on the other hand, have been explored mainly to understand how better information can encourage more energy efficient behaviour, i.e. reductions in total consumption.

Making customers more aware of their energy consumption, how it breaks down by end-use for example or how consumption this week compares to last week, has the potential to encourage changes in consumer behaviour. Darby (2006) reviews the evidence on the effectiveness of feedback on energy consumption at a household level and divides the types of feedback into two categories: (i) direct feedback, i.e. from the meter or a display monitor; and (ii) indirect feedback, i.e. information that has been processed in some way, for example billing. Energy savings from direct feedback in the surveyed studies is in the region of 5 to 15% and energy savings from indirect feedback from 0 to 10%. One of the main conclusions of the study is that a user-friendly display should form part of any new meter specification to improve the level of direct feedback to customers.

Table 4: Summary of time-differentiated pricing studies

| Study | Sample size (residential customers) | Pricing/scheme | Results | Comments |
|---|---|---|---|---|
| Atkinson, 1981 (Arizona) | 140 | TOU: off-peak, mid-peak and peak; 3 groups; variations in price ratios | Peak own-price elasticity: -0.68 to -0.78 | Compensation payment: adjustment of monthly bill |
| Atkinson, 1981 (Wisconsin) | Approx. 700; over-sample of urban, high consumption | TOU: off-peak and peak; 3 groups; variations in price ratios | Peak own-price elasticity: -0.81 to -0.83 | No compensation payment |
| Gallant and Koenker, 1984 (North Carolina) | 514 | TOU: 13 groups with off-peak, mid-peak and peak; variations in price ratios | Net welfare gain of 5c per day vs. costs of 10c per day for metering | No compensation payment |
| Filippini, 1995 (Switzerland) | 220 in 19 Swiss cities where time-differentiated tariffs offered to all customers | TOU | Peak (off-peak) own-price elasticity: -1.25 to -1.41 (-2.30 to -2.57)<br>Elasticity of substitution peak/off-peak: 2.56 | Partial elasticities: total electricity expenditure held constant |
| Herter, 2007 (California) | 457; representative of California population | CPP: critical peak price on average 3 times the TOU peak price and 6 times the off-peak price | Mean peak-load change kWh/h during CPP events: High use: -0.21 Low use: -0.02<br>Average bill savings: High use: 1.7% Low use: 4% | Fixed participation payment over pricing pilot of $175 |
| Keirstead, 2007 (UK) | 118 UK PV households | PV installation | 6% reduction in electricity consumption post-PV installation | Respondents significantly older, wealthier and better-educated than average |

Wood and Newborough (2007) explore the main options for energy display types and in particular focus on the types of information that should be accessible through the display. They conclude that it is important to avoid overloading customers with extremely detailed information for each appliance in the home as attention may be distracted from the main energy-consuming appliances. They suggest a display that combines information on a small number of end uses with access to more detailed appliance-specific information for those who require it. In a previous study, the same authors explore the feedback from smart meters and displays, focusing on individual appliances – in this case domestic cooking. They observe a much greater response from those receiving information from an electronic display attached to the electric cooker than those receiving paper-based information alone (Wood and Newborough, 2003).

A recent analysis by Dulleck and Kaufmann (2004) of an electricity information programme in Ireland provides some useful insights into the short-run and long-run impacts of improved access to information. The programme was targeted at small business and household users. Customers were given information leaflets on energy efficiency and energy efficiency certifications for appliances were introduced. Overall electricity demand was reduced by approximately 7%. Interestingly, the programme had a larger impact on long-run demand with very little impact on short-run demand because the information affected the long-run investment decisions of customers. These information-based studies are summarised in Table 5.

Table 5: Summary of information-based energy studies

| Study | Type of information | Results | Comments |
|---|---|---|---|
| Darby, 2006 | Direct feedback:<br>-self-meter reading<br>-direct displays<br>-interactive feedback via PC<br>-prepayment meter<br>-energy advice with meter reading<br>-cost plugs on appliances | 5 to 15% savings | Range of studies with different types of direct feedback |
| Darby, 2006 | Indirect feedback:<br>-more frequent bills<br>-frequent bills based on readings plus other historical/comparative/detailed information | 0 to 10% savings | Range of studies with different types of indirect feedback |
| Wood and Newborough, 2003 | Electronic feedback via consumption indicator attached to electric cooker | 15% reduction | 44 UK households; focus on electricity for cooking |
| | Paper-based information pack on electricity consumption of cooking appliances and electricity savings tips | 3% | |
| Dulleck and Kaumann, 2004 | Information leaflets on energy efficiency; introduction of energy efficiency appliance certifications | 7% reduction in electricity demand | Impact on long-run rather than short-run demand |

*Smart metering as a tool for active demand* Smart meters with advanced communications are a gateway to increasing the participation of the demand-side in the electricity market through facilitating new pricing structures and overcoming information asymmetry. They can also act as a platform for automated forms of demand response by connecting with smart appliances, such as the smart thermostat, to control loads directly. Improving the flexibility of network operation is likely to become even more important in the future with the further integration of intermittent energy resources such as wind to the network. More responsive electricity demand will be important in contributing to this flexibility (Stadler, 2008); advanced communications, control methods and information technologies including more sophisticated metering will be central in achieving this goal (Strbac et al., 2006).

The liberalisation of electricity markets has changed the incentive structure for investing in a more active demand-side by dispersing the value among the various actors in the liberalised market (IEA, 2003). Furthermore, as a tool for increasing demand-side participation, investing in smart metering has wide-ranging impacts on the entire supply chain. Any adjustments to the incentives in place for end-users to consume power in one segment of the market have an impact on end-users in the rest of the market and on the electricity system as a whole. Changes in the way domestic consumers use power throughout the day through dynamic or time of use pricing mechanisms, for instance, can change domestic load profiles. These changes may have an impact on electricity prices for other consumer segments, generation investment decisions and consequently the carbon intensity of the electricity system.

Evaluating the costs and benefits of smart metering is therefore a complex process and one in which international comparisons in terms of experience with technology, market organisation and methodology of analysis are instructive.

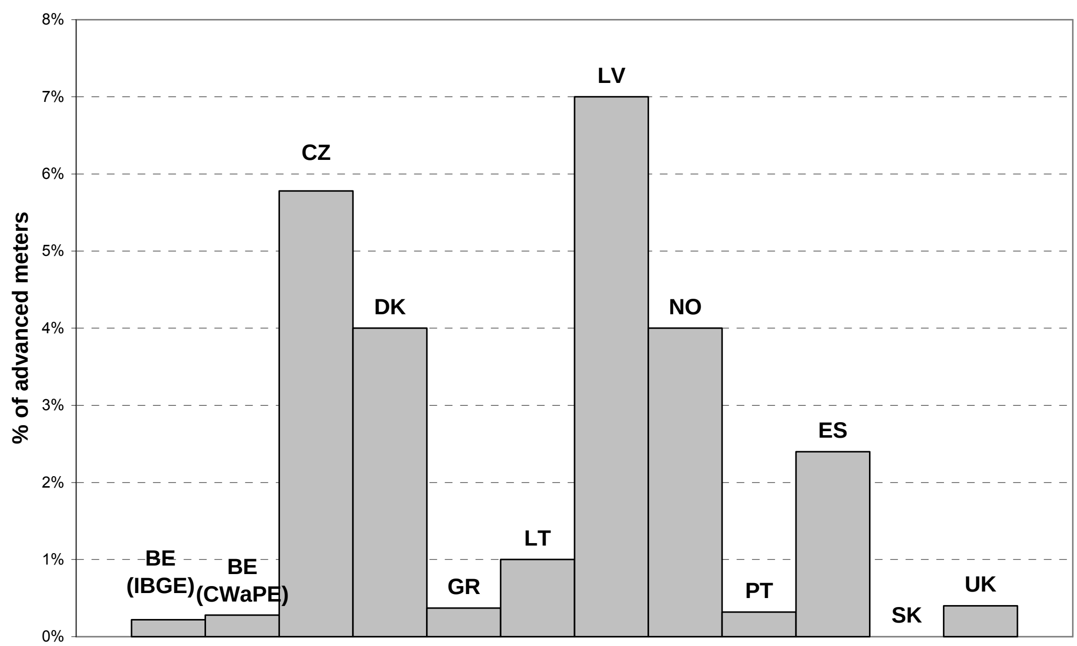
## 3. Metering technology overview

### *3.1. Technology trends*

In the UK and most other countries, the traditional electromechanical Ferraris meter is still the predominant means of measuring energy consumption in homes and small businesses. Traditional electricity meters display consumption in kWh only, record consumption cumulatively and are read manually. Because of the need for a meter reader to periodically inspect the meter for an accurate reading or for customers themselves to report a meter reading to the supplier, billing is often based on estimates of consumption rather than on actual consumption and correction of estimates may only occur with a long delay.

Where more advanced electronic meters have been installed, customers with high levels of average annual consumption (typically industrial and large commercial users) and higher levels of peak load are usually the first to be targeted. Figure 2 shows the penetration of advanced electricity metering in a number of European countries where percentage shares are less than 8%. In Denmark and Norway, each with advanced metering shares of 4%, advanced meters have been installed where annual consumption exceeds 100,000kWh; in Great Britain half-hourly metering (interval metering) is mandatory for users with maximum demand over 100kW (DTI, 2006, p. 22). Companies under this threshold can choose to install half-hourly metering once they are prepared to pay the additional charge and upgrade the meter (Carbon Trust, 2007). Collectively this group of users is referred to as Code 5.

Figure 2: Advanced electricity meters in Europe: countries with relatively low penetration levels




*Source:* ERGEG (2007) and Carbon Trust (2007)

Table 6 gives a breakdown of the number of electricity meters, type of billing and the corresponding average annual consumption of the 8 electricity profile classes and Code 5 customers in Great Britain. While customers in the Code 5 category account for a small share of total meters (less than 0.5%), their share of total electricity consumption is close to 50% (Devine-Wright and Devine-Wright, 2006; and Table 2). Accurate billing for large consumers is particularly important because any inaccuracies could potentially be large relative to overall consumption levels (Carbon Trust, 2007).

Table 6: Electricity meters, billing type and consumption by profile class in Great Britain

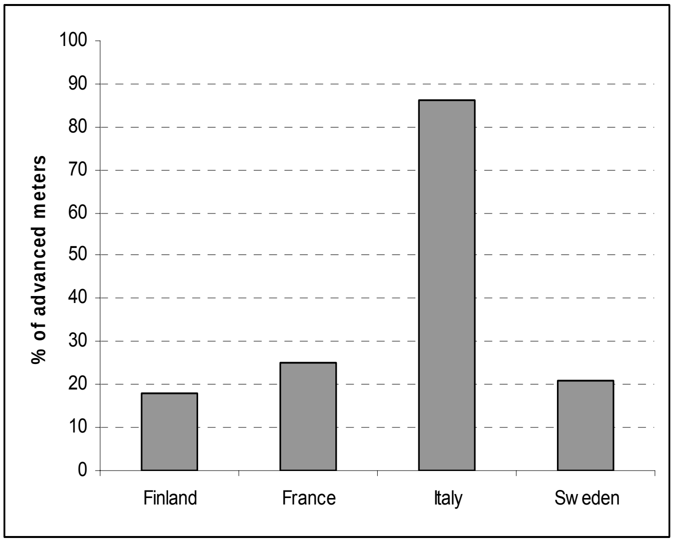
| Group | Description | General billing type | Number of meters | Average annual consumption | % of total demand[5] |
|---|---|---|---|---|---|
| Profile Class 1 | Domestic Unrestricted | Estimated/ Prepayment | 18,656,100/ 3,600,000 | 4,457 kWh[6] | 36% |
| Profile Class 2 | Domestic Economy 7 | Estimated | 3,300,000 | | |
| Profile Class 3 | Non-domestic unrestricted | Estimated | 1,662,800 | 14,900 kWh | 18% |
| Profile Class 4 | Non-domestic economy 7 | Estimated | 506,700 | 24,800 kWh | |
| Profile Class 5 | Non-domestic 0-20% load factor | Estimated | 38,000 | 81,600 kWh | |
| Profile Class 6 | Non-domestic 20-30% load factor | Estimated | 53,700 | 109,800 kWh | |
| Profile Class 7 | Non-domestic 30-40% load factor | Estimated | 27,600 | 128,900 kWh | |
| Profile Class 8 | >40% load factor | Estimated | 48,100 | 142,300 kWh | |
| | | **Subtotal** | **27,893,000** | | |
| Code 5 | High consumption[7] | Accurate | 107,000 | 1,339,010 kWh | 46% |
| | | **Total** | **28,000,000** | | |

*Source:* Adapted from Carbon Trust (2007) and DTI (2006)

The countries shown in Figure 3 have at least 18% shares of advanced electricity meters installed, with plans to significantly expand implementation in the coming years. Implementation in Italy is the most advanced with over 85%.

[5] This is percentage of total consumption for profile classes 1 to 8 and code 5 in Great Britain; it does not include consumption direct from high voltage lines or electricity produced via autogeneration.
[6] This figure is for 2006 average domestic consumption for profile classes 1 and 2, taken from electricity consumption data at regional and local authority level in 2006 reported in DUKES (2006).
[7] Industrial sites where peak consumption exceeds 100kWh for three consecutive months

Figure 3: Advanced electricity meters in Europe: countries with relatively high penetration levels




*Source:* ERGEG (2007) and Ofgem (2006a)

Results from ERGEG (2007), a survey of metering across Europe, indicate that although some consideration is being given to promoting smart meters in the gas sector, the current levels of implementation in Europe are very low.[8] In the US, the overall penetration level of advanced metering is relatively low at 6% nationally. However, there are considerable differences between penetration levels on a state by state basis. Pennsylvania and Wisconsin stand out as frontrunners with 53% and 40% respectively for overall levels of advanced metering in both the electricity and gas sectors (FERC, 2006). Comparing countries and regions is a difficult task, however, because there is no single definition of what it means for a meter or a metering system to be 'advanced' or 'smart'.

### *3.2. The electricity meter: from ' traditional' to 'smart'*

The smart gas or electricity meter is a device that forms a small but integral part of a smart metering system. It provides consumption information in more detail than a traditional meter and a range of additional functions once the meter is connected to a communications network. In general when the term smart meter is used, it is implied that the meter is capable of two-way communications. In this section we will focus on different existing types of electricity meters as international experience with the variety of functions and costs is more widespread than in either the gas or water sectors.

[8]Belgium and Spain were the only countries to report figures for smart meters in the gas sector and both reported percentage shares of 0.05%.

