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Journal Article

Technical and governance considerations for Advanced Metering Infrastructure/smart meters: technology, security, uncertainty, costs, benefits, and risks

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Abstract

The fundamental role of policymakers when considering Advanced Metering Infrastructure (AMI), or 'smart meters' for energy and water infrastructure is to investigate a broad range of complex interrelated issues. These include alternative technical and non-technical options and deployment needs, the cost and benefits of the infrastructure (risks and mitigation measures), and the impact of a number of stakeholders: consumers, distributors, retailers, competitive market operators, competing technology companies, etc. The scale and number of potential variables in the AMI space is an almost unprecedented challenge to policymakers, with the anticipation of new ancillary products and services, associated market contestability, related regulatory and policy amendments, and the adequacy of consumer protection, education, and safety considerations requiring utmost due-diligence. Embarking on AMI investment entails significant technical, implementation, and strategic risk for governments and administering bodies, and an active effort is required to ensure AMI governance and planning maximises the potential benefits, and minimise uncertainties, costs, and risks to stakeholders. This work seeks to clarify AMI fundamentals and discusses the technical and related governance considerations from a dispassionate perspective, yet acknowledges many stakeholders tend to dichotomise debate, and obfuscate both advantages and benefits, and the converse.

Keywords: Governance; Advanced Metering Infrastructure; Smart meter.

1 Introduction

In 2009, after the politically disastrous implementation of electricity 'smart meters' in the Australian state of Victoria, the Victorian Auditor General recommended several approaches to minimise risk and independently assess the potentially large costs and benefits of AMI. These included the necessity for engaged government agencies dedicating sufficient governance resources, particularly to understand potential perverse outcomes, risks, and unintended outcomes for consumers for the distribution of costs and benefits. The Victorian Auditor General (2009) report criticised accelerated mandatory deployments of AMI technology in advance of state, national, and international standards and frameworks, and represented an unacceptably high implementation risk. Due to the complexity of AMI investments, regular and detailed stakeholder education and consultation forums were

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recommended, inviting a spectrum of consumer advocacy groups in addition to electricity industry stakeholders to discuss elements beyond initial AMI technical and functionality considerations.

The investment in AMI or smart meters are more than just a new electricity or water meter. AMI can be described as three elements: systems that measure; systems that collect/communicate the measured data, and; systems that analyse the data. AMI 'systems' themselves can be generally categorised as hardware, software, and communication systems (Sood et al., 2009). AMI is not restricted to the electricity sector and are also directly applicable in gas, heat, and water supply sectors. AMI investments are technically ambitious. Selecting some technology types increases technical risks, and numerous trials now underway in Australian states are a fundamental risk mitigation strategy. However, there is much attention on how consumers may or may not capture the net benefits of AMI investments, and will require significant investigation by energy regulators and government administrators, as the known large consumer pushback on 'smart meter roll-outs' (the 'Bakersfield effect'), must be understood carefully (Gogn and Wheelock, 2010). Apart from basic AMI technology functionality issues, it is fundamental for AMI administrators to understand the aims, business cases, competitive positions, and regulatory environment to anticipate future developments, particularly between major energy players. Nonetheless, technology and regulatory regime risks of AMI implementation are primarily related to the technical design capacity of equipment, and the cost structures they operate within. Comprehensive and relevant information relating to benefits, costs, and risks of potential AMI technology options are necessary when assessing whether projects (or components of projects) are desirable, viable, and achievable. The rigorousness of the analyses must be commensurate to the unique complexity, scale, and potential consumer impact of AMI projects (Victorian Auditor General, 2009). This research uses the example of Australia, and in particular AMI considerations for the Western Australian (WA) South West Interconnected System (SWIS). The WA SWIS is an electricity network spanning a very large geographical area, with an associated high demand variability susceptible to large climatic variables. The SWIS, like many networks around the world is in need of large investments to accommodate growth in peak demand, enable larger penetrations of distributed large and small scale renewable energy technologies, and to cater for an expansive growth from increasing residential electricity demand, and new large energy intensive processes (McHenry, 2009, 2012a, b; McHenry et al., 2011).

2. The sensitivity of benefits and threats of AMI pertinent to administrators

Electricity networks themselves are becoming a major limiting factor in the provision of efficient and cost-effective electricity services for the growing number of consumers, particularly with the increasing availability of new high-consumptive electric appliances exacerbating daily and seasonal peak demand. The potential applications and benefits of AMI integration into electricity networks are potentially numerous and substantial: interval measurement of electricity consumption; remote reading and switching capabilities; automatic meter data processing and transfer; increased electricity retail competition; a diversity of new energy service providers; increased generation, transmission, and distribution efficiency; two-way communication for increased customer information and enablement; real-time decision-making and control for both consumers and utilities (fault management, network reconfiguration, forecasting, modelling and planning); enabling of third-party assessment of network operator cost statements; etc. (Cavoukian et al., 2010; Deconinck, 2010). Yet, the potential hazards of AMI are also abundant and significant: privacy and security concerns; digital-averse consumer backlash; information and communication technologies (ICT) dependent systems, unknown technology implementation needs; high capital costs, unknown operating costs, unknown utility and advanced capability uptake; unknown technical reliability; communication technology uncertainty; potentially major competitive market changes; etc. (Deconinck, 2010). The AMI administering entity is fundamentally responsible for establishing, and reviewing the ongoing AMI project viability, engagement with stakeholders, the identification and management of risks and unintended consequences (Victorian Auditor General, 2009). The advantage of exploring AMI investments at the present time is that much of the initial Australian national and

