A Review of Current Knowledge

Smart Meters and Domestic Water Usage

FR/R0023
May 2015

© Foundation for Water Research

Price: £15.00
(20% discount to FWR Members)

Foundation for Water Research
Allen House, The Listons,
Liston Road, Marlow,
Bucks SL7 1FD, U.K.
Tele: +44(0)1628 891589
Fax: +44(0)1628 472711
E-mail: office@fwr.org.uk
Home page: www.fwr.org

This review is one of a series of Reviews Of Current Knowledge (ROCKs) produced by FWR. They focus on topics related to water supply, wastewater disposal and water environments, which may be the subject of debate and inquiry. The objective of each review is to produce concise, independent scientific and technical information on the subject to facilitate a wider understanding of the issues involved and to promote informed opinion about them.

© Foundation for Water Research 2015

Copyright

Apart from any fair dealing for the purposes of research or private study, or criticism or review, as permitted under the UK Copyright, Designs and Patents Act (1998), no part of this publication may be reproduced, stored or transmitted in any form or by any means, without the prior permission in writing of FWR.

Disclaimer

Whilst every effort has been made to ensure accuracy FWR will not accept responsibility for any loss or damage suffered by any person acting or refraining from acting upon any material contained in this publication.

Appropriate professional advice should be sought when making important decisions to ensure the information is correct, up-to-date and applicable to specific circumstances.

Review of Current Knowledge

Smart Meters and Domestic Water Usage

Cover page image © Thames Water Utilities Ltd

Authors: **Alexis Pericli and James O. Jenkins**
University of Hertfordshire
Department of Biological and Environmental Sciences

CONTENTS

Page

1 Introduction: the need for smart water metering 3
2 Smart metering: definition, benefits, and challenges 4
2.1 Smart metering defined 5
2.2 Benefits of smart metering 8
2.3 Smart metering challenges 10
3 Applications of smart water metering 11
4 The governance backdrop to smarter water metering 20
5 Smart metering technology: installation, design, and interaction 27
5.1 Installation 28
5.2 Design 29
5.3 Interaction 30
6 The influence of socio-demographic, contextual and behavioural factors 36
7 Changes in management and water usage as a result of smart meters 40
8 The role of water efficient household appliances and fittings 43
8.1 The impact of efficient devices on water demand 43
8.2 Attempts to benchmark water efficient fittings and appliances 46
9 Conclusion: making smart meters work 49
10 References 52

1 Introduction: the need for smart water metering

As global demand for water increases and shows no sign of abatement, the metering of domestic water usage, and the application of ‘smart’ or ‘intelligent’ meter technologies, is increasingly viewed as being central to reducing the demand for water and facilitating more effective management. Smart meters are argued to encourage more equitable allocation, through application of the user-pays principle. This results in the water user paying for what they actually consume, while seeking to associate usage and cost in order to provide a fairer and more sustainable management solution (Westerlund, 1996; Boyle *et al.*, 2013).

From a broad perspective, numerous studies have identified the positive impact the metering of domestic water users can have on reducing water usage (Grigg, 2011; Memon & Butler, 2006). It is argued that a reduction in usage occurs because metered users become more aware of the economic consequences of their water usage behaviour, with them subsequently reducing their usage to minimise the associated economic costs (Bakker, 2001; Chambouleyron, 2004). Smart meters subsequently offer consumers the opportunity to not only monitor their water usage more easily and remotely, via a computer or smart phone, through improved bills, and in-home displays, but also more frequently through real-time [or near real-time] instant access (Darby, 2010; Lima & Navas, 2012). This affords the user the opportunity to become more informed about their water consumption.

By gaining information with regard to usage, consumers can become more informed about their water usage behavior. This is central to encouraging efficiency and more sustainable management of water resources. Approaches such as metering have the potential to empower the consumer through increased awareness of both consumption and the volumetric cost of water. The user-pays principle, which is intrinsic to metering, can also encourage individuals to have a greater sense of responsibility for their practices due to it emphasizing the consequences of their actions (Darby, 2010).

From the perspective of the water industry in the United Kingdom [UK], particularly in the context of England and Wales, plans to fully embrace water metering technology are currently at a crossroad. For example, although some companies plan to embrace smart meters for all of their consumers [e.g. Thames Water], many are focusing on more traditional or ‘dumb’ forms of metering [e.g. Affinity Water] due to an inability to demonstrate a positive cost benefit case to the water regulator. However, even when smart metering technology is embraced, there are many issues that need to be considered if the technology is to facilitate a change in behaviour. For instance; how often does data on usage need to be collected to affect a change in behaviour; how will the collected data be communicated to the consumer; and how will the consumer interact with their data to inform and subsequently adjust their behaviour. Although smart meters have the potential to empower water users to make more informed choices with regard to their usage, and greater environmental stewardship, many consumers are not aware of the scientific foundation behind metering. This lack of awareness and knowledge is also limited in the context of user behaviour, which if better understood could have a profound impact on the effectiveness of such technologies.

As a result of the aforementioned issues, this review aims to create a more coherent and integrated understanding of how water metering, through smart meters in particular, can affect domestic demand for water. It also considers the influence of additional factors that serve to shape the effectiveness of metering technologies. It is important to note that the contextual and governance focus of this review, whilst centred on the UK, does draw upon research and information that is more global in scope.

The following review is separated into five main sections. The first section provides an overview and definition of smart metering, as well as considering the benefits and challenges of smart meters. The second section focuses on the applications of smart water metering, subsequently highlighting the governance backdrop. The third section outlines smart meter installation, design, and interaction, as well as drawing attention to the influence of human behaviour and socio-demographic variables on water efficiency through smart metering. The fourth section details how smart meters can change water management and usage, with it also outlining the role played by water-saving household appliances. The concluding section seeks to remind the reader of the key findings of the review, in addition to detailing a rationale for why smart meters are necessary and how they can play a key role in encouraging and facilitating greater water efficiency in the UK.

2 Smart metering: definition, benefits, and challenges

The water industry and national governments have sought to apply demand management approaches in response to a range of variables, including; supply-side management limitations; the need for more integrated resource planning; as well as compliance with the principles of conservation and sustainability (Gleick, 2000; Dziegielewski, 2003). As a result, metering has emerged as a key component of demand management, with traditional meters being embraced due to a range of benefits over flat-rate tariff pricing (Staddon, 2007).

In essence, metering has been driven by a preference to recover costs directly from the consumer, and in doing so apply the user-pays principle which seek to allow the consumer to pay for the actual amount of water used (Staddon, 2010; Ofwat, 2011; Boyle *et al*., 2013). Despite these benefits, traditional forms of metering have given rise to a number of problems. Firstly, the meters themselves can be difficult to access, which can restrict users from being able to determine their water consumption. Secondly, data from the meter is frequently provided long after the usage itself, thereby preventing informed and responsive changes in behaviour. Lastly, traditional meters also generate recurrent financial costs for water providers, as a meter-reading service must be undertaken in order to gain data on usage (Beal *et al*., 2014).

In response to the limitations of traditional [‘dumb’] meters, ‘smart’ metering [also defined as ‘intelligent’ metering within this review] has emerged as a vital tool in the evolution and application of demand management approaches. The development of smart metering technology has mainly occurred in the energy sector, in which smart gas/electricity meters have been more widely applied (Owen & Ward, 2007). However, as the potential benefits of this technology have been recognised, water providers have also sought to implement this type of metering incrementally in an attempt to increase water efficiency, improve services, and stimulate changes in consumption/user behaviour (Sarni & Pechet, 2013). The following sub-sections focus on defining smart metering, outlining the characteristics that differentiate smart meters from traditional ‘dumb’ types, as well as considering the benefits and challenges associated with smart metering technology.

2.1 Smart metering defined

Smart or intelligent water metering is subject to differing definitions, especially when communicated to consumers (Boyle *et al*., 2013). At present, the water industry does not appear to demonstrate agreement as to what constitutes smart metering, although some recent attempts have been made to define smart meter functionalities and the range of features supplementary to providing a single accumulated total. Notably, the European Standard EN14154 [Part 4 Additional Functionalities for Water Meters] highlights a range of features that smart meters should include, such as; improved communication with the consumer; alarm facilities for leakage or tampering/manipulation; as well as the ability for multiple readings at set intervals. As a consequence of the variable interpretations of what a smart meter is, this section seeks to clarify what smart meters can be defined as encompassing.

In the context of this review, it is possible to form a definition by identifying how smart meters differ from traditional types (see Figure 1). This can be highlighted through four important characteristics, namely those that; recognise and identify consumption in greater detail; communicate via networks and allow data to be used by consumers as well as utility providers for monitoring and billing purposes; measure and store data at specific pre-determined time intervals; and enable communication between the supplier and consumer (Climate Group, 2008; Boyle *et al.*, 2013; Beal *et al.*, 2014). These four characteristics are outlined in more detail below.

Firstly, when smart and traditional meters are compared it is apparent that data recorded in relation to water use is generated in a different way. Smart meters allow a greater and more precise resolution in relation to time, with it being possible to gain multiple measurements by using series of linked sub-meters. Secondly, although less common in a household/domestic setting, smart meters have the ability to record extra information, such as data relating to the quality and temperature of water, which can provide a clearer picture of water status and give the user a more in-depth understanding of the resource they are using (Beal *et al.*, 2014). Thirdly, in contrast to traditional meters, automated reading and communication of data is made possible by smart metering, with this being achieved via automated drive-by readings or data transfer using networks (Hunn, 2010; Hill, 2011). Finally, smart meters also enable greater access and interaction with collected data. In this case, data access is important for customers, who may use an internet portal, in-home display, or application, as well as utility providers who can make use of real-time data to monitor the supply network and respond to issues such as leakages (Idris, 2006).

TRADITIONAL METERING

- Accumulation based measurement of consumption
- Meters are read manually - often by staff of the utility provider, and over a longer time period
- A single consumption value is given to the consumer based on a meter reading

SMART METERING

- Accumulation, pulse or time interval based measurement of consumption
- Data logger and transponder
- Remote meter reading
- Multiple consumption values based on different time variables
- Consumption data available through network connection

Figure 1: A comparison of metering technology (Boyle *et al.*, 2013; Beal *et al.*, 2014)

According to Britton *et al* (2013), although there is no single definition with regard to how a given metering system is considered to be smart or intelligent, three key characteristics are determinable. Firstly, it is argued that smart meters store and communicate measurements at specified time intervals (van Gerwen *et al*., 2006; Darby, 2010). Secondly, they have the potential to collect a registry of data relating to end use water consumption, with this data helping in terms of household leakage detection (Stewart *et al*., 2010; Willis *et al*., 2011). Thirdly, the implementation of smart metering and communication technology enables the rapid transfer of high resolution water consumption data. This data can then be analysed by the utility provider in order to highlight unusual patterns of usage (Ferreira *et al*., 2007). The importance of generating, storing, and transferring this type of customer data should not be overlooked, as it can assist in identifying households, or areas, with excessive consumption that may indicate inefficient usage or leakage (Beal & Stewart, 2014). This means that management approaches, such as leakage investigation and response or water-saving awareness/educational schemes, can be directed appropriately (Stewart *et al*., 2010).

In terms of data processing, the contrast between dumb and smart meters is illustrated in Figure 2. Essentially, traditional dumb meters produce a simple transfer of data that relies on manual collection and processing, with customers only being able to access this data through a bill issued at a specific interval e.g. every three or six months. In contrast, smart metering systems can facilitate a transfer of more complex data, giving households or businesses [and water providers] direct access to this real-time [or near real-time] data. This can help customers and the utility provider to better understand their water usage over a set time period and/or in relation to specific activities (Beal *et al*., 2014).

The terms ‘smart’ or ‘intelligent’ metering are often arbitrarily used to describe some combination of technology that is more advanced than traditional dumb forms of metering (Boyle *et al*., 2013). However, to both the public and industry actors, these definitions are ambiguous and serve to highlight the wide range of specifications that may be defined under the umbrella of smart metering technology. Previous research defines smart or intelligent metering as having a vital characteristic, namely the ‘intelligence’ referring to enhanced communication capabilities and functionalities for monitoring water consumption/usage (Idris, 2006). This understanding is further developed to argue that the intelligence of smart meters is manifest through two distinct factors. Firstly, through meters that use technology to gain data with regard to water usage; and secondly, based on the communication systems in place that transfer water usage data instantaneously in real-time [or near real-time] (Darby, 2011). For example, Boyle *et al*, (2013) define this as a standard or high resolution water meter that utilises data logging technology, in order to enable the water provider or user to continuously read the meter and obtain relevant information with regard to water use. This process allows for meter reading to be done remotely by the provider. Subsequently, water usage data can be provided through different 'feedback channels' [such as an online portal, in-house display, or a smart-phone application], thus offering the customer accessible information and potentially helping to adjust behaviour.

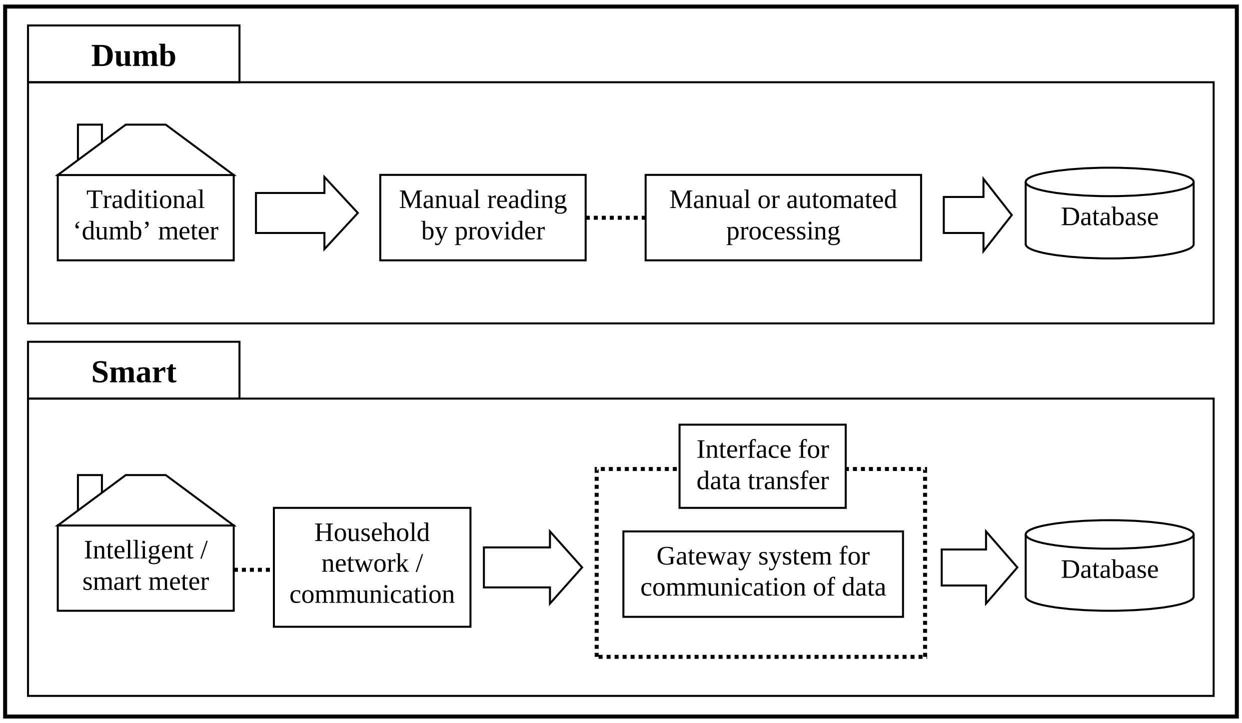

Figure 2: Differences between the traditional ['dumb'] and smart metering data process (van Gerwen *et al*., 2006)

2.2 Benefits of smart metering

Alongside the particular characteristics of smart meters, it is also possible to highlight a range of benefits that provide greater advantages over traditional meters, with these advantages serving to justify the adoption of smarter metering.

Smart meters are designed to enable user involvement by affording customers the opportunity to gain real-time [or near real-time] data with regard to consumption (Boyle *et al*., 2013; Sempere-Payá, *et al*., 2013). This is beneficial as it can enable a better understanding and awareness of consumption, potentially leading to improved water efficiency. Smart meters can facilitate user involvement by providing the possibility for local and remote meter-reading, with this taking place in two ways. One, 'advanced' meters are more basic and allow one-way communication from consumer to provider. Two, fully smart meters measure and store data at specific time intervals, and allow two-way communications alongside operation as part of a network that enables both users and utility providers to access consumption data (Darby, 2010).