*Electromechanical* The electromechanical meter displays electricity consumption in kWh and records it on a cumulative basis. It is the most common type of meter in homes and small businesses in the UK and internationally. The customer, residential or commercial, receives an estimated monthly bill for cumulative consumption; this estimate can be adjusted at a later stage once a meter reader has visited the premises or a customer has reported a reading to the supplier. Tariffs are set by the supplier and are based on a unit (kWh) rate. Suppliers may offer a tariff that charges a higher unit rate for consumption over a certain level, however in most cases the tariff rate is independent of time of use.

As the meter records consumption cumulatively, there is no record of previous consumption. Certain types of electromechanical meters have multiple mechanical registers that can record cumulative consumption according to different times of the day. Economy 7 meters in the UK provide two different readings: one for day-time and one for night-time usage[9]. Suppliers can apply a different rate to electricity consumption during the night when electricity is not as costly to produce (usually 7 hours from around 1am to 8 am) and customers are given an incentive to shift some consumption from peak to off-peak times. Some Economy 7 customers opt for suppliers to control their systems automatically via a radio teleswitch; timing can be varied manually or in some cases remotely using teleswitch. Electric storage and hot water heating, for instance, can be controlled to switch on only once the night-time rate has been activated. Demand response effects of this type of metering solution are limited and rely primarily on the role of the supplier in managing electricity demand (Bilton et al., 2008). Billing is still based on estimated consumption and the information that reaches the customer is limited.

*Retrofitting electromechanical meters* The functionality of traditional meters can be improved by adding a variety of external attachments to them. For example, it is possible to fit a prepayment attachment to a standard meter so that a customer can continue to use its existing metering system but with the added flexibility that prepayment tariffs may provide.[10] Another type of simple retrofit is the addition of a real-time display unit to the existing meter. The most basic form of display is a device which can be clipped on to an existing electromechanical meter. A sensor clip is attached to the mains electricity cables leading from the meter box to the fuse box. The sensor plugs in to a transmitter which

[9] Economy 7 meters are usually used only where gas for heating is not available.
[10] Actaris metering manufactures this type of prepayment attachment (PayGuard) using a smart card to transfer data from the customer to the utility: http://www.actaris.com/html/products-385.html

sends a signal to an external display located somewhere visible in the home.[11] It is anticipated that providing consumers with real-time data on their consumption patterns will help them to become more aware of their electricity usage, reduce consumption and ultimately lead to carbon savings.

There is a variety of display devices currently on the market but the basic concept remains the same and they can be used for measuring and displaying electricity consumption only. The displays generally offer consumers approximate information on their electricity consumption in monetary units and energy units and certain models also display the amount of $CO_2$ emissions this corresponds to. For this information to be displayed, however, the customer must be actively involved in inserting price and emissions information. Depending on the design of the product the displays offer consumers various ways to alert them when consumption goes over a certain level, for example by setting an alarm or by triggering a warning light. The metering system remains the same, however, and customers continue to be billed on an estimated basis.

In the UK, the government initially proposed mandating electricity suppliers to provide real-time display devices on a new and replacement basis and to any customer that requested one. This proposal was reversed in 2008 because of widespread concerns that the requirement would delay the roll-out of smart meters and increase the costs of such a roll-out. Nevertheless, certain suppliers have started to provide display devices to customers as part of energy saving packages.[12] The government also intends to reach a voluntary agreement with suppliers and does not rule out the possibility of real-time displays being part of metering policy in advance of a smart meter roll-out (BERR, 2008a).

Electromechanical meters can also be retrofitted to become part of a completely new metering system, as has been the case in certain parts of the US. In California, for example, Pacific Gas and Electric's (PG&E) initial plans to implement advanced metering in its service territory relied on retrofitting 54% of existing electric meters and 96.1% of existing gas meters by fitting the meters with a communications module (PG&E, 2005). Installation on this basis began in November 2006, however PG&E has since filed a request with the California Public Utilities Commission (CPUC) to upgrade electromechanical meters to more advanced digital counterparts to enhance both customer and operational benefits (PG&E, 2008). While retrofitting electromechanical meters with communications modules

[11] The Wattson display and Electrisave displays operate in this way. See for example: http://www.diykyoto.com/wattson/how-wattson-works

[12] EON UK, for example, is offering customers a free energy monitor if they sign up to their Energy Saver 5 package.

has the advantage of not rendering the existing meters obsolete (and hence lowers stranded costs), more advanced meters have become more cost-effective in recent years and have the potential for greater functionality and therefore added benefits for customer, supplier and the rest of the electricity system.

*Electronic* Electronic, solid-state electricity meters (i.e. those that do not contain moving parts), come in a variety of forms, with varying degrees of functionality. An interval electronic meter is most likely to be the metering device in a smart metering system. Interval meters are essentially electronic meters that have the capability to record electricity consumption over a short period of time, usually 15, 30 or 60 minute intervals. This allows for more complex time-varying pricing structures to be implemented and is the driving force behind the potential demand response benefits that interval meters can provide. Beyond this basic requirement, there is a range of functions that can be added to the meter to increase the smartness of the meter and the metering system. The meters can be read manually or they can be equipped with communications technology so that the supplier can read the meter remotely and in some cases also communicate back to the customer/meter. Meters can also be fitted with the functionality to switch between credit and prepayment (FERC, 2006; NERA, 2007b).

Two-way communications systems offer a wide variety of extra options for the supplier and services for the customer, including remote connection and disconnection, outage or loss of supply detection and communication to the supplier, and the ability to interface with load control technology. Furthermore, some meters have the capability to record electricity that is imported from the grid as well as electricity that is exported to the grid, allowing for the measurement of output from micro-generators. As is the case with electromechanical meters, electronic interval meters can also be fitted with an external display to provide a more visible means for customers to track their consumption and its related cost.

Electronic prepayment meters are often referred to as 'semi-smart' because although they provide customers with more information on their consumption and a closer connection between the different levels of consumption and their financial implications, their communications capabilities are generally limited. Within the prepayment category, there are however an increasing number of technological options. Prepayment meters make up approximately 14% of domestic meters in Great Britain. Just over a third (36%) are token meters; 42% are key meters and the remainder are smart card meters (Owen and Ward, 2007, p. 40).

Token meters are the oldest type of prepayment meter technology and are on the decline mainly because of their high servicing costs and greater susceptibility to fraud and misdirected payments (Ofgem, 2005). Even at the most basic level of prepayment meter technology, the customer has more control over expenditure than with the traditional electromechanical meter because it is a 'pay as you go'-type system. Customers have a card with their account details and transactions and this card is used to buy credit at specified outlets. In return for payment, customers receive paper tokens for their meter. The customer is therefore not subject to estimated billing and may be more aware of electricity consumed over a shorter period of time than the usual credit customer's billing period. The meters, however, have to be manually adjusted after every price rise. Furthermore, the tariffs charged to prepayment customers tend to be higher to reflect the higher servicing costs of the meters and there is also some correlation between customers on prepayment tariffs and those on low incomes (Ofgem, 2005). For key and smart card prepayment meters, the system of payment is similar and the keys or cards are recharged once the customer adds more money to their account.

Prepayment meter technology has advanced considerably in recent years and the costs of new prepayment systems relative to previous systems have declined substantially. One of the clearest examples of this is in Northern Ireland. After an initial trial of keypad electricity prepayment meters in 200 homes, Northern Ireland Electricity started to roll-out the new meters in the year 2000. There are currently 190,000 meters installed, approximately 25% of residential customers (Owen and Ward, 2007, p. 41).

Customers purchase credit from local agents (e.g. supermarkets and cash machines), over the phone or online and they receive a 'PowerCode' number to enter into the meter once their purchase is complete. There is also a 2.5% reduction off the standard electricity rate for customers using keypad meters (NIE, n.d .).

As well as reducing the costs of the metering system (doing away with expensive token/key/card systems), the new prepayment technology offers a range of new functions for customers and suppliers. These include a detailed customised user display with information on credit time in days and information on costs over the previous day, week and month; unit rates and number of units used at these rates; previous purchase information; load limiting rather than disconnection; and the ability to programme the meters through vend codes rather than site visits (Ofgem, 2006a and PRI, n.d .). Remotely programming the meters further reduces costs by eliminating the need for site visits to switch the meter between prepayment and credit (Owen and Ward, 2007).

*3.3. Adding communications: the smart meter as part of the smart system*

Communications technology is central to the most advanced types of metering systems that are currently available. Adding communications capabilities to meters provides an enhanced level of functionality and allows for a greater level of interaction between the various actors in the supply chain. Meters that are not connected to a communications system require readings and any changes to the programming of the meter (for example connection/disconnection, switching from prepayment to credit) to be carried out manually.

Advanced Metering Infrastructure (AMI) refers to the entire infrastructure of meters, communication networks and data management systems required for advanced information to be measured, collected and subsequently used. Through this infrastructure, the meter is connected to the supplier, other market actors and can potentially be linked to appliances in the home through the Home Area Network (HAN). Without the surrounding infrastructure, however, smart meters can only be used in much the same way as traditional electromechanical meters because most of their additional functionality cannot be supported.

Figure 4 shows a simplified picture of how the various communication networks link parts of the AMI together. There are three main types of network: the Home Area Network (HAN), Local Area Network (LAN) and the Wide Area Network (WAN). The meter can act as a platform for coordinating with other devices in the home (display devices, appliances, lights, thermostats, HVAC systems) and with the customer through the HAN and with the rest of the electricity system through the LAN and WAN. There are two main categories of advanced metering systems that are differentiated by their levels of communication: Automated Meter Reading (AMR) and Automated Metering Management (AMM).

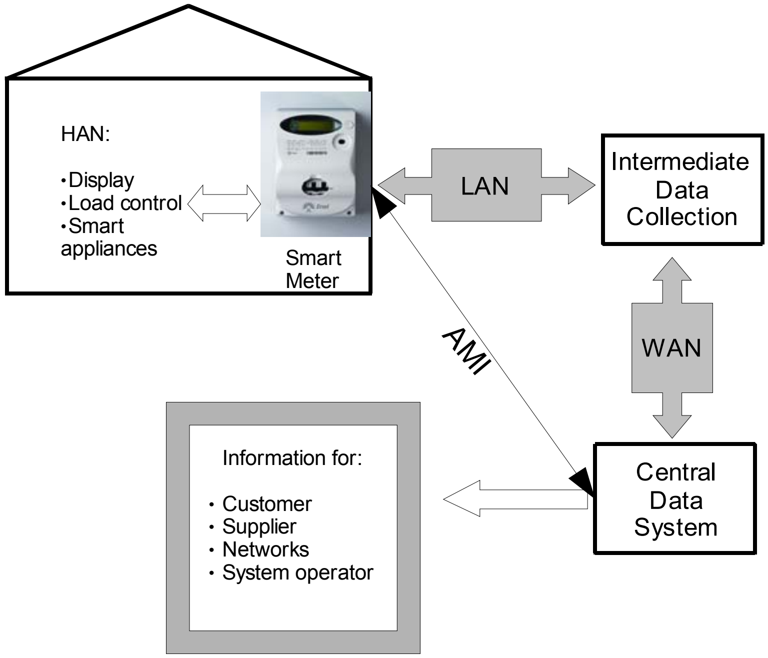
*Automated Meter Reading (AMR)* AMR allows for readings to be collected without the need for physical access to the meter. The simplest form of AMR connects the meter temporarily via a radio link to an electronic meter reading device. In the early days of residential AMR, particularly in the US, meter readers used handheld meter reading devices and connected to the meter as they walked or drove by the premises. AMR can also be implemented using a permanent communications link between the meter and supplier. Various forms of wireless and wired communications technologies can be employed for this purpose. Both the simple and more advanced forms of AMR allow for accelerated meter readings and more accurate billing. Electromechanical or electronic meters can be used as part of the AMR system.

Sites with half-hourly metering in the UK are usually equipped with some form of AMR so that suppliers can base billing on accurate consumption. How quickly the data can be accessed by customers depends on the individual supplier; a 2005 survey by the Carbon Trust found that the time it took energy suppliers to make data available varied from 24 hours up to one month (Carbon Trust, 2007). Generally, the information can be viewed online through the supplier's website. Businesses are often equipped with a related software package (automatic monitoring and targeting software) so that energy consumption data can be monitored and usage optimised. Some of this equipment may be eligible for tax relief under the Enhanced Capital Allowance scheme in the UK for energy saving technologies (Carbon Trust, 2008).

*Automated Meter Management (AMM)* AMM goes a step beyond AMR and refers to the process of two-way communication between the meter and the rest of the network. This type of remote management allows for commands/messages to be uploaded to the meters as well as data to be downloaded. Remote management of the meter includes the capability for remote connection/disconnection and remote changes in contracted power or price schemes. In general, electronic interval meters are used as part of an AMM system.

For most communications solutions, the LAN connects the meters to intermediate data concentrators and the WAN transmits the data further to a central data system. In Italy, ENEL uses Power Line Carrier (PLC) for the LAN and the public telecommunications network for the WAN. PLC communications send signals over power lines between zone substations and meters. Distribution Line Carrier (DLC) communications can also be used for the LAN; in this case the low voltage distribution network is used as a communication medium. Mesh radio is an alternative to both PLC and DLC and is a private network radio technology which uses meters as repeaters in a mesh configuration before the data is transmitted to a concentrator.

Figure 4: Advanced metering infrastructure and the Home Area Network




It is also possible to establish a direct connection between the meter and the central data system by using the public switched telephone network (PSTN), a mobile data connection (GSM/GPRS) or Ethernet/internet interfaces. There are a range of communication protocols that can be used for the HAN, for example Wi-Fi, Zigbee (a wireless standard) and Bluetooth.

*Interoperability* An open or interoperable metering system permits transparent access and integration among equipment and applications. By permitting vendor-independent solutions, an open system improves competition, gives greater flexibility and allows for future development rather than lock-in to one specific solution. Proprietary solutions by contrast limit the meter variations that can be used and restrict access to metering data. Internationally there are examples of both types of solutions. ENEL in Italy and PG&E in California use proprietary solutions; Ontario, Canada and SCE in California use open solutions (NEMMCO, 2007).

### *3.4. Smart metering technology in international context*

*Recent implementation* A number of countries and regions within and outside Europe stand out because of their relatively high penetration levels of advanced metering. The technologies used; the incentives behind implementation; and the recovery of costs differ as can be seen in Table 7 and in Table 8. In Europe, Italy is the frontrunner where smart metering has been rolled out to 85% of low voltage customers.