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international experiences with AMI have provided administrators with a level of insight, some standards and frameworks, and much needed advice for the unique responsibilities of administrators. For example, in contrast to independent regulators, AMI administering departments have a broader and enduring societal responsibility, particularly within a disaggregated corporatised or privatised electricity market. While WA AMI projects will be couched within a national regulatory context that will determine to some extent the relationship between the electricity network operator and electricity retailers, there is likely to be significant consumer concerns (and lack of information and comprehension) regarding the aggregated influence of AMI and non-AMI market changes and future impacts (Electric Power Research Institute, 2010). For example, WA residential electricity consumers may benefit from AMI investments on average and in the long term, however, there is likely to be increased costs (both related and unrelated to AMI) for consumers (and/or taxpayers) over the short-to-medium term. It will be a challenge politically to communicate to communities that further increases in the short-term total electricity costs are necessary when electricity prices have already increased markedly in recent years in WA.

2.1. AMI information application considerations for policymakers

More efficient and reliable electricity networks are a fundamental driver of AMI investments (Corbett, 2013; Gjukaj, 2011). AMI can introduce several efficiencies in network distribution operations, including determining investments based on real (rather than inferred) transformer and power line data (Valigi and Di Marino, 2009). Thus, AMI can be perceived as obtaining the knowledge required to re-engineer the electricity network (particularly the distribution infrastructure) for greater functionality and efficiency. The traditional electricity network in WA (and most industrialised jurisdictions) were designed for radial, centralised generation, dependent on manual restoration (Sood et al., 2009). Re-engineering this historical legacy will likely be more expensive than initial AMI deployments, and will likely take at least 20 years for the majority of large networks with large sunken investment costs.

A significant component of new network re-engineering will likely be an expansion in distribution automation (DA)[1] technologies and demand-side management (DSM) options. The communication of data from a wide geographical network of meteorological stations in WA, coupled with a dynamic rating of network equipment will enable DA technologies to harness benefits of dynamic powerline ratings. Dynamic ratings increase efficiency of the electricity sector as many network electrical components are 'derated' with increasing temperatures (such as gas turbines, transmission and distribution lines). This is significant in WA as high electricity demand is positively correlated with increased temperatures (Independent Market Operator Western Australia, 2007, 2008, 2009, 2010, 2011). The government owned natural monopoly SWIS network operator, Western Power, have sought to explore the use of dynamic ratings on both the distribution and transmission network. This allows equipment to be rated according to ambient conditions, enabling network components to operate outside of standard ratings when meteorological conditions allow. Significantly for administrators, substation and distribution network automation does not require direct consumer education or engagement to achieve dynamic voltage control in a multi-way distribution network (Gogn and Wheelock, 2010). However, indirectly both the benefits and the costs of DA are similar to processes and analyses required for full AMI investments, and also highly sensitive to technology selection and existing market arrangements (MacDonald, 2007).

AMI real-time and two-way distributed and centralised communications and data processing enables a number of new technical and market options (Sood et al., 2009). This requires communications designed for different regions, which often necessitates using multiple communication technology types, which in-turn create regional cost and benefit variability (Deconinck, 2010). Despite large industrial consumers generally already having real-time metering (or similar), the increase in availability and quality of information derived from AMI in the

[1] Distribution automation will require communication technologies that permit Supervisory Control System and Data Acquisition (SCADA) functions and decisions to be undertaken without human intervention (Sood et al., 2009).

residential sector is anticipated to comprise the majority if overall electricity supply cost reductions (including distribution, communications, data management, and integration, etc). The entity responsible for collecting and processing metering information to other entities that require the data are generally known as a 'Meter Data Management Agency' (MDMA). Once AMI data and their collection requirements are determined for a jurisdiction, the communication bit transfer rate baseline for the bandwidth can be calculated with relative precision. The bandwidth requirements will require knowledge of what are the most fundamental appliances and sensors that will assist operators in monitoring, making decisions, and executing various optimisation options. Adding the security latency, plus an estimate of the future possible data transfer demands (both to and from devices), the communication technology capability can be forecast (this is often over and above the data transferred on a daily basis and space will be required for additional functions, such as mapping and timing of outages and failures etc.) Like many jurisdictions, the structure and function of a WA MDMA and where it will reside is relatively undeveloped at present. As 'smart grids' have been likened to a merger of energy, ICT, and telecommunications industries, this is a notable deficiency in terms of technical and governance considerations, and will likely become a major new sector in time. It will be necessary to ensure proper consideration and due diligence for how MDMA's will collect, process, and distribute metering data, as these activities will to a large extent determine the 'value' of the AMI investment, and will vary depending on the various stakeholders and who bears the costs and risks, and how benefits are distributed.