The application of smart metering can also encourage consumers to increase their efficiency due to an incentive driver, namely financial (Bakker, 2001; Walker, 2009; Sarni & Pechet, 2013). This is achieved by giving the user access to real-time consumption data, which can help shape their behaviour so that they are driven to save water in order to reduce their personal costs [It is worth noting that a range of complex variables, not only financial incentives, can influence water usage and efficient behaviour. These are discussed in further detail within section 6]. Furthermore, by encouraging a shift towards incentivising water efficiency, an important feature of smart metering emerges, namely the ability to apply volumetric pricing and more sophisticated tariffs (Dresner & Ekins, 2006; Wessex Water, 2012). Volumetric pricing can generate a more equitable allocation of resources with the consumers only paying for the water they use, with the application of more flexible tariff structures helping to encourage step-changes in water efficient behavior in the long-term (Zetland, 2011).

When considering the benefits of real-time data, it is important to note that attention has also shifted to the wider societal benefits of smarter metering. In this sense, the role of smart technology has been considered within the context of aspects such as assisted living. This explores the combination of real-time data and ‘machine-learning algorithms’ to monitor the consumption patterns of vulnerable users. When these patterns differ from the norm the possibility of ill-health or other issues may be identified, and thus an alert can be relayed to the relevant authority or care provider (DECC, 2015).

From the perspective of the water provider, there are also a range of operational drivers that serve to encourage the implementation of smart metering. Smart meters can enable better customer service through a range of factors, including; the capacity to read a meter on demand [and when a property has a change in occupier]; a quick response and improved ability to deal with customer enquiries; as well as more accurate billing. These advantages can lead to fewer complaints and an improved ‘service incentive mechanism’ [SIM] score for a given provider. This involves both quantitative and qualitative benchmarks that consider factors such as number of complaints, unwanted contacts, and quality of customer experience (Ofwat, 2015). Other operational drivers also emerge in relation to smart technologies, particularly; the development of new services, especially for business/non-household customers; reduced meter reading service costs; as well as the potential for an improved early leakage detection system. In terms of this last point, as a consequence of improved [real-time] access to consumption data, smart meters can help to detect leakages in the water network, thus reducing wastage and minimising the amount of non-revenue water loss for the utility provider (Britton *et al*., 2013).

2.3 Smart metering challenges

Despite the benefits offered by smart metering technology, a range of challenges are identifiable. In a wider context, Boyle *et al.* (2013) suggest that particular challenges relating to privacy and security, data management, reporting to customers, technical capacity, and customer support, need to be overcome to ensure the widespread implementation of smart meters. Beal *et al.* (2014) highlight additional challenges relating to the higher cost of smart metering technology, poor understanding and communication of smart metering benefits, as well as the need for reliable, secure communication systems. Meanwhile, van Gerwen *et al.* (2006) also draw attention to the complexities of smart metering implementation, such as the risk of an uneven distribution of benefits, and go on to claim that successful implementation depends heavily on water policy and the decisiveness [in decision-making] of both national government and water providers. In a UK context, five key challenges to smart metering have been outlined by government, namely; consumer engagement and behaviour change; the uneven distribution of benefits; roll-out timescale and cost; public concern for health effects; as well as concerns relating to data access, privacy, and unauthorised access or potential ‘cyber-attacks’ (HOP, 2014). By understanding these challenges, future research can gain a greater sense of direction.

Firstly, in terms of consumer engagement and behaviour change, it is recognised that widespread implementation relies on engagement for both the initial adoption of smart meters and subsequent interaction that can change behaviour. Secondly, the uneven distribution of benefits is a twofold challenge. One, consumer groups are concerned that water providers will not pass on the financial savings smart meters may lead to. Two, there are concerns relating to the benefits of smart metering not being achievable by lower income groups due to a limited ability to change practices because of housing, work, health, and income restrictions. Thirdly, the roll-out phase may pose a challenge if it is not managed appropriately to minimise costs, with the implementation process being prolonged by reluctant consumers, technical problems, logistical issues, or lack of preparation by utility providers (see HOP, 2014). Next, public health concerns relate to the electromagnetic fields produced by smart meters. In order to ease these concerns and reassure the public, it is deemed important to keep consumers well informed with regard to guidelines in place and ongoing research (PHE, 2012; PHE, 2014).

Lastly, concerns and challenges have also emerged in relation to authorised and unauthorised access to data, and ‘cyber-attacks’. In terms of authorised access, concerns are raised about privacy and potential unauthorised data usage and manipulation to reduce bills (see HOP, 2014; Ward, 2014).

From the perspective of the water provider, a range of additional challenges can be highlighted. In contrast to smart energy metering, one of the main challenges in England and Wales involves the apparent lack of political support for smart water metering, as government legislation and guidance has often been limited (Utility Week, 2014a). Another challenge stems from the difficulties of communicating water use and consumption data to customers in an accessible and meaningful way. This is an important point, as poor communication can potentially limit user interaction having a negative effect on water efficient behaviour (Darby, 2010). Next, issues relating to accessibility also emerge for providers. This occurs as water meters are often located underground and some distance away from a given property and the required network (Sarni & Pechet, 2013). Lastly, an apparent lack of standards and common protocols for smart metering implementation generates another challenge for water companies. This situation means that smarter systems become difficult to select or develop, as various options may be applicable in different settings. For instance, a highly populated urban area will have different system requirements when compared with a less populated rural area.

Another challenge of smart metering emerges through the aspects of engineering and limited available technology. In this sense, many smart meters communicate their data through radio transmission and despite a wide range of systems available, a lack of inter-compatible types and guidelines or standardised protocols relating to implementation remain an issue. This can be a significant obstacle for water companies when choosing a smart metering system [and service] to implement within their network (Boyle *et al.*, 2013). Also, a notable challenge related to technology is apparent in terms of meter battery life, which can be limited and result in a negative variable as part of any cost-benefit analysis carried out by the provider. In this case, a meter battery can influence the storage capacity and transmission range of data, with this impacting on information that can be presented to the customer and the time taken for this data to be received (Hunn, 2010; Sempere-Payá *et al.*, 2013).

3 Applications of smart water metering

The following section discusses the historical application of metering and the subsequent emergence of smart metering in the UK. It also outlines the current position of UK water providers with regard to both metering and smart metering.

Historically, water in the UK has not been priced using a volumetric approach based on metering, but rather through the use of ‘rateable value’ charges. In this case, the price of water is defined according to a ‘property rateable value’ that reflects the annual rental value of a given property (Ofwat, 2014a). These valuations [the most recent being carried-out in 1990] were calculated and provided by local authorities; with specific criteria for valuation being very poorly represented (Ofwat, 2014a).

Since the 2000s, central government has sought to encourage the adoption of volumetric charging for water via the application of metering (Defra, 2006). A shift towards the inclusion of this approach as part of the water management agenda initially occurred through the implementation of traditional forms of metering. This was considered to be more equitable as customers only paid for what they used, and more likely to encourage efficient usage of water due to customers wanting to avoid unnecessary costs (Defra, 2006).

In terms of metering, volumetric water pricing is set by each provider based on two key aspects. Firstly, the pricing structure consists of a ‘standing’ charge which is fixed, and includes a range of costs associated with; pipe infrastructure; meter maintenance; as well as reading and billing services for instance. A subsequent ‘variable’ charge is incurred based on the volume of water consumed over a given time period, as indicated by the meter (Ofwat, 2014b). By 2006/07 approximately 26% of households in England and Wales had adopted metering, with this having increased to approximately 40% today (Defra, 2006; CCFW, 2014). However, the majority of meters installed are still traditional ‘dumb’ types (CCFW, 2014).

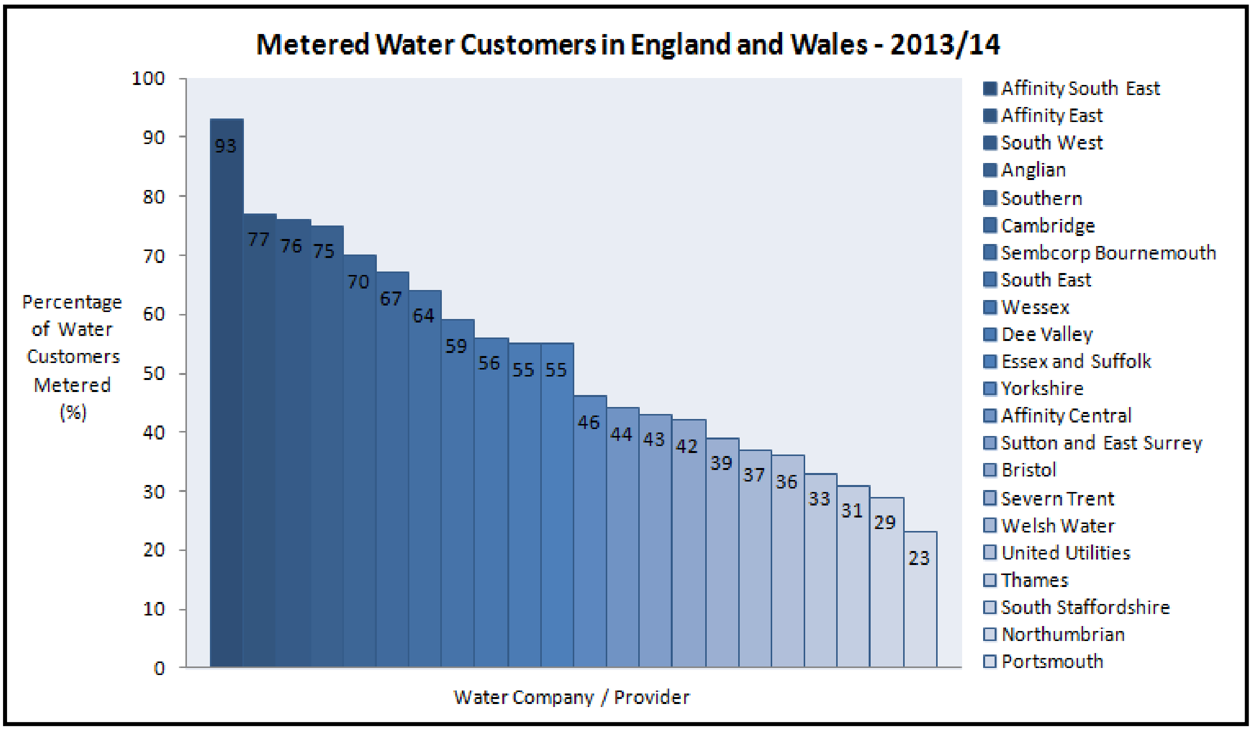

Figure 3: Percentage of metered customers in England and Wales [as of 2013/14]. The chart shows disparities between different water companies/providers with regard to meter application (Utility Week, 2014b).

Water metering is currently offered by providers as an optional water-saving measure in many areas, with consumers having the right to adopt it or continue to be charged through the rateable valuations (Bakker, 2001). However, metering is required for businesses or commercial users, thus allowing providers to charge according to the volume of water used (Ofwat, 2011). In relation to domestic users, metering is required in certain circumstance, notably; in the case of all new homes; if a reverse osmosis water softening unit is used; if a customer is the new occupier of a property [provided the water company has not already sent this customer an unmetered bill]; as well as for high consumption activities and non-essential uses such as filling swimming pools or using lawn sprinkler systems (Bakker, 2001; Staddon, 2007; Ofwat, 2011). Selective or fully compulsory metering occurs if an area has been designated as ‘seriously water stressed’, or if the government allows a water company to widely implement meters as part of a plan for water security (Ofwat, 2011).

Even though metering is not compulsory for changes in occupier [for domestic properties] a given provider may choose to install a meter at this point, with this often being dependent on relative management policies (Bakker, 2001). Consequently, although the penetration of traditional metering has increased over time, rateable values continue to be used as the basis of charging for the majority of consumers that do not have a meter, or do not choose to have a meter fitted (Thomas & Ford, 2005). As shown in Figure 3, although metering has been adopted in England and Wales, it is evident that its adoption has been variable (Staddon, 2010; Utility Week, 2014b).

Despite the various drawbacks associated with traditional forms of metering [as noted in section 2], benefits such as greater efficiency and the ability to apply the user-pays principle have seen traditional technologies increasingly embraced (Staddon, 2007; Ofwat, 2014b). However, in an attempt to overcome the limitations of traditional meter types, a move towards the introduction of 'smart-metering' or 'advanced-metering' approaches has been observed (Boyle *et al.*, 2013). By embracing smarter technology, it is argued that the full potential of metering can be realized in an attempt to reduce water consumption, encourage greater efficiency, and enable more effective management of the water supply system (Giurco *et al.*, 2010).

Within the context of the UK water industry, a practical shift towards smart metering has been observed to a limited extent, with larger companies/providers developing schemes that seek to promote seemingly smarter [or advanced] forms of metering - or the adoption of smarter technologies. However, it is important to highlight that this application of smarter metering and technology has also been highly variable. Table 1 serves to demonstrate this by outlining the current position of UK water providers in relation to metering and smart metering. [The table is based on publicly available and accessible information, such as water provider/company reports, website information, and other documents.]

Table 1: Water company/provider approaches to metering and smart metering based on publicly available information

WATER PROVIDER	POSITION WITH REGARD TO SMART METERING
1. Affinity Water	▪ Implementation of traditional meters only, with these being optional. ▪ Compulsory 'dumb' metering for groups such as; those with new homes receiving a charge for the first time; those with a property with a swimming pool, pond, or use of fitted garden watering apparatus; those with a property that has a previously installed meter. ▪ Smart meters are not offered to household users.
2. Albion Water	▪ Implementation of traditional meters only. ▪ All supply is metered using traditional forms. ▪ Smart meters are not offered to household users.
3. Anglian Water	▪ Implementation of traditional meters for household domestic users, with this being optional.

WATER PROVIDER	POSITION WITH REGARD TO SMART METERING
	▪ A 'pay-as-you-flow' pricing system. ▪ Smart meters available to business customers. Water usage readings are taken by the provider and made accessible via a 'WaterSmart' website/portal online.
4. Bristol Water	▪ Implementation of traditional meters for household domestic users, with these being optional. ▪ Metering of properties if a change of occupier takes place. ▪ The provider is responsible for reading the meter [every six months], with users being able to manually read their meter and submit readings to the provider. It is recommended that a reading is carried-out monthly by household users and weekly for business users. ▪ Smart meters are not offered to household users.
5. Cambridge Water	▪ Implementation of traditional meters for household domestic users, with these being optional. ▪ Compulsory metering applies to all new properties. In addition, meters are required for properties built pre-1990 that have swimming pools, ponds, and sprinklers or automatic watering systems; short stay accommodation properties; and some mixed use properties. ▪ Business users have the right to be charged by meter. These meters can be read using a remote device, although in many cases this still involves the provider visiting the site to obtain a reading. ▪ Smart meters are not offered to household users ▪ Provider offers a 'meter data collection' service to larger business customers, which involves the use of a smarter meter. This system utilises a data logger and connects the meter to the internet to allow customers access to consumption information, local network leakage, as well as analysis of system efficiency.
6. Cholderton and District Water	▪ Implementation of traditional meters for domestic household users. ▪ Meters are installed for new buildings; those who opt to install a meter; those with large water consuming apparatus such as swimming pools; as well as change of owner/occupier properties. ▪ Smart meters are not offered to customers.
7. Dee Valley Water	▪ Implementation of traditional meters for domestic household users, with these being optional ▪ The provider is responsible for reading the meter through a manual reading service. However, users can also read their meter and submit these values online. ▪ Smart meters are not offered to customers.
8. Dŵr Cymru Welsh Water	▪ Implementation of traditional meters for household domestic users and business users, with these being optional. ▪ The provider offers the service of adding a temporary [for at least 14 days] 'meter logger' that gives more detailed information with regard to water consumption. ▪ Smart meters are not offered to customers.
9. Essex and Suffolk Water	▪ Implementation of traditional meters for household domestic users and business users.