In countries such as Sweden, France and Finland AMR was initially implemented but plans for AMM have since developed. A large-scale pilot project is planned by EDF in France; and although legislation in Sweden only requires more frequent electricity readings, AMM is increasingly being adopted by distribution companies. Technology choice is also a function of context-specific considerations. Prior to the trial and roll-out of keypad prepayment metering in Northern Ireland, basic prepayment metering was widely used by Northern Ireland Electricity. One of the main drivers for replacing the prepayment system was the decrease in operating costs. Improved functionality also allows for load to be limited rather than disconnected which was an important feature in overcoming concerns of the regulator and consumer groups over self-disconnection.

Table 7: Recent and ongoing implementation of advanced electricity metering in Europe

| | **Meter** | **Communications** | **Timeline** | **Incentives/Cost recovery** |
|---|---|---|---|---|
| **Italy** | Interval electronic | AMM: PLC and public telecommunications; proprietary solution | 2001: ENEL (largest DNO – 85% of low voltage customers) begins Telegestore project<br>2005: Acea Roma and Asmea Brescia start smart meter installations<br>2007: 31 million digital meters installed; 8 million remote operations and 180 million readings<br>2008: Mandatory installation by all other DNOs due to commence; gas consultation under way | From 2004, metering service tariffs guarantee recovery of investments for low-voltage customers; efficiency gain targets for metering service 2008-2011 recognize AMM's potential in cutting operating costs |
| **Sweden** | Interval; some Zigbee-enabled | AMR to begin with; more recently AMM; PLC and public telecommunications | 2003: Legislation requires monthly readings for all electricity users by 1 July 2009 | Regulatory requirement to improve meter readings |
| **Northern Ireland** | Keypad prepayment | Remote management of meters via vend codes | 2000: Roll-out by Northern Ireland Electricity (NIE) beings after initial trial in 200 homes<br>2008: Approx. 190,000 installed | Incentive payments to NIE as part of supply price control in 2000 and extended in 2005; Transfer of metering assets to transmission and distribution from April 2007 |
| **Finland** | Some retrofitting of existing meters | AMR; wide variations across DNOs; some AMM plans more recently; mobile phone | 2008: All customers with main fuses > 63 A have hourly metering<br>2008: In May Vaasan | Mandatory hourly metering for customers with fuses >63 A |

| | | | | |
|---|---|---|---|---|
| | | network | Sähköverkko Oy announces AMM plans for 60,000 customers<br>2009: Vattenfall expects all of its 900,000 meters to support remote reading | |
| **France** | Electronic | AMR (handheld); plans for AMM systems | 1990s: EDF starts installing AMR in small businesses and homes (approx. 9 million)<br>2008: EDF planning an AMM pilot for 300,000 homes in 2010 | Regulator planning to publish AMM requirements following on from commissioned cost benefit analysis in 2007 |

*Source*: Villa (2008), Owen and Ward (2006), Ofgem (2006a), ERGEG (2007), Oland (2005), Vigneron (2007), PRI (n.d.), Metering.com (2008), NIAUR (2007)

Table 8 summarises implementation and studies of advanced metering outside Europe. The largest-scale recent implementation in California offers an interesting case study in the approaches taken by utilities in the region. Southern California Edison (SCE), after its first analysis of smart metering in 2005, concluded that available technologies were not cost-effective in their present form (SCE, 2005). Since then, SCE has worked with meter manufacturers to improve functionality and to develop an open architecture information system that will allow for future communication channels, e.g. cell phones and other mobile devices. Pacific Gas & Electric (PG&E) in 2005 decided to proceed with a proprietary metering system rather than to wait for an open solution (PG&E, 2005). In the meantime PG&E has decided to upgrade its smart metering programme to allow for the integration of more advanced automation systems through the home area network (HAN) (PG&E, 2008).

Table 8: Implementation and studies of advanced electricity metering outside Europe

| | **Meter** | **Communications** | **Timeline** | **Incentives/Cost recovery** |
|---|---|---|---|---|
| USA: California | Interval and some retrofitting | AMM: PLC and radio frequency (RF) | 2007/2008: 3 main investor-owned utilities PG&E, SG&E and SCE commencing deployment of approx. 12 million electricity and 5 million gas meters | California Public Utilities Commission requested proposals from utilities and authorizes funding for AMI |
| Canada: Ontario | Interval | AMM: PLC and public telecommunications; open solution | 2007: Target of 800,000 meters (20%)<br>2010: Target of 4.5 million meters (100%) | Cost recovery through distribution rates approved by Ontario Energy Board |
| Australia: Victoria | Interval; Zigbee-enabled | AMM | 2006: Government endorses roll-out to all homes and businesses<br>2008: Installation of approx. 2.6 million meters to commence | Cost recovery through metering charges regulated by Essential Service Commission to be collected from retailers of all small consumers |
| India: New Delhi | Prepayment; tamper detection | AMR: PLC | 2008: Pilots in New Delhi<br>2010: Target of 500,000 | Pilot project initially with contract between Grinpal |

| | | | | |
|---|---|---|---|---|
| | and load limitation | | meters (Grinpal Energy Management) | and distributors |
| India: Andhra Pradesh | electronic; recalibration of old meters for small users | AMR: Satellite communications from distribution feeders; meter reading for monthly data downloads | 2000: Electronic meters installed for high-value customers to start with; focus on 11-kilovolt feeders with high line losses and on 114 towns for residential customers (53% of consumption) | Reduce electricity theft and increase revenue |
| Lebanon: study for Électricité du Liban | Electromechanical and electronic | AMR | Study undertaken in 2003 | Minimise losses due to theft and fraud |

*Source:* IT Web (2008); Bhatia and Gulati (2004); Ghajar and Khalife (2003);

New Delhi is one example of advanced prepayment and remote reading technology in a developing country context. Although the system planned for New Delhi is described as AMR, there is also some two-way communication involved as part of the project, with remote disconnection and reconnection, remote switching between credit and prepayment metering and messages sent to residential customers from the utility via mobile phone or a display connected to the meter (IT Web, 2008). The state of Andhra Pradesh has also had some experience in improving metering systems, mainly to reduce electricity theft and increase revenue. Electronic meters and remote meter reading instruments were installed to improve the accuracy and information flows for industrial, commercial and some residential customers. As a result, transmission and distribution losses were reduced from approximately 38 percent in 1999 to 26 percent in 2003 (Bhatia and Gulati, 2004).

A study in Lebanon for Électricité du Liban, the national electricity company investigated the potential of AMR to minimise losses due to theft and fraud. The levels of total losses are approximately 50% - this includes both technical and non-technical losses. The study concludes that a combination of electromechanical and electronic meters equipped with RF communication modules should be implemented; the electronic meters would account for 14% of total installed meters and would be used for large consumption and problematic customers (Ghajar and Khalife, 2003).

*Likely international developments* The international metering landscape is one that is constantly changing due to advances in technology and in international experience. In order to get a flavour of what lies ahead in Europe, it is helpful to look at the locations and types of technology trials that are currently being undertaken as well as the preliminary plans/ targets that have been announced by energy regulators and/or by relevant market actors.

Some of the main European trials are summarised in Table 9. Developing metering and billing policies that are in line with the EU Energy Services Directive has been a strong driver across the EU for trials and studies of smart metering. In countries such as Great Britain and France, the trials follow on from cost benefit analyses that have been conducted. In Great Britain in particular, the Energy Demand Reduction Pilot is under way to further inform the direction of smart metering policy and to identify if a stronger regulatory role is required.

Table 9: A selection of smart metering technology trials in Europe

| | **Technology** | **Implementation** |
|---|---|---|
| **Austria** (electricity) | AMM systems | 2 grid operators; domestic; independent of government/regulator (ERGEG, 2007) |
| **Czech Republic** (electricity) | AMM systems; various projects | DNOs; domestic; independent of government/regulator (ERGEG, 2007) |
| **France** (electricity) | AMM systems; PLC-based | EDF; 300,000 households; March-September 2010; first stage in 35-million meter roll-out . |
| **Germany** (electricity) | AMM; several data communications technologies | RWE (supplier); 100,000 households in one town (Muellheim a. d. Ruhr); from mid-2008 for 3 years. |
| | AMM; internet-based communication | Yello (supplier); 1,000 households; to commence 2008; partnership with Microsoft. |
| **Great Britain** (electricity; gas) | Remotely read meters with displays | EDF (supplier); 3,000 households in London; managed by National Energy Action; funded by DEFRA. |
| (electricity; gas) | Remotely read meters; smart meters with visual displays; display units alone; prepayment meters | "Energy Demand Reduction Pilot" 2007-2010 managed by Ofgem with 23,000 homes; implemented by EDF Energy, E.ON UK, Scottish & Southern Energy, ScottishPower (suppliers); funded by BERR, DEFRA and match-funded by suppliers. |
| (electricity; gas; water) | Remote collection and access to metering data; communications solutions site-specific | Carbon Trust 2004-2006; 582 advanced meters in SMEs across UK |
| **Ireland** (electricity) | AMM; system architecture to be determined | ESB Networks managed by Commission for Energy Regulation; 25,000 homes in varied geographic locations from April 2008. |
| **Spain** (electricity initially) | AMM; PLC-based; open and non-proprietary system architecture | Small-scale testing mid-2007 by Iberdrola in LV network; 2007-2009 further preparations with deployment from 2009 (Powerline Related Intelligent Metering Evolution – PRIME) |

*Source:* Carbon Trust (2007), CER (2008), ERGEG (2007), PRIME (2008), Verivox (2008), Vigneron (2007), Yello Strom (2008).

In other countries such as Ireland and Spain, the first stages of deployment are being used as a means to inform later stages. The large-scale pilot in Ireland follows on from a qualitative review of smart metering by the regulator and is an exercise in determining meter design, system architecture and functionality through engagement with the network operator, suppliers and other stakeholders. A full cost-benefit analysis will be conducted based on the results of the pilot. The Irish regulator is working closely with the regulator in Northern Ireland to ensure that supplier competition in the all-island market will not be inhibited by a lack of interoperability (CER, 2008).

In Germany, the two main trials that have been announced to date are being undertaken by two suppliers, RWE and Yello. In contrast to other European countries, the trials in Germany, Austria and the Czech Republic are taking place independently of the government and/or the regulator.

The metering survey undertaken by the European Regulators Group for Electricity and Gas (ERGEG, 2007) gives an idea of what to expect in Europe over the next 5 to 10 years in countries where activity in smart metering is currently in its early stages. Table 10 summarises smart metering targets for these countries; reaching the targets will in many cases depend on the outcomes of ongoing trials. Details on the functionalities and applications of future smart meter installation from the survey were lacking; drawing conclusions on technology differences is therefore difficult and highlights continuing uncertainty in Europe.

Table 10: Smart metering projections for Europe

| | **Smart Metering Target** | **Comments** |
|---|---|---|
| Denmark | 13% by 2010 | |
| Finland | 60% by 2015 | |
| Ireland (electricity) | 100% by 2012 | Large-scale pilot as part of deployment in 2008(AMM) |
| Latvia | 22% expected by 2012 | |
| Netherlands (electricity and gas) | 100% by 2014 | Due to commence mid-2008 w/ 2-yearly assessment (AMM) |
| Norway | 100% by 2013 | Possible deadline for implementation |
| Spain (electricity) | 65% by 2015; 100% by 2019 | Due to commence deployment 2009 (AMM) |
| United Kingdom | 100% by 2018 | Medium and large businesses to be targeted first; further consultation on small business and domestic during 2008 |

*Source:* ERGEG (2007), CER (2007), BERR (2008a).

# 4. Economic assessment of smart metering

Regardless of their level of intelligence, meters provide information generally for billing purposes and they allow the end-user to interact with other market actors in the supply chain. The electricity sector has traditionally been supply-oriented. Consequently, electricity metering for small users in particular has been based on very limited information on consumption, manual reading of this information and a very slow and one-way interaction between the meter and the meter reader.

The range of new functions offered by a smart metering infrastructure improves the information available and expands the potential for interaction; and the end-user is given the opportunity to become a more active participant in the market for electricity. The economic and social implications of these changes are widespread and differ according to how smart metering is implemented. In this section we will take a closer look at smart metering functionality and its application; we will then discuss the main categories of costs and benefits, what they are sensitive to and how they are distributed.

## *4.1. New functionality and its application*

Although there is no single definition for a smart meter, the most common interpretation implies that the meter device itself is advanced and that it is supported by a two-way communications system. There is a wide range of functions that can fall under this definition. Using the recent in-depth national Australian study on smart meter functionality as a basis (NERA, 2007b), Table 11 divides the range of new functions into two main categories: those that are considered ‘core’ and those that are ‘additional’ features.

Table 11: ‘Core’ and ‘additional’ smart meter functions and applications

| | FUNCTION | APPLICATION |
|---|---|---|
| **Core** | | |
| Measurement | Half-hourly measurement and recording | Load profile measurement; accurate billing; basis for time-differentiated tariffs |
| | Remote reading (weekly) | Accurate billing |
| | Local reading by meter reader or end-user | Back up in case of communications failure; customer awareness |
| | Remote time synchronization | Ensure clock accuracy so that readings correspond to actual time-of-use |
| Security | Communications and data | Data is securely transmitted from and to the |

| | | |
|---|---|---|
| | security | meter; two-way communications |
| | Tamper detection | Communication of tampering remotely |
| Load management | Support existing load management arrangements | Allows continuation of load control via broadcast of turn-on/turn-off commands, e.g. for some Economy 7 users in the UK |
| **Additional** | | |
| Measurement | Daily remote reading | More timely information on energy usage; potential for greater demand response |
| | Power factor measurement | Monitoring of power factor and targeted improvements |
| | Import/export metering | Facilitates micro-generation |
| Switching | Remote connection/disconnection | Facilitates supplier switching |
| | Remote switch between credit and prepayment | Greater customer flexibility |
| Load management | Supply capacity control | Emergency limits following outages; contractual limits on supply to customers |
| | Interface with load control technology and smart appliances (white goods), e.g. through HAN | Direct load control through an open standard platform (the HAN) |
| Quality | Detection and notification of supply losses and outages | Faster outage detection; improved quality of service data |
| Customer interaction | Interface to HAN | Potential for integrated additional services e.g. security, fire safety (see Figure 4) |
| | In-home display device | Customers awareness; instantaneous information |
| | Interface for other metered data (gas, heat, water) | Integration of other utilities with the existing local communications infrastructure |
| Configurability | Remote reconfiguration | Settings e.g. times for load control, tariffs, and supply capacity control can be changed remotely |

*Source:* Based on NERA, 2007b

The 'core' set of features creates the foundation for price-responsive tariffs, accurate billing, greater customer awareness and secure two-way communications. The additional functions could increase the potential for demand response by providing more frequent information on energy usage and improving how the customer interacts with and responds to this information through, for example, the HAN.