2.2. Present major uncertainties and information sources

While many AMI investments can recoup some costs through operational improvements and efficiency, there is uncertainty regarding the most appropriate options for utilities, consumers, and regulators in terms of open and technology neutral standards that maximise investment benefits and reduce unintended consequences (Executive Office of the President, 2011). There is no universal approach for AMI introduction (Gjukaj, 2011), and the available diversity and rate of change of metering and communication technology and functionality is accelerating (MacDonald, 2007). Whilst staged smart meter and other enabling equipment investments will reduce technical risk, there are other cost and benefit uncertainties that AMI will influence net benefits (Gjukaj, 2011). There is a risk that regulatory bodies will be influenced to impose high costs/barriers for new market entrant service providers (particularly in the retail segments which may see large increases in data processing administration and consumer inquiries) once AMI technology is available (Executive Office of the President, 2011). Furthermore, utilities/commercial entities that do manage to capture benefits may not pass on benefits (including any accelerated roll-out stranded capital costs) to consumers, will lessen the primary case for AMI investment (MacDonald, 2007). Recent international experience demonstrates that consumers are also highly sensitive to AMI technology, and AMI policy will require a significant interface with consumer groups (Executive Office of the President, 2011).

AMI costs and benefits accrue to various entities, yet the average consumer does not directly benefit from two major benefits – the social benefits of peak energy reduction, and any reduction is emission factors from enabling increased penetration of renewable/clean energy (MacDonald, 2007). Traditional electricity utility business and regulatory structures incentivise investing in more infrastructure to sell more electricity, rather than assist energy efficiency of consumers (Executive Office of the President, 2011). Electricity network utility-led AMI projects may not have sufficient inherent incentives to tightly manage risks and cost minimisation, and cost overruns are expected to be a major concern for regulators and administering agencies (Victorian Auditor General, 2009). Alternatives to network and retailer-led AMI projects included third-party models, yet this may be at odds to real-time network integrity, and reduce the ability to use the distribution network as a communications option, such as broadband over powerline (BPL) options (Alinta AE, 2008). Notably, it is generally unclear to what extent and over what period AMI investment will influence electricity generation investment (Hoch et al., 2008). As such, regulators and administering bodies should seek intellectual capital from others with greater experience with AMI investments (Executive Office of the President, 2011).

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The risks of AMI financial costs are comparable to other major electricity infrastructure investments, and with independent economic and regulatory oversight, entails comparable financial risk than other options (Alinta AE, 2008). However, the anticipation and management of both the number and diversity of intended and often unintended benefits and their costs are unique to AMI projects, and are key to AMI governance (Victorian Auditor General, 2009). Australian policymakers have the benefit of the existence of the National Smart Metering Program (Australia)[2], a historical reference site that retains numerous publications, guidelines, technical documents, reporting and information sharing, interface standards, (etc.) that provide details on many AMI factors required to be understood in detail. Additionally, the International Smart Grid Action Network (ISGAN)[3] is an international partnership created for multilateral, government-to-government collaboration with a focus on six principal areas: policy; standards and regulation; finance and business models; technology and systems development; user and consumer engagement; and workforce skills and knowledge (Executive Office of the President, 2011). The National Institute of Standards and Technology (NIST)[4] also have a dedicated webpage for AMI particularly focussing on interoperable AMI standards. These and many other resources can be used by policymakers to assess the validity and uncertainties of AMI investment 'cost-benefit analyses' (CBAs). Many benefits of AMI technologies are expected to flow from reducing or moderating the pressure on future electricity provision costs (new infrastructure, carbon prices, and fuel price increases), yet such benefits are not readily apparent, particularly to consumers (Hoch and James, 2010). The onus is on CBA developers to clarify modelling assumptions when assuming the transfer of economic benefits from one group of stakeholders to another, and in particular how the electricity distributers will pass on their savings to retailers, and how retailers will pass them onto consumers (Victorian Auditor General, 2009). For example, the Australian Ministerial Council on Energy's 2008 national AMI study overestimated the demand-related customer benefits of Victoria's AMI roll-out due to the methodology and assumptions, leading to unexpectedly lower net benefits. In addition to financial risks, the lack of international standards[5] means the communication technologies will need to evolve with developing a smart grid while dealing with legacy and new technology (Sood et al., 2009), introducing further technical risk.

Additional major AMI uncertainties are strategic risks of AMI implementation. An accelerated mandatory deployment of new and unproven technologies in advance of state, national, and international standards and frameworks will have the potential to significantly alter the competitive market landscape, further increasing implementation risk (Victorian Auditor General, 2009). For, example, without an appropriate framework establishing rights and responsibilities of a network-led AMI investment over time, a commercialised network utility may be in a position where they have little or no incentive to pursue ongoing AMI technical improvements that are of no benefit to their direct business model (Alinta AE, 2008). There is likely a push for a dominant entity to impose anti-competitive standards, requirements, or ownership structures that reduce competition at any point in the value chain of the electricity sector (i.e. telecommunications, information sharing, and DSM) (Executive Office of the President, 2011). As there is strong interest in AMI opportunities (particularly DSM and energy management) from data, information technology (IT), and telecommunications companies (such as Cisco, Intel, Verizon, Vodafone, IBM, and Microsoft), they may become new major players in the energy and water sectors, offering an expanded service range (Gogn and Wheelock, 2010). Therefore, enabling the extraction of major AMI benefits along the entire value chain, and over time, while minimising unintended negative consequences becomes a major consideration for AMI administering agencies.