WATER PROVIDER	**POSITION WITH REGARD TO SMART METERING**
	▪ Metering is optional for users [‘optant basis’], although compulsory metering is in place for all new properties, those which have a change in occupier [although the new customer can opt out], and those which have had major alteration or have large ‘water using apparatus’ such as swimming pools. ▪ All unmetered customers continue to be charged according to the rateable value of their given property ▪ Smart meters are not offered to customers.
10. Independent Water Networks	▪ Implementation of traditional meters for all household domestic users and business users. ▪ Advanced meters used, but meters readings still only taken every three months. ▪ Fully smart meters are not offered to customers.
11. Northern Ireland Water	▪ Implementation of traditional meters for household domestic users and business users. ▪ Metering is optional for existing customers, or applied as mandatory for new properties, change in occupier properties, or those with high usage items such as swimming pools or garden watering apparatus. ▪ Non-metered users are charged according to the rateable value. ▪ Manual meter readings are done by the provider in situ, although users can read their own meter. ▪ Smart meters are not offered to customers.
12. NorthumbrianWater	▪ Implementation of traditional meters for household domestic users and business users. Household domestic users can apply for a meter, and the provider will assess their application and apply metering through a selective process. Business users may be selected for the fitting of a meter or indeed may opt to have a meter installed [thus not having to wait to be selected]. ▪ Smart meters are not offered to customers.
13. Portsmouth Water	▪ Implementation of traditional meters for household domestic users and business users. ▪ Compulsory metering for properties that have apparatus which use large quantities of water ▪ Smart meters are not offered to household customers. ▪ Business/commercial users have access to an ‘E-metering’ service which provides continuous data-logging of consumption, and access to this data.
14. Scottish Water	▪ Implementation of traditional meters for household domestic users, with these being optional. ▪ Unmetered users are charged according to rateable value. ▪ Business users are offered a range of a range of ‘standard’ or ‘non-standard’ meters [from a ‘meter menu’], with some of these having ‘advanced’ or ‘smarter’ facilities such as; pulse units; transmitters; and radio modules. ▪ Business users also have the option of installing a data-logging system alongside their meter, thus providing continuous data with regard to water use. This data is transferred to an accredited data-logging

WATER PROVIDER	POSITION WITH REGARD TO SMART METERING
	service provider, which can then relay this information on to the relevant business user. ▪ Smart meters are not offered to household customers.
15. Severn Trent Water	▪ Implementation of traditional meters for household domestic and business users, with these being optional and led by customers. ▪ Meters are read by the provider - or also by the consumer. ▪ Compulsory metering for those properties with high water usage apparatus, for example properties with swimming pools or garden watering systems. ▪ Smart meters are not offered to customers.
16. South East Water	▪ Implementation of traditional meters for household domestic users, with these being optional. ▪ Compulsory metering for household customers with apparatus that require large amounts of water [high usage] such as swimming pools. ▪ Rollout of ‘customer metering programme’ which aims to have all users metered by 2020. ▪ The majority of business users are metered, but this is again optional. ▪ An ‘E-metering’ service is made available to business users. This enables users to access up-to-date water consumption data online through a secure website. An associated ‘Aquanet’ customer software application is offered to users, and provides a tool to interpret water flow and consumption data. ▪ Smart meters [or ‘smarter’ services] are not offered to household domestic users.
17. South Staffs Water	▪ Implementation of traditional meters for household domestic users, with these being optional. ▪ Compulsory metering for household domestic users based on; new homes; change of occupancy; or substantial amounts of water used ‘above and beyond’ normal household use as defined by the provider [for example, swimming pool or garden sprinkler systems]. ▪ The provider ‘reserves the right’ to install a smart meter, which is defined as being capable of recording the value of water used during particular months or at particular times of day. ▪ Non-household [business] users are subject to compulsory metering. ▪ Smart meters [that allow the remote transfer of data] are not offered.
18. South West Water	▪ Implementation of traditional meters for household domestic users, with these being on an ‘opt-in’ basis. ▪ Compulsory metering for new homes, change of occupier, and high usage properties such as those swimming pools and gardening water systems. ▪ Business users are charged based on measured [metered] and unmeasured [rateable value] pricing structures. ▪ Smart meters are not offered to users.
19. Southern Water	▪ Implementation of traditional meters for household domestic and business users, with these being optional. ▪ ‘Intelligent’ Automatic Read Meters [AMRs] have also been implemented. This technology enables the provider to read meters

WATER PROVIDER	POSITION WITH REGARD TO SMART METERING
	remotely using ‘drive-by’ technology, with meters read every six months. These types of meter also have an alarm system fitted to monitor leakage, although detection only occurs when a drive-by reading takes place. ▪ Fully smart meters that allow customers to access their water consumption data are not offered. ▪ It is interesting to note that the provider has fitted ‘intelligent’ electricity meters at operational sites to manage their own consumption of electricity.
20. Sutton and East Surrey Water	▪ Implementation of traditional meters for household domestic and business users, with these being optional. ▪ Compulsory metering occurs in the following cases; change of occupancy; high water usage at the given property due to the use of a sprinkler system or swimming pool for instance; the property is new or newly converted. ▪ Most domestic meters are Automatic Read Meters [AMRs], thus enabling the provider to take readings locally via radio frequency. ▪ Fully smart meters for household domestic users are not offered. ▪ Most commercial properties and business users are metered using traditional types. The provider also permits the [third-party] installation of data-logging telemetry devices in order to allow business users to gain data regarding water consumption. This process is only overseen by the provider. ▪ Smart meters are not offered to users.
21. Thames Water	▪ Implementation of traditional meters, with these being optional for household domestic and business users. ▪ A smart meter programme has been developed and is being implemented in order to replace all traditional forms with smart types as part of a connected wireless network. This will eventually allow the provider to achieve a fully metered supply network, with all customers having a smart meter installed. The plan is scheduled for implementation over a fifteen year period. ▪ Business users [that are metered] have the opportunity to install data-logging equipment alongside their meter. This can allow a more comprehensive understanding of consumption, with installation meeting specific requirements as defined by the provider.
22. United Utilities Water	▪ Implementation of traditional meters, with these being optional for household domestic and business users. ▪ Those opting to be metered are likely to have an Automatic Meter Reading meter [AMR] installed. Many domestic meters are also being converted to AMRs. This technology enables the provider to take readings locally by using a drive-by method in which data is received via a radio frequency. ▪ Unmetered customers are charged based on rateable value. ▪ Metering for new homes; change in occupier; and high usage apparatus such as swimming pools or garden watering systems.

WATER PROVIDER	POSITION WITH REGARD TO SMART METERING
23. Wessex Water	▪ Implementation of traditional meters, with these being optional for household domestic and business users. ▪ Compulsory metering for new homes; change in ownership properties; and high usage apparatus such as swimming pools or garden watering systems. ▪ Smart meters are not offered to users.
24. Yorkshire Water	▪ Implementation of traditional meters, with these being optional for household domestic and business users. Readings can be performed by the user, or the provider will take a reading twice each year. ▪ Compulsory metering for new properties; change in occupier; and those properties with high usage apparatus such as swimming pools. ▪ Smart meters are not offered to customers.

(Sources: Dee Valley Water, 2009; Affinity Water, 2013; Albion Water, 2013; Anglian Water, 2014; Bristol Water, 2014; Cambridge Water, 2014; Cholderton Water, 2014; Dŵr Cymru, 2014; Essex and Suffolk Water, 2014; Independent Water Networks, 2014; Northern Ireland Water, 2014; Northumbrian Water, 2014; Portsmouth Water, 2014; Scottish Water, 2014; Severn Trent Water, 2014; South East Water, 2014; South Staffs Water, 2014; South West Water, 2014; Southern Water, 2014; Sutton and East Surrey Water, 2014; Thames Water, 2014; United Utilities, 2014; Wessex Water, 2014; Yorkshire Water, 2014).

As Table 1 demonstrates, the majority of water providers in the UK do not offer smart forms of metering to their domestic customers, with few offering ‘smarter’ services to business customers. Indeed, whereas traditional forms of metering have gained a reasonably good footing within the water sector, smarter forms of metering have not. For instance, it is evident that all water providers have a scheme of optional traditional metering in place, with compulsory metering being applicable in certain cases [as previously noted]. In contrast, just seven of the twenty-four water companies operating in the UK [at present] offer some form of ‘smarter’ or ‘advanced’ metering to their household or business customers.

Moreover, in the case of the UK water industry, the definition of smart or intelligent water metering is found to be vague and somewhat confusing for the consumer. For instance, water providers often use different ways to describe smart metering, using terms such as; meters with attached data-logging capabilities; e-metering services; intelligent automatic meter reading meters; drive-by technology meters; or advanced meters [see examples in Table 1]. Many of these terms and defined types do not reflect what a smart meter is viewed as being in the wider literature [as outlined in section 2.1].

Water providers/companies appear to fail to clearly describe how smart meters differ from traditional types. Although many water providers use interchangeable definitions for automated metering systems [AMRs], which are standard meters that facilitate drive-by reading, this is not the case in terms of academic definitions. As Beal *et al.* (2014) argue, AMRs that utilise drive-by readings are merely forms of “intelligent communication” rather than fully smart or intelligent meters. In essence, the difference between AMRs and fully smart/intelligent meters may be more plainly understood in terms of the difference between a standard mobile phone and a smart-phone. Whilst the standard phone allows for communication [calls and SMS messaging], the smart phone facilitates the rapid, instantaneous, and continuous transfer of data, alongside numerous features for monitoring and accessing this data [for example through instant messaging and applications].

4 The governance backdrop to smarter water metering

When seeking to better understand smart metering, it is important to consider the governance backdrop that serves to shape its adoption (Hargreaves, 2014). From a wider perspective, the governance backdrop can be understood through direct governmental/parliamentary responses as well as the positions of key water industry actors [which are both governmental and non-governmental]. In essence, the direct governmental response emerges through policy, guidance, and reports published by parliamentary committees and departments such as the Environment Agency, the Department for Environment, Food and Rural Affairs [Defra], and the Department of Energy and Climate Change [DECC] for instance. Key actors in the context of the UK water sector include; the Water Services Regulation Authority [Ofwat]; the Consumer Council for Water [CCFW]; Water UK; the Drinking Water Inspectorate [DWI]; and Waterwise.

The Water Industry Act of 1991 offers general guidance and provisions for volumetric pricing of water through the use of a meter. The conditions under which water companies or customers can choose to switch from unmetered to metered charges are also specified. The legislation defines the three ways in which a water meter can be installed, with the customer being charge in terms of recorded volume. These include: when a customer requests a meter; when a water company is permitted to install a meter; and if there has been a change in occupier with regard to a given property.

Under Statutory Instrument 3442 [of 1999] applicable to water companies in England and Wales, four methods of introducing measured charges and compulsory water meters were brought into effect. These include:

(i) Premises or buildings that are not used exclusively as a dwelling, but where part of the building is used as a dwelling.

(ii) Where the customer uses water for any of the following activities; watering a garden, not by hand, but by using apparatus such as a sprinkler system; replenishing a pond or swimming pool by consuming more than 10,000 litres; filling a bath with a capacity of more than 230 litres; operating a power shower [as defined by the Water Supply (Water Fittings) Regulations 1999]; as well as operating a device that involves the process of reverse osmosis.

(iii) When a region is defined as an area of water scarcity by the Secretary of State.

(iv) If the Secretary of State determines that a region is an area of serious water stress, where the least-cost option in terms of the water resource management plan is to meter everyone.

The amended Statutory Instrument 2457, formed in 2007, sought to allow compulsory metering in areas of water stress as part of an overall water resources plan. It is through this legislation that many of the metering programmes implemented by water companies have been applied.

The direct government response emerging from parliament in relation to smart metering in the context of water has been limited, with the main direction on this topic being in the context of energy usage (Jones *et al.*, 2013). As Maurice-Smith and Brogden (2008) argue, smart water metering is less advanced in comparison to the energy sector as a result of different regulatory frameworks and legislation, with political drivers serving to shape the potential development of smart metering in a different way within the water sector.

The government response to smart metering has emerged through the energy sector, with definitions and expected smart meter functionality being put forward by the DECC (2009). In this case, characteristics that are expected from smart meters are outlined by the DECC, which itself serves to provide a definition for what smart meters should fundamentally enable and achieve in a UK context. This position is also driven by the development of European Standards. Firstly, smart meters are required to facilitate the remote transfer and reading of data over a set period of time, with customers having access to this information. Secondly, two-way communication between the meter and the utility provider is deemed to be important, alongside user access to information with regard to consumption. Next, smart meters are considered to be ‘smart’ based on their ability to provide real-time [or near real-time] information through a network that links the meter system with the consumer and provider. This can occur through the internet or through the use of in-house displays. Finally, it is claimed that smart meters should help support a range of provider requirements, including; the support of tariffs based on accurate data; remote control of the supply networks; as well as the ability to control provisions and deliver more effective demand-side management (DECC, 2009).

In relation to the water sector, the government response to smart metering can be identified through agencies and departments such as the Environment Agency and Defra. Fundamentally, the Environment Agency is a statutory body with the duty to manage water in England and Wales (NAO, 2005). It aims to ensure the management and development of water is achieved in a sustainable manner. In practice the agency is responsible for continuous review of the water resource position (NAO, 2005; Environment Agency, 2014). Defra is responsible for policy and regulation in terms of many areas including; the environment and biodiversity; sustainable development and the green economy; food, agriculture and fisheries; animal health; rural communities; as well as pollution control and environmental protection (NAO, 2007). More specifically in terms of water, Defra focuses on a range of activities such as the management of water resources in general; dealing with floods; and improving water quality (Defra, 2006).

The Environment Agency has an influence on metering in terms of providing assessment guidelines through which water providers can categorise a given area as being ‘water stressed’ - according to factors such as water body stresses and exploitation indices (Environment Agency, 2013). From a governance viewpoint, this allows compulsory metering to be applied once the provider can demonstrate that metering would indeed be the most efficient and cost-effective method to reduce consumption in this area, and thus mitigate water stress (HOP, 2014). The agency has also offered recommendations through a report investigating the potential alignment of smart water metering alongside energy sector smart metering (see Maurice-Smith & Brogden, 2008). The report itself offers a definition of smart metering, highlighting the opportunities and benefits of this technology and application in terms of demand management. Subsequently, two key recommendations are put forward in order to help guide policies and the water industry as a whole. On the one hand, a strategic policy group is deemed necessary, which should set the agenda with regard to policy for intelligent energy and water metering, as well as encouraging dialogue from both sectors (Maurice-Smith & Brogden, 2008). The Environment Agency also recommends that the water industry should recognise and act upon the opportunity of interaction with the energy sector and the associated smart energy metering programme being implemented (Maurice-Smith & Brogden, 2008).

In contrast, whilst the Environment Agency has explored smart water metering from the perspective of interaction with the energy sector, Defra has sought to explore this as well due to its potential within the water industry. Defra has had a notable influence on governance through resultant white papers (Defra, 2011) and the commissioning of independent reviews such as 'The Independent Review of Charging for Household Water and Sewerage Services', also known as the 'Walker Review' (Walker, 2009). Furthermore, the Defra 'Water for Life' White Paper (Defra, 2011) concluded that there was [at the time of writing] 'no economic case' for a blanket policy of dumb or smart water metering, as the nationwide benefits of metering are deemed to be highly variable. This influence on government policy outcomes and governance in general can be seen in practice, as at present many UK households remain un-metered, and metering schemes or initiatives remain optional for the customer in many cases (Bakker, 2001; NAO, 2005).

In relation to water metering and associated pricing issues, the Walker Review outlines a range of topics and challenges facing the water industry (Walker, 2009). In particular, the review considers; fairness principles; distribution of water charges; future charging systems for water supply and sewerage; efficiency, affordability, and debt; as well as the potential role of traditional and smart metering (Walker, 2009).

Specifically in the case of metering, the review produced a range of findings and recommendations, with some of these being applied in practice. Firstly, it is argued that meters currently being implemented by water providers have the potential to become AMR type meters, although the majority are traditional dumb types which severely limit the use of sophisticated tariffs that require frequent interval meter readings. Secondly, an opportunity to exploit and 'piggyback' communications systems used for smart energy metering is highlighted, with this being proposed as a method of reducing infrastructure costs associated with smart water metering. The review also suggests that leadership of smart metering initiatives in relation to water should be assumed by Ofwat, with a smart meter group being formed to determine the costs and benefits of smart water metering as well as maximising 'synergies' between the water and energy sectors. Notably, this recommendation was achieved in practice through the formation of a Smart Meter Advisory Group, led by Ofwat and inclusive of other relevant water and energy sector actors, namely; the Environment Agency; Defra; the DECC; the CCFW; and the Energy Saving Trust (Utility Week, 2013).

More recently, the Parliamentary Office of Science and Technology has produced an overview of the government position in relation to smart metering, with the general outcomes being linked to both the energy and water sectors respectively (HOP, 2014). It should be noted that the government has a plan for the national implementation of smart meters for electricity and gas, whereas the case for smart water metering is claimed to be variable and dependent on the specific water provider operating in a given region. At present, there are no government plans for the implementation of smart water meters at a national level. Secondly, it is argued that the changes in behaviour deemed necessary to achieve sufficient savings [or improved efficiency] through smart metering remain dependent on extensive and sustained consumer engagement. Lastly, the government also expresses concern relating to; potentially high costs associated with implementation; issues of uneven distribution of benefits for different sectors or industries and social groups; as well as emerging privacy and ‘cyber-security’ challenges associated with increased amounts of data produced by smart metering systems (HOP, 2014).