### *4.2. Costs of smart metering*

The three main cost categories for smart metering are as follows:

1. Meters
2. Installation
3. Communications and data systems

We will deal with each of these categories in turn and will discuss how each category may be affected by differences in roll-out strategies. Finally we will consider the role of stranded costs.

*Meter costs* Adding functionality increases the capital costs of metering. Table 12 gives an overview of meter purchase costs from two recent studies in Great Britain (Frontier Economics, 2007a; Owen and Ward, 2007). The costs refer to the initial purchase cost of the meter devices, from an electromechanical meter to a relatively advanced smart electricity meter.

Table 12: Meter purchase costs in Great Britain 2007

| **Meter/device type** | **Purchase cost** | **Features** | **Study** |
|---|---|---|---|
| *Electromechanical/basic prepayment* | | | |
| Domestic credit electricity | £7-8 | | Owen and Ward, 2007 |
| Domestic key prepayment electricity | £45-50 | | |
| Domestic credit gas | £18-20 | | |
| Domestic prepayment gas | £75-100 | | |
| Real-time electricity display | £15 | | Frontier Economics, 2007a |
| *Smart meter* | | | |
| Domestic electricity | £25-35 | Core plus remote switch credit/prepayment | Owen and Ward, 2007 |
| | £72-80 | Core plus separate visual display; remote connect/disconnect; remote switch credit/prepayment; import/export metering | Frontier Economics, 2007a |
| Domestic gas | £40-60 (£70-100) | Core (includes credit/prepayment switch) | Owen and Ward, 2007 |
| | £73-103 | Same as second domestic electricity smart meter | Frontier Economics, 2007a |

*Source:* Owen and Ward, 2007; Frontier Economics, 2007a

The costs of basic prepayment meters are substantially higher for both electricity and gas than their credit counterparts. In fact, innovation in metering for prepayment customers has been a strong driver for more advanced meters as in the case of Northern Ireland. There is a wide range of purchase costs for both smart electricity and smart gas meters depending on the additional features that are included. For example, the addition of a separate visual display adds £15 to the base purchase cost of the meter in the Frontier study.

Table 13 gives a breakdown of the additional lifetime cost of providing certain functions in the meter itself based on the Australian national study (NERA, 2007b). As can be seen from the table, there are a number of functions that do not require any additions to the meter; and the most significant cost addition is providing an in-home display device, followed by providing an interface for other utilities.

Table 13: Present value costs of adding functionality to smart meters in Australia 2007

| | **Present value cost (per meter) in 2007 Australian dollars** | | |
|---|---|---|---|
| **Function** | **Low estimate** | **High estimate** | **Main assumptions** |
| Remote reading (daily) | 0 | 0 | 1. 15-year time period<br>2. From 2014<br>3. 8% discount rate (6.5% and 9.5% for sensitivity testing)<br>4. 9.64 million customers |
| Export/import metering | 0 | $0.53 | |
| Remote connect/disconnect | $7.07 | $11.57 | |
| Supply capacity control | 0 | 0 | |
| Interface to HAN | $9.70 | $12.13 | |
| In-home display | $18.19 | $84.89 | |
| Interface for gas and water meters | $10.91 | $13.34 | |
| Loss of supply and outage detection | 0 | 0 | |
| Remote reconfiguration | 0 | 0 | |

*Source:* NERA, 2007b

Although there are no additional meter costs involved in adding functions such as daily remote reading and export/import metering, there are other cost categories which are affected, in particular the IT system and management costs associated with an increase in data.

The lifetime costs of the meters are sensitive to the discount rate chosen and the assumed lifetime of the meter. The discount rate reflects the perspective of the analysis, i.e. if it is a business case analysis, the discount rate is commercial and based on the cost of capital; a lower discount rate is chosen to assess the present value to society of the meter and other costs. Smart meters have a shorter technical life than traditional electromechanical meters; a lifetime of 15 years is typically assumed (NERA, 2007b; Carbon Trust, 2007) compared with 40 years for traditional meters. Nevertheless, the certified life of a traditional meter in Great Britain is up to 20 years rather than the full 40 years (Frontier Economics, 2007a).

The responsibility for and the speed of the meter roll-out may have an impact on meter costs. In theory due to economies of scale, larger scale roll-outs where, for example, one party (i.e. a DNO) is responsible for meter purchasing in a geographic area have greater potential to reduce meter unit costs than smaller scale roll-outs. Consultations with meter vendors in Australia, however, indicated that costs per meter are unlikely to fall considerably for volumes above 250,000 (NERA, 2008, p. 40). The speed of the roll-out also affects the number of meters purchased each year; economies of scale could be achieved with an accelerated roll-out (Frontier Economics, 2007a).

*Installation costs* The annual installation costs for meters capable of AMR and AMM from a 2006 analysis by Ofgem are outlined in Table 14. The existing cap on total annual metering charges for domestic electricity credit meters is £1.12 in Great Britain (Ofgem, 2006b); the installation costs alone for the simple and sophisticated electricity credit meters in Table 11 are greater than the price cap.

Table 14: Metering installation costs in Great Britain

<table>
<tr><th>Smart meter type (domestic)</th><th>Installation cost/year</th><th>Main assumptions</th></tr>
<tr><td>‘Simple’ electricity credit</td><td>£1.17</td><td rowspan="4">1. Simple: AMR<br>2. Sophisticated: AMM with core smart functions<br>3. 10% discount rate<br>4. 15-year asset life<br>5. Large-scale instantaneous roll-out</td></tr>
<tr><td>‘Simple’ gas credit</td><td>£1.01</td></tr>
<tr><td>‘Sophisticated’ electricity credit</td><td>£1.60</td></tr>
<tr><td>‘Sophisticated’ gas credit</td><td>£1.01</td></tr>
</table>

*Source*: Ofgem, 2006a

Installation costs are affected by differences in roll-out schedules. For example if metering systems are deployed on a new and replacement basis only, that is when new and renovated buildings require meter installation and when existing meters need to be replaced[13], lifetime installation costs are relatively low. Accelerating the roll-out schedule increases the costs of installation due to an increase in the number of physical installations over a shorter period of time. The coordination of the roll-out has an impact on the magnitude of this cost increase. If the roll-out is coordinated by region, travel time between sites can be minimised; and if the roll-out is coordinated so that electricity and gas meters are installed simultaneously, the number of site visits can be reduced (Frontier Economics, 2007a).

*Communications and data systems* Difficulties in estimating cost differences between communications options have been cited as a source of uncertainty in a number of smart metering studies (e.g. Ofgem, 2006a; Frontier, 2007a). A detailed 2005 study in Victoria, Australia investigates some of the factors influencing the cost-effectiveness of communications technology choice (CRA, 2005); the study was followed by technology trials conducted on behalf of the Victorian government (DPI, 2007). The results of the study and trials indicate that customer density is a particularly important factor in determining technology choice. When customer density is low, in rural and remote areas, Power Line Carrier tends to be cost-effective even though the rates of data communication are slower relative to other solutions. Mesh radio, where meters are used as repeaters in a mesh configuration, is more suitable and cost-effective in areas of high customer density.

The likelihood of future upgrades to the communications network is another important factor. In the 2005 Victoria study, the costs of wireless networks was found to be prohibitively high because of the assumption that existing technology is expected to be replaced in the short to medium term. This would require meter and network upgrades, substantially adding to costs (CRA, 2005).

*Stranded assets* When an existing meter is replaced before replacement is required, the value inherent in the meter is lost as it is unlikely to be re-used elsewhere. The costs associated with stranding can be a significant barrier to roll-out; and in Great Britain this additional cost category falls on the supplier. The speed of any roll-out affects the extent of asset stranding; accelerating roll-out above the annual replacement rate increases stranded costs. The business case for smart metering from a supplier's perspective must incorporate these costs; based on the 2001 price control review for network operators in GB, the

[13]As an example, the replacement rate for electricity and gas meters in Great Britain is approximately 5% per annum (DTI, 2006, p. 21).

Carbon Trust derived prices for stranding of electricity meters as £15 and gas as £17 (Carbon Trust, 2007).

Investigating the case for smart metering from a country or regional perspective does not require inclusion of costs associated with the redundancy of the existing stock of traditional meters. As sunk costs, they are not relevant to the analysis of whether to proceed with a roll-out or not (NERA, 2008). The UK-wide analysis conducted by the Carbon Trust excludes these costs as they imply no net cost to the UK; they are, however, included in the sensitivity analysis and the overall effect is minimal (Carbon Trust, 2007).

The risk of stranded assets also applies to any new meters installed. Suppliers in the UK have often been reluctant to install smart meters due to the risk that they may become redundant or lose some of their value if a customer chooses to switch supplier. This risk can be reduced in a number of ways: Suppliers can enter into churn contracts with each other to guarantee continued use of the meter; they can offer customers longer supply contracts; and interoperability standards can be put in place, an area that Ofgem is currently addressing (Carbon Trust, 2007; Ofgem 2006b).

### *4.3. Benefits of smart metering*

The benefits of smart metering can be divided into two main categories: operational benefits and demand response (DR) benefits. As is the case when looking at the costs of meters and metering systems, the magnitude of benefits is influenced by a number of factors, including the level of functionality, deployment speed, coordination and behavioural change.

Table 15 gives an overview of various smart metering functions and the corresponding net benefit per meter from the recent national Australian study (NERA, 2007b). This time, the functions are divided by benefit category; study assumptions are briefly summarised. The assessment is based on identifying the additional benefit of adding each increment of functionality to the meter and subtracting the additional cost; this gives the net benefit per meter for each function listed. Where the additional cost outweighs the benefit, the net benefit is negative; the net benefit is positive when the additional benefit outweighs the cost.

Table 15: Net benefits by function for smart electricity metering in Australia

| Benefit category | Function | Net benefits p/meter (lower and upper) in Australian dollars (2007) | | Assumptions |
|---|---|---|---|---|
| Operational/ DR | Remote reading (daily) | -$4.51 | $15.88 | 1. DNO-led roll-out<br>2. 15-year evaluation period from 2014<br>3. 8% discount rate (6.5% and 9.5% for sensitivity testing)<br>4. 9.64 million domestic electricity customers |
| Operational | Export/import metering | $4.06 | $4.59 | |
| | Remote connect/disconnect | $7.09 | $15.59 | |
| | Supply capacity control | -$4.68 | -$2.44 | |
| | Interface to gas and water meters | -$29.12 | -$19.25 | |
| | Quality of supply recording | -$6.28 | $9.75 | |
| | Loss of supply and outage detection | $6.70 | $8.04 | |
| | Remote reconfiguration | $14.17 | $15.05 | |
| DR | Interface for other load control devices | -$24.24 | $57.89 | |
| | In-home display | -$73.51 | -$18.19 | |
| | Interface to HAN | -$44.59 | $75.92 | |

Note: £1 = $2.39 at annual average exchange rate for 2007 (Bank of England Statistics)
*Source:* NERA, 2007b

The range between lower and upper estimates of net benefits depends on assumptions made for each function. For instance, in the case of the interface to the HAN and load control devices, these functions could potentially contribute the highest net benefits per meter; however the additional benefits depend on assumed customer participation rates and corresponding demand response. Where these assumptions are more conservative, the additional costs of adding these interfaces could outweigh the benefits. The most convincing additions from this evidence are daily remote reading, export/import metering, remote connection/disconnection/configuration and loss of supply/outage detection.

*Operational benefits* The main operational benefits of increased functionality for network companies and suppliers are a result of the overall improvement in the efficiency of metering services. How these benefits are distributed depends on industry structure at the time of deployment. We will consider this in more detail in the next section. The avoided cost of meter reading is one of the most significant operational benefits and is facilitated by the remote reading function. Deployment speed has an impact on this and other operational benefits; in general, slower deployment can have an adverse effect on total benefits.

With meter reading costs a slower roll-out leads to a more costly metering transition period. For example, if roll-out is on a new and replacement basis, the gradually decreasing density of remaining traditional meters will result in a higher cost per meter read over a longer period of time. If the roll-out can be regionally coordinated, it may be possible to increase or keep constant the density of traditional meters; the costs of managing the traditional meter network may fall and the benefits of reduced meter reading costs can be maximised (Frontier Economics, 2007a).

On the other hand, there may be an option value associated with waiting to invest if investing now will result in lock-in to a particular type of inferior technology. We will discuss this in section 5 when we look more closely at a range of international cost benefit studies and the potential for innovation and future cost reductions.

Better outage detection, faster response times to outages, improved quality of supply recording and accurate billing also improve the efficiency of metering services. The main benefits to the network and supplier stem from the reduction in customer service costs due to a lower level of customer complaints. Non-technical loss reduction, losses due to theft for instance, can also be an important benefit. Its magnitude depends on country context; where electricity theft has been an important issue, the potential to reduce losses may be a strong driver for smart metering deployment.

The benefits of a more efficient service and a greater level of choice are ultimately passed on to the customer. Operationally, smart meters offer customers more choice in terms of payment options (e.g. easier switching between credit and prepayment to manage debt), improved consumption information, and they facilitate micro-generation. Whether the metering of electricity generated in the home is a benefit to the customer or the network depends on who was responsible for this metering prior to the roll-out of smart meters (NERA, 2008).

*Demand response benefits* Smart meters can influence customer demand in a number of ways: first, by facilitating direct load control of appliances; second, by facilitating the introduction of time-varying prices; and third, by providing additional consumption information either via the meter, external display or directly from the supplier. Direct load control and time-varying prices have the potential to shift consumption from peak to off-peak periods; and time-varying prices and information may lead to changes in average consumption levels.

Demand response impacts of smart metering depend on the tariffs offered by suppliers, the number of customers that avail of new tariffs and/or load control options, and the change in customer demand in response to new tariffs.  As we saw in Table 15, the net benefits of demand response functions are subject to a greater amount of uncertainty than the operational functions of smart metering. Much of this is due to the need for customer acceptance and behavioural change.

Changes in demand can have a number of benefits for networks, suppliers, the customer and society. Shifting consumption from peak to off-peak periods may defer the need for peak network investment; this shift may also defer investment in peak generating capacity. More cost-reflective pricing may also help suppliers to minimise their hedging costs, i.e. the premium over wholesale prices that suppliers typically incur to fix the price they pay for energy (KPMG, 2007). The impact on carbon emissions depends on whether there is an overall reduction in demand; it also depends on the carbon intensities of marginal plants during peak and off-peak periods (Frontier Economics, 2007a).