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[2] The National Smart Metering Program (Australia) http://share.aemo.com.au/smartmetering/default.aspx

[3] The International Smart Grid Action Network (ISGAN) http://www.iea-isgan.org/main/

[4] The National Institute of Standards and Technology (NIST) http://www.nist.gov/smartgrid/

[5] In relation to the lack of AMI international standards, Australia would likely follow the currently common practice of following International Electrotechnical Commission (IEC) standards and 'Australianise' them to cater for local nuances (Australian Electrical and Electronic Manufacturers' Association, 2007).

3. Background for the focus areas for the AMI Administrators:

3.1. Fundamental general technical functionality considerations:

There are major implementation risks associated with AMI investments. These risks are often directly related to unproven/unknown technologies (Victorian Auditor General, 2009), particularly in relation to stranded asset costs in an accelerated AMI roll-out (MacDonald, 2007). The evolution of technology that enables AMI will present new opportunities as well as vulnerabilities (Executive Office of the President, 2011). High AMI costs are often associated with extracting important benefits, the net of which is highly technology dependent (MacDonald, 2007). Technology risks can increase the cost of development and integration of AMI technology when unexpected challenges arise, and can delay or prevent the accrual of expected benefits (Victorian Auditor General, 2009). For example, the digital circuitry in solid state meters is relatively sensitive to voltage surges compared to the current accumulation meters, and electrical storms may generate transients and surges exceeding the number and magnitude that standards require present smart meters to tolerate (Electric Power Research Institute, 2010)[6]. In a scenario assuming a network operator-led AMI investment, detailed assurances from the network utility should be obtained to ensure technologies of choice are capable of achieving expected service provision and functionality (Victorian Auditor General, 2009). Besides candidate/preferred options, there remain a number of AMI alternatives. For example, a 'smart grid' is possible without the installation of residential 'smart meters', as improved substation monitoring and communications can provide distribution data, although there will be little or no benefits from influencing end user behaviour (Deconinck, 2010). Conversely, there may be greater benefits for an expanded installation of residential AMI in collaboration with other utilities/sectors (water, electricity, gas, etc.) (MacDonald, 2007). The ability for new technologies to extract benefits and minimum net cost is thus dependent on the historical legacy of each local region.

3.2. Communication considerations:

AMI technology deployments are proceeding before standards development, particularly in relation to communications components (Gogn and Wheelock, 2010). Designing an AMI communication system that can meet the complex potential applications of smart grids over time is a fundamental challenge (Sood et al., 2009), and communication networks are required to be fully operational prior to scheduled reading of interval meter data (Energy Networks Association Limited, 2011). Various AMI communication technology types likely to be in concurrent use (even within a single network) will include hard-wired links, fibre-optics, wireless, microwave, satellite, etc. (Sood et al., 2009). However, the high life-expectancy of control systems and low latency of communications for real-time control is unique to the electricity industry (Executive Office of the President, 2011). These communication technologies must be able to provide suitable real-time and dependable options that combine redundancy, fast response, and dependability (Deconinck, 2010). Communication technologies must also be secure, support current and probable future technologies, have sufficient bandwidth to retrieve, cull, manage, store, and integrate large datasets generated by millions of devices in the vast majority of the electricity network[7]

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[6] Beyond the known generic failure rate profiles (high early failure rates trending low operational life failures and to rising end of life failures), the technical performance of the millions of solid state meters installed globally since the 1990s (and associated accuracy) has been encouraging (Electric Power Research Institute, 2010).

[7] It is expected to require 2-5 Mbits/s (a relatively low to medium data rate) of bandwidth to transfer basic three-phase data sampled at around 1000 times per second and computed quantities (phase amplitude, phase angle, etc.) and the

(Sood et al., 2009). The communications technology challenge on the scale of a large AMI will have a significant bearing on total project costs (Victorian Auditor General, 2009).

At this time it is not possible to select one location-independent communication technology that can cost-effectively supply AMI communications to all urban, suburban, rural, and remote locations, small and large buildings, houses, basements, etc. (Energy Networks Association Limited, 2011; MacDonald, 2007). Defining an appropriate communications architecture can be assisted by dividing requirements between the home and the concentration point, the concentration point and the data managers (MacDonald, 2007), or the home area network (HAN), local area network (LAN), or wide area network (WAN). Communication interoperability entails both software and hardware standards are based on open architecture and compatible interfaces (Deconinck, 2010). Ideally the communications protocol will be independent of the NAN/LAN/WAN technology type, and options may include wireless fixed, including PSTN, 2G, 3G, WiMAX, and new emerging options (Cheng and Kunz, 2009; MacDonald, 2007).