Moving on, it is important to consider the position of key water industry actors with regard to smart metering to form a picture of the wider governance backdrop. The prominent water industry/sector actors within the UK include; Ofwat; Water UK; the CCFW; Waterwise; and the individual water providers/companies. The position of each of these actors with regard to smart metering is briefly outlined below.

Ofwat

As the official water services regulation authority, Ofwat is primarily responsible for regulating the water industry and protecting the consumer (NAO, 2007). In terms of traditional and smart metering, Ofwat fully encourages the uptake of meters in order to help increase efficiency and encouraging fairer charging of water for consumers (Ofwat, 2011). It is suggested that in order to encourage the uptake of metering in general, three aspects should be achieved, namely; establishing the advantages and disadvantages of traditional and smart metering in order to help consumer decision-making; offering a range of tariffs directly associated with meters; as well as offering fully smart meters as an option to customers (Ofwat, 2011).

In terms of the roll-out of metering, Ofwat assumes that water companies will continue to install traditional meters. This is based on uncertainty regarding the costs and benefits of smart meters over traditional types. Thus, it is claimed that the role of smart metering still requires further analysis, and at present smart meters and AMRs are not considered in planning scenarios that are used to analyse future developments of the water sector/industry (Ofwat, 2008; Ofwat, 2011). In a practical sense, Ofwat tends to consider the arguments put forward for traditional or smart metering on a case by case analysis, and within the context of a given water provider's business plan and water resources management plan.

However, in the Ofwat report exploring the costs and benefits of metering (Ofwat, 2011), it is stated that the advent of smart metering may generate or increase benefits to both household and business consumers. These are manifest through aspects such as; better leakage management and control, as well as allowing consumers to monitor their consumption using in-home displays similar to the energy sector. Perhaps the most important signal of intent by Ofwat with regard to smart metering can be seen through the formation of a Smart Meter Advisory Group [which was disbanded in 2013 after failing to meet set objectives] (Darby, 2010; Defra, 2011; Utility Week, 2013). The Smart Meter Advisory Group [SMAG] was formed as a direct response to the Walker Review, and in order to bring together different actors that play a role in the general planning and implementation of smart metering within all utility sectors. The group sought to give advice on the role of smart metering in helping to deliver benefits for consumers and the environment. SMAG was led and driven by Ofwat and included actors such as; the Environment Agency; Defra; the DECC; the CCFW; and the Energy Saving Trust (Ofwat, 2011; Utility Week, 2013). Notably, the advisory group claimed that although smart metering is indeed feasible in the case of water, it would be greatly assisted through the usage of infrastructure put in place by the energy sector (Ofwat, 2011; HOP, 2014). In particular, it was argued that the transfer of data into the home through a local network may be problematic, as the majority of water meters are installed external to the property, and so this can inhibit the transmission of data from meter to home (Ofwat-SMAG, 2011; HOP, 2014).

Water UK

Water UK acts as a representative of the main water and wastewater service providers in England, Wales, Scotland, and Northern Ireland. The organisation focuses on influencing policy development at a national and European level, serving to represent water providers' interests via engagement with government and regulatory agencies (Water UK, 2014a). In relation to traditional forms of metering, Water UK uphold the viewpoint that the approach itself is indeed a more equitable and sustainable form of charging for water services. However, they also call for central government to offer a 'clear and effective policy framework' to better facilitate a shift towards widespread metering (Water UK, 2014b). In contrast, when considering the response to smart metering, it is apparent that the information put forward by Water UK is limited, with the most prominent being the response to the DECC consultation regarding the Ofgem Energy Smart Metering Implementation Programme (Water UK, 2010). The response to this consultation, which was developed alongside members and stakeholders, serves to highlight a range of viewpoints considered below.

Firstly, the development and implementation of smart metering technology is endorsed, with opportunities for cooperation between the energy and water sector in rolling-out smart metering recognised. Secondly, it is noted that the water industry is ‘some way’ from developing a coherent strategy on smart metering, and this requires some form of legislative steer. Water UK calls for the smart energy metering framework to be developed with flexibility so as to allow the integration of smart water metering via a single system. Finally, concerns are also raised in relation to issues surrounding the ownership and usage of smart metering data, the privacy of and access to data, as well as the additional costs that may be incurred by water companies in relation to storing data and providing required data services (Water UK, 2010). In relation to data privacy, the role of data governance has also been highlighted and explored by Water UK. In this respect, a range of concerns were identified as a consequence of the high time interval resolution generated by smart metering data. For example, concerns are based on water companies potentially being able to determine property occupancy, as well as when a given property is occupied.

Consumer Council for Water

The CCW acts as a representative of water and sewerage consumers in England and Wales, seeking to ensure that these consumers remain at the centre of the industry and their ‘collective voice’ is heard as part of the national water debate (NAO, 2007). In terms of traditional water metering, the CCW supports the view put forward by Defra that recognises the approach as being a more equitable form of charging. In relation to smart metering, three important aspects are identified. Firstly, it is stated that there is no current government directive which acts to compel water providers to implement smart water meters (CCFW, 2014). Secondly, the CCW maintains that each specific water company should decide which type of meter to install, with this being either traditional or smart types. Lastly, concerns relating to ‘electromagnetic sensitivity’ have also been identified, and this type of public health concern has been associated with smart meters based on their operation using radio waves and networks (PHE, 2014). In this case, consumers are referred to the appropriate agencies such as Defra and Public Health England.

Waterwise

Waterwise is an independent non-profit organisation, which considers itself to be a ‘leading authority on water efficiency in the UK’ (Waterwise, 2014b). The organisation seeks to promote engagement with water efficiency and actively works on a range of key activities, notably; campaigning; marketing; brokering partnerships; policy consultation; research; as well as water efficiency auditing services (Waterwise, 2014b; NAO, 2007).

Waterwise outlines a range of topics and viewpoints with regard to smart water metering, as made evident within the response to the DECC consultation on smart metering (Waterwise, 2012). In particular, they argue that the water industry should seek to build on government commitments within the energy sector and develop potential synergies with smart energy meters and infrastructure to generate savings (Waterwise, 2012). As a result, smart metering is viewed as referring to any smart type of meter that gives customers access to real-time usage data, with this data ‘steering’ behaviour (Waterwise, 2012). The final topic raised by Waterwise involves the practical application of smart meters and their networks. This considers the required acceptance and usage of specific network/radio frequencies in order to enable the roll-out of smart metering at a national scale. For instance, it is claimed that the water industry deems it necessary for smart infrastructure to accept frequencies, or indeed adopt variable signals, so that the [costly] requirement of additional meter modules or household network ‘bridges’ is minimized, thus helping to increase compatibility and connectivity as well as reducing costs (Waterwise, 2012).

5 Smart metering technology: installation, design, and interaction

In order to better understand smart metering it is necessary to further expand the somewhat vague definitions associated with this technology. This can be achieved through a better understanding of three variables that comprise smart metering technology and its implementation, namely; the drivers of *installation*; the process and system of *design*; as well as consumer *interaction*. Firstly, the term installation refers to the main drivers of smart metering and examples of application. The concept of design outlines the intelligent metering process, which involves different procedures that attempt to monitor and analyse water use. Lastly, the variable of interaction refers to management dynamics, barriers, and consumer attitudes in relation to smart metering, as well as how this interaction is manifest in reality through socio-demographic, contextual, and behavioural influences that serve to shape the consumer response.

5.1 Installation

When considering the factor of installation, a range of drivers associated with the deployment of smart metering can be highlighted as motives for implementation. For example, drivers of installation may include: attempts to better understand time-specific residential consumption; recognising the potential for water end-use savings in the home; exploring the potential for the application of different pricing structures; helping to identify and reduce leakages within the supply network; as well as seeking to encourage changes in behaviour and greater efficiency (Boyle *et al.*, 2013; Beal *et al.*, 2014).

As previously stated, the practical installation of smart water metering in the UK has been limited, with just a small number of water providers undertaking implementation. In this case, the driving motive of installation, as claimed by government and water providers, is to establish a fairer and more equitable system of allocation, in tandem with increasing efficiency (Darby, 2010; HOP, 2014).
In contrast, the deployment of smart water metering in Australia, specifically in regions such as Queensland, has been more rapid and widespread when compared to the UK. In this setting, prominent drivers for implementation included; dealing with acute scarcity; a need for proactive demand management; and the need to better understand end usage patterns in order to reduce wastage and over-consumption (Beal *et al.*, 2011).

Smart metering in the United States, specifically in states such as Utah and California, has been driven by the primary need to reduce consumption as a direct response to scarcity, while also recognising managing water resources during periods of high usage (Wells, 2013). Notably, smart meters have also been vital in allowing for the implementation of more complex tariffs and pricing structures, to encourage a shift towards more efficient behaviour (Wells, 2013). From a wider viewpoint, the installation of smart water meters in developing nations is seen to be a key aspect of demand management, with installation being driven by; the need to demonstrate transparency and accountability; more readily detecting leakage within the distribution system; as well as encouraging water conservation (Satterfield & Bhardwaj, 2005; Sarni & Pechet, 2013).

Moreover, in the case of smart energy metering, motives for implementation can often vary based on context, with some common principal motives being evident. For instance, in the United States [California] and Canada [Ontario] smart metering is primarily used as a tool for managing load/consumption and also reducing peak usage. In The Netherlands, the primary motive is demand reduction via more efficient behaviours. In Italy and Malta smart metering is utilised with a view to controlling and reducing issues of fraud (see Darby, 2010).

5.2 Design

Moving onwards, the second variable of smart metering technology involves the concept of design. This refers to how smart metering technology is implemented and how its position can be understood as part of the relationship and dynamic between a utility [water] provider and the consumer. With regard to the design-implementation process, previous research highlights how intelligent/smart metering is effectively a selection of components and procedures brought together to achieve better monitoring and analysis of water usage. This then helps to inform decision-making and planning in relation to water management (Boyle *et al*., 2013; Sarni & Pechet, 2013). According to Boyle *et al.* (2013) smart or intelligent metering systems and associated technology infrastructures are, by design, essentially ‘information feedback’ mechanisms that can be used as tools to aid decision-making. Fundamentally, intelligent metering systems are framed by four design processes, these are: measurement; the transfer of data; processing and analysis; as well as the feedback and communication of water use data (Boyle *et al*., 2013). These processes are outlined below;

Firstly, measurement refers to the type of technology used to gain information in relation to water consumption, with different meters being used such as displacement [piston], velocity [turbine], or electromagnetic variants. Measurements are gained using a form of data logging technology and may be taken in accumulation, pulse, or interval formats. More specifically, accumulation is based on a single reading of accumulated consumption; a pulse configuration provides a reading when a given pre-defined amount is used, with interval formats giving measurements of consumption over fixed periods of time (Sempere-Payá *et al*., 2013; Beal *et al*., 2014). In the UK, displacement [piston] meters are mainly used for households and small non-household premises, with turbine and electromagnetic types being used for the larger non-household customers [typically where a meter 50 mm and above is required].

Secondly, data transfer considers the means by which data gained by the meter is subsequently relayed to the utility provider and the customer. In this case, smart metering technology should allow data to be transferred from the meter/data logger via internet, in-home displays, or radio networks, with the frequency of data governed by the provider and the type of meter installed.

Thirdly, the processing and analysis of data involves the method through which data is gained and manipulated with this being communicated back to the consumer. Data may be aggregated and analysed in order to better understand usage patterns or trends, for instance helping to assess leakage, end-use status, or peak demand (Boyle *et al*., 2013; Britton *et al*., 2013).

Finally, the feedback and communication phase involves the pathway by which analysed data is communicated back to consumers through postal billing, email services, access through an online web portal, in-home display; or via smart-phone application (Boyle *et al*., 2013). The frequency of which this data is communicated depends on the provider, with access being in real-time, daily, monthly, and so on. However, the resolution of this data and feedback is once again dependent on the provider and the available technology both in terms of the meter system and the infrastructure in place (Boyle *et al*., 2013). It is also noted that the feedback phase itself, which should aim to facilitate suitable access to data over an appropriate timeframe, is crucial when seeking to frame an effective change in behaviour, and encourage a shift towards greater efficiency and reduced consumption (Lima & Navas, 2012; Beal *et al*., 2014). [The impact of behavioural influences is explored further within section 6.]

5.3 Interaction

After considering the factors of installation and design, it is important to reflect on the concept of interaction, which refers to the social and management interface of smart metering. In particular, this involves; utility providers dealing with management challenges; relationships between the provider and consumer; real-world limitations or barriers to uptake; as well as public interaction and attitudes to smart metering (Beal *et al*., 2014). The concept of interaction is explored through two main topics; firstly through management dynamics and barriers to uptake, and secondly through consumer attitudes to smart metering and the influences of socio-demographic, contextual, and behavioural factors. In addition, some findings from research relating to smart energy metering trials are also included within this section, as these serve to highlight consumer interactions with metering and are particularly relevant to potential application and interaction in the case of water.

Management dynamics and the producer-consumer relationship

As part of understanding the interaction process of smart metering, it is important to consider management dynamics associated with the approach, and how the dynamics of the producer-consumer relationship may become changeable due to the onset of smart metering technology. An alternative understanding of smart metering and its management [from a social and psychological perspective] emerges through ‘technical development pathways’ (see Marvin *et al.*, 1999), which attempt to comprehend how smart metering can develop along different paths as a result of specific influences. Essentially, it is argued that metering is a technical issue that can be analysed in further detail rather than merely through individual variables such as efficiency savings or cost of maintenance (Staddon, 2007). Smart water meters can instead be understood through social and technical development pathways, which aim to comprehend emerging restructured relationships between consumers and water providers (Devine-Wright, 2007; Staddon, 2007; Marvin, *et al.*, 2011).

In the context of the UK, the technical development pathway understanding suggests that new smart metering technology is emerging within the context of competing sector interests, namely; private water providers/companies, regulatory bodies, meter producers, telecommunication service providers, non-governmental groups, and consumers (Dooley, 1992; Staddon, 2007). It is claimed that each of these groups seeks to pursue their own technical interests, thus meaning that the socio-economic and environmental benefits of smart metering technology are fundamentally driven by often conflicting priorities, such as: financial costs; technology choices; access to data and privacy [of this data]; health concerns; as well as social acceptance (Guy & Marvin, 1995; Marvin *et al.*, 1999; Giurco *et al.*, 2010).

Marvin *et al.* (1999) emphasise that technological outcomes such as smart metering can often be shaped by different ‘logics’ [essentially different social representations] that subsequently shape technological development as a whole (Devine-Wright, 2007). In particular, it is argued that different ‘pathways’ may result in the marketing and installation of smart metering devices that would produce different technological contexts, which can cause individual behaviours that are reflective of this context (Devine-Wright, 2007; Marvin *et al.*, 2011). For example, a specific pathway may be designed to prompt minimal engagement with the consumer, with a different pathway seeking to encourage regular interaction and engagement. These contrasting technical pathways would likely result in two very different contexts for interaction, through factors such as user response and acceptance, awareness, motivation to be more efficient, as well as real-world action (Devine-Wright, 2007; Marvin *et al.*, 1999). It is worth noting that two distinct technical development pathways can be observed in relation to smart metering, namely; producer-led and user-led. These are explored below.

A producer-led technical development pathway involves the application of intelligent meters that can be remotely programmed by the utility provider and have their functions modified in real time, as well as more basic meters that gain enhanced communication abilities when these are added over time (Marvin *et al*., 2011). In essence, the producer-led aspect is based upon the utility provider having the ability to extend their control by offering additional services that gain information and help the provider structure tariffs and services accordingly. Thus, the offered tariffs and services can serve to influence how the consumer interacts with the smart metering system (Marvin *et al*., 2011; Zetland, 2011).

A user-led technical development pathway [which is poorly developed in the UK] shares similar technical components in comparison with the producer-led type, however the structure and organisation of interaction occurs in a very different way (Marvin *et al*., 2011). Essentially, instead of following the producer-led model by gaining information from the consumer and controlling tariff structures accordingly in an external way, the user-led pathway shifts the flow of data [consumption trends, tariffs, and conservation options for instance] and programming abilities in favour of the consumer (Marvin *et al*., 2011). This interaction is driven by the user and attempts to make the metering system more transparent, with consumption itself becoming more visible to the consumer (Staddon, 2007). In the UK, the user-led pathway has been severely limited by changes in the structure of the water industry, in particular caused by regulation such as the Water Act of 2003 (Staddon, 2007).

