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Can Smart Meters Create Smart Behaviour?

Candice Moy, Damien Guirco, and Thomas Boyle

Abstract**—**Intelligent technologies are increasingly facilitating sustainable water management strategies in Australia. While this innovation can present clear cost benefits to utilities through immediate leak detection and deference of capital costs, the impact of this technology on households is less distinct. By offering real-time engagement and detailed end-use consumption breakdowns, there is significant potential for demand reduction as a behavioural response to increased information. Despite this potential, passive implementation without well-planned residential engagement strategies is likely to result in a lost opportunity. This paper begins this research process by exploring the effect of smart water meters through the lens of three behaviour change theories. The Theory of Planned Behaviour (TPB), Belief Revision theory (BR) and Practice Theory emphasise different variables that can potentially influence and predict household water engagements. In acknowledging the strengths of each theory, the nuances and complexity of household water engagement can be recognised which can contribute to effective planning for residential smart meter engagement strategies.

Keywords**—**Behaviour, information, household, smart meters, water.

I. Introduction

SUSTAINABLE water management in cities is an increasingly important global challenge as urban populations continue to grow. Australia is a highly urbanised country and as a result of extensive droughts are progressing the implementation of efficient water use in cities. Reduced rates of per capita water demand depended on two factors, the accelerated installation of efficient devices (such as low flow shower heads, efficient clothes washers), mandated restrictions (limited or no outdoor irrigation) and changed voluntary behaviours (e.g. shorter showers). On the supply side, Australian cities are no longer rain-fed, but rely on supplementary supplies including recycled water and desalination plants. This presents a more complex system and increased information (particularly about technology and behaviours underpinning patterns of demand) is needed to effectively manage this more complex system in an era of climate uncertainty. Such information is increasingly available from new generation smart water meters. Despite the likelihood of increased deployment as costs come down over the next decade, there has been a lack of critical research into the potential of smart meters to revolutionise urban water management [1]. It is yet to be determined what measures and system innovations are required during implementation to ensure positive benefits are realised and negative aspects minimised and managed.

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This paper puts particular focus on the link between smart meter feedback and behaviour change theories. It begins by contrasting three theories of behaviour change and how they could be used to understand the impact of smart water meters on households. The paper then explores experiences from smart metering in the electricity industry to propose a new research agenda to ensure smart metering feedback and household behaviour is better understood and contributes to sustainable urban water management.

II. How Can Theories of Behaviour Change Help to Understand the Impact of Smart Water Meters?

To explore the ways that information, technology and behaviour could potentially integrate through smart water applications we have selected three different behaviour change theories as a lens to predict how increased information through technological advancement could affect household water behaviours. Each of the selected theories emphasise different variables as the key determinants in predicting behaviour change. By presenting a variety of behaviour change theories we aim to illustrate the complex nature of socio-technical engagements as well as acknowledge the usefulness of multiple theoretical frameworks. Each theory presents aspects that are relevant to the analysis of household relations with smart metering technologies and will help to inform the research agenda of this project.

A. Theory of Planned Behaviour

The Theory of Planned Behaviour (TPB) [2] can be used to predict and explain human behaviour in specific contexts. Much of the literature employing the Theory of Planned Behaviour has been in health psychology to predict health-related behaviours [3], [4] including smoking [5], diet [6], weight loss [7] and exercise [8], [9]. In short, TPB predicts that the likelihood of partaking in behaviour can be predicted from one's attitude toward the behaviour, the opinion of others (subjective norms) and one's confidence in their ability to undertake the behaviour (perceived behavioural control). Together these form one's intention to carry out the behaviour, which according to [2], is the key predictor of behaviour.

A distinguishing component of the theory is *perceived behavioural control,* which refers to one's belief that the behaviour in question is achievable. The *perceived behavioural control* however must be context-specific, not a generalised predisposition. For example, one must feel confident that they can drive to a specific location, not their ability to drive generally. Reference [2] argues that the perceived behavioural control usually varies across situations, which is why context is a key determinant of action or inaction. If one is confident in successfully undertaking a task in a given context, and there is intention to do so (have a positive attitude towards the behaviour), the theory of planned` behaviour predicts that this action is highly likely to take place.