As dedicated communications for smart grids-only are likely to be very expensive by themselves, 'piggybacking' on existing infrastructure may be less expensive (MacDonald, 2007). The LAN is likely to be provided by a range of technology vendors using both alternative and similar options to reduce overall installation and stranded costs, and the WAN is likely to be comprised of a swathe of technology types and exhibit less competition (MacDonald, 2007; Markel et al., 2009), including large data carriers using cable or fibre optics (Markel et al., 2009). The HAN at present is a highly contested space, with a number of communication options. At present most HAN are radio technologies such as ZigBee and Z-Wave. ZigBee is designed for wireless sensing and automation applications based on the Institute of Electrical and Electronics Engineers (IEEE) 802.15.4 standard, operates in the 2.4 GHz and 900 MHz bands, and can reach 250 kbit/s of throughput (Cheng and Kunz, 2009; Markel et al., 2009). Z-Wave is a proprietary protocol also designed for home automation also using wireless mesh radio, but only operates in the 900 MHz band (for HVAC, lights, security, etc.), with a low bit rate of 9.6 kbit/s (Markel et al., 2009). ZigBee HAN devices operating at 2.4 GHz have a low power consumption (<1 mW), but have a 100m line of sight range making it suitable for urban and sub-urban areas, but not rural or remote areas (Cheng and Kunz, 2009; Markel et al., 2009). A technical alternative to ZigBee and Z-Wave is Homeplug. 'HomePlug 1.0' was developed to carry 14 Mbps was designed to connect household devices, and 'HomePlug BPL' for high-speed internet access using powerlines (Cheng and Kunz, 2009). HomePlug uses the home electrical wires so unintended broadband over powerline transmission may occur, which is why the AES encryption is used (Markel et al., 2009). ZigBee, HomePlug, and Z-Wave all use the 128-bit Advanced Encryption Standard (standardised by the National Institute of Standards and Technology) to secure transmitted data (Cheng and Kunz, 2009; Markel et al., 2009; Metke and Ekl, 2010). Transmission over the mobile phone network may not be suitable for electricity network communications, although new security proposals are anticipated. Similarly, while mobile phone devices consume more electricity than low power devices such as Z-Wave and ZigBee, they offer a relatively long-range wireless option with bit rates of over 100 kbit/s, and dedicated frequency bands that exhibit less traffic collisions (Markel et al., 2009). In contrast, interference between ZigBee, WiFi, Bluetooth, and cordless phones in the 2.4 GHz range is well documented, yet there is a growing number of technical options that reduce packet collisions (Cheng and Kunz, 2009; Markel et al., 2009). Nonetheless, all BPL, ZigBee, Z-Wave, and mobile phone options have sufficient throughput rates to relay expected AMI data.

Standards that assist interoperability, open protocols, technology neutrality, security, and ensure future usability of AMI investments can reduce technical uncertainty, transaction costs, and provide a level of security to consumers (Cavoukian et al., 2010; Executive Office of the President, 2011). The major risk with any HAN

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communications protocol, node data (usually the point of delivery where the meter is), and data correction/detection, (etc.) (Sood et al., 2009).

communication technology is whether suppliers of home appliances incorporate compliant network devices in their products, and how effective such technologies will be (Victorian Auditor General, 2009). The hierarchical operational profile commonly used in the telecommunications industry is a likely model to support AMI, which are commonly based on the International Telecommunications Union's fault, configuration, accounting/administration, performance, and security (FCAPS) model (Sood et al., 2009). There will be a range of data sent from gas/water/electric meters that are not for billing purposes, but to assist the customer and several service providers (for example to offer DSM or undertake network diagnostics, etc.) (MacDonald, 2007), and AMI HAN technology adoption should take into account DA requirements (Australian Electrical and Electronic Manufacturers' Association, 2007). Mesh radio and powerline communication systems both require concentrators to communicate between the meter and the network management system (NMS) and communication technologies between the concentrator and the NMS should be standardised while communication between concentrators and meters can be vendor specific, yet with interoperability (Australian Electrical and Electronic Manufacturers' Association, 2007; Gjukaj, 2011). Whichever HAN communication technology (or technologies) are eventually used, coping with the extreme time sensitivity of electricity network will require minimal latency (Sood et al., 2009). Requiring home area network and NMS communication interoperability is necessary prior to AMI roll-outs (Australian Electrical and Electronic Manufacturers' Association, 2007).

3.3. Communication technical background:

Open protocols and physical interface interoperability are fundamental to ensuring a balance between promoting communication technology competition and also assisting hardware differentiation for additional functionalities if required (Australian Electrical and Electronic Manufacturers' Association, 2007). Open standards, plug and play approaches, minimise stranded technologies (Sood et al., 2009), and AMI trial data should ideally be analysed by specialists (both internal and external), and be technology agnostic to ensure results and transparent and objective (Victorian Auditor General, 2009). In WA, the Western Power's current smart meter trials include the assessment of around 10,500 meters, mesh radio communications (using ZigBee), demand load control (DLC), automated meter reading, theft identification, remote connect and disconnect, HAN, time-of-use, in home displays (IHD), communications and data management requirements (with associated business model arrangements), and required changes to regulations, technical standards, and policy (Energy Networks Association Limited, 2011). Western Power operates several radio equipment types in the 900 MHz band: the tele-protection system, 32 in the 852/929 MHz; SCADA, 11 in the 853/929 MHz band, and; and the mesh radio/smart meter/repeater system (12,000 at the 915/928 MHz and 2.4 GHz band) (Bell, 2011). Western Power note that the 2.4 GHz ZigBee HAN technology has performed very well with 98% of coverage in flat urban areas, 94% in hilly leafy suburban terrain, with external antennas used to improve coverage, and ZigBee-enabled DLC test events reduced peak consumption by 20% per household (Energy Networks Association Limited, 2011).