Alongside the dynamics of management, a range of perceived ‘barriers’ to smart/intelligent water metering can also be identified, which serve to generate challenges for implementation and interaction. These barriers often impact both utility providers and consumers. Firstly, an important barrier to be recognised in relation to smart water metering involves the issue of water providers needing to handle and analyse large volumes of data (Beal *et al*., 2014). In this sense, data must be stored and analysed in the correct way in order to maximise consumer access and engagement. For many providers this will require the development of new management skills, and even if data services are entrusted to specialist companies the understanding and translation of data into company policy remains necessary (Beal *et al*., 2014). The data gained from smart meters can be conceptualised as moving through a staged process, from ‘end use micro-component’ sets to ‘applied function’ data sets and to giving strategic direction (see Figure 4). As a result, it is this process that requires the development of management skills to understand data and utilise it as justification for a given management path.

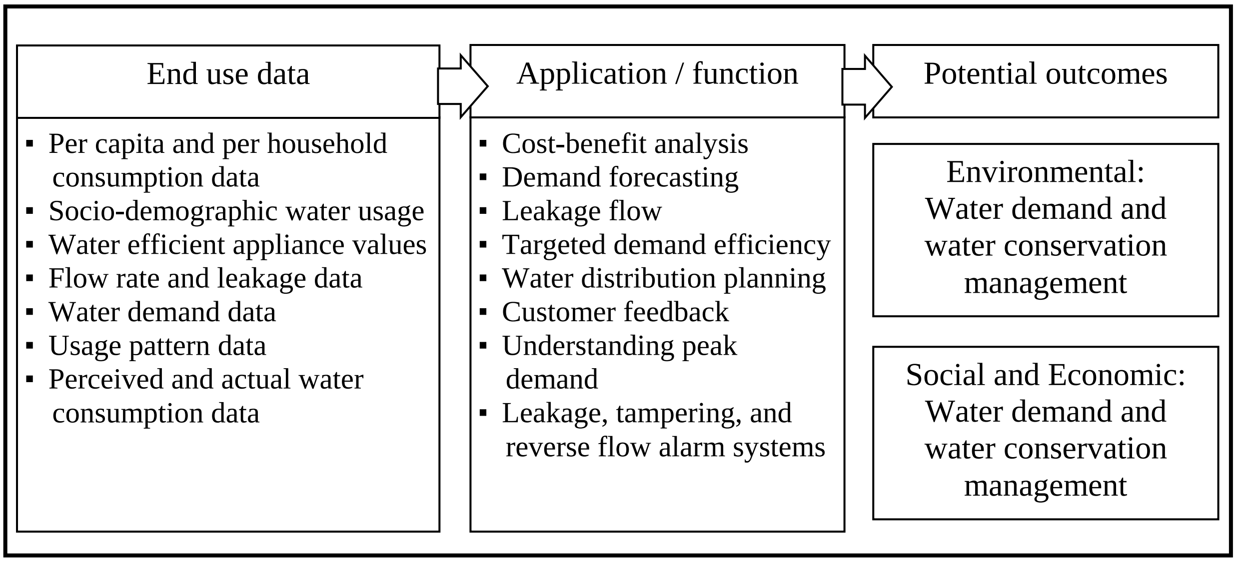

Figure 4: Management through smart water metering and resultant end-use data (Beal *et al.*, 2014)

Another important challenge generated by smart metering emerges through changes in the utility-customer relationship. The very foundation of smart metering, and its focus on increasing communication and access to information, means that the importance of this relationship is emphasized. For instance, customers having access to their water usage data should [ideally] help to improve the provider-user relationship. However, if a provider has a poor understanding of customer needs, this may be further highlighted by the smart metering system, thus potentially leading to lack of trust or even customer criticism, as illustrated by Costello (2012) in terms of customer service, as well as Robins (2012) in the case of the Australian electricity sector. It is argued that a utility-customer relationship may be negatively impacted by factors such as; service interruptions; problems with smart metering infrastructure; lack of transparency and poorly explained pricing or tariff structure changes; as well as security and privacy concerns with regard to data (Giurco *et al.*, 2010; Beal *et al.*, 2014).

The final barrier to be identified in this section is concern regarding data privacy and security, which emerges as a result of network control and the collection, analysis, and communication of data by the smart metering process. With regard to the topic of privacy, Giurco *et al* (2010) highlight potential issues such as usage data showing when a property may be vacant, or data revealing when customers have used more water than permitted during drought period restrictions. Although there is less concern if data is owned by the water provider, potential issues could arise if data is managed by a third party company (Rial & Danezis, 2011; NAO, 2011). Furthermore, indirect [less visible] privacy issues must also be considered as these can emerge as a result of data mining and customer profiling being done by the water provider (Giurco *et al.*, 2010; NAO, 2011). In this sense, targeted advertising could be used to promote products or services based on the type of water user, as defined by the obtained data. For example, garden products could be offered to those customers who consume more water for their garden, with incentivised plumbing services being advertised in areas with a high frequency of leakage (Beal *et al.*, 2014).

Alongside these privacy issues, the problem of [cyber] security also becomes evident. Smart meters often use onboard software [firmware] and are connected to a local network and the internet in order to communicate data (Ward, 2014). Therefore, a poorly protected device could be ‘open’ and vulnerable to manipulation. This issue is highlighted by Ward (2014), who comments on smart energy meters being ‘hacked’ and manipulated in order to mis-represent user data, falsify recordings, and under-report the amount of energy used by the consumer.

Before considering the role of provider and consumer attitudes to smart metering, it is important to highlight the findings of research produced by the UK national regulatory authority for energy [Ofgem - Office of gas and electricity markets] through the Energy Demand Research Panel, which relates to smart energy metering trials (Ofgem, 2011). These findings identify aspects with regard to consumer interactions with smart metering, such as; general application; advice; real-time/in-home displays; as well as practical and technical issues.

Initially, with regard to general application of smart meters, it is argued that the experience of getting and having a smart meter can itself cause an initial reduction in consumption (Ofgem, 2011). The findings suggest that this experience can prompt initial action, although long-term savings may require support through other additional measures, such as improved billing services or more information and advice about efficient behaviour for instance. Indeed, in the case of smart energy metering, consumers expected greater engagement regarding instructions after installation, and would have benefitted from greater engagement with the utility provider (Ofgem, 2011). This is an important point, as the findings of the EDRP study are consistent with the wider literature by agreeing that advice to guide more efficient behaviour can encourage a reduction in annual consumption.

Secondly, real-time displays are shown to play a role in terms of consumer interaction with smart metering, often prompting reductions in consumption, although these reductions can vary widely. Information regarding financial cost of usage was considered to be more important that basic unit information. These findings were also in agreement with the wider literature by claiming that appliance-specific feedback often influences efficiency [energy savings], with portable in-house displays being a feature deemed necessary by consumers (Ofgem, 2011).

Lastly, practical and technical issues are also identified by the research, with the notion that "one-size does not fit all" becoming apparent with regard to smart metering technology (Ofgem, 2011). For example, a range of challenges can often emerge, including; smart meter radio signal strengths being variable and dependent on geographical location; limitations when using networks for real-time displays, especially in the case of apartment buildings and communal housing; as well as the location of a smart meter within the boundaries of a given property (Ofgem, 2011). All of these factors influence the effectiveness of smart meter communication, as well as impacting on customer interaction and engagement, and more efficient behaviours.

Attitudes to smart metering technology

The second aspect of smart metering interaction, which operates alongside the dynamics of management and producer-consumer relationships, is argued to emerge through industry [provider/producer] and public [customer/ user/consumer] attitudes (Staddon, 2007; Darby, 2010).

From the perspective of the water sector, attitudes to smart metering are changing towards greater interaction, with this being shown by a [small] selection of providers who are pioneering the implementation of smart technology. In relation to consumer attitudes, it is possible to highlight a range of aspects that serve to shape meaningful interaction with smart metering technology. Firstly, it is argued that consumer attitudes may often be severely limited by a lack of knowledge when interpreting usage data that is communicated back to them by the water provider (Kempton & Layne, 1994). This can lead to limited engagement with the water saving process. Secondly, expanding on the point of limited knowledge in the context of energy smart metering, Krishnamurti *et al.* (2012) argue that users may often confuse smart meters with other 'enabling technologies' [such as in situ data displays], with the concept of perceived risk emerging as a consequence of limited knowledge or lack of transparency by the utility sector. In this sense, users can show concern for risks including: a feeling of reduced control with regard to usage; a notion of smart technology causing a violation of privacy; as well as the likelihood of increased costs associated with smart meters and continuous monitoring (Krishnamurti *et al*., 2012).

Kidd and Williams (2008) suggest that the fundamental understanding of consumption [in this case energy] remains a challenging cognitive issue for many users, with the display and communication of usage being vital in potentially adapting attitudes to smart technologies and shaping end-use behaviour (Hargreaves *et al.*, 2010) DECC (2012) recognise that a key motive to adopting smart metering technology is the opportunity to gain economic benefits from a change in behaviour or habit, for example by saving money through reducing consumption or gaining products and services from the water provider. Indeed, economic benefits or incentives are widely considered to be one of many key components when seeking to facilitate a change in ‘pro-environmental’ behaviour, with the case of smart metering being no different. The motive to save money often emerges as a key influence on attitude and positionality on a given topic, and this motive is considered to underpin the emergence and development of lower consumption habits (DECC, 2012).

Lastly, Krantz and Picot (2012) emphasise that attitude can be an influential determining factor with regard to intention, and subsequent changes in behaviour that can generate tangible outcomes. As a construct itself, attitude is noted as being potentially shaped by factors such as: the perceived usefulness of a given technology; the perceived ease of use for this technology; to what extent required changes in lifestyle will be worthwhile; and a consciousness in relation to economic costs (Krantz & Picot, 2012). It is also suggested that normative beliefs, which are often shaped by secondary sources, can emerge as important drivers of smart technology adoption, with the environmental concerns held by a given individual greatly influencing user attitudes and intention. For example, it is evident that an individual with greater concern for environmental damage and the effects of over-consumption is more likely to adopt smart technologies in an attempt to mitigate their concerns (Krantz & Picot, 2012).

The complexities are many and varied when considering social and psychological variables such as attitude in terms of the acceptance of smart technologies that aim to encourage more efficient behaviour. As a result, when attempting to better understand human interaction with smart metering technology, it is important to recognise the role and impact of socio-demographic, contextual, and behavioural factors. These variables extend the discussion on interaction, specifically in relation to the influence of consumer attitudes, and are briefly outlined in section 6 below.

6 The influence of socio-demographic, contextual and behavioural factors

A key aim of smart metering is to encourage water efficiency. However, this process of achieving greater efficiency, and essentially reducing wasteful consumption, is argued to be influenced by a range of variables (Darby, 2010; Krantz *et al.*, 2010; DECC, 2012; Krishnamurti *et al.*, 2012). Therefore, when considering attitudes to water conservation through smart metering and subsequent interaction with this technology, it is possible to broadly categorise the influences using four main groups. These include; socio-demographic factors [for instance; age, gender, and level of education]; contextual factors [such as access to technology and availability of suitable infrastructure]; external factors [such as institutional, economic, social, and cultural variables], as well as internal factors [for example; environmental concern, motivation, knowledge, awareness, perceived risk and control, perceived responsibility, and attached emotion] (Kollmuss & Agyeman, 2002; Gilg & Barr, 2006; Barr, 2007; Steg & Vlek, 2009; Jenkins & Pericli, 2014).

By understanding how smart metering is positioned in relation to these variables, we can recognise potential barriers to the acceptance of smart meters, whilst also considering the extent to which public engagement is limited or made possible (Staddon, 2007; Honebein *et al.*, 2009; Darby, 2010; Jenkins & Pericli, 2014). These different groups are explored in Table 2 below, with each variable being outlined and given meaning alongside a description of the influence it can have on consumer attitudes and smart metering.

Table 2: Influences on consumer attitude, water efficiency, and smart metering

Variable category	Influences on consumer attitudes and behavior
Socio-demographic ➩ **Age** Different groups represent varying ideas and perceived responsibilities ➩ **Gender** An inherent disposition to certain norms, which are often formed and shaped by other variables ➩ **Education** Level of education and access to resources that enable users to better understand issues such as water scarcity	▪ Exploration of socio-demographic variables, in terms of represented attitude and behaviour, has highlighted the importance of background conditions in the adjustment of attitudes towards efficient water usage. ▪ Gender exists as both a barrier [for males] and catalyst [for females] due to inherent values and attitudes associated with each group. Younger age groups often have a greater awareness, concern, and perceived responsibility for environmental issues such as water scarcity. ▪ Public communication is acknowledged as a key component of water conservation and smart metering. The process has often been implemented within an educational framework, which operates through the direct dissemination of information. Education can facilitate or limit engagement, for example in general terms regarding concepts of scarcity and the need for greater efficiency ▪ Socio-demographic factors may interact with other attitudinal constructs such as personal affect, social constructs, and subjective perceptions of risk, which often involve a convergence of knowledge, awareness, and concern. ▪

Variable category	Influences on consumer attitudes and behavior
Contextual ⇨ **Access to Technology** The access an individual has to smart metering technology and other necessary tools [In-home display or smart-phone] ⇨ **Infrastructure** The system and network in place used to facilitate smart metering ⇨ **Available services** The services offered by the utility provider to operate a smart system ⇨ **Information access** The ease of access given to the consumer with regard to usage data	▪ Contextual factors govern an individual's ability to implement a change in attitude through their subsequent behaviour. Behaviour remains partly dependent on adequate contextual or situational factors, and often, it is a combination of values, attitudes, and contextual opportunities that prompt a change in habits or activities. ▪ Individuals often represent positive basic intentions with regard to reducing water usage, despite evidence that many households are limited by the practical contextual or situational constraints such as; limited access to smart technology; lack of available [smart] infrastructure and [data transfer] services; infrequent billing; and poor access to usage information. ▪ It is unlikely that more efficient activities, such as the acceptance of smart meters or accessing usage data, will be adopted without the appropriate standard and availability of services or infrastructure. For instance, suitable infrastructure must be in place, namely; a fully smart meter; a smart grid or network; a tool for the communication of data. ▪ Provider services are also required, such as; data storage; data analysis; the transfer and communication of usage data; an online portal or smart-phone application; as well as frequent billing. ▪ A change in behaviour enabled by contextual factors may still be moderated [or limited] by internal and external variables.
Internal ⇨ **Concern** The concern represented by a given individual in relation to water scarcity, smart metering, and associated issues such as health and privacy/ security issues ⇨ **Knowledge** The knowledge held by consumers in relation to smart metering ⇨ **Motivation** Consumer motivation to adopt smart metering technology and reduce water consumption ⇨ **Perceived risk** The potential risks faced as a result of smart metering, as perceived by the consumer	▪ In relation to water consumption, efficiency, and smart metering, other dimensions of consumer attitude and behaviour emerge through concepts that are relative to a given individual, such as; concern, motivation, emotional involvement, responsibility, and perceived control or risk. ▪ Emotional links to specific topics or issues are widely shown to be very important in forming and developing core values, beliefs, attitudes, and cognitive judgements with regard to the environment and, more specifically in this case, water efficiency/conservation. ▪ Individuals may often represent a skewed perception of personal responsibility, through which water scarcity is considered to be a dilemma that is caused by other individuals or groups, in effect concluding that there is no need to take responsibility [often in economic terms through price increases or real costs defined by meters] for necessary solutions ▪ Factors such as motivation and perceived responsibility can decline through a lack of efficacy or ease of use [of a given technology], limited situational control, and, perhaps most damaging to potential behaviour change, a lack of trust in governing agents, institutions, and utility companies/providers. ▪ Internal variables may compel particular attitudes and patterns of behaviour. For instance, a personal experience [internal variable] of

Variable category	Influences on consumer attitudes and behavior
⇨ **Perceived Control** The control held in terms of accessing data and monitoring usage, as perceived by the consumer ⇨ **Responsibility** The responsibility a consumer feels in terms of adopting a smart meter and saving water ⇨ **Emotion** The emotional involvement a consumer has in a given issue such as water scarcity	water shortage conditions [contextual variable] may prompt an individual to form a positive attitude toward conservation [internal variable]. This can potentially encourage the adoption of new technology [smart metering] and facilitate a change in behaviour in order to avoid personal risks [for example risk to health, lifestyle, or increasing economic costs, which may vary depending on a given individual, situation, and context].
External ⇨ **Institutional trust** The trust consumers have in institutions, government agencies, and water providers ⇨ **Economic status** The economic setting at both a wider scale and in terms of an individual consumer ⇨ **Culture** The inherent disposition of a given culture with regard to smart metering, and related aspects such as accepting new technology and issues of privacy or security	▪ External factors, including institutional trust, economic status [both individual and collective], as well as cultural norms and values can influence attitudes and the potential acceptance/adoption of new technologies such as smart metering. ▪ Proposed water saving measures [such as smart metering] are often most effective when customers fully trust the guidance of government and water providers. For example, initiatives may be more effective when consumers understand the need to conserve water, recognise the potential consequences of inaction, and when they represent a sense of social responsibility. ▪ Limited access to information and a lack of transparency [by companies/providers] can lead to a lower level of consumer trust, which may cause users to be less willing to follow recommended actions as proposed by providers. This condition can encourage a sense of disengagement or disassociation with a given issue or proposed technology [such as smart metering] ▪ Economic ability can act as a catalyst for behaviour change, by affording a given individual more opportunities to adopt more efficient behaviour. For example, the ability of a company or individual to install a smart meter may be partly dependent on economic ability, if a smart meter is not currently offered by the water provider. ▪ The influence of culture on consumer attitude is recognised, but often difficult to analyse due to variation within a given national context.