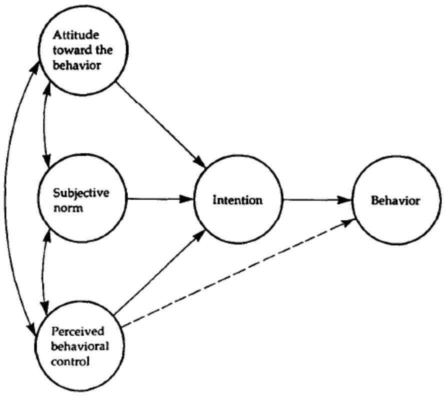

Fig. 1 Theory of Planned Behaviour [2]

This concept acknowledges that one's perception of confidence varies between situations, highlighting the flaws in assuming that one's perceived behaviour control will be constant - situations and peers have a marked affect in determining one's confidence as well as action. This influence is particularly relevant to the household context, as the members within one's household can influence the type of behaviours that will be performed. For example, while intent may be strong to reduce household water consumption, a dominant householder may influence one's confidence in believing the behaviour is achievable and/or worthwhile. Similarly, while efficient water practices may take place in one's own home, this type of water use is likely to differ outside of this environment when context specifications are altered.

The wide application of TPB has yielded many positive results in predicting behaviour change. Reference [10] carried out a comprehensive analysis of 185 TPB studies to measure its effectiveness in predicting behaviour concluding TPB to be a good predictor of intentions and behaviour and that the perceived behavioural control (PBC) was particularly influential and important component of the theory.

While TPB offers tools to analyse behaviour, its application has revealed limitations to its usefulness and predictability. Reference [11] has commented on the limitations of cognitive perspectives by stating that they do not place great importance on the origins of beliefs and note that the work of [12] states a need for greater conceptualisation, definitions and explanatory factors. There are critiques that, that attitudes and intentions can be formed and influenced by factors not included in the theory [13], and that the theory largely overlooks the impact of emotion and religion on behaviour [11]. The emotional aspects of behavioural engagement could have significant relevance for smart water meters and behaviour as water is widely recognised as a value-laden resource [14]-[16] that has direct relevance in the household context. Despite being an essential human need, water is also bound up within cultural ideas of cleanliness and luxury [17]-[19], both of which are particularly relevant to water use in the modern home.

B. Theory of Planned Behaviour and Smart Water Meters

As discussed, the TPB has been widely used to test its predictability in health related behaviour. While these have yielded promising results overall, the question for sustainable urban water management is how well this theory can cross disciplines to predict household water use.

Reference, [20] found that the influence of others (subjective norms) was a significantly better predictor of intention than personal attitudes, with the influence of friends being the most important component of the social norm. This is an important finding when analysing the impact of smart meters on behavioural changes, as is it highlights that additional knowledge itself is not the key determinant of behaviour, but that the social network within which behaviour takes place can be more influential. He notes however, that a study [21] applying the Theory of Planned Behaviour to electricity consumption, around the same time as [20] found that personal attitudes were more influential than social norms in differentiating 'conservers from non-conservers'. As these are fluid social constructs, further research in to the origins of these beliefs and constructs would be useful in developing how 'non-conservers' may become 'conservers'.

In a study by [22] using TPB to predict household recycling, 'pro-recycling' attitudes were also found to be the major determinant of behaviour. Here it was found that having the opportunities, facilities and knowledge were the most influential components of attitude formation. This finding puts less emphasis on the social and cultural dimensions of the behaviour, but suggests that if a household is provided with the adequate access and information, the behaviour is likely to occur. While the findings do not stress sociocultural context of behaviour, it flags an important issue for smart meters and sustainable urban water management in general. Households need to be provided with supplementary information that addresses the 'opportunities' and 'facilities' in shifting behaviour. For example, feedback indicating how a behaviour can be carried out using less water, that does not challenge the physical requirements of time, space and convenience [22] is unlikely to equip households with the necessary combination of ability and knowledge to make a shift toward less water intensive practices. This emphasises that consumption data (such as that available from smart metering), without access, ability or knowledge to behave differently, is unlikely to have an affect on household water use.

Despite the diversity of findings on the strength and influence of TPB variables in relation to water behaviours, the theory has provided a better understanding of a broad range of human behaviours [23] and therefore warrants consideration when designing smart meter feedback.

C. Belief Revision Theory

It is recognised by many social theorists that knowledge acquisition is pivotal in gaining a competitive advantage for organisations. This view centres on the premise that information-rich organisations are better equipped to develop contextualised knowledge which can inform the approaches, strategic directions and effective responses to internal and external change. Reference [24] has explored the theory of Belief Revision to interpret knowledge acquisition and competitive organisational advantage. They flag the subjective nature of 'knowledge' and suggest that 'belief' is a more appropriate term as it captures the subjective interpretation of information.