Despite successful technical performance to date, the risks of unanticipated developments remain. The Australian Communications and Media Authority (ACMA) planned a harmonisation of the 928-933 MHz bands for radio mesh technology, potentially preventing Western Power from continuing to use the 915-928 MHz band (Bell, 2011). Furthermore, the radiofrequency communication technology proposed to be used by many AMI proponents is also been in use for hospital critical patient care and monitoring. Electromagnetic interference from radiofrequency identification technology (both passive and active) has been known to induce potentially hazardous incidents in critical care medical equipment (such as inadvertent switching off mechanical ventilators and syringe pumps), and necessitate updating of international standards (van der Togt et al., 2008).

There are likely to be several energy and water utilities establishing AMI-type technologies within the same geographical region, often government owned, and who may or may not actively be working together to ensure harmonisation. The government owned water utility in WA, the Water Corporation have installed AMI pulse meter installations for 13,500 services for commercial, industrial and residential users on the Kalgoorlie-Boulder Town

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Water Supply. This system also uses low frequency radio communications (Marmion, 2011; Water Corporation, 2011), and such systems may interfere. The Water Corporation trial uses alternative WAN communications than Western Power. The Water Corporation radio mesh networks transmit the hourly meter readings at 24 h intervals via low frequency radio and then onto the 3G network to Water Corporations business systems (Water Corporation, 2011). However, the Water Corporation and Western Power are now working together on an AMI trial combining electricity and water services with all the benefits of collaboration, and economies of scale. Yet with these benefits, such collaboration risk selected technology entrenchment as a consequence of early adoption through being industry leaders. Nonetheless, it is highly likely that AMI communication technology will evolve in ways that are difficult to anticipate and there will always be some issues with stranding and upgrading (Alinta AE, 2008).

3.4. Security and privacy considerations[8]:

AMI may make details of home energy consumption available that can remotely indicate whether a home is occupied or not, which appliances are used, the frequency of use, occupancy travel and work habits, socioeconomic status, food consumption patterns, and depending on communication platforms used, personal computer data may also be available (through both legitimate or illegitimate means) (U.S. Department of Energy, 2010). Therefore, security and reliability of the AMI data and networks will likely become the top priority in the development of AMI policy frameworks (Executive Office of the President, 2011; Gogn and Wheelock, 2010; Metke and Ekl, 2010). Personal information protection and security of the grid from hacking is an area that requires much attention from authorities and also significant consumer education (Cavoukian et al., 2010; Executive Office of the President, 2011; Markel et al., 2009; Metke and Ekl, 2010; U.S. Department of Energy, 2010). Electricity consumer opt-in arrangements to data sharing at time of installation may be one way where such concerns are managed (U.S. Department of Energy, 2010). Consumer privacy default settings can be influential in determining the eventual utility of the AMI investment and data availability when regarding opt-in/opt-out default options, and methods to streamline consumer authorisation of third-party access should be considered (Executive Office of the President, 2011). Consumer data will likely be valuable to a number of entities such as third-party marketeers, law enforcement agencies, insurance companies, researchers, and criminals. As the smart meter information is likely to be both personal and valuable, consumers (and consumer representatives) are likely to require consumers to have ownership and control over access to their own data (Cavoukian et al., 2010; U.S. Department of Energy, 2010). Therefore, consumers will require enablement to understand how to timely access to their own data and control how it is accessed and used (Executive Office of the President, 2011). Privacy laws that stipulate what information belongs to customers and what must be protected by utilities should be in place prior to roll-out, particularly in relation to personally identifiable information (U.S. Department of Energy, 2010). Broad consultation outside of the electricity industry in relation to consumer privacy can achieve greater consistency of AMI-associated privacy standards development and other comparable sectoral requirements (Cavoukian et al., 2010; Executive Office of the President, 2011; Metke and Ekl, 2010).

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[8] The NEM has a Consumer Advocacy Panel (CAP) that was established under the AEMC (Australian Energy Market Commission) Establishment Act (2008). The CAP has the responsibility of granting funding for advocacy and research on electricity and gas issues. (http://www.advocacypanel.com.au). The Consumer Advocacy Panel is funded through AEMC in its role as the 'rule maker' for national energy markets. If the WEM had something like the NEMs CAP, we would have more of a targeted consumer advocacy body here to forward specific AMI information to other than a general body such as WACOSS (Western Australian Council of Social Service). Here, the ERA has a Licensing, Monitoring and Customer Protection Division, but there is little consumer advocacy representation in the electricity and gas markets to date.

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Customer relationships with electricity utilities are traditionally borne out of necessity rather than preference (Cavoukian et al., 2010), and there has been a recent growth of AMI-resistive consumer groups (Gogn and Wheelock, 2010). These groups are particularly concerned with AMI privacy, costs, and 'sanctity of the home' considerations (Cavoukian et al., 2010; Victorian Auditor General, 2009). Who owns the consumers data collected from essential public services is a major issue (U.S. Department of Energy, 2010). Customers energy usage, access to their own data in a useable format, knowledge of what data and to whom this data is passed onto, and with what frequency, should be made available to the consumer (Cavoukian et al., 2010; U.S. Department of Energy, 2010). There are also risks that legitimate third-parties will not have access to the same data as electricity retailers, who will thus have a competitive advantage in offering improved energy services, and an ability to expand their own range of service provision outside of traditional energy and water services (Executive Office of the President, 2011). Enforceable privacy protections explicitly for AMI data flows (including the data use, retention, and security) both to and from meters (considering DLC options and considering that electricity is an essential service) from utilities, retailers, demand-side aggregators, and third party entities will be required (Cavoukian et al., 2010; U.S. Department of Energy, 2010). In general at present, the electricity industry and AMI administering agencies have exhibited low levels of awareness of privacy implications, formal information collection standards and procedures, definitions of what personally identifiable information is, and also network vulnerability (Cavoukian et al., 2010; Metke and Ekl, 2010).