(Sources: Schahn & Holzer, 1990; Appelgren & Klohn, 1999; Lam, 1999; Stern, 1999; Blake, 2001; Kollmuss & Agyeman, 2002; Vining & Ebreo, 2002; Gilg & Barr, 2006; Barr, 2007; Randolph and Troy, 2008; Krantz & Picot, 2012; Beal *et al.*, 2014; Jenkins & Pericli, 2014)

Although an understanding of the relationship between smart metering and consumer behaviour has been somewhat limited in a UK context, notable work has been carried out by industry bodies such as the Intelligent Metering Initiative [IMI] and UK Water Industry Research advisory group [UKWIR].

The IMI has sought to help the water industry to understand the potential value of smart/intelligent metering, as well as exploring consumer interaction and addressing the challenges of long-term implementation. The IMI holds a range of key objectives, including: developing a knowledge base and communicating information with regard to meter policies; identifying challenges to the water industry in terms of metering; as well as coordinating research in order to address challenges facing the water industry when implementing smart metering. In terms of consumer attitudes, appropriate cost-reflective tariffs are identified as an important potential outcome of smart metering.

UKWIR has produced a wide range of research [along with the IMI] that examines factors such as: costs and benefits of metering; functionality and roles in relation to both the provider and consumer; as well as forming a better understanding of consumer attitudes. Research investigating customer expectations and attitudes to smart water metering has generated some relevant findings. Initially, it has been claimed that customers often expected smart water metering to emerge alongside the roll-out of smart metering by the energy sector. This was seen as an opportunity to increase customer awareness and improve engagement, as well as building familiarity with the technology. Also, customers were shown to attach importance to certain smart meter features like leakage alarms, accurate billing, and in-home displays.

7 Changes in management and water usage as a result of smart meters

This section considers the role played by smart metering within the context of management approaches, water provider functions, as well as changes in water usage. Essentially, smart meters can generate a range of opportunities in relation to water provider functions and management practices, in particular with regard to; urban water planning; infrastructure planning; demand-side management; and customer engagement (Beal *et al.*, 2014). Each of these functions, which can be shaped by smart metering and cause subsequent changes in management and water usage, are considered in further detail below.

In the case of urban water planning, smart meters can be utilised in order to better understand patterns of water usage for residential, commercial, and industrial customers (Stewart *et al.*, 2010; Beal *et al.*, 2014). By having the ability to better understand consumption trends, urban planners can subsequently develop more efficient supply systems and use an integrated resource planning technique to consider potential changes to future demand and available supply (Stewart, 2011; Beal *et al.*, 2014). Smart metering can have a major influence in guiding the planning process based on a more comprehensive understanding of consumption and water usage patterns over a range of timescales (Beal *et al.*, 2014).

At the development level, a greater amount of data relating to peak demand helps to guide planning, with the identification of high leakage areas serving to ensure that utility provider resources for fixing leaks can be focused and applied appropriately (Beal *et al.*, 2014). Furthermore, in terms of long-term planning, smart meters may be used to gain large quantities of data that can help government agencies and water providers to better understand and analyse the potential outcomes of different strategies and future scenarios (Beal *et al.*, 2014). For instance, during periods of scarcity, smart meters can help providers better comprehend the potential for water savings through approaches such as direct restrictions or pricing changes, thus avoiding the need to expand infrastructure and increase supply using more expensive initiatives [such as desalination]. According to Beal *et al.* (2014) effective urban water management and planning often requires frequent and consistent data in order to better inform the decision-making process. In this sense, smart metering technology as well as the associated networks and infrastructure can be vital in supporting and facilitating more effective planning.

Alongside improved urban water planning, smart meters can also shape the planning and management of infrastructure. By utilising a smart metering system, the data made available relating to demand, supply, and water usage can assist with a range of management functions that directly relate to infrastructure and the supply system. These include: identifying leakages in households and the wider distribution system; monitoring patterns of water demand; as well as helping to produce more accurate predictive models regarding water and waste-water systems (Beal *et al.*, 2014). The capacity to achieve these functions can improve infrastructure planning and management, with this being demonstrated by Carragher, *et al.* (2012) within the context of an intelligent metering study in Australia. In this case, as a result of smart metering and the provision of real-time consumption data, it was possible to gain a greater insight into supply infrastructure management. A reduction in peak consumption and demand was highlighted, due to the use of more efficient appliances and fittings. This had a positive knock-on effect for the supply/distribution network, which benefited due to a reduced burden on pipe infrastructure and pumps, allowing them to be used for longer time periods and thus avoiding the need for expensive upgrades, as well as providing energy savings (Carragher *et al*., 2012).

Smart metering can also play an important role in facilitating more effective demand management approaches. According to Beal *et al.* (2014) water demand management may be considered in terms of five main aspects. These include: engineering [installing more efficient fittings and water-saving appliances]; economics [shaped by pricing structures and tariffs]; enforcement [achieved through restrictions or intermittent supply during drought periods]; encouragement [through public engagement and incentives to save water]; as well as education [promoting greater efficiency and water-saving practices such as switching-off the tap when brushing teeth or using a bucket to wash the car]. Smart metering is considered to be a vital component to improving the decision-making process, based on the frequent and high resolution data that can be transferred to the provider. The use of this data can enhance demand management strategies and facilitate a shift away from traditional ad-hoc and reactionary approaches which are prevalent in the water sector (Kennedy, 2010; Farrelly & Brown, 2011).

Demand management functions can be enhanced by smart metering through a variety of ways, with the three examples of demand forecasting, leakage reduction, and tariff reform subsequently outlined. In the case of demand forecasting, smart meters can provide descriptive statistics, such as flow rate, that can give the necessary inputs for more detailed demand management forecast models. These models may then be used to identify, analyse, and track changes in consumption. They can also serve to guide decision-making and highlight opportunities for measures design to better manage demand and changes in the supply system (Beal *et al*., 2014).

In terms of leakage reduction, high resolution smart meters can be used to identify and better manage leakages or non-registered flow. Through real-time monitoring, which is a key aspect of smart metering technology, water providers can respond quickly to major water leaks and also minimise operational costs, water waste/loss, and service issues for customers (Britton *et al*., 2008). Furthermore, smart metering can help water providers form new [or adapt existing] tariffs, which may further help to influence consumption behaviour and reduce demand. For example, tariffs may be based on time-of-use when seeking to reduce consumption in scarcity or peak usage periods (Dresner & Ekins, 2006; Zetland, 2011). As explored by Cole *et al.* (2012), smart tariffs are shown to have the potential to target specific users relative to water consumption, time periods, and types of usage, giving a type of flexibility and individual application that is often not possible through traditional tariff structures (Dresner & Ekins, 2006). Indeed tariff reforms within the energy sector serve to highlight the potential for this application.

Finally, in the context of water management and provider functions, smart metering also has the capacity to improve customer engagement. In contrast to current approaches and traditional forms of metering, smart metering technology provides a platform for the transfer of water usage data directly to the consumer (Darby, 2010; Beal *et al*., 2014). The functionality and operation of a smart system can help to encourage customer engagement and increase responsibility with regard to water usage as well as offering the customer a greater sense of ownership of the water they use (Darby, 2010). Therefore, by enabling consumers to take ownership, engage, and have a better understanding of their water consumption practices, it is possible to make them feel more empowered, and potentially support them to accept and apply targeted actions for improved efficiency and the conservation of water (Darby, 2010; Kennedy, 2010; Beal *et al*., 2014). A smart metering system can be an important tool for water providers and governments when transferring knowledge to consumers, with knowledge and direct engagement being an important aspect of a potential attitude and behaviour shift towards more efficient water usage.

8 The role of water efficient household appliances and fittings

Alongside the implementation of smart metering technology, it is important to consider the role of household appliances and fittings in achieving greater water efficiency. Within this section two main aspects are explored. Firstly, the influence of more efficient devices and appliances on water consumption and demand are discussed. Secondly, efforts to benchmark water efficient fittings and appliances are outlined in the context of emerging guidelines within both a UK and European context.

8.1 The impact of efficient devices on water demand

It is evident that household water consumption is dominated by shower, tap, washing machine, and toilet usage, with lesser amounts being consumed for dishwashers, baths, garden irrigation, and loss due to leakage (see Carragher *et al*., 2012). Through the identification of estimated usage, upgrades to more efficient fittings and appliances can be carried out.

Work by Willis *et al.* (2013) considers the relative water savings in households that use efficient devices, with a specific focus on showerheads and washing machines [termed 'clothes washers']. In this case, shower usage was the highest water consuming household activity, with it noted that high efficiency, low-flow showerheads can save significant amounts of water (see Mayer *et al*., 2004). For instance, based on an Australian case study; high efficiency showerheads consume just 6-7 litres per minute; medium efficiency showerheads use around 9-15 litres per minute; with standard [non-efficient] showerheads consuming between 15-25 litres per minute (see Willis *et al*., 2013). Washing machine efficiency can also vary greatly, as high efficiency types can use approximately 40-79 litres per wash; medium efficiency types require between 80-119 litres per wash; and standard [low] efficiency models can use as much as 120-170 litres per wash (see Willis *et al*., 2013). Thus, it is claimed that by replacing a low efficiency washing machine with a high efficiency type, a saving of around 14 cubic metres [or 14kL - kiloliters] per person per year is feasible (see Willis *et al*., 2013). Subsequently, Willis *et al.* (2013) go on to suggest that the combination of installing or retrofitting higher efficiency appliances/fittings can result in a significant reduction in overall water usage, with estimated savings of approximately one third of total water consumption. Indeed, the rationale for the application of more efficient appliances is further backed by associated financial benefits, through savings and reduced costs, as well as reasonable payback periods for consumers when purchasing more efficient appliances (Willis *et al*., 2013).

Appliance efficiency is also explored by Rathnayaka *et al.* (2014). In this case, it is considered a significant factor that greatly influences household water use, with the potential impact of appliances being noted to be greater during lower water usage and variability [the aspect of usage and variability in this sense relates to changes in consumption during times in the year]. The findings of this research claim that household size tends to be the most significant variable when determining residential water demand (Rathnayaka *et al*., 2014). However, household water consumption and demand is also shown to be strongly influenced by appliance/fitting efficiency, thus illustrating the importance of demand management schemes involving the installation or retrofitting of water efficient devices (Rathnayaka *et al*., 2014). Fittings and appliances such as efficient shower heads, dual flush toilets, and frontloading washing machines are shown to increase the potential for greater household efficiency (Rathnayaka *et al*., 2014). Each of these listed water efficient appliances are documented to provide significant water savings (see Makki *et al*., 2013), with Roberts (2005) arguing that more efficient front loading washing machines consume approximately 51% less water than standard low efficiency variants.

The influence of more efficient appliances on water consumption is summarised in Table 3. This brings together some relevant findings to highlight different conservation practices, appliances, and their resultant water savings (Lee *et al*., 2011).

Table 3: Estimated water savings from more efficient fittings and appliances

Study information	**Water saving fittings and appliances**	**Water savings** [GPHD][a]	 [LPHD][b]
Beal, Stewart, Huang & Rey (2011): Residential end-use study considering the influence of appliance efficiency.	Water efficient washing machine	**8**	**30.3**
	High efficiency shower head	**9.4**	**35.6**
Tsai, Cohen, & Vogel (2011): Impact assessment of water use and conservation strategies [retrofit kits].	Low water demand toilet	**11.4**	**43.1**
	Water efficient washing machine	**15.6**	**59**
Cooley et al. (2010): Considers the potential capacity for water savings. More efficient appliances are analysed, with this also being carried out alongside meters, changes in behaviour, and financial incentives.	Low flow high efficiency toilet	**23.8**	**90.1**
	High efficiency shower head	**12.1**	**45.8**
	Water efficient washing machine	**27.9**	**105.6**
	Tap aerator	**1.7**	**6.4**
Mayer et al. (1999): Study considering residential end-uses of water and how these differ based on the installation or retrofitting of conserving devices. Identifies variation in water used in relation to fittings and appliances.	Ultra low flow toilet	**29.4**	**111.3**
	High efficiency shower head	**10.2**	**38.6**
	Water efficient washing machine	**20.1**	**76.1**
	Tap with aerator and sensor	**9.3**	**35.2**

[a] GPHD: Gallons per household per day
[b] LPHD: Litres per household per day

(Sources: Beal *et al*., 2011; Lee *et al*., 2011; Tsai, *et al*., 2011; Cooley *et al*., 2010; Mayer *et al*., 1999)

Before moving on to consider attempts to benchmark water efficient appliances and fittings, it is important to outline two important aspects relating to smart metering and appliance use. Firstly, the use of smart technology to control appliance use is an emerging management tool for encouraging efficiency, with this being primarily promoted in terms of energy but also becoming relevant with regard to water. For example, by controlling appliance use, water efficient appliances can be switched on or off relative to tariff status or in order to manage periods of peak demand. Secondly, a link between energy use and water use can also be highlighted. Smart technology is argued as having the potential to strengthen this link, due to the significant amounts of energy used to heat water. Such potential 'synergies' are suggested to also be worthwhile and necessary by the Walker Review (Walker, 2009). In particular, it is highlighted that smart meters and efficient appliances/fittings play a key role in facilitating resource [water and energy] savings, while also enabling greater financial savings for the consumer based on reduced water consumption, which also results in less energy usage.

8.2 Attempts to benchmark water efficient fittings and appliances

Historically, a focus has often been placed on improving fittings, such as taps, bathroom fittings, and water-saving toilets for instance (Defra, 2008). More recently attention has shifted to also include household appliances (Carragher *et al.*, 2012). In the context of the UK, efforts to encourage and benchmark water efficient fittings and appliances have been driven through Defra, and to a lesser extent Waterwise. Within the broader context of the EU, work has also focused developing an EU water labelling scheme for fittings and appliances. This scheme has arisen via the support of a wide range of national government agencies and relevant water industry organisations (Orgill *et al.*, 2014). The following section outlines these relevant advances with regard to the development of water efficient appliances and fittings, as well as associated guidelines and benchmarks.

Defra - ECA water technology list

In order to benchmark and better understand the efficiency of water fittings, appliances, and devices, Defra and HM Revenue and Customs [within the context of the UK] have developed an Enhanced Capital Allowance [ECA] scheme for water efficient technologies (ECA, 2014). This initiative seeks to encourage investment in new water efficient fittings, devices, and appliances, and is currently applicable for business users. In essence, it allows these users to purchase efficient technology and benefit from an economic incentive of claiming tax relief or allowance (ECA, 2014; HMRC, 2014). As part of the ECA scheme, a technology list has been compiled to give users guidance in relation to suitable water efficient choices to be installed. For example, the list gives guidance for a range of efficient fittings and appliances, including: showers; taps; toilets; washing machines; industrial cleaning equipment; as well as devices such as flow controllers and water meters (ECA, 2014).

Waterwise

In a UK context, Waterwise has sought to provide water saving advice which includes research on household attitudes to water efficient appliances, as well as guidance for technology, appliances, and actual changes in practice.

A report on household attitudes to water economy and efficient appliances has served to highlight a range of key points with regard to appliances and their role in facilitating more efficient future pathways (Waterwise, 2009). Firstly, it was found that there was greater potential for the installation of water saving appliances or facilities through retrofitting existing homes, with refurbishment [often apparent in homes with recent change of occupier] more likely to prompt the installation of new water efficient appliances and fittings (Waterwise, 2009). Secondly, it was noted that the cost-savings given by more efficient appliances were the main driving factor for installation and change, with water efficient showers and dual-flush toilet being more popular than comparable bath and tap options (Waterwise, 2009). Lastly, the report highlights an apparent attitude change after consumers were given more information with regard to the potential water and monetary savings afforded by more efficient appliances and fittings. On the one hand, a positive attitude change emerged through the acceptance of dual-flush toilets, with water efficient taps considered to be less favourable due to their perceived inconvenience being greater than associated [perceived] benefits (Waterwise, 2009).