### *4.4. Market models*

There are two predominant metering market models in Europe: the regulated model and the liberalised model, although there are many variations between countries as we saw in section 2. The choice of market model has an impact on the way in which costs and benefits are distributed across the supply chain; this can have a significant influence on the decision of whether and how to implement smart metering. From a technology diffusion perspective, Zhang and Nuttall (2007) show that rolling out smart meters on a random and geographically dispersed basis and encouraging competition between suppliers in the metering market can be effective strategies. From a cost-benefit perspective, Frontier Economics (2007a) shows that there are significant cost savings from a co-ordinated roll-out, both on a geographic and dual-fuel basis.

In Great Britain and Australia, this debate has been central to smart metering policy. Cost benefit analyses that compare roll-out scenarios based on different metering market models have been undertaken in both countries to guide policymaking. BERR’s 2008 analysis (BERR, 2008b) compares two market models quantitatively: a mandated supplier-led rollout and a mandated regional franchise rollout. Frontier Economics (2007a) investigates the same market models with slightly different assumptions. Market model scenarios are also central to the recent national Australian smart metering study (NERA, 2008). Three scenarios are considered quantitatively: a distributor-led rollout; a supplier-led rollout; and a centralised communications system as part of a supplier-led rollout. Table 16 compares a selection of results from the three studies.

From Table 16 we can see that the choice of market model has an impact on total costs and final net present value. Both studies of GB anticipate lower total costs for similar rollout programmes when the responsibility for delivery of smart metering services lies with a regional franchisee. The franchisees would be selected through a tendering process; once selected they would purchase metering services via competitive tendering at the regional level. Both scenarios in the Frontier study result in an overall net benefit, although the size of the net benefit under the regional franchise model is just over 6 times that under the supplier-led model. Neither of the BERR scenarios results in a net benefit, although the size of the net cost is slightly less under the regional franchise model.

Table 16: Total smart metering costs and NPV by market model

| Market model | Technology | Rollout | Total costs | Final NPV |
|---|---|---|---|---|
| *BERR, 2008b* | | | | |
| Supplier-led | AMM (core functions): all domestic electricity and gas | 10-year: domestic and micro businesses | £13.4bn | £-1.3bn |
| Regional franchise | | 10-year: domestic and micro businesses | £12.7bn | £-1.0 |
| *Frontier Economics, 2007a* | | | | |
| Supplier-led | AMM (core plus advanced): 28 million electricity; 22 million gas | 10-year: domestic and small business | £6.7bn (incremental) | £546m |
| Regional franchise | | 7-year: domestic and small business | £6.1bn (incremental) | £3.5bn |
| *NERA, 2008* | | | | |
| Distributor-led | AMM (without HAN): 10 million electricity meters | 6-year: domestic | \$2.7bn to \$4.3bn (incremental) | \$179m to \$3.9bn |
| Supplier-led | | | \$3.6bn to \$6.0bn | \$-1.9bn to \$2.4bn |
| Centralised communications | | | \$3.3bn to \$5.6bn | \$-1.5bn to \$2.7bn |

Note: £1 = \$2.39 at annual average spot exchange rate for 2007 (Bank of England Statistics)

In the Australian study, there is a clear contrast between the regulated and liberalised models: the distributor-led rollout relies on the regulatory framework to provide incentives for least cost delivery; and the supplier-led rollout relies on competition between retailers to provide incentives for efficiency. The results indicate that total costs are lower and potential net benefits higher under the distributor-led scenario; when the communications system is provided by a centralised agency, costs are lower and potential net benefits higher than under the full supplier-led scenario. BERR considers the distributor-led rollout qualitatively in its 2008 assessment; a number of concerns are raised however surrounding restricted technology choice, innovation and efficiency. In addition, NERA concludes that all viable alternatives to a regulated model should be considered because of the limited information basis available for regulators to benchmark efficient costs for smart metering rollouts. The franchise model is suggested as a model that should be considered in more detail as it removes the need for regulatory review of technical infrastructure options (NERA, 2008).

As well as differences in costs and overall net benefits across market model scenarios, there are differences in how these costs are allocated due to changes in responsibilities. Table 17 compares the two extremes of a distributor-led (regulated) and supplier-led (liberalised) rollout according to the allocation of costs.

Under the distributor-led model, the DNO can recover some of the costs through regulated charges which are then passed on to the customer; when the model is supplier-led, costs are also ultimately passed on to the customer but in a competitive setting. Standards for meters, communications and data become even more crucial in a competitive environment. The risks of investing without having standards in place can be prohibitively high; the supplier cannot be sure that the investment will not become stranded, if, for example, a customer switches to another supplier who is not in a position to or does not agree to use the same technology (Wissner and Growitsch, 2007).

Table 17: Allocation of smart metering costs between market model scenarios

| | **Distributor** | **Supplier** | **Market operator** |
|---|---|---|---|
| **Distributor-led** | Meters<br><br>Meter data & communications management<br>Communications<br>Distributor systems | Supplier systems | Market meter & data transactions management |
| **Supplier-led** | Distributor systems | Meters<br><br>Meter data & communications management<br>Communications | Market meter & data transactions management |

*Source*: Adapted from NERA (2008)

Although one party incurs the majority of the costs in both distributor-led and supplier-led scenarios, there is a wide range of benefits for all market actors. Table 18 gives an overview of the main benefits for each actor regardless of the market model adopted.

Table 18: Allocation of benefits independent of market model scenario

| |
|---|
| **Customer/Society** |
| Bill savings from reducing and/or shifting consumption<br>Accurate billing: better customer service<br>Increased quality of service<br>Easier switching of supplier<br>Reduction in carbon emissions<br>Avoided investment in peak generation capacity |
| **Supplier** |
| Accurate information for billing purposes; fewer complaints<br>Reduction in unpaid bills |
| **Distribution** |
| Avoided peak investment<br>Reduced technical and non-technical (theft) losses |
| **Transmission** |
| Avoided peak investment |

Reduced meter reading costs are not included in the table. This important operational benefit of smart metering is allocated to the party responsible for meters and meter data and communications management; it therefore depends on the given market model.

## 5. International evidence on the costs and benefits of smart metering

There is rarely a straightforward answer to the question of whether the benefits of smart metering outweigh the costs or vice versa. This is not only due to differences in the types of available metering systems and functionality but also to context-specific deployment drivers and questions, market structure, and methodology in analysing the costs and benefits. In this section, we assess the cost-benefit analyses conducted internationally. We first present an overview of the results of a number of studies; we then turn our attention to some of the interesting details of these analyses in terms of the main categories of costs and benefits.

### 5.1. *International overview*

The outcomes of international smart metering studies depend on several factors; the institutional actors involved, the main objectives at the outset of the study, the methodology used and the structure of the metering market all have an impact on findings and subsequent policies. Table 19 gives an overview of some recent international cost-benefit analyses, including GB studies, according to these criteria.

The institutional actors involved and their degree of involvement has had an impact on the definition of objectives for the studies and as a result the methodology used. In all cases, the regulator and/or a relevant government department have been involved in either conducting or requesting studies to be conducted.

In California, the regulator requested AMI deployment plans from all investor-owned utilities in order to increase the level of demand response in the state; avoiding another electricity crisis and controlling peak consumption were the main policy aims. A more exploratory approach was undertaken in Great Britain, the Netherlands, Norway and in the national Australian study to identify the full range of costs and benefits and to assess any barriers to implementation. In France, the analysis focused on investigating technology options for flexible demand and in providing more information to consumers. The existing case for distribution companies to implement advanced metering solutions is investigated; the costs and benefits for suppliers and energy producers are also evaluated.

In Ontario by contrast, the government set a target for full implementation of smart metering in the province and requested the regulator to prepare an implementation plan to achieve this target. The methodology of the study was affected by this more prescriptive approach: it is assumed at the outset that smart metering will proceed and the focus is on the operational costs and benefits rather than on the wider range of benefits to the customer and economy. In Victoria, the analysis was also narrowly defined by the government to assess the case for mandating two-way communications as part of an interval meter roll-out that had previously been decided upon.

Table 19: Overview of international smart metering cost benefit analyses

| | **Institutional actors** | **Objectives** | **Methodology** | **Market structure** |
|---|---|---|---|---|
| **Great Britain:** Ofgem, 2006a (domestic | Ofgem (regulator) | Identify costs and benefits to inform policy direction | -Business case for supplier<br>-Social CBA: | Competitive metering market: supplier decides who to engage |

| | | | | |
|---|---|---|---|---|
| electricity and gas) | | | Supplier, network and customers | for installation and operation |
| **Great Britain:** BERR, 2008b (domestic electricity and gas) | BERR (government department) | Assess the case for government intervention in encouraging smart meter roll-out | -Social CBA: Consumer, supplier, other | As above; regional franchise model assessed as alternative policy option |
| **France:** Capgemini, 2007 (electricity and gas) | Commission for the Regulation of Energy (regulator) | Assess range of meter technologies for more flexible demand and improved information | -Business case for DSO<br>-Producer, Distribution, Supply analysis | Regulated metering market: DSO responsible for all services |
| **Netherlands**: SenterNovem, 2005 (domestic electricity and gas) | Ministry of the Economy | Assess how costs and benefits differ across actors; understand how implementation process should develop | -Social CBA: Households, metering companies, grid operators, suppliers, producers, national authorities/environment | Competition in meter provision and meter services (at time of CBA): customer decides who to engage for installation and operation |
| **Norway:** Econ, 2007 | Norwegian Water Resources and Energy Directorate (regulator; part of Ministry of Petroleum & Energy) | Decide whether to set a target date for implementation or offer economic incentives | -Social CBA: Suppliers, generators, measurement/balancing, consumers, network firms | Regulated metering market: DNO responsible for all services |
| **Ontario:** OEB, 2005 (domestic electricity) | Government and Ontario Energy Board (regulator) | Strategy for achieving government target of full smart meter implementation | -Overview of costs and benefits<br>-Only operational benefits of meter reading quantified | Regulated metering market: DNO responsible for all services |
| **Victoria:** CRA, 2005 (electricity) | Department of Infrastructure – Energy and Security Division | Decide if two-way communications should be mandated as part of meter roll-out | - Analysis of incremental costs and benefits of adding communications to interval meters<br>- Supplier/network benefits quantified only | DNO responsible for roll-out of meters; Retailer responsible for meter service and data provision |
| **Australia:** NERA, 2008: Overview Report | Ministerial Council on Energy | Phase I: Incremental assessment of functionalities<br>Phase II: Cost benefit analysis of roll-out by jurisdiction | In-depth studies of:<br>-Consumer Impacts<br>-Retailer Impacts<br>-Network Impacts<br>-Economic Impacts<br>-Allocation of costs | Metering arrangements for smaller customers regulated at state level;<br>DNO or retailer responsible for metering – mainly DNOs for purchase and installation |
| **California:** PG&E, 2005 (electricity and | California Public Utilities Commission | Cost-effective deployment plan for greater demand | -Utility business case analysis | Integrated utility (retail and T&D) |

| | | | | |
|---|---|---|---|---|
| gas) | | response | | |
| **California:**<br>SCE, 2005<br>SCE, 2007<br>(electricity) | California Public Utilities Commission | Cost-effective deployment plan for greater demand response | -Utility business case analysis | Integrated utility (retail and T&D) |

Where market structure is concerned, methodology is affected by the need to focus on the actor responsible for making investment decisions. For example, in the French analysis the business case for distribution companies is central, whereas in Great Britain the focus is on the supplier business case. Table 20 presents some of the main findings and conclusions for the same studies. For many of the studies, the benefits of smart metering outweigh the costs only when the analysis is extended to include wider benefits, particularly those to the customer. The Dutch study, for example, finds that there is a net gain for society as a whole which is strongly underpinned by significant benefits to households. The costs for all other actors in the market, however, outweigh the benefits. This raises the question of how much consumers would be willing to pay for these benefits; this is an area that requires further study.

Table 20: Findings of international smart metering cost benefit analyses

| | **Main findings** | **Conclusions** |
|---|---|---|
| **Great Britain:**<br>Ofgem, 2006a<br>(domestic electricity and gas) | -Business case not positive for a simple or sophisticated meter<br>-Sophisticated meter gives net benefit under customer CBA (load and peak demand reductions) | Competition in metering is the best way forward; more work on removing barriers and forming standards required. |
| **Great Britain:**<br>BERR, 2008b<br>(domestic electricity and gas) | -Mandated 10-year AMR roll-out only smart meter option with positive NPV (central assumptions)<br>-Highest annual cost per meter under mandated 10-year AMM roll-out with regional franchise model | Further work is necessary to refine the impact assessment, particularly re: treatment of risk, market structures, technology functionality and communications. |
| **France:**<br>Capgemini, 2007<br>(electricity and gas) | -Negative net benefit for all scenarios for DSO<br>-Positive net benefit for more advanced systems looking at entire value chain from generation to supply | For customer and in terms of overall benefits, most advanced technology scenario is best; regulator expected to publish requirements for AMM soon. |
| **Netherlands**:<br>SenterNovem, 2005<br>(domestic electricity and gas) | -Positive net benefit for society as a whole<br>-Household benefits significantly outweigh costs<br>-Costs for all other actors outweigh benefits | Large-scale implementation will not happen without government intervention |
| **Norway:**<br>Econ, 2007 | -Negative net annual benefit (approx. 120NOK per meter)*; | Network firms biggest beneficiaries followed by customers; best to set a deadline for installation |
| **Ontario:**<br>OEB, 2005<br>(domestic electricity) | -Incremental monthly cost of $3-4 per meter for residential customers** | Phased deployment recommended starting with customers with peak demand > 200kW |

| | | |
|---|---|---|
| **Victoria:**<br>CRA, 2005<br>(electricity) | -Net benefit for accelerated roll-out positive except when wireless communications used<br>-Net benefit negative for slower roll-out with small customers on new and replacement basis only | Accelerated roll-out with advanced communications recommended |
| **Australia:**<br>NERA, 2008:<br>Overview Report | -Positive net benefit for distributor-led roll-out under minimum and maximum estimates<br>-Negative net benefit for retailer-led roll-out under minimum estimates; and positive for maximum | Results appear to indicate national roll-out could be justified on avoided meter costs and business efficiencies alone; MCE to develop recommendations on the basis of the study |
| **California:**<br>PG&E, 2005<br>(electricity and gas) | -Operational and demand response benefits outweigh costs | Proceed with deployment; application approved July 2006 for 5.1 million electric meters and 4.2 million gas – upgrade application filed December 2007 |
| **California:**<br>SCE, 2005<br>SCE, 2007<br>(electricity) | -2005 analysis: technology not sophisticated enough to proceed<br>-2007 analysis: open architecture system developed: benefits outweigh costs | Deployment of open architecture system compatible with different communications channels and interface with home area network; application filed July 2007 and waiting approval (as of August 2008) for 5.3 million electric meters |

*£1 = 11.7 NOK at annual average spot exchange rate 2007 ** £1 = $2.2 at annual average spot exchange rate 2005 (Bank of England Statistics).

