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Integrated intelligent water-energy metering systems and informatics: Visioning a digital multi-utility service provider

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A R T I C L E I N F O

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A B S T R A C T

Advanced metering technologies coupled with informatics creates an opportunity to form digital multi-utility service providers. These providers will be able to concurrently collect a customers' medium-high resolution water, electricity and gas demand data and provide user-friendly platforms to feed this information back to customers and supply/distribution utility organisations. Providers that can install low-cost integrative systems will reap the benefits of derived operational synergies and access to mass markets not bounded by historical city, state or country limits. This paper provides a vision of the required transformative process and features of an integrated multi-utility service provider covering the system architecture, opportunities and benefits, impediments and strategies, and business opportunities. The heart of the paper is focused on demonstrating data modelling processes and informatics opportunities for contemporaneously collected demand data, through illustrative examples and four informative water-energy nexus case studies. Finally, the paper provides an overview of the transformative R&D priorities to realise the vision.

1. Background

1.1. Digital multi-utility futures

Imagine a future where a technology company is the retailer of water, wastewater, electricity and gas services, for your home or business. At first thought this concept seems confounding but in reality this future is not too far away, as integrated digital metering, advanced communications and big data analytics paves the way for the creation of a global multi-utility service provider catering for millions, if not billions, of customers.

Digital disruption has already transformed a number of other industries globally, but the utility sector has been slow to embrace digital transformation technologies. This is largely because of their conservative nature, often underpinned by a natural monopoly status that is government-owned or tightly regulated, thereby preventing the easy access of entrepreneurs' reinventing typical business supply chains (Kiesling, 2016; Tayal, 2016). But, for instance, the rapid rise of *Uber™* has shown us that even highly regulated and protected industries, such as the taxi industry, will

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inevitably be pressured to open up to innovative products offering unprecedented customer savings and value-adding services.

This position paper will firstly provide a background and a vision for an integrated digital multi-utility service provider. The system architecture for such a provider will be discussed along with the opportunities and benefits, as well as impediments and challenges, for utility transition. The paper then hones in on its core objective, which is to demonstrate the opportunities and benefits of modelling concurrently collected and autonomously analysed water and energy data by presenting case studies and empirical data examples. The paper finishes with a discussion on the core research and development priorities to realise the vision of a digital multi-utility.

1.2. Changing utility sector paradigm

Traditional provision of water and energy (electricity or gas), until quite recently, was a conservative process whereby quasi-government owned utilities offered a unidimensional, one way service to their customers. As expectations to provide a greener, leaner and customer-focussed utility sharply rise, it has become clear that conventional means of water and energy provision are becoming outdated and will not be able to meet the requirements of the digital information age (Kabalci, 2016). By necessity in meeting these changing needs, utility meters are being transformed from simple measurement devices where manual collection of only 1 data point (i.e. consumption) via mechanical meters on a monthly or quarterly basis, to more complex and "intelligent" metering. In 1999, Marvin et al. termed such 'smart' meters as socio-technical systems where enhanced informational and communication capacities allowed for a deeper and dynamic understanding of both the supply and demand metabolism of the utility. Nearly 20 years on, there is now a wealth of literature documenting the paradigm shift toward the digital water and energy utility (e.g. Stewart et al., 2010; Depuru et al., 2011; Fang et al., 2012; Stewart et al., 2013; Gans et al., 2013; Beal and Flynn, 2015; Cominola et al., 2015; Tuballa and Abundo, 2016; Pitì et al., 2017).

As the momentum gathers, there is increasing pressure on the utility sector to transition to the digital age. Tuballa and Abundo (2016) describe the breadth of energy utilities that are embracing disruptive technologies to improve the efficiency and customer service of their business – including Europe, North America Asia, and Australia. While the water sector has been slower to adopt such disruptive technologies, the impetus is growing, driven largely by customer expectations and increasingly expensive water operations. There is a growing realization by water utilities that the enormous opportunities digital metering provides need to be harnessed, and a broader systems and futures perspective used, to determine the extent and direction of those opportunities (Turner and White, 2017).

With digital metering comes many challenges, including capital costs, technology redundancy, business transformation, risk mitigation and customer expectations while maintaining billing equity. One of the main challenges, however, is likely to be how the vast volume of continuously accumulating information is used to ensure that digital technology enhances urban water, electricity and gas management. Addressing this 'big data' challenge through targeted modelling of concurrently collected utility data is the key focus of this paper.

1.3. Advent of intelligent metering technologies

A smart water or energy grid essentially refers to the integration and remote communication of information via enabling technologies such as sensors, meters, and automated controls that continuously and remotely monitor the water, electricity or gas distribution system. The advent and advancement of these innovative enabling technologies has allowed an almost endless capacity to monitor many different parameters. For water distribution this includes pressure, quality, flow rates, temperature and leaks. In energy distribution systems, peak load shifting, losses and theft, resource storage and time of day demand are all key features of a smart energy grid (Depuru et al., 2011; Rhodes et al., 2014).

Within a decade, technology has rapidly become more sophisticated, from needing separate hardware and software to collect, store, transfer and analyse a gigabyte of data, to now having one piece of technology that combines hardware, software and firmware to provide near-real time, tailored reports to utilities and customers. Selected examples of research studies presenting digital metering technology and its applications for managing water and energy distribution are provided in Table 1.

1.4. Big data informatics

Emerging technologies and the associated big data informatics, once fully understood and exploited, are the truly "smart" components of a digital water, electricity or gas grid, and these informatics can be used for a wealth of applications (Stewart et al., 2013; Zhou et al., 2016). Intelligent metering uptake however, remains relatively slow, due largely to the unexploited benefits from the back-end of the smart grid, including meters and sensors.

Informatics applying a range of mathematical, statistical and rule-based approaches can be used to reveal important information on demand from the available data provided at second, minute or hourly intervals (e.g. Nguyen et al., 2015; Makki et al., 2015). Such information is powerful for government, utility and customer planning and decision making (Zhou et al., 2016; Erevelles et al., 2016). In the energy sector, in-home devices (IHD) such as visual displays, smartphones, or web-based portals fed by raw metering data, have been used for some time now as a demand management tool (Darby, 2010). IHD have the potential to combine energy data with information such as billing data, saved CO_2, and consumption benchmarking; the goal being to supply consumers with more valuable and enriched information for energy savings (Pitì et al., 2017).

There are few papers that comprehensively discuss the applications and benefits of collecting this data concurrently from water, gas and electricity utilities, storing it within the same database, and correlating it together to extract even further useful data on demand. In particular, such an integrated database allows customers to unpack the water-energy nexus as described in the next section.

1.5. Water-energy nexus

Water-energy links related to the use of water is emerging as a key pathway for integration of water and energy retail services provision (Conrad et al., 2017). The advanced status of water, electricity and gas metering and data, has contributed to the current dynamic nature of research regarding links between water and energy of consumers. A range of priorities have been identified in this area including the need for "integrated water-energy data storage" enabling data-warehousing to capture full performance metrics (Kenway et al., 2013a). Big data informatics can be used at city-wide (Lundie et al., 2004; Hall et al., 2011; Lane et al., 2015) or household scales (Beal et al., 2012; Escriva-Bou et al., 2015; Binks et al., 2016; Hussien et al., 2017).

Such information can be used by utilities and customers to explore a range of efficient technologies and strategies that can be used to reduce household water and energy consumption and can underpin the decision making process for sustainable management