The fundamental concept behind Belief Revision theory is that new information can trigger a person to change their existing beliefs. The theory asserts that a person's *belief set* can be challenged by new information and consequently modified. For a new belief to be accepted, some pre-existing beliefs need to be sacrificed. These relinquished beliefs are those considered least valuable, which is those least *epistemically entrenched.* These new beliefs must require the least amount of change (*the Principle of Minimal Change*) to enable a belief revision. For new information to become new knowledge it mustn't significantly contest one's entire belief set, but challenge those beliefs which are least entrenched. This new knowledge then replaces previous, now defunct beliefs.

The Principle of Minimum Change implies that Belief Revision Theory is best used to explain incremental changes in belief and action. A radical revision of beliefs, which subsequently create an entirely new set of behaviours will not be explained through Belief Revision Theory. It could be assumed that incremental changes in beliefs and actions are more commonly experienced than radical transformations, which makes Belief Revision relevant to the ways that people interpret and act on new information. Fig. 2 illustrates the incremental nature of Belief Revision showing that new information will join an aspect of existing knowledge, and together these two information components will form a revised belief set.

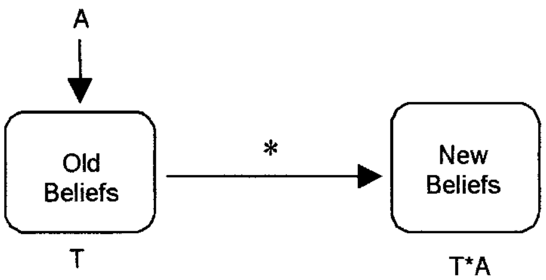

Fig. 2 Belief Revision [24]

Despite the strengths of Belief Revision theory, its limitations are worth noting. The *Principle of Minimal Change* is a central component of Belief Revision Theory which asserts that for new information to be accepted as knowledge, it mustn't deviate too far from one's existing belief set. The Principle however, does not provide insight into *how* the differences between two beliefs are measured [24], therefore gives no insight into which belief is most likely to change and how this can be determined. Another limitation is the lack of understanding regarding the origins of epistemic entrenchment. What creates the entrenchment of one belief over another? Where does the strength of a belief originate? Lastly, like the TPB, Belief Revision does not acknowledge the role of emotions in knowledge development. The emotional response that one has to information may significantly affect the how it is interpreted. Similarly, a person's emotional state at a given point in time may have the potential to influence the degree of engagement with new information and whether or not this information is processed or rejected.

D. Belief Revision Theory and Smart Water Meters

How could Belief Revision theory be a useful concept for smart water meters and knowledge creation? This evolving technology will have markedly different effects on information acquisition and knowledge creation for utilities and households. As discussed by [24], knowledge acquisition can be a distinct competitive advantage for organisations, which for the case of smart water meters can enable utilities to develop an improved service due to an enhanced understanding of household water consumption patterns and maintenance issues. Leak detection, maintenance and management can be tailored to promptly meet the needs of the household by identifying and repairing otherwise unrecognised technical failures. To attain the competitive advantage made possible through smart water meters, efficient information analysis and knowledge management will be essential considerations for utilities to act upon and improve service and management. Belief Revision Theory provides useful concepts to help utilities to realise the potential offered from smart water meter data, but must be mindful and strategic in converting the immense volumes of information into useful, valuable and context specific knowledge.

Belief Revision concepts can also be useful in understanding how households will engage with the additional information provided by smart water meters and the impact this could have on domestic water use. *Articulated knowledge* is a component of Belief Revision Theory which could significantly impact the way householders' process information and subsequently engage with household water. Reference [24] argues that when information is contextualised and understandable a person is given the opportunity and motivation to analyse and discuss (articulate) this new information with others. Through the process of articulation, new information that resonates with a householder will be processed as knowledge, while conflicting elements can be challenged by existing beliefs. Smart water meters have the potential to create many avenues for new knowledge development and generate communication channels between parties, who share an interest or who have also acquired new knowledge.