A similar conclusion was drawn in the French analysis looking at the entire value chain from generation to supply and in Ofgem's analysis for Great Britain at the difference between the business case for the supplier and the social cost benefit analysis. These findings suggest that there may be a market failure due to split incentives for investment in smart metering. Where the benefits to the customer and in some cases to the networks are not incorporated into the decision of whether or not to invest, some type of intervention in the market or further work to remove barriers may be necessary. This may also suggest that DNOs should be responsible for collecting finance for smart meters through regulated charges.

Changes in technology and cost reductions are constantly occurring in the metering industry and even within the same region this has led to marked differences in approaches. In California, for example, the paths of PG&E and SCE diverged from the outset: in 2006 the CPUC authorised funding of $1.74 billion for PG&E to proceed with its deployment plan even though technological barriers, i.e. the lack of an open architecture solution, persisted; SCE delayed deployment choosing instead to develop an open and interoperable solution. SCE filed its final application in July 2007 and is awaiting approval for $1.72 billion Even since the 2005 analysis, PG&E's deployment plans have been updated to allow for a more advanced system with remote connection/disconnection, remote upgradability and an interface with the HAN; approval for this upgrade (and a further $623 million) is pending (Roberts, 2008). The CPUC has directed PG&E to continue to monitor the evolution of the technology and to consider further upgrades to its programme in due course.

### *5.2. International analysis: Smart metering costs*

In this and the following section we will build on the discussion of costs and benefits from Section 4 to investigate the differences across international studies. In table 21, we have selected a number of cost benefit analyses to compare according to the shares of three main cost categories as a percentage of the present value of total costs. Some of the analyses surveyed for this paper could not be included due to the lack of details on the breakdown of costs. There are, however, interesting results from other studies that will be discussed in a more qualitative manner later in the section.

Some of the studies (both GB and Victoria) assess in detail the effects of adjusting the parameters in the analysis, for example the technology of the meter, the type of roll-out, or the communications system. Where multiple scenarios are conducted, the description and the results of the alternative scenario are in parentheses. Comparing the annual per meter costs across studies requires some caution: the studies are not directly comparable because of a range of differing assumptions, including discount rates and the length of time used to compute present value cost streams. Furthermore, where both electricity and gas meters are installed, per meter costs differ by utility.

Table 21: Meter, meter installation and communications costs as a percentage of total cost

| **Assumptions** | **Total incremental cost (PV)** | **Meters** | **Meter Installati on** | **Communications system (capital, installation & management)** |
|---|---|---|---|---|
| **Great Britain**<br>(Ofgem 2006a)<br>-electricity only<br>AMM: core plus display<br>-(AMR)<br>-business case: 20-year evaluation; 10% cost of capital<br>-instantaneous roll-out<br>-28 million meters | £7515m - £13.42 per electricity meter p.a.<br>(£4110m - £7.34 per electricity meter p.a.) | 58% (44%) | 12% (16%) | 18% (16%) |
| **Great Britain**<br>(Frontier 2007a)<br>-gas & electricity<br>-AMM: core plus display, remote connection/switching, import/export | £4663m - £4.66 per meter p.a.*<br>(2: £6738m - £6.724 per meter p.a.) | 47%<br>(2: 41%)<br>(3: 44%) | 1%<br>(2: 3%)<br>(3: 1%) | 30%<br>(2: 33%)<br>(3: 24%) |

| | | | | |
|---|---|---|---|---|
| metering<br>-Current industry structure<br>-Replacement schedule<br>-(2: 10-year roll-out)<br>-(3: 7-year roll-out with restructuring so that one party responsible for metering services regionally)<br>-Social CBA: 3.5% discount rate; additional cost of capital included at 10% cost of capital<br>-20-year evaluation<br>-GSM<br>-28 million electricity meters; 22 million gas meters | (3: £6109m - £6.10 per meter p.a.) | | | |
| **Netherlands**<br>(SenterNovem, 2005)<br>-gas & electricity<br>-AMM: core plus remote connection and load limiting<br>-10-year roll-out<br>-Social CBA: 30-year evaluation; 7% negotiable interest<br>- 40% PLC; 40% internet; 20% GSM<br>-6.7 million households | €2003 - €10 per household p.a.* | 40% | | 38% |
| **Victoria, Australia**<br>(CRA, 2005)<br>-electricity only<br>-AMM: core plus remote connection<br>-relative to roll-out of interval meters w/o communications<br>-4-year roll-out<br>-PLC (mesh radio)<br>-6.5% discount rate<br>-18-year evaluation<br>-2.4 million meters | $371m - $8.60 per electricity meter p.a.<br>($406m – $9.40 per electricity meter p.a.) | 59% (53%) | 19% (18%) | 20% (26%) |
| **California, US**<br>(PG&E 2005)<br>-gas & electricity<br>-AMM: core<br>-5-year roll-out<br>-evaluation: 17 years at 7.4% discount rate<br>-PLC for electric meters<br>-5.1 million electric<br>-4.2 million gas | $2258m - $14.28 per meter p.a.* | 36% | 16% | 21% |

*These per meter per annum figures are averaged over the total number of gas and electricity meters although meter costs and installation vary by type of meter

*Meters* The most significant share of total project costs across studies is the purchase of new meters. From Ofgem's 2006 study, we see that decreasing the level of functionality of the meter (from an AMM to an AMR-capable meter) decreases this share from 58 to 44%, i.e. almost a 25% reduction; there will, however, be a parallel reduction in the benefits derived from the smart meter. The lowest percentage share for meter costs is 36% in PG&E's analysis. Costs for this analysis are based on retrofitting just over half of the electricity meters and 96% of the gas meters; PG&E has since altered its initial strategy because of the restricted functionality of its original system proposal. The Dutch study has the lowest cost per meter per annum; however this is based on a 30-year period of evaluation (the longest of all studies in the table) and meter functionality is not as advanced as the Frontier study.

*Meter installation* The Frontier study of GB illustrates the effect of both deployment speed and industry structure on installation costs. When meters are deployed on a replacement basis, installation costs are just 1% of total costs; when the speed increases to a 10-year schedule, costs rise to 3%. Installation costs in the Ofgem analysis, where roll-out is assumed to be instantaneous, are 12% of total costs; and in Victoria they are almost a fifth of total costs based on a 4-year roll-out.

Industry structure has an impact on installation costs in the Frontier study for two reasons: First, when the roll-out is coordinated on a geographic basis with one party responsible for metering services (scenario 3), travel time between installation sites can be minimised; and second a coordinated geographic roll-out facilitates the simultaneous installation of gas and electricity meters. PG&E in California benefits from both of these factors because it supplies both gas and electricity in a defined region.

*Communications system* Uncertainty is a unifying characteristic in international analyses of the costs of communications systems. The Victorian study is one of the most detailed in looking at differences in communications costs. The first scenario assesses the costs and benefits of using existing Power Line Carrier (PLC) technology; the communications system amounts to 20% of total costs. In the second scenario, mesh radio is used and the share of total costs is slightly higher at 26%.

The Frontier analysis focuses exclusively on GSM due to the lack of available information on other systems. Ofgem does not choose a particular communications solution to assess, citing limited information and wide cost ranges as the main barriers. Of the studies in Table 21, Ofgem's analysis has the lowest share for communications; there are, however, factors other than uncertainty at work. The main scenario in the Dutch analysis includes 3 different communications solutions that are simultaneously adopted; and the share of communications costs is more than double the Ofgem share. This may offer a more realistic basis to study communications costs as it does not assume one solution for all customers. When the effects of moving to PLC (Power Line Carrier)-only and internet-only solutions are explored, however, the size of the net benefit in the same study increases by 25% (from €1.2 to 1.5 billion) and 33% (from €1.2 to 1.6 billion) respectively. A GSM-only solution by contrast reduces the net benefit by 100% (from €1.2 billion to 0) as full nationwide coverage is lacking.

Changes in overall benefit/cost ratios depend on country and regional geographic context, particularly in relation to customer density. In lower density areas, PLC tends to be a cost-effective solution but slower relative data communication rates may be a barrier to widespread implementation (CRA, 2005). Widespread internet-based solutions may offer additional positive externalities in terms of increasing the level of internet access penetration as a by-product of deploying smart metering. In Germany, a number of suppliers are investigating the potential for internet-based solutions, for example Yello in partnership with Microsoft.

*Further evidence on costs from France and Great Britain* In the French smart metering study (Capgemini, 2007), the costs are not broken down according to the same level of detail as the studies in Table 21. Nevertheless, there are a number of lessons in terms of the effects of technology differences and deployment speeds on costs. Three technology scenarios are considered in the study; their main features are outlined in Table 22. All three scenarios have different levels of AMM and are differentiated by the resolution of the data retrieved from the meters, frequency of meter readings and the facility for communication with other meters and devices. The scenarios have the following functions in common: remote connection/disconnection; change of tariffs; power limitation; and the facility for the meter to communicate with appliances (heating, washing machine, etc.).

Table 22: Technology scenarios from the French cost benefit analysis

| | **Reading** | **Other** |
|---|---|---|
| Scenario A | -Once monthly and on demand | |
| Scenario B | -Half-hourly data<br>-Once monthly and on demand | -Prepayment option through computer or call centre<br>-External display optional<br>-Data available to customer in week following reading |
| Scenario | -5- or 10-minute interval data | -Interfaces for gas and water meters |

| | | |
|---|---|---|
| C | -Reading once a week and once a day if service depends on it | -Data available electronically to customer the day after reading |

*Source:* Capgemini, 2007

Between the three scenarios, differences in overall costs are as follows: a 7% increase from scenario A to B; and an 8% increase from scenario B to C. These cost differences are described as weak in the report and are contrasted with the cost differences that occur when deployment speeds are varied. Deploying the project in 10 years rather than 5 years reduces overall costs by approximately 14% (across scenarios). This reduction is due to the cost advantages for distribution companies from lower installation and lower stranded costs.

The Carbon Trust 2007 study investigates the costs and benefits of smart metering for SMEs in GB; it gives some useful insights into the potential for future cost reductions. Table 23 gives an overview of meter and related service costs under both current and future cost scenarios. The study concludes that under current costs, there is a net benefit only for high volume SME customers; under the future cost scenario, there is a net benefit for both electricity and gas smart metering for all SME users.

Table 23: Current versus future smart metering costs for SMEs

| **Component** | **Costing scenario** | |
|---|---|---|
| *Meter costs* | Current (£) | Future (£) |
| Site survey | 218 | 44 |
| Meter (inc. installation) | 343 | 120 |
| Total | 561 | 164 |
| *Service costs* | Current single/multi sites (£/year) | Future (£/year) |
| Data only | 242/120 | 20 |
| Data and advice | 522/176 | 70 |
| Personal contact | 936/507 | N/A |

*Source:* Carbon Trust (2007)

Comparisons can be drawn between the lower end of the SME market and the household market for smart metering; the main common characteristic being that both markets have a large number of single sites. These are more costly for energy suppliers to serve and with insufficient financial incentives for suppliers, the market is likely to develop slowly, in a very fragmented way and with limited economies of scale (Carbon Trust, 2007).

Economies of scale and service innovations are the main factors that drive the future capital and service cost reductions studied by the Carbon Trust. Service innovations are driven by increasing competition and the entry of larger players to the market. The Carbon Trust estimates that the cost reductions in Table 23 could be realistically achieved by 2012 if there are clear market signals and a defined time frame (Carbon Trust, 2007). Innovation in smart home services and smart appliances could increase the potential for demand response; quantifying these benefits before the technology options are fully developed is inherently difficult (BERR, 2008b).

Experience in California has shown that there may be an option value associated with waiting to invest if investing now will result in the deployment of and even lock-in to an inferior technology. If the metering system is open rather than proprietary, however, future development within the same system is possible. Interoperability has been driving innovation in recent years and has characterised the divergence in paths between PG&E and SCE in California.

*Stranded assets* The costs of potential stranding have been included explicitly in a number of business case analyses of smart metering. Table 24 compares stranded costs per meter per annum and as a percentage of total costs for Ofgem's 2006 study of Great Britain and Capgemini's study of France.

Table 24: Stranded costs of metering

| | **Stranding per meter p.a.** | **% of costs** |
|---|---|---|
| Ofgem, 2006<br>-instantaneous roll-out<br>-20-year analysis<br>-10% cost of capital | £1.76 electricity | 12% of supplier costs (AMM credit) |
| | £1.95 gas | 13% of supplier costs (AMM credit) |
| Capgemini, 2007<br>-5.25% real discount rate<br>-33.4 million electricity and gas meters | €0.91** (5-year roll-out based on €586m total costs over 20 years) | Basic AMM*: 11%<br>Advanced AMM: 9%<br>(of DNO's costs) |
| | €0.44 (10-year roll-out based on €355m total costs over 25 years) | Basic AMM: 8%<br>Advanced AMM*: 7%<br>(of DNO's costs) |

Notes: *Basic AMM refers to Scenario 1 of the study, i.e. AMM with core functions and display; Advanced refers to Scenario 3, i.e. AMM with advanced functions. For more details see Table 11.
** £1 = €1.46 at annual average spot exchange rate for 2007 (Bank of England Statistics).

A longer roll-out lowers stranded costs per meter and as a percentage of total costs. In addition, when the metering system is more advanced, stranded costs constitute a smaller share of overall metering costs.

### *5.3. International analysis: Operational benefits of smart metering*

Comparing benefits across international studies is not as straightforward as comparing the costs, mainly due to differences in approaches to their classification and in some cases a lack of quantified benefits. In this section, we compare operational benefits across a number of studies. First we look at the benefits to suppliers and networks; and then we discuss the economic and customer benefits of improved operational efficiency and service quality.

### *5.3.1. Suppliers and network operational benefits*

*Meter reading* Reducing the costs of meter reading tends to be the largest operational benefit of smart metering; it is consequently a major driver in considering a smart meter roll-out. In Table 25, the reduction in meter reading costs as a percentage of total benefits to the supplier and the network (and metering companies in the case of the Netherlands) are shown for a number of international studies. Some of the studies (Ofgem, Victoria) subdivide the benefits into savings from regular manual readings and savings from special reads, e.g. final meter readings when a customer moves house. In order to compare across studies, meter reading costs in the table include both categories. Assumptions are the same as those presented in Table 21; alternative scenarios are in parentheses.