AMI security concerns have also pointed out the deficiencies of conventional SCADA security systems and standards inconsistencies (Metke and Ekl, 2010). The infamous Stuxnet worm was designed to target and imbed itself in SCADA systems that were not connected to the internet and existed for months despite updated software patches and malware protection devices (Gogn and Wheelock, 2010). New DA, DLC and DSM applications generate new potentials for malware that may be used to cause physical damage by changes in electricity demand (Metke and Ekl, 2010). Regulatory authority over unauthorised or malicious access, disclosure, or misuse by third parties should be looked at carefully. In some jurisdictions electricity utilities are prevented from selling, making available for sale, or authorising the sale of customer data (Cavoukian et al., 2010; U.S. Department of Energy, 2010). Conversely, aggregated or minimal data can be given to third parties that is customised to the relevant services they offer, and terms of use may prevent data from being correlated with other sources, without the individual's explicit consent (Cavoukian et al., 2010).

3.5. Competitive considerations (DSM, storage, EVs, and consumer behaviour):

Reducing the daily and seasonal peak demands is often the initial and primary focus for AMI introduction, and consumers with high electricity use patterns in the peak period who shift their consumption will likely see benefits more readily (although this will depend on their tariff) (Hoch and James, 2010). DSM innovation from AMI investment enables a number of options for new services to consumers through retailer competition, although AMI user interface usability will determine to a great extent the level of consumer participation and resultant personalised energy savings (Executive Office of the President, 2011). The electricity retail and DSM markets will likely be altered with external IT and communications businesses capitalising on their own existing customer relationships to compete with conventional electricity utilities (Gogn and Wheelock, 2010). While large commercial and industrial users at present have more opportunity to participate in DSM markets (Executive Office of the President, 2011), a track record of how residential consumers respond to variable tariffs will likely determine the aggregate value to a market (Hoch et al., 2008). Whilst much attention is focussed on marketing of AMI technology benefits to residential consumers (to reduce losses that to achieve gains and how they perform against their peers/neighbours) (Executive Office of the President, 2011), their value to the market will likely rest on how the electricity market views their DSM contribution (i.e. firm/responsive, or otherwise) and will be contrasted against DLC options (Hoch et al., 2008). Greater knowledge of how consumers view and/or adopt and combine time-of-use tariffs, DSM, DLC, and energy efficiency is needed (Alinta AE, 2008). There will likely to be a difference between reported consumer opinions of AMI in the media and actual uptake that more accurately reflects consumer preferences (Gogn and Wheelock, 2010). Parallel unrelated changes in electricity tariffs may also be an influencing factor in AMI roll-outs: customers commonly incorrectly attribute increased bills to new meter installations, which are often subsequently identified to be due to seasonal consumption variations or a tariff increase (Energy Networks Association Limited, 2011).

While general increases in energy service provision costs are a key motivator for AMI, there are geographical differences of costs and benefits of AMI (Alinta AE, 2008), particularly in a in a dispersed network such as the WA SWIS. A smart grid will decentralise many operations, and will alter the centralised data analysis and associated costs (Sood et al., 2009). Conventional distribution network support, metering, manual meter reading, connection and disconnection costs in a business as usual approach remain significant for network utilities, and introducing AMI for such applications will require relatively little legislative, market rule, or regulatory changes[9] (Hoch and James, 2010). Technical options such as DA may become the most important element of AMI projects (Gogn and Wheelock, 2010). In the USA (Oklahoma), DA systems have been found to reduce the restoration of electricity services subsequent to an outage blackout for an average of 30% (Executive Office of the President, 2011). Various forms of energy storage can be implemented in the distribution network through AMI investments, particularly when integrated with environmental-related changes (such as temperature) in relation to generation, transmission, and distribution performance (Executive Office of the President, 2011; Mullan et al., 2011). As refrigerators, air conditioners, and washing machines commonly reduce power factors when in operation, by introducing capacitance for power factor correction, the current flow and thus associated resistive losses are reduced without significantly affecting the meter registering units consumed (Misakian et al., 2009). It has long been known that using simple technical alternatives such as adding capacitance to distribution services to cater for average air-conditioning loads, and the network utility will save an estimated 1 cent per day (based on a saving of 52.8 Wh per day) for each 12 hour use of a central air-conditioner (Grebe, 1996; Misakian et al., 2009). Reduced overall distribution network service costs via cost-effective technical options will constitute a monetary benefit to all consumers, regardless of the level of behavioural change an individual household makes, which is essentially a form of cross subsidy (Hoch and James, 2010). However, these incremental changes will not be able to appreciably reduce peak demand, and do not provide the benefits of operational network utility savings as AMI-based DSM or DLC options (Hoch et al., 2008), particularly for new major residential consuming technologies such as electric vehicles (EVs). As EVs operational costs seem to be cost competitive with internal combustion engines, are parked around 90% of the time, and the battery component represents a significant storage capability, then they may play a significant role in future of the WA SWIS network depending on market penetration (Markel et al., 2009; Mullan et al., 2011). EVs have the potential to reduce investment in underutilised distribution capital by shifting loads, even at relatively low EV penetrations (Mullan et al., 2011). Without additional EV demand occurring in off-peak periods, EVs may simply add to distribution network concerns. EV battery performance and life-cycle modelling that incorporates time-resolution and price data can quantify the value to customers (with or without time-of-use tariffs or AMI) (Markel et al., 2009; Mullan et al., 2011), yet preventing high costs to the distribution network will require at least time-of-use tariffs.