In the case of household water use, not only are beliefs about water *epistemically entrenched*, but the bodily enactments of water use are also *entrenched*. Much of our water practices are not conscious decisions to engage with designated volumes of water, but are habitual by-products of social expectations and cultural norms surrounding hygiene and cleanliness [17], [25]. The relationship between water and cleanliness are *entrenched* in everyday practices, which may mean that these beliefs may rarely reflect the Principle of Minimal Change. Similarly, new information that may be logical, practical and resonate intellectually may be at odds with the emotional experiences that water brings a householder. While Belief Revision does not specifically explore these dimensions of decision-making, practice theory recognises the influence of emotional and cultural elements an may therefore be useful in design household targeted feedback.

E. Practice Theory

Practice theory aims to contextualise consumption within sets of social practices that reflect how, why and when we undertake behaviours. Unlike Belief Revision and the Theory of Planned Behaviour, Practice Theory does not explore knowledge and information as separate from a specific activity, but seeks to understand how information and knowledge are embedded in everyday practices. Although most practices involve the appropriation and use of goods and services, people first think of themselves being involved in meaningful practices rather than being involved in consumption. Consumption as such is seldom meaningful, and it makes little sense to say that people have a desire to ‘consume’. Motivations and wants are the outcomes of practices, and the conventions of standards of practices steer behaviour [26]. In the household context water is a core material used to carry out a series of social practices whether it be washing, cooking, cleaning or gardening. For this reason it may be more useful to look at how smart water meters can communicate with householders through the language of everyday practices rather than focusing bulk, non-contextualised consumption data.

Unlike Belief Revision Theory and TPB, Practice theory recognises the importance of emotions in undertaking a practice and that one’s emotional state can influence the meaning of the practice. On the other hand, in line with the other two theories, Practice Theory recognises the importance of beliefs and context in shaping action and contextualises knowledge acquisition through a larger cultural lens. Knowledge is an amalgamation of history, culture and meaning that is embodied in a practice rather than knowledge as objective information that is separate to a specific activity.

F. Practice Theory and Smart Water Meters

Research in the electricity sector has explored the use of smart meters and the role of information on behaviour change. Reference [27] has stressed the importance of positioning household consumption information within a broader socio-cultural context by focusing on household practices rather than presenting bulk consumption figures. This work on feedback systems and their influence on household behaviour change have found that these devices do little to challenge the comfort and cleanliness norms which dominate domestic energy and water consumption. Reference [27] has identified that information on levels of consumption alone fails to identify the particular practices the consumption is attributed to, and gives no insight into what is an acceptable and/or appropriate level of consumption for this task.

Practice theory provides an opportunity for smart meter feedback systems to communicate with the householder in a language that is relevant to their particular environment. There are few applied studies that have employed Practice Theory, which limits the lessons that can be drawn upon in a practical context. However, being mindful of the broader social and cultural elements that influence how a practice is undertaken may help to generate a new, innovative approach to how smart meter feedback could be communicated.

III. Lessons Learnt from Smart Meters in Electricity

Over the last decade smart meters have been increasingly trialled in the electricity sector both internationally and in Australia. Evaluations of their introduction have highlighted strengths and limitations of their application that are essential for the water sectors to be mindful of in order to maximise their successful roll-out. While there are some fundamental differences between smart meter application in the water and energy sectors, much of the research exploring the ways that consumption information can be communicated and its associated behaviour changes cross over these sectoral boundaries. This section will briefly explore considerations for smart water meters with regard to mode and design of communication, frequency and resolution of information as well as the potential impacts on privacy.

A. Mode and Design

The ways that information is delivered to the public is ever increasing, which has provided people with numerous options as to how they choose to receive new information. In the case of smart meters, the mode of information delivery could be pivotal in optimising the potential for behaviour modifications. Reference [28], a comprehensive research on feedback regarding household electricity consumption has explored the multiple modes of feedback and their effectiveness. She found that direct feedback (immediate) reduces consumption by 5-15%, while indirect feedback (processed) had a savings range of 0-10%. For the future of smart metering, [28] has concluded that smart metering needs to be guided by consideration of the quality and quantity of feedback that can be supplied to customers. Direct displays in combination with improved billing show promise for early energy and carbon savings, at relatively low cost. They also lay the foundations for further savings through improved energy literacy.

With this recommendation in mind, both direct displays and improved billing raise many questions regarding the degree detail and appropriate design elements that are optimal in communicating relevant, effective messaging. The design possibilities for communicating consumption messages are endless. Qualitative studies into the effects of various feedback designs have highlighted the strengths and limitations of various approaches illustrating the complexity in this type of knowledge transfer. Much of the research has found that direct displays of communicated consumption whether it be through ambient lighting or graphic symbolism can be effective in prompting conservative behaviours, but their pervasive presence also has the potential to evoke negative and frustrated reactions [29] as well as stress and anxiety [30].