Table 25: Reduction in meter reading costs as a % of total supplier/network benefits

| **Study** | **Supplier/network benefits (PV)** | **Reduction in meter reading costs** |
|---|---|---|
| PG&E, 2005 | \$2362m - \$14.94/meter p.a. | 46% |
| Frontier, 2007a:<br>Scenario 2<br>(Scenario 3) | £3286m – £3.29/meter p.a.<br>(£5132m - £5.13/meter p.a.) | 47%<br>(39%) |
| Ofgem, 2006:<br>AMM<br>(AMR) | £6.21/ electricity meter p.a.<br>(£2.81/meter p.a.) | 19%<br>(42%) |
| CRA, 2005 – Victoria:<br>PLC scenario | \$433m - \$10.02/electricity meter p.a. | 80% |
| Ontario, 2005 | \$4.69/electricity meter p.a.* | 92% |
| Netherlands, 2005 | €1160m - €5.77/household p.a. | 26% |

*This figure does not include demand response benefits as they are not quantified in the study.

Note: £1 = $2.39 Australian; £1 = $1.82 US; £1 = $2.2 Canadian; £1 = €1.46 at annual average spot exchange rates for 2005 (Bank of England Statistics).

Some of the variation in the table is accounted for by differences in the number of benefit categories quantified. In the case of Ontario for example, where reduced meter reading costs account for 92% of supplier/network benefits, no demand response benefits are quantified; in fact, the only other benefit included is the savings from eliminating estimated reads. Many of the other operational benefits to the network are not considered quantitatively, although they are mentioned in the accompanying discussion. The same is true for Victoria where a lack of information from stakeholders is cited as the main reason for the narrow range of benefits quantified.

In the Dutch study, benefits to metering companies and a wider range of quantified benefits are included, for example reductions in customer service costs and faster detection of fraud. The same is true for the two Frontier scenarios. Ofgem's analysis also includes a wider range of operational and demand response benefits; even compared with the Frontier and the Dutch studies, however, the share of reduction in meter reading costs is low. One of the assumptions of the study in particular affects this share: that the requirement for a two-yearly physical inspection of meters remains in place. This may reduce the overall benefits to suppliers in Great Britain of remote meter reading compared with other countries. It is a barrier that has been recognised by Ofgem; and although the requirement will remain in place for the time being, suppliers can request a derogation if they can demonstrate that customers will be better off and safety not compromised (Ofgem, 2007). When meter technology is more advanced (AMM versus AMR), the share of reduced meter reading costs is lower due to the increase in the size of other operational and demand response benefits.

*Customer service* Improving the accuracy of bills reduces the frequency of customer complaints and the costs of re-issuing bills in response to queries. Reductions in activity at customer service call centres have been used in a number of studies to quantify the benefits to the supplier or utility. Billing benefits due to savings in re-issuing bills and the reduced costs of switching customers from credit to prepayment metering are the other main categories. Table 26 summarises the shares of lower customer service costs for three studies. Information on the categories included is also listed as the definitions of customer service costs vary across studies. The respective shares of all three studies give an idea of how the various components add up and contribute to total supplier/network benefits.

Table 26: Lower customer service costs as % of total supplier/network benefits

| Study | Lower customer service costs | Categories included |
|---|---|---|
| PG&E, 2005 | 2% (11%) | Reduced customer contact (plus billing benefits) |
| Ofgem, 2006a (AMM) | 18% (28%) | Reduced customer contact and billing benefits; (plus lower debt management) |
| Frontier, 2007a (10-year roll-out) | 44% | Call centre savings; billing benefits; lower debt management |

In the PG&E study a 2% share is attributed to the direct benefits of reduced customer contact and a further 11% to the billing benefits derived from an end to estimated bills. In the Ofgem analysis, these two benefit categories together account for 18% of total supplier and network benefits; lower debt management costs, i.e. switching customers from credit to prepayment and vice versa, account for a further 10%. In the Frontier study the same three categories account for 44% of total supplier/network benefits.

*Losses and outage detection* Other operational benefits include reductions in technical and non-technical losses and faster detection of and response time to outages. In Table 27, the main assumptions for each of these categories are summarised for a number of recent studies. Reduced technical losses may result from having a more complete demand profile for any given node on the electricity and gas networks (Frontier Economics, 2007a; Ofgem, 2006a). Although many studies have recognised technical loss reduction as a potential network benefit, Ofgem's analysis is the only one to quantify this reduction. SCE in California decided that the amount of losses incurred by the pre-existing customer load profile system was not significant enough to warrant further study its potential.

Reducing non-technical losses, i.e. from energy theft, have not been quantified in all studies. In the Australian national study, CRA's work on the network benefits of smart metering identifies theft reduction as a network benefit but does not quantify it due to a lack of information. SCE on the other hand discusses the potential for reduced theft as a societal benefit and does not include it in its financial analysis. Society benefits from a reduction in energy theft because it is a cost that is borne by all consumers; any reduction will allow SCE to spread its revenue requirement over more energy sales, thus reducing rates (SCE, 2007). BERR's assumption of a 10% reduction considers only the marginal savings that will be passed on to society; Ofgem assumes a 25% reduction and considers the benefits to suppliers of recouping costs from customers.

Improved response to outages has been measured in two main ways: Ofgem and CRA use the reduction in minutes off supply or customer minutes lost (CML) to estimate its potential impact; SCE estimates the reduction in field visits due to improved accuracy in identifying and verifying outages.

Table 27: Technical losses, theft and improved response to outages

| Study | Technical loss reduction | Theft reduction | Improved response to outages |
|---|---|---|---|
| | £ per meter per year | | |
| Ofgem, 2006a | 1% loss reduction: DNO benefit per meter £0.08 elec. £0.03 gas | 25% reduction: £0.61 elec. credit £0.27 gas prepay | 10% reduction in CML: £0.05 elec. |
| BERR, 2008b (AMR) | Recognised as potential network benefit; n.q. | 10% reduction: £0.20 | Recognised as potential network benefits; n.q. |
| BERR, 2008b (AMM) | n.q. | £0.20 | Recognised as potential network benefits; n.q. |
| SCE, 2005 and 2007 | n.q.; amount of losses not significant enough to warrant further investigation | Societal benefit; n.q. | Reduced field visits due to accuracy in verifying outages through meters; 2% of operational benefits |
| CRA, 2008 (Australia) | Recognised as potential network benefit; n.q. | Recognised as potential network benefit; n.q. | Reduction in minutes off supply of between 3% and 7.5% |

Note: n.q.: not quantified

### *5.3.2. Economic and customer operational benefits*

Increasing the operational efficiency of metering and reducing costs for suppliers, metering companies and the networks ultimately leads to savings being passed on to the customer. Where metering charges are regulated as part of the electricity networks, this happens through the actions of the regulator. Where metering charges are determined in a competitive market, competition between suppliers and/or metering companies improves outcomes for customers.

In addition to cost savings from operational benefits, there are dynamic benefits for customers and the economy as a whole. Remote reading and remote disconnection/connection of meters may facilitate supplier switching and improve the level of competition in energy supply. In the Dutch study, easier supplier switching in electricity constitutes 23% of total benefits to households due to the improved level of choice and the assumed decrease in the price of electricity (Senternovem, 2005). BERR’s 2008 study assumes savings of £100m per year due to a smoother supplier switching process (BERR, 2008b).

The organisation of the metering market has an impact on the magnitude of dynamic benefits particularly in the long-run. Where metering competition exists, there is a tendency for smart metering implementation to occur slowly and in a more fragmented manner. However, once the barriers to competition have been adequately dealt with (for example data standards and access to metering data by third parties); the level of choice and innovation in retailer and complementary services encouraged by competition in the metering market may lead to more efficient long-run outcomes (Carbon Trust, 2007). Competition may allow for a broader range of metering technologies and solutions to develop in contrast to a situation in which market actors or policy makers attempt to pick a winner early in the technology's development.

Smart meters may reduce barriers to microgeneration if the import/export metering function is included; this would remove the cost to customers of installing additional metering equipment to link the microgeneration units to the grid. BERR's 2008 study estimates these savings as a few pence per meter per annum but considers more work necessary in this area (BERR, 2008b). The national study conducted in Australia concludes that the cost of installing an additional meter relative to the cost of the microgeneration unit itself is small; and as a result it is unlikely to act as a major barrier to adoption (NERA, 2008).

Tackling fuel poverty in Great Britain is high on the government's agenda given that fuel prices are expected to increase in the future. Reducing the costs of prepayment technology and giving customers the choice to switch between credit and prepayment metering is a benefit that may be particularly valuable to those on lower incomes. The benefits from giving all customers more control over their consumption and consequently their fuel budgets are difficult to quantify; giving this control particularly in the context of fuel poverty is an important social target. It is important that safeguards are in place to ensure that new functionality protects customers, e.g. fair terms for switching customers from credit to prepayment (Owen and Ward, 2007) and protection against self-disconnection (Owen and Ward, 2006).

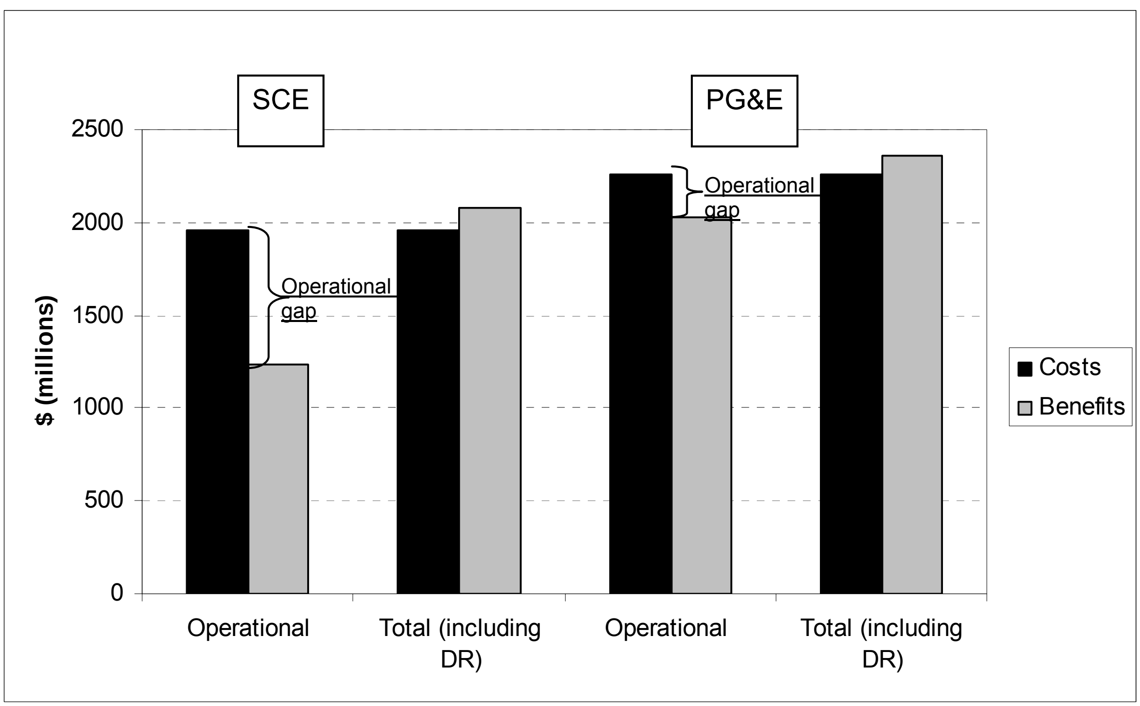
### *5.4. International analysis: Demand response benefits of smart metering*

Demand response benefits are more uncertain than operational benefits; however their analysis has the potential to make or break the case for smart metering. The impacts of peak shifting and reductions in overall energy consumption have implications for all market actors and act as drivers for smart metering in different ways across countries. To illustrate this, we present a brief case study of California; we then consider how the wider economic and customer benefits of demand response have been analysed.

*California case study: Demand response and the utility business case* In California, the initial drive for smart metering came from the regulator but the methodology for decision-making has since been driven by the business case analyses of the three major utilities. For both PG&E and SCE in California, when the benefits of demand response to the network are not included in the analysis, there is an "operational gap", i.e. a gap between total costs and total operational benefits. With demand response benefits, total benefits outweigh total costs as can be seen from Figure 6.

PG&E's operational gap decreased from $1.2 billion (in earlier analyses) to $409 million (in the 2005 analysis featured in figure 6); this means that a larger proportion of the project costs can now be covered by operational benefits to the utility. This is mainly due to implementation cost reductions. As the operational business case improves, "the importance of debating the precise value of key drivers of demand response, such as participation rates, elasticities, and the value of capacity has diminished" (PG&E, 2005, p. 40).

Figure 5: Operational gaps and demand response: SCE and PG&E, California




*Source:* SCE (2007), CPUC (2006)

Demand response benefits from changes in customer demand are driven by automated load control, time-varying prices and improved information. Changes in behaviour may result in reductions in overall energy consumption and/or shifting of consumption from peak to off-peak times.

For an integrated utility, the main impacts of these changes are three-fold:

- System reliability benefits:
  With increased flexibility in dispatching and reducing load from more price-responsive demand, the effective capacity margin can be increased and the loss of load probability reduced (PG&E, 2005).

- Avoided or deferred improvements to transmission and distribution networks:
  Peak load investment in the networks can be avoided or deferred due to shifts in peak consumption.

- Reduced costs of procuring energy:
  If customers use less electricity and/or shift consumption from a more expensive to a less expensive period, the costs of procuring energy for customers is reduced. This saving could be passed through to customers in lower charges if accounted for by the regulator (CPUC) as an adjustment in revenue requirement.

Identifying the magnitude of these benefits requires: (i) estimating how responsive demand will be to different forms of pricing, information and load control; and (ii) calculating the value of the response.

PG&E and SCE based their analyses on a pricing pilot conducted in California in 2003/2004. All three California utilities took part in the pilot and it is one of the most extensive of its kind conducted internationally. 2,500 residential and small business customers were involved; residential customers were placed on a time-of-use (TOU) pricing scheme with a two-part tariff (peak and off-peak prices) for most of the year. On up to 15 days during the year, a critical peak could be announced one day in advance where peak period prices were on average 3 times the TOU peak price and 6 times the off-peak price.