As AMI is a major utility business transformation requiring major investment, a unilateral government and/or government-owned utility delivery and implementation of AMI projects are likely to miss some key potential benefits and increase the total costs of AMI investments (Alinta AE, 2008). Data management for utilities will be a key component of successful AMI roll-outs and will require major re-alignment of utility business

[9] While AMI investment will enable remote meter reading, servicing will need to continue (albeit at less regular intervals), as the meter batteries will require replacing at roughly five-year intervals when operated at an mean of 25°C. Note that the life of batteries decreases with increasing operating temperatures, while the battery capacity increases with increasing temperatures.

processes, interfaces, and possible outsourcing of such capabilities (Gogn and Wheelock, 2010). There are also fundamental issues relating to the incentives for utilities to generate, transport, and sell less energy and operate more efficiently (Executive Office of the President, 2011). An empowered, representative, and senior industry decision-making body is one option to design and oversee AMI investments and associated changes to rules, procedures, regulation, and systems and focuses on business requirements prior to technology (Alinta AE, 2008).

3.6. AMI CBA assumptions and sensitivity considerations:

Leading edge technologies have high implementation risks, require appropriate risk management, critical analysis of AMI trials, and have major implications for CBAs (Victorian Auditor General, 2009). There is currently high uncertainty of the magnitude of benefits relative to costs of AMI investments (MacDonald, 2007), and several discrepancies between AMI economic projections by independent groups (Victorian Auditor General, 2009). The result of any AMI CBA is dependent on the scope of what is included in the analysis (i.e. EVs vs no EVs, cost uncertainties, customer behavior, fraud savings), what is deemed as a cost and benefit, the actors involved, and the discounted time horizon (Deconinck, 2010). Some benefits are difficult to include in CBAs, for example during emergency situations AMI-enabled DLC options can be used to ensure some level of electricity supply to all customers but reduce their total usage (Hoch and James, 2010). Furthermore, it is often unclear how much and to which entity benefits will flow, and who will ultimately bear the cost of AMI implementation. This can lead to a several unintended consequences, including the transfer of benefits from consumers to industry, and also between industry players (Victorian Auditor General, 2009). For example, there is little benefit of AMI investment for retailers, and any benefits will likely be passed onto consumers if retail competition arises (Hoch and James, 2010). Therefore, energy retailers are unlikely to be motivated participants in an AMI roll-out if it is led by the network utility. Furthermore, a highly sensitive component of AMI CBAs are the level of consumer behaviour change, as it is often location dependent, yet is generally very small in terms of energy savings (<10 - <5%)(Faruqui et al., 2010). As such, the market value from residential consumer behaviour change is highly sensitive to assumptions regarding the level of eventual penetration and firmness (Faruqui et al., 2010; Hoch and James, 2010).

4. Conclusion

The full benefits of AMI are contingent on how the interval meters are coupled with other enabling technologies, and the ability for various stakeholders to use such technology and information to extract benefits while minimising costs, and the sensitivity of each element (Energy Networks Association Limited, 2011; Faruqui et al., 2010). There is relatively high confidence in the magnitude of benefits from improved network operation and metering efficiencies from AMI investments (Hoch and James, 2010). These expected network benefits include greater DSM, increased supply efficiency from remote monitoring and switching options, and increased supply reliability from improved network and fault management (Victorian Auditor General, 2009). These benefits include many elements that will not be captured by a reduced electricity supply costs, such as reduced outage times, reduced inconvenience, and lower food spoilage, etc. Whilst the potential benefits from AMI investments are very large, yet the 'additional' and more uncertain benefit components are highly sensitive (Hoch and James, 2010). A significant uncertainty is the extent to which retailers will invest in data handling and processing of AMI-enabled datasets and how these investment costs will be passed onto consumers (Victorian Auditor General, 2009). Furthermore, any benefits from residential consumer behavioural change is dependent on their current tariff and payment methods, and the characteristics of the required behavioural changes themselves (Faruqui et al., 2010; Hoch and James, 2010). Therefore, it is clear that the scale of AMI investments are an almost unprecedented challenge to energy policymakers. The consideration of yet undeveloped energy ancillary products and services, market contestability, regulatory and policy amendments, consumer protection, public education, and general safety considerations requires a collaborative investment in technical, logistical, and strategic risk for governments and administering bodies. A focus on intensively managing AMI governance and planning is required to maximise the numerous potential benefits and minimise the comparable uncertainties, costs, and risks to the large number and variety of stakeholders.

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