Moreover, alongside this research, Waterwise also provides advice to consumers in terms of specific areas of water usage, namely; the bathroom; kitchen; garden; workplace; and also personal activities (Waterwise, 2014a). For example, in the bathroom, advice is given relating to water efficient toilet, bath, and tap installations as well as leakage detection and repair. Advice is also given in relation to improving individual water usage practices, such as changing showerheads and also attempting to reduce shower duration. Next, in the kitchen, the installation of new efficient appliances and fittings is encouraged, such as more efficient dishwashers and taps, with advice relating to outdoor garden activities focused on avoiding the use of sprinklers [and other inefficient/high consumption equipment]. In addition, workplace advice is also provided, with this highlighting the need for: site maintenance, such as using water audit services and checking for leaks; more efficient kitchen fittings [such as spray taps] and appliances; and notably, the need to educate employees in the importance and practice of water efficiency (Waterwise, 2014a).

EU water label

In a European context, a water labelling scheme for appliances has been developed with the support of national government agencies and industry actors. The scheme is operated by an independent organisation [named The Water Label Company], and has been recognised in a range of countries, such as France, Germany, and the UK (Orgill *et al.*, 2014). The label itself has been designed in order to provide a easy to use guide of the water consumption values of different products, mainly bathroom and kitchen water-using products. It aims to offer freedom of choice for consumers and is based on the labelling used in the energy sector. The performance of a given product is displayed in terms of different 'performance bands' that differentiate the extent to which water is used by a specific product or fitting according to a unit of measurement (see Figure 5).

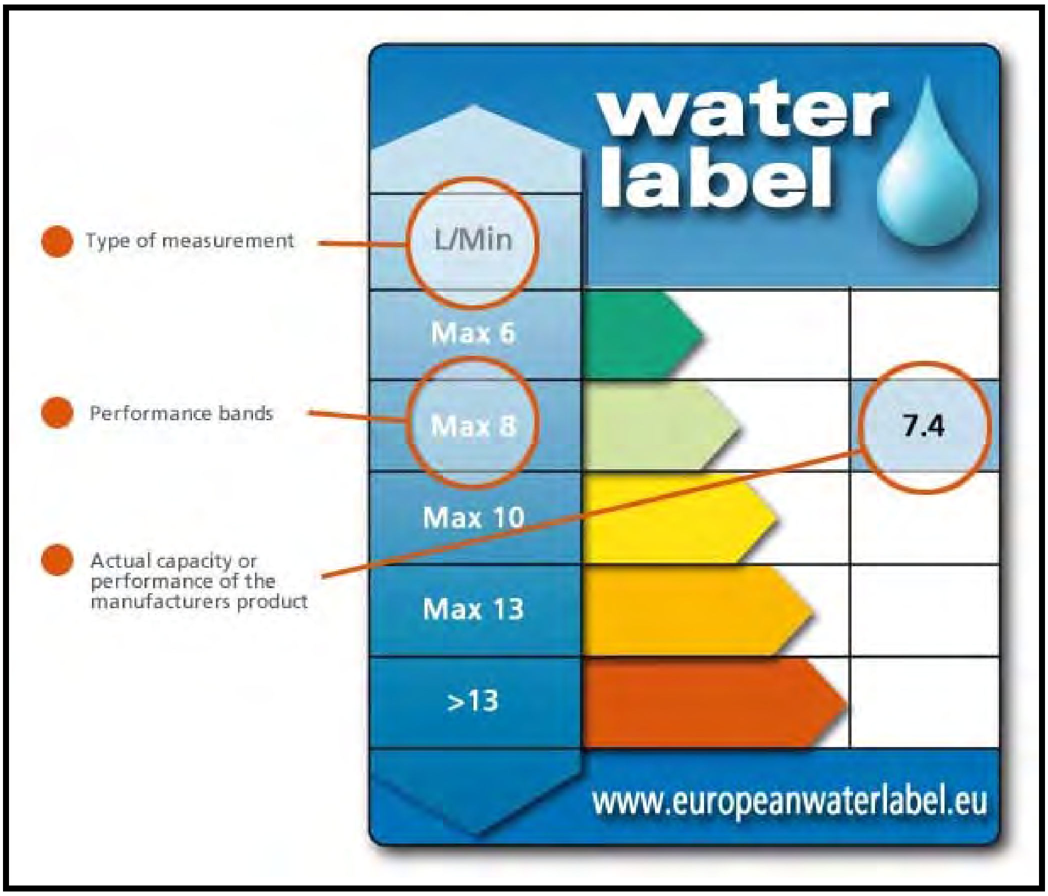

Figure 5: EU water label (EU Water Label, 2014)

Approximately twelve different product categories are defined as part of the scheme, with each of these categories containing a range of products made by different manufacturers. These categories include: baths; basin taps; shower controls; shower handsets; grey water recycling units; kitchen taps; electric showers; replacement WC flushing devices; supply line flow regulators; urinal controllers; cisterns; and WC suites (EU Water Label, 2014; Orgill *et al*., 2014).

The rationale for the labelling scheme is manifest through the desire to save water by encouraging more efficient choices, with a widespread initiative being seen as a way to make it easier for consumers to select products based on a more informed selection process. Manufacturers or brands can register with the scheme, with specific products [put forward as part of the labelling scheme] then being listed in a database and categorised using measures and performance to give a label classification (Orgill *et al*., 2014). Products are audited in order to check compliance, with labelling and related consumption information found on products or their packaging, in catalogues, at the point of sale, or within an online database (EU Water Label, 2014).

9 Conclusion: making smart meters work

(1) This review has sought to provide a broad understanding of smart metering, which is viewed as being vital to reducing water demand and facilitating more effective management of water resources. Smart metering technology has the potential to enable governments and water providers to more effectively and sustainably manage water resources.

(2) A definition of smart metering has been formed. In particular, smart meters can be defined as meters that; recognise, identify, and communicate consumption in greater detail; communicate via networks and allow data to be used by consumers as well as utility providers for monitoring and billing purposes; measure, store, and communicate data at specific pre-determined time intervals; facilitate the rapid transfer of data that can be analysed to identify leakages; and enable improved communication between the supplier and consumer.

(3) Smart metering offers a range of benefits, in particular: providing a better understanding of water usage; enabling user involvement by giving customers the opportunity to gain real-time [or near real-time] data with regard to consumption; encouraging consumers to increase their efficiency due to an incentive driver; having the capacity for automated reading and communication of data; enabling greater access and interaction with data; as well as allowing utility providers to

make use of real-time data to monitor the supply network and respond to management issues such as leakages.

(4) This review has served to highlight five key challenges in relation to making smart meters work. These are:

(i) The need for a clearer definition of smart metering [in a UK context], with ambiguous or interchangeable definitions potentially serving to hinder the public understanding of smart metering technologies.

(ii) From a UK perspective, the governance backdrop relating to smart metering definitions, guidelines, and implementation procedures has been important in shaping the response and adoption of this technology in the energy sector. In contrast, the government response to smart metering of water usage has been limited. It is argued that smart water metering is less advanced [in comparison to the energy sector] as a result of different regulatory frameworks and legislation, with politics serving to shape the potential development of this technology.

(iii) Attitudinal, behavioural, and social variables have been highlighted as having a major influence on water efficiency initiatives, and more specifically smart metering. Therefore, such variables as: socio-demographic factors [age, gender, income, education]; contextual factors [access to technology and availability of suitable infrastructure/technology]; external factors [institutional, economic, social, and cultural variables]; as well as internal factors [concern, knowledge, awareness, motivation, perceived risk, personal responsibility, and emotional involvement], require further research.

(iv) The need to recognise the important role of other water-saving tools or initiatives, such as the use of more efficient fittings and household appliances. These can offer benefits when utilised alongside smart meters, potentially allowing for people to respond to usage information conveyed to them via smart meters and subsequently alter their behaviour.

(v) There is a need to consider the practical and technical issues of smart metering, which involve limitations associated with engineering and available technology. For example, these issues include: a lack of inter-compatible meter types and guidelines on the selection and implementation of meter types and systems; limitations of meter battery life; issues when using networks for real-time displays, especially in buildings such as apartments; smart meter radio signal strengths that are variable and dependent on geographical location; as well as issues relating to the location of a smart meter within the boundaries of a given property.

(5) A range of operational drivers are associated with smart metering, which may influence implementation by the water provider. For instance, smart meters can enable better customer service through a range of factors, such as: the capacity to read a meter on demand; a quicker response and improved ability when dealing with customer enquiries; as well as more accurate billing. Other operational drivers also emerge including; the development of new services; reduced meter reading costs; and improved leakage detection.

(6) There is real potential for a link between energy and water smart metering. Potential synergies are suggested to be worthwhile and necessary, especially as energy is often used as part of water consumption. Furthermore, smart technology can play a key role in controlling appliance use, and acting as a management tool for encouraging greater efficiency. For example, water efficient appliances can be switched on or off according to tariff status or in response to peak demand.

(7) The widespread application of smart meters could see many benefits as well as long term financial savings through aspects such as leakage reduction for instance. However, it must be noted that smart metering should not be seen as the saviour of water [demand] management. Such a view would be naive, as it should be recognised that a diverse array of issues can influence the impact smart meters have. Smart metering is just one potential aspect of water management that must work alongside the variables of attitude and behaviour, which remain perhaps the most difficult to change due to a gap between attitude and tangible behaviour (Kollmuss & Agyeman, 2002; Jenkins & Pericli, 2014). Consequently, smart metering should not be seen as a final outcome in itself, but instead as a tool that has the potential to meet the needs of supply and demand management, thus helping to achieve the objectives of sustainable water management in the future.

10 References

Affinity Water (2013) Metering. Accessed November 17th 2014 from: https://www.affinitywater.co.uk/metering.aspx

Albion Water (2013) Metering information. Accessed November 17th 2014 from: http://www.albionwater.co.uk/customer_read-meter.php

Anglian Water (2014) Water meters. Accessed November 17th 2014 from: http://www.anglianwater.co.uk/household/water-meters/

Appelgren, B. & Klohn, W. (1999) Management of water scarcity: a focus on social capacities and option. *Physics and Chemistry of the Earth:* Part B, *24*(4), 361-373.

Bakker, K. J. (2001). Paying for water: water pricing and equity in England and Wales. *Transactions of the Institute of British Geographers*, *26*(2), 143-164.

Barr, S. (2007). Factors influencing environmental attitudes and behaviours. *Environment and Behavior*, *39*(4), 435-473.

Beal, C. and Stewart, R. (2014). Identifying Residential Water End Uses Underpinning Peak Day and Peak Hour Demand. *Journal of Water Resources Planning and Management*, 140(7).

Beal, C., Stewart, R., Giurco, D., & Panuwatwanich, K. (2014). Intelligent metering for urban water planning and management. In. Adeyeye, K. (Ed.). *Water efficiency in buildings: theory and practice*. West Sussex, U.K: John Wiley & Sons.

Beal, C., Stewart, R. A., Huang, T., & Rey, E. (2011). Smart water systems and metering: SEQ residential end use study. *Journal of the Australian Water Association*, *38*(1), 80-84.

Blake, D. E. (2001). Contextual effects on environmental attitudes and behavior. *Environment and Behavior*, *33*(5), 708-725.

Boyle, T., Giurco, D., Mukheibir, P., Liu, A., Moy, C., White, S., & Stewart, R. (2013) Intelligent metering for urban water: a review. *Water*, *5*, 1052-1081.

Bristol Water (2014) Water meters. Accessed November 17th 2014 from: http://www.bristolwater.co.uk/your-home/water-meters/

Britton, T., Cole, G., Stewart, R., & Wisker, D. (2008) Remote diagnosis of leakage in residential households. *Water: Journal of the Australian Water Association*, *35*(6), 89-93.

Britton, T. C., Stewart, R. A., & O’Halloran, K. R. (2013) Smart metering: enabler for rapid and effective post meter leakage identification and water loss management. *Journal of Cleaner Production*, *54*, 166-176.

Cambridge Water (2014) Meters. Accessed November 17th 2014 from: http://www.cambridge-water.co.uk/customers/meters

Carragher, B., Stewart, R., & Beal, C. (2012) Quantifying the influence of residential water appliance efficiency on average day diurnal demand patterns at an end-use level: a precursor to optimised water service infrastructure planning. *Resources Conservation and Recycling*, *62*, 81-90.

CCFW – Consumer Council for Water (2014) Electromagnetic sensitivity and smart water meters. Accessed November 12th 2014 from: http://www.ccwater.org.uk/waterissues/currentkeywaterissues/electromagnetic-radiation-and-smart-water-meters/

Chambouleyron, A. (2004) Optimal water metering and pricing. *Water Resources Management*, 18(4), 305-319.

Cholderton Water (2014)Water plans - metering. Accessed November 17th 2014 from: http://www.choldertonwater.co.uk/catalogue.php?cat=256

Climate Group (2008) Smart 2020: Enabling the Low Carbon Economy in the Information Age Report by The Climate Group on behalf of the Global eSustainability Initiative (GeSI). Available at: http://www.gesi.org/

Cole, G., Stewart, R., & O'Halloran, K. (2012) Time of use tariffs: implications for water efficiency. *Water Science and Technology: Water Supply*, 12(1), 90-100.

Cooley, H., Christian-Smith. J., Gleick, P. H., Cohen, M. J., Heberger, M., Ross, N., United States: Pacific Institute.

Costello, K. (2012) Should utilities compensate customers for service interruptions? *The Electricity Journal, 25*(7), 45-55.

Darby, S. (2010) Smart metering: what potential for householder engagement. *Building Research and Information, 38*(5), 442-457.

Darby, S. (2011) Communicating energy demand: measurement, display, and the language of things. In Whitmarsh, L., O'Neill, S., & Lorenzoni, I. (Eds.). *Engaging the public with climate change: behaviour change and communication*. London, U.K: Earthscan.

DECC - Department of Energy and Climate Change. (2009) *Towards a smarter future: government response to the consultation on electricity and gas smart metering*. London, U.K: The Stationery Office.

DECC - Department of Energy and Climate Change (2012) *Smart meters: research into public attitudes*. London, U.K: DECC.

DECC – Department of Energy and Climate Change (2015). *Smart meters, smart data, smart growth*. London, U.K: DECC.

Dee Valley Water (2009) Your water meter. Accessed November 17th 2014 from: http://www.deevalleywater.co.uk/article.php?id=55

Defra (2006) Archive: water metering and charging. Accessed November 5th 2014 from: http://archive.defra.gov.uk/environment/quality/water/industry/metering/

Defra (2008) Consumer attitudes to water efficiency of bathroom fittings: quantitative research. London, U.K: Defra.

Defra (2011) Water for life. U.K: The Stationary Office.

Devine-Wright, P. (2007) Energy citizenship: psychological aspects of evolution in sustainable energy technologies. In Murphy, J. (Ed.). *Governing technology for sustainability*. Oxon, U.K: Earthscan.

Dooley, T. (1992) Which way through the metering maze? *Electrical Review*, 33-34.

Dresner, S. & Ekins, P. (2006) Design of environmentally and socially conscious water metering tariffs for the UK. *Journal of Environmental Planning and Management*, *49*(6), 909-928.

Dŵr Cymru (2014) Water meter. Accessed November 17th 2014 from: http://www.dwrcymru.com/en/My-Account/Water-Meter.aspx

Dziegielewski, B. (2003) Strategies for Managing Water Demand. *Journal of Contemporary Water Research and Education*, 126(1), 29-39.

ECA (2014) New technology application. Accessed December 5th 2014 from: http://wtl.defra.gov.uk/start_tech_app.asp?section=51

Environment Agency (2013) Water stressed areas: final classification. Bristol, U.K: Environment Agency.

Environment Agency (2014) What we do. Accessed November 22nd 2014 from: https://www.gov.uk/government/organisations/environment-agency/about

Essex and Suffolk Water (2014) Water meters - options. Accessed November 17th 2014 from: https://www.eswater.co.uk/your-home/your-account/considering-a-water-meter.aspx

EU Water Label (2014) The label. Accessed December 8th 2014 from: http://www.europeanwaterlabel.eu/thelabel.asp

Farrelly, M. & Brown, R. (2011) Rethinking urban water management: experimentation as a way forward? *Global Environmental Change, 847*.