Sampling was stratified by building type and climate zone; within each stratum potential participants were randomly selected and contacted with enrolment packages promising a participation incentive payment of $175 over the course of the pilot. About 20% of those contacted accepted the invitation and the final sample was representative as a cross-section of California residents by appliance holdings, income, education and a selection of other variables (Herter et al., 2006).

Some residential and small business customers were placed on a slightly different pricing programme where advance notification of the critical peak could be as short as four hours. Commercial participants were offered a smart thermostat free of charge to automate demand response during critical peak periods. The residential participants, 122 in total, were chosen from a large thermostat load-control program in SDG&E’s service territory because they already had smart thermostats installed. The thermostat would automatically adjust the air conditioning setting when critical peak prices were in effect; customers could override the change if they wished (CRA, 2006).

Among the most important findings for the utilities were: (i) the response of customers in hotter climate zones, with higher levels of central air conditioning, was more than double the response in other areas; (ii) information only did not result in sustainable demand response during critical peak times; and (iii) not all customers (only 30%) accepted an enabling technology (the smart thermostat) even though it was offered free of charge (George and Faruqui, 2005).

In terms of the magnitude of customer price response, a selection of key findings are summarised in Table 28. Average prices were about 10 cents/kWh off-peak, 20 cents/kWh at peak times, and 60 cents/kWh during critical peak hours. The differences in response according to end-use patterns (presence of air-conditioning in particular) and income level would suggest that it may be more effective for utilities to target certain segments of their customer base first in order to maximise demand response benefits. Overall in the California pilot, 30% of the customers provided 80% of the demand response.

The average residential response during 2-hour critical peak periods for customers with smart thermostats ranged from load reductions of 13% to 41%. All participants in this group were high-use (>600kWh per month) single-family homes with air conditioning (Herter et al., 2006).

Table 28: Results of the California Pricing Pilot 2003/2004

| **Customer group (residential)** | **Critical peak load reduction** | **Conservation effect** |
|---|---|---|
| Average | 13% | No change in total energy use observed based on average pilot prices |
| Central A/C | 17% | |
| No central A/C | 8% | |
| Average annual income: $100,000 | 17% | |
| Average annual income: $40,000 | 11% | |
| Average daily use: 200% of average | 15% | |
| Average daily use: 50% of average | 12% | |

*Source:* George and Faruqui (2005)

*Demand response: economic and customer benefits* The economic and customer impacts of demand response facilitated by smart metering are typically more difficult to quantify. Analyses in Great Britain and particularly Australia have been the most detailed in their treatment of the potential economic impacts of both energy conservation and peak shifting. In Great Britain, the demand response benefits are valued in particular for their potential contribution to carbon emissions reductions, overall energy efficiency and tackling fuel poverty. Frontier Economics (2007a) calculates the value of demand response benefits for Great Britain according to three main categories: (i) energy savings; (ii) carbon savings; and (iii) avoided peak network capacity.

All three categories are affected by both lower levels of demand and shifts in demand from peak to off-peak hours. The benefits to the network were discussed in the previous section; energy and carbon savings from the Frontier study are summarised in Table 18. Energy savings from both lower demand and load shifting account for the largest share of demand response benefits across the three scenarios; total demand response benefits including network benefits from avoided capacity account for between 47 and 56% of overall benefits.

These results assume a reduction in consumption of 2% for domestic gas and electricity credit customers, 1% for domestic gas and electricity prepayment customers and 0.25% for small business gas and electricity customers. The study also assumes that 20% of domestic customers will opt for a time-of-use tariff. In Great Britain, the extent of benefits from reductions in average consumption is important in determining whether smart meters should be mandated or not. If domestic credit customers' average reduction drops to 1%, only the regional franchise model scenario shows a net benefit (Frontier, 2007a).

Lower demand and load shifting have opposite effects on carbon savings in Table 29. Load shifting has a slightly negative impact due to the generation merit order assumptions made in the study. In Great Britain, coal tends to be the marginal plant more often during off-peak periods and gas during peak periods. Significant shifts of consumption from peak to off-peak periods will therefore lead to an increase in average emissions for a given level of total consumption.

Table 29: Frontier study of Great Britain: Green benefits of smart metering

| | **Replacement basis roll-out; supplier-led** | **10-year roll-out; supplier-led** | **7-year roll-out; regional franchise model** |
|---|---|---|---|
| *Energy savings* | 1,549 | 2,349 | 2,634 |
| Lower demand | 1,533 | 2,324 | 2,607 |
| Load shifting | 16 | 24 | 27 |
| *Carbon savings* | 614 | 924 | 1,028 |
| Lower demand | 618 | 930 | 1,035 |
| Load shifting | -4 | -7 | -7 |
| **Total DR benefits** | **2,636** | **3,999** | **4,477** |
| Total benefits | 4,717 | 7,285 | 9,609 |
| Incremental costs | (4,663) | (6,738) | (6,109) |
| **Net benefit** | **54** | **546** | **3,499** |
| CBA ratio | 1:1 | 1:1.1 | 1:1.6 |

*Source*: Frontier (2007a)

The same is true for most Australian jurisdictions where a significant proportion of peak plants are gas and hydro (CRA, 2007). Shifting consumption from peak to off-peak periods, however, has additional economic benefits in terms of deferring the need for investment in peak plants. Depending on the size of the shift, this may significantly alter generation investment decisions.

Customer benefits from demand response tend to be sensitive to variation due to their reliance on behavioural change. The Netherlands analysis calculates that household benefits range from approximately €1.5 billion to €7.5 billion (Senternovem, 2005). By contrast, however, a detailed study recently conducted at a national level in Australia has estimated the demand response impacts on consumers according to various levels of meter and system functionality. The methodology used considers the changes in consumer surplus and the redistribution of surplus from suppliers, network operators and generators to consumers. The net societal benefit from changes in consumption is also estimated. Each function that allows for greater demand response in the analysis (daily remote reading, in-house displays and direct load control) results in a net increase in consumer surplus (NERA, 2007a).

Further innovation in enabling technologies for demand response can be promoted by smart metering, for example interfaces with appliances in the home via automated monitoring and control.[14] This type of innovation may reduce the uncertainty surrounding estimates of demand response and has the potential to increase the size of demand response benefits in the future.

### 5.5. **Minimum functionality requirements**

Choosing the level of functionality of smart metering systems is a central question in international studies and is closely connected to the analysis of costs and benefits. As is the case with the preceding studies, international approaches to regulating the functionality of smart metering systems, once the decision has been made to proceed with deployment, have differed. To illustrate this, Table 30 contrasts two approaches to establishing minimum functionality for smart metering.

As can be seen from the table, the Italian approach has been to specify the functions that are required of the meter and communications system. AEEG, the Italian regulator, published these minimum requirements at the end of 2006 after significant installations of smart electricity meters had already been undertaken by Enel. The decision by Enel to deploy smart metering was an independent decision based on its own business case. Acea Roma and Asmea Brescia followed suit shortly afterwards with their own smart metering programmes. It is now mandatory for other distribution companies to implement smart metering from 2008.

The Californian regulatory approach has been quite different from the Italian approach for a number of reasons. As we discussed previously the CPUC initiated the drive for more advanced metering in the region and called on the utilities to submit their business case analyses for approval. Avoiding another electricity crisis by activating a more responsive demand and controlling the peaks were of paramount importance from the CPUC's perspective. This focus on the overarching aims rather than the specific means is reflected in the minimum functionality requirements. The aims rather than the details of the functions are specified, allowing for greater flexibility of implementation.

[14] For an interesting discussion of how this type of demand-side management can be applied using internet-enabled monitoring and control to make more efficient use of refrigeration, air conditioning, space heating and lighting , see Hong et al., 2008.

Table 30: Minimum functionality requirements for smart metering systems in Italy and California

| | Italy | California |
|---|---|---|
| **Pricing** | (1) Four price bands<br>(2) 5 intervals (time-bands) to apply price bands to | Implementation of price-responsive tariffs for all consumers |
| **Meter and meter display** | (1) Active energy withdrawn in hourly load profiles<br>(2) Total accumulated consumption & 4 separate consumption registers (in up to 5 time-bands)<br>(3) Daily programming Monday to Saturday; Separate programme for Sunday and holidays<br>(4) Minimum storage for data: 36 days<br>(5) Meter to display consumption per register; current price band; date and time; instantaneous power consumption; messages | (1) Interval data that allows for greater customer understanding of hourly usage patterns and how these relate to energy costs<br>(2) Flexible customer access to energy usage data |
| **Communications** | (1) Guaranteed security of data withdrawal from meters and data concentrators<br>(2) Remote transmission of messages to meter display<br>(3) Transmission of status word to AMM control centre reporting hardware/functional abnormalities | (1) Compatible w/ applications that provide customer education; customised billing; energy management info; improved complaint resolution<br>(2) Compatible w/ utility applications that promote and enhance system operating efficiency and service reliability<br>(3) Capable of interfacing w/ load control communication technology |

*Source:* AEEG (2006a), AEEG (2006b), CPUC (2004).

There is also a strong focus in the California specifications for the communications system to be compatible with a range of applications and other technologies. This question of interoperability is perhaps even more crucial to the market in Great Britain where there is competition in metering activities. Interoperability in this sense refers to supporting both communication between the system, market actors and other platforms in the home area network, as well as supporting innovation within metering and other related technologies. It also requires a framework that uses open standards where possible, thereby avoiding proprietary communications systems (ERA, 2008b). The Energy Retail Association in the UK has engaged, and continues to engage, with a range of stakeholders to discuss these issues and build consensus on the requirements for such a system in Great Britain.

# 6. Conclusions

Assessing the case for smart metering is a complex process. Regardless of the country or regional context, there is a need for systematic analysis of impacts across the supply chain. The impacts of investing in smart metering can be traced from retail through to distribution, transmission, the wholesale electricity market, and ultimately to the consumer. The main costs can be divided into three categories: (i) meters; (ii) meter installation; and (iii) the communications system (including capital, installation and management). Stranded costs may also be an important cost component when considering the business case for investment. Benefits for market actors and the market as a whole are derived from both operational improvements and the facilitation of demand response.

Some of the most important questions in considering the case for smart metering are as follows. First of all, is there a business case for investing in smart metering for all consumers? Many countries already employ some form of advanced metering for industrial customers but the policy question here relates more specifically to smaller users, i.e. SMEs and households. In a number of international studies, the costs of implementing smart metering in these sectors still outweigh the benefits when looking at the business case from either a supplier or network operator perspective (Carbon Trust, 2007; Ofgem, 2006a; Capgemini, 2007; SenterNovem, 2005). Where operational and demand response benefits are more integrated, the business case has tended to be positive as in the case of the California utilities; this requires separating financing from the customer via regulated charges.

In Great Britain and Australia, alternative market models have been quantitatively explored in order to assess how changing responsibilities affects total costs and the cost/benefit ratio, as well as the allocation of costs and benefits across market actors. Findings suggest that there may be significant cost savings from a more coordinated regional rollout strategy. A return to a distributor-led metering system in Great Britain, however, is not the only way of achieving this; the regional franchise model could be a viable alternative. Competition in the tender process has the potential to drive innovation and the delivery of the least cost solution.

The second question is whether the benefits of smart metering outweigh the costs from a societal perspective. This is particularly important where the business case for investment is not positive. Furthermore, investigating the impacts of smart metering investment on all market actors, consumers and the electricity market and comparing the respective net benefits or costs helps to reveal who stands to gain or lose the most. If the case for investing in smart metering is positive for society as a whole but is unlikely to be positive from a business perspective, we are left with a key question: Is there a role for government and/or the regulator to tackle any remaining barriers or uncertainties?

Where it has been found that from a societal perspective the case for smart metering is positive and the business case negative, approaches have differed internationally. In the Netherlands, the government intervened in the metering market to promote large-scale implementation; in France the regulator is expected to publish minimum requirements for smart metering to overcome some of the market uncertainty; in Great Britain the regulator has been working to resolve uncertainty regarding data access, data formats and minimum standards and by undertaking a large-scale energy demand pilot; and in Norway the government is considering setting a deadline for installation of smart meters as was the approach previously adopted in Sweden. All of these approaches aim to deal with one or more aspects of uncertainty in the market, policy and customer behaviour.

The third set of questions relates more specifically to smart metering technology: how advanced should the technology be and how do different technology scenarios have an impact on costs and benefits? We have seen that very few studies to date have analysed the incremental costs and benefits on a function-by-function basis. The national Australian study is an exception and provides a useful benchmark in developing a more detailed discussion. Choosing technologies or regulating how they are chosen is a significant challenge given the speed with which improvements and cost reductions have taken place in recent years. The challenge involves setting standards while continuing to encourage innovation and cost reductions. An interoperable framework, such as that developed by SCE in California, allows for a variety of solutions to emerge and develop and reduces the option value of waiting for a superior future alternative.

Related to this is the question of technology deployment: how do different roll-out schedules have an impact on costs and benefits? The consequences of changing deployment strategies have been explored in a number of studies. In general, deploying smart metering systems over a shorter period of time increases the costs associated with installation and stranded costs. However, installing the system over a shorter period of time allows for greater overall savings, both operationally and in terms of demand response. Coordinating the installation of gas and electricity smart metering has the potential to decrease installation and communication costs while increasing total operational and demand response benefits.

There is widespread consensus that improving the participation of the demand-side should be a central goal for policy in liberalised electricity markets. The main barriers to greater participation are inelasticity of demand and information asymmetry. More innovative forms of metering provide platforms for these barriers to be overcome. However, there are a number of challenges that first need to be addressed in order for smart metering to contribute to this goal. Assessing costs and benefits in a systematic way is the first step in identifying barriers, e.g. split incentives, and in comparing results with other countries and regions. Assessing how costs and benefits change according to different deployment or ownership scenarios is also crucial before the government or regulator intervenes to change metering market structure or to mandate specific roll-out schedules. Incorporating analysis of future costs and categorising costs by functionality would strengthen analysis and create a sound basis for which to develop minimum functionality criteria for smart metering systems.

Once these challenges are adequately addressed, smart metering has the potential to contribute in a cost-effective way to a number of policy goals including improving security of supply, facilitating the integration of renewables to the grid, avoiding peaks in fossil generation and tackling fuel poverty. Smart metering, however, should not be seen as a goal in itself but rather as a tool in promoting more active demand and innovation in equipment for demand-side management. A policy and regulatory framework that encourages innovation, cost reductions and above all interoperability will ensure that smart metering is a tool that can evolve in response to the needs of customers, networks, suppliers and the electricity market as a whole.

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