To maximise the effectiveness of feedback methods and messaging, information content and mode of delivery needs to be tailored to suit the internal motivations of the specific household as ‘without the motivation to conserve, information about how well you perform in this discipline is useless’ [31]. Motivations that have emerged from qualitative smart water research include cost, information gathering, technological interest [30] environmental concerns [30], [31]. The numerous motivations that inspire people to act illustrate the complexity in tailoring messages that resonate with many different households. It is also important to recognise heterogeneous nature of households, which can present difficulties in providing information that appeals to and resonates an entire household [32].

Of equal consideration is the degree of interaction and engagement households have in understanding their consumption as technological advancements accelerate towards automated (smart) homes. Reference [33] has noted that while society is inevitably moving towards automated (smart) homes, this direction is further disengaging people from their immediate environments, widening an already existing knowledge gap. Reference [33] has explored the impacts of passive and interactive technologies upon households behaviours by comparing an automated home, a home that employs subtle reminders, and a teaching home. The results found that the possibilities for technology to empower the householder to engage with their immediate environment through the teaching home presents exciting opportunities for knowledge transfer.

> Pervasive computing can be used not only to motivate behaviour, but to teach at the moment when the behaviour is undertaken. Systems that automatically make control decisions generally miss this opportunity—users can become complacent if the system functions perfectly. Although a computer system might try to present the user with educational messages to explain the actions it is taking, to do this without interrupting and irritating the user is a challenge [33, p78].

This study illustrates that for technologies and information to have maximum impact on behavioural changes; technologies need to engage the householder with operations regarding their environment. While current smart meter technologies are in their infancy, envisaging the optimal outcomes that smart meters could have on behaviours can help to direct the early stages of research and development.

B. Frequency and Resolution

The mode of delivery, content, and design presentation of information are inextricably linked with the frequency of messaging and level of resolution. While much of the literature on in-home displays explores immediate feedback, which is commonly deemed the optimal degree of frequency [28], [31], like message design, there is potential for constant messaging to have a negative effect and trigger disengagement. However, in-home displays are costly and the technology remains in its early stages. For this reason, smart water metering must equally consider the role of improved billing as way of transitioning towards standardised in-home displays. In many parts of Australia, current water billing operates on a quarterly basis, presenting cost, volume consumed and comparative consumption. This offers households little information as to how and where water is used in the home, which everyday practices are consuming various volumes or specific options as to how this can be reduced. Reference [34] explored the relationship between more informative billing and improved energy efficiency in the home. Results clearly revealed that more informative and frequent billing resulted in more energy efficient behaviour, with consumption decreasing by 10%. This savings is consistent with the most successful savings of indirect feedback found by Darby [28] indicating that frequency of information may be as powerful as mode of delivery. This is further supported by [34] who isolate frequency as the main stimulant to conservation.

Clearly the impact of billing frequency on efficient behaviour is a key consideration for smart water meter rollouts in Australia, but what is the role of resolution? While [34] included additional information in the form of comparative data and energy saving tips, it did not provide a breakdown of where in the house, or how much energy was used. Frequent billing that provides a breakdown of water use has the potential to further increase household efficiency as discussed by [34]. Reference [1] has provided an example of how smart water metering can provide disaggregated end-use that can be communicated to the household (see Fig. 1). This type of feedback is working towards understanding water consumption in a practice-based framework. This end-use breakdown can help to promote household discussions (prompting by contributing to basic level of household water use knowledge. While a more detailed breakdown promoted by practice theorists could further this understanding, this level of detail will nonetheless improve the basic water-use literacy levels that is absent in most urban Australian households.

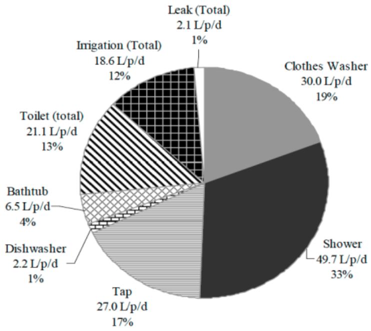

Fig. 3 End use breakdown, Gold Coast [35]

C. Privacy

Despite the endless potential for smart water meters in promoting transitions towards efficient household behaviours, the implications for privacy must be considered. These considerations are twofold; privacy concerns regarding the increased information for external bodies (utility) and privacy concerns regarding the increased information for within-household members.