Ferreira, V., Fleming, P., Stuart, G., Patel, P., Webber, P., Conway, S. (2007) Low hanging fruits or cost effective energy and water savings using intelligent metering and monitoring systems? In Proceedings of European Council for Energy Efficiency. Summer Study. 739-742.

Gilg, A. & Barr, S. (2006) Behavioural attitudes toward water saving? Evidence from a study of environmental actions. *Ecological Economics*, *57*(3), 400-414.

Giurco, D., White, S. & Stewart, R. (2010) Smart metering and water end-use data: conservation benefits and privacy risks. *Water*, *2*(3), 461-467.

Gleick, P. H. (2000) The changing water paradigm: a look at twenty-first century water resources development. *International Water Resources Association*, 25(1), 127-138. consumption. *Journal of Applied Social Psychology*, *33*(6), 1261-1296.

Grigg, N. S. (2011) *Water finance: public responsibilities and private opportunities*. New Jersey, United States: John Wiley.

Guy, S. & Marvin, S. (1995) Pathways to ‘smarter’ utility meters: the socio-technical shaping of new metering technologies. Working paper number 56.

Centre for Urban Technology, Department of Town and Country Planning, University of Newcastle.

Hargreaves, T. (2014) Smart meters and the governance of energy use in the household. In Stripple, J. & Bulkeley, H. (Eds.). *Governing the climate: new approaches to rationality, power and politics*. Cambridge, U.K: Cambridge University Press.

Hargreaves, T., Nye, M., & Burgess, J. (2010) Making energy visible: a qualitative field study of how householders interact with feedback from smart energy monitors. *Energy Policy, 38*, 6111-6119.

Hill, T. (2011) The smart grid for water. *Water Efficiency: the journal for water resource management*, May-June, 50-51.

HMRC (2014) Enhanced capital allowance scheme. Accessed December 5th 2014 from: http://www.hmrc.gov.uk/capital-allowances/fya/water.htm

Honebein, P. C., Cammarano, R. F., & Donnelly, K. A. (2009) Will smart meters ripen or rot? Five principles for embracing customers as co-creators of value. *The Electricity Journal, 22*(5), 39-44.

HOP – Houses of Parliament: Parliamentary Office of Science and Technology. (2014). Smart metering of energy and water. no 471. London, U.K: The Parliamentary Office of Science and Technology.

Hunn, N. (2010). *Essentials of short-range wireless*. Cambridge, U.K: Cambridge University Press.

Idris, E. (2006) Smart Metering: A Significant Component of Integrated Water Conservation Systems. Proceedings of the 1st Australian Young Water Professionals Conference, Sydney, Australia, 15–17.

Independent Water Networks (2014) The benefits of a meter. Accessed November 17th 2014 from: https://www.iwnl.co.uk/domestic/your-meter-reading.php

Jenkins, J. & Pericli, A. (2014) Understanding consumer response to water efficient strategies. In Adeyeye, K. (Ed.). *Water efficiency in buildings: theory and practice*. West Sussex, U.K: Wiley Blackwell.

Jones, R., Pykett, J., & Whitehead, M. (2013). *Changing behaviours: on the rise of the psychological state*. U.K: Edward Elgar.

Kempton, W. & Layne, L. L. (1994) The consumer's energy environment. *Energy Policy,* 22(10), 857-866.

Kennedy, A. (2010) Using community-based social marketing techniques to enhance environmental regulation. *Sustainability, 2*(4), 1138-1160.

Kidd, A., Williams, P. (2008) The Talybont trial: exploring the psychology of smart meters. U.K: The Prospectory.

Kollmuss, A. & Agyeman, J. (2002) Mind the gap: why do people ac environmentally and what are the barriers to pro-environmental behaviour? *Environmental Education Research, 8*(3), 239-260.

Krantz, J. & Picot, A. (2012) Is it money or the environment? An empirical analysis of factors influencing consumers' intention to adopt smart metering technology. AMCIS Proceedings Paper 3.

Krantz, L. M. U., Gallenkamp, J., & Picot, A. O. (2010) Exploring the role of control - smart meter acceptance of residential consumers. *AMCIS 2010 Proceedings.* Paper 315.

Krishnamurti, T., Schwartz, D., Davis, A., Fischhoff, B., de Bruin, W. B., Lave, L., Wang, J. (2012) Preparing for smart grid technologies: A behavioural decision research approach to understanding consumer expectations about smart meters. *Energy Policy, 41*, 790-797.

Lam, S. P. (1999) Predicting intentions to conserve water from the theory of planned behaviour, perceived moral obligation, and perceived water right. *Journal of Applied Psychology, 29*(5), 1058-1071.

Lee, M., Tansel, B., Balbin, M. (2011) Influence of residential water use efficiency measures on household water demand: A four year longitudinal study. *Resources, Conservation and Recycling, 56*, 1-6.

Lima, C. A. F. & Navas, J. R. P. (2012) Smart metering and systems to support a conscious use of water and electricity. *Energy, 45*, 528-540.

Makki, A. A., Stewart, R. A., Panuwatwanich, K., & Beal, C. (2013) Revealing the determinants of shower water end-use consumption: enabling better targeted urban water conservation strategies. *Journal of Cleaner Production, 60*, 129–146.

Marvin, S., Chappells, H., & Guy, S. (1999) Pathways of smart metering development: shaping environmental innovation. *Computers, Environment and Urban Systems, 23*(2), 109-126.

Marvin, S., Chappells, H., & Guy, S. (2011). Smart meters as obligatory intermediaries: reconstructing environmental action. In Guy, S., Marvin, S., Medd, W. & Moss, T. (Eds.). *Shaping urban infrastructures: intermediaries and the governance of socio-technical networks*. London, U.K: Earthscan.

Maurice-Smith, M. & Brogden, J. (2008) Intelligent metering for water - potential alignment with energy smart metering. London, U.K: Environment Agency.

Mayer, P. W., DeOreo, W. B., Opitz, E. M., Kiefer, J. C., Davis, W. Y., Dziegielewski, B. (1999) Residential end uses of water. Dever, CO: American Water Works Research Association Foundation and American Water Works Association; 1999.

Mayer, P., DeOreo, W., Towler, E., Martien, L., & Lewis, D. (2004) *Tampa Water Department Residential Water Conservation study: The Impacts of High Efficiency Plumbing Fixture Retrofits in Single-Family Homes*. United States: Aquacraft.

Memon, F. A. & Butler, D. (2006) Water consumption trends and demand forecasting techniques. In. Butler, D. & Memon, F. A. (Eds.). *Water demand management*. London, U.K: IWA Publishing.

NAO – National Audit Office (2005) *Environment Agency: efficiency in water management*. London, U.K: National Audit Office.

NAO – National Audit Office (2007) *Ofwat: meeting the demand for water*. London, U.K: National Audit Office.

NAO – National Audit Office (2011) *Preparations for the roll-out of smart meters*. London, U.K: The Stationary Office.

Northern Ireland Water (2014) Read your meter - and other information. Accessed November 19th 2014 from: http://www.niwater.com/read-your-meter.aspx

Northumbrian Water (2014) Water meters - considering a water meter? Accessed November 19th 2014 from: https://www.nwl.co.uk/your- home/your-account/considering-a-water-meter.aspx

Ofgem. (2011). *Energy Demand Research Project: Final Analysis*. Hertfordshire, U.K: AECOM.

Ofwat (2008) *Response to the Energy Smart Metering Implementation Programme Prospectus*. Birmingham, U.K: Ofwat.

Ofwat (2011). *Exploring the costs and benefits of faster, more systematic water metering in England and Wales*. Birmingham, UK: Ofwat.

Ofwat (2014a) Paying by rateable value. Accessed November 10th 2014 from: http://www.ofwat.gov.uk/consumerissues/chargesbills/unmetered/rv

Ofwat. (2014b) Metered charges. Accessed November 10th 2014 from: http://www.ofwat.gov.uk/consumerissues/chargesbills/metered/

Ofwat. (2015). Service incentive mechanism. Accessed March 20th 2015 from: http://www.ofwat.gov.uk/regulating/aboutconsumers/sim

Ofwat-SMAG (2011) Ofwat – water sector smart meter advisory group 7th meeting. U.K: Defra.

Orgill, Y., Woolliscroft, T., & Brindley, D. (2014) Water-efficient products and the water label. In Adeyeye, K. (Ed.). *Water efficiency in buildings: theory and practice*. West Sussex, U.K: Wiley Blackwell.

Owen, G. & Ward, J. (2007) Smart meters in Great Britain: the next steps? *Sustainability First*, 1-68.

PHE - Public Health England Advisory Group on Non-ionising Radiation (2012) *Health Effects from Radiofrequency Electromagnetic Fields*. U.K: PHE.

PHE – Public Health England. (2014) Smart meters – information. Accessed November 25th 2014 from: http://webarchive.nationalarchives.gov.uk/20140714084352/http://www.hpa.org.uk/Topics/Radiation/UnderstandingRadiation/UnderstandingRadiationTopics/ElectromagneticFields/RadioWaves/SmartMeters/

Portsmouth Water (2014) Reading your water meter - and other metering documents. Accessed November 19th 2014 from: http://www.portsmouthwater.co.uk/customer_services/default.aspx?id=1058

Randolph, B. & Troy, P. (2008) Attitudes to conservation and water consumption. *Environmental Science & Policy, 11*(5), 441-455.

Rathnayaka, K., Maheepala, S., Nawarathna, B., George, B., Malano, H., Arora, M., Roberts, P. (2014) Factors affecting the variability of household water use in Melbourne, Australia. *Resources, Conservation and Recycling, 92*, 85-94.

Rial, A. & Danezis, G. (2011) Privacy-preserving smart metering. WPES Proceedings of the 10th annual ACM workshop on privacy in the electronic society, 49-60.

Roberts, P. (2005) Residential end-use measurement. Melbourne, Australia: Yarra Valley Water.

Robins, B. (2012) Intelligent meters too toxic to touch. *Sydney Morning Herald,* September 6.

Sarni, W. & Pechet, T. (2013) *Water tech: a guide to investment, innovation and business opportunities in the water sector*. Oxon, U.K: Routledge.

Satterfield, Z. & Bhardwaj, V. (2005) Water meters. In Lehr, J. H. & Keeley, J. (Eds.). *Water encyclopaedia: volume 1*. United States: John Wiley & Sons.

Schahn, J. & Holzer, E. (1990) Studies of individual environmental concern: the role of knowledge, gender, and background variables. *Environment and Behavior, 22*(6), 767-786.

Scottish Water (2014) Metering services. Accessed November 19th 2014 from: http://www.scottishwater.co.uk/business/our-services/metering-services/metering- services

Sempere-Payá, V., Todolí-Ferrandis, D., & Santonja-Climent, S. (2013) ICT as an enabler to smart water management. In Mukhopadhyay, S. C. & Mason, A. (Eds.). *Smart sensors for real-time water quality monitoring*. London, U.K: Springer.

Severn Trent Water (2014) Benefits of water meters - and other information. Accessed November 19th 2014 from: http://www.stwater.co.uk/saving-for-the-future/benefits-of-water-meters/

South East Water (2014) Water meters. Accessed November 19th 2014 from: http://www.southeastwater.co.uk/your-account/water-meters#.VIb1Pyc_k4Q

South Staffs Water (2014) Water meters - why have a meter. Accessed November 19th 2014 from: http://www.south-staffs-water.co.uk/your_home/water_meters.asp

South West Water (2014) Water meters. Accessed November 20th 2014 from: http://www.southwestwater.co.uk/index.cfm?articleid=7702

Southern Water (2014) Water meters and efficiency. Accessed November 20th 2014 from: https://www.southernwater.co.uk/water-meters

Staddon, C. (2007) Water metering: a summary of available literature. U.K: Consumer Council for Water.

Staddon, C. (2010) Do Water Meters Reduce Domestic Consumption? A Summary of available Literature. Defra, London, UK.

Steg, L. & Vlek, C. (2009) Encouraging pro-environmental behaviour: an integrative review and research agenda. *Journal of Environmental Psychology, 29*(3), 309-317.

Stern, P. C. (1999) Information, incentives, and pro-environmental consumer behaviour. *Journal of Consumer Policy, 22*(4), 461-478.

Stewart, R. (2011) Verifying the end-use water savings from contemporary residential supply scheme. Waterline Report No. 61, National Water Commission, Canberra, Australia.

Stewart, R. A., Willis, R., Giurco, D., Panuwatwanich, K., & Capati, G. (2010) Web-based knowledge management system: linking smart metering to the future of urban water planning. *Australian Planner*, *47*(2), 66-74.

Sutton and East Surrey Water (2014) Water meters. Accessed November 20th 2014 from: http://www.waterplc.com/pages/home/water-meters/

Thames Water (2014) Water meters - benefits and information. Accessed November 20th 2014 from: http://www.thameswater.co.uk/your-account/16244.htm

Thomas, D. A. & Ford, R. R. (2005) *The crisis of innovation in water and wastewater*. U.K: Edward Elgar.

Tsai, Y., Cohen, S., & Vogel, R. M. (2011) The impacts of water conservation strategies on water use: four case studies. *Journal of the American Water Resources Association*, *47*, 687–701.

United Utilities (2014) All about water meters – and automatic water meters. Accessed November 20th 2014 from: http://www.unitedutilities.com/about-water-meters.aspx

Utility Week (2013) Unequal measures. Accessed November 9th 2014 from: http://www.utilityweek.co.uk/news/unequal_measures/912822#.VIcC5yc_k4S

Utility Week. (2014a) Where there’s a will.... Accessed March 15th 2015 from: http://utilityweek.co.uk/news/where-there%E2%80%99s-a-will%E2%80%A6/1038132#.VRLpE47yDb4

Utility Week. (2014b) A smart move for water. Accessed November 9th 2014 from: http://www.utilityweek.co.uk/news/a-smart-move-for-water/975152#.VIZjWic_k4S

van Gerwen, R., Jaarsma, S., & Wilhite, R. (2006) Smart metering. Accessed October 17th 2014 from: www.leonardo-energy.org

Vining, J. & Ebreo, A. (2002) Emerging theoretical and methodological perspectives on conservation behaviour. In. Bechtel, R. B. & Churchman, A. (Eds.). *Handbook of environmental psychology*. New York, United States: John Wiley & Sons.

Walker, A. (2009) Walker Review - an independent review of charging for household water and sewerage services. London, U.K: Defra.

Ward, M. (2014 Smart meters can be hacked to cut power bills. Accessed October 20th 2014 from: http://www.bbc.co.uk/news/technology-29643276

Water UK (2010) Smart metering – an industry perspective. Response to the DECC consultation on the Ofgem Energy Smart Metering Implementation Programme Prospectus.

Water UK (2014a) About us - role and responsibilities. http://www.water.org.uk/about-water-uk

Water UK (2014b) Metering. http://www.water.org.uk/policy/resilience/metering

Waterwise (2009) Attitudes to water efficiency: household attitudes to water economy and water efficient appliances. U.K: Savills.

Waterwise (2012) Response to DECC Consultation on the Smart Metering Implementation Programme. U.K: Waterwise.

Waterwise (2014a) Water saving advice. Accessed December 7th 2014 from: http://www.waterwise.org.uk/pages/water-saving-advice-and-tips.html

Waterwise (2014b) About us. Accessed November 28th 2014 from: http://www.waterwise.org.uk/pages/about-us.html

Wells, Q. (2013) *Smart grid home*. New York, United States: Cengage.

Wessex Water (2012) Towards sustainable water charging: Conclusions from Wessex Water's trial of alternative charging structures and smart metering. U.K: Wessex Water.

Wessex Water (2014) Water meters. Accessed November 21st 2014 from: http://www.wessexwater.co.uk/customers/threecol.aspx?id=220&linkidentifier=id&itemid=220

Westerlund, H. (1996) To meter or not to meter: that is the question. In Howsam, P. & Carter, R. (Eds.). *Water policy: allocation and management in practice*. London, U.K: E & FN Spon.

Willis, R. M., Stewart, R. A., Giurco, D. P., Talebpour, M. R., & Mousavinejad, A. (2013) End use water consumption in households: impact of socio-demographic factors and efficient devices. *Journal of Cleaner Production, 60*, 107-115.

Willis, R.M., Stewart, R.A., Panuwatwanich, K., Williams, P.R., & Hollingsworth, A.L. (2011) Quantifying the influence of environmental and water conservation attitudes on household end-use water consumption. *Journal of Environmental Management*, *92*, 1996-2009.

Yorkshire Water (2014) All you need to know about water meters. Accessed November 21st 2014 from: http://www.yorkshirewater.com/your-water-services/water-meters.aspx

Zetland, D (2011) *The end of abundance: economic solutions to water scarcity*. United States: Aguanomics Press.