With smart metering comes real time information into our daily household practices. While this presents exciting opportunities for planning and behaviour change, it raises privacy concerns as utilities will have intricate knowledge of household operations. Reference [36] has flagged that in the energy sectors the risks associated with privacy are significant.

> Though this is advantageous for the electricity suppliers' planning purposes, and also allows the customers a more detailed look at their usage behaviour, it means a considerable risk for privacy. The detailed information can be used to judge whether persons are in the household, when they come home, which electric devices they use (e.g. when they watch TV), and so forth [36, p2].

While noting similar concerns, [1] have extended the potential privacy risks in the form of surveillance during mandatory water restrictions and the stigmatisation of cultural groups for 'unusual' water practices. Real-time feedback also raises privacy issues for individual householders regarding within-household surveillance. Monitoring whom in the house is using water, when they are using it, and for what purpose has the potential to cause conflict and affect how householder relations. While these types of surveillance may seem trivial to some, when these potential privacy risks are combined they provide a strong case for public resistance towards smart water meters. When state roll-outs are undertaken, these issues must be clearly addressed to ensure that householders feel confident their privacy is protected and as well as recognising the benefits in its application. Without this clear communication it unlikely households will support their implementation.

IV. What Does This Mean for Smart Water Meters in Australia?

This paper has aimed to highlight the intricacies involved with the public response to, and acceptance of smart water metering. At a micro level, technological details such as design, mode, message framing, frequency and resolution are issues that need to be carefully considered. Similarly, the socio-cultural environment within households needs to be understood to determine how peer influence, everyday-practices and issues of cleanliness and convenience influence consumptive decision-making. On a broad scale, considering whether or not the populations who are exposed to smart water meters will see value in their implementation is a fundamental concern. As each of the behavioural theories presented in this paper stress the importance of context, the broader cultural context at the time of smart meter rollouts will influence their degree of perceived value, necessity and relevance.

This cultural environment will be influenced by the climatic context of the time. In NSW, severe droughts have prompted a cultural recognition of the importance of working towards sustainable urban water management. These climatic conditions gave rise to the construction of a desalination plant in Sydney, state-wide mandatory water restrictions and substantial government subsidies for rainwater tanks and water efficient technologies. As part of this cultural shift, there was an impetus on households to take responsibility for their individual and household water consumption in order to collectively reduce the pressures on a stressed supply. Inconveniences experienced by households, such as those during mandatory water restrictions, were socially accepted due to visible and highly publicised water pressures being experienced throughout the country. However, with the alleviation of water restrictions in June 2009 [37] and the consistently high rainfall experienced in from 2010-2011 [38] the acceptance of previously invasive measures may no longer appear to be culturally valuable. It is envisaged that this will have direct repercussions on the rollout of smart water meters.

Such repercussion are illustrated through the public resistance to the potential rollout of smart electricity meters has been evident in Victoria [39]. Without presenting communities with a strong, contextualised sense of why this technology is necessary, opposition to their rollout is a strong possibility. Reference [40] has stressed the importance of community involvement when introducing new and innovative technologies to avoid a transfer of old consumptive habits to new 'eco' situations. He asserts that focus equally needs to be on education programs centred on ensuring that communities *want* to make the changes that innovative technologies facilitate. For smart water meters, clearly communicating why, during a time of high rainfall and state wide flooding, this technology is not only beneficial for utilities, but for households will be pivotal in their successful utilisation. Failure to communicate how the benefits of this technology outweigh the costs will also be crucial in the public overcoming the potential privacy infringements, the pervasive nature of the technology as well as the possible 'big brother' perceptions that could otherwise overshadow their contribution to sustainable urban water management.

It is currently unknown what impact smart water meters will have on sustainable urban water management or how the Australian public will respond to the technology. Lessons from the electricity sector have flagged the importance of feedback methods, as well as the influence that sociocultural environments will have on the way information is interpreted and acted upon. These aspects of smart metering deserve focused attention if their successful implementation is to be realised. In exploring smart water meters through three different behaviour change theories it is advocated that the complexities and nuances in how people may relate to information and technologies is recognized. Simply promoting smart water meters as a positive advancement, without detailing why the public should embrace such a detailed water-tracking system, is likely to encounter public resistance and result in a lost opportunity for sustainable urban water management.

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