Curtin University Sustainability Policy Institute

Creating a Sustainable Energy Model – Integrating Solar and Storage into Electricity Systems by Aligning the Interests of Consumers, Utilities and Government

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Doctor of Philosophy

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DECLARATION

I, Anant Dev Tayal, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the Curtin University Sustainability Policy Institute, is wholly my own work unless otherwise referenced or acknowledged.

To the best of my knowledge and belief this thesis contains no material previously published by any other person except where due acknowledgment has been made. This thesis contains no material which has been accepted for the award of any other degree or diploma in any university.

The research presented and reported in this thesis was conducted in accordance with the National Health and Medical Research Council National Statement on Ethical Conduct in Human Research (2007) – updated March 2014. The proposed research study received human research ethics approval from the Curtin University Human Research Ethics Committee (EC00262), Approval Number #RDHU-0816.

Anant Dev Tayal

21 May 2017

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The hundreds of participants, interviewees, friends and colleagues, thank you for your responses, insights, contributions and assistance. This research relies on your perspectives, opinions and recommendations, and I am excited by the prospect of all our exploratory and theoretical discussions becoming a reality. Your time is greatly appreciated.

To my family. You have a special ability to provide unconditional support behind every one of my adventures. Mum, Dad, Richa and Tim, thank you for your love and endless positivity.

And finally, to my beloved, Uwana. You're a fellow dreamer, and without you by my side throughout this journey I would not have believed it to be possible, nor this enjoyable. The writing that makes up this research reflects your wisdom, support and guidance. Thank you.

ABSTRACT

An increasing number of residents and businesses across the world are installing solar photovoltaic (PV) panels and battery storage systems, satisfying not just their interest in clean energy, but also taking advantage of reduced technology costs and mitigating against future electricity price rises. This doctoral thesis assesses the impact of these new energy technologies, using the Western Australian electricity network as a case study, where their adoption in recent years has been very rapid. It identifies the role of innovative technologies both as a disruptive threat to the centralised service model and as a source of opportunity for incumbent electricity utilities, governments and customers. The research is presented through six corresponding research papers on the topic, each summarised below with details on significant findings.

The first paper conducts a thorough literature review and outlines the drivers of disruption for electricity utilities. The energy sector has been navigating rapid technology innovation, slowing demand, and rising electricity prices. A steady shift towards renewable energy products is also exacerbating the disruption of utility business models. The paper explores potential risks and opportunities as traditional business models evolve to embrace these disruptions going forward.

The second paper builds on this foundation, further detailing the barriers and opportunities for residential solar PV and storage in the energy sector. It outlines how solar PV panels coupled with storage systems present an opportunity to move towards a resilient, affordable, flexible and secure electricity network, particularly in Western Australia given the unique set of conditions (isolated network, high solar radiation, and rising electricity prices), but increasingly in all energy markets around the world. However, a number of barriers are still obstructing the transition to renewables, and

through a series of interviews with several Western Australian energy market participants, these barriers are identified and qualified.

Paper three continues by investigating how utilities can best adapt, exploring how existing business models will need to evolve beyond traditional energy economics. It is suggested that new characteristics and business models be adopted in a modular approach, to ensure capabilities are maintained, costs minimised and customers retained.

Paper four conducts an online survey of one hundred residential electricity consumers in Western Australia to analyse their perceptions of solar PV and battery storage systems, electricity cost drivers, willingness to change consumption behaviour, and acceptance of various electricity pricing structures. The majority of respondents indicated strong enthusiasm to change their behaviour and reduce electricity usage providing it saves sufficient money on electricity bills and appropriately rewards solar and storage technologies, suggesting the appetite for retail tariff reform is strong and could even be customer-led.

Paper five investigates how important technology innovation is to facilitating the transition occurring in the energy sector, and investigates how to best create an environment to remove obstacles and enable innovation in energy products and services. The research outlines that if effective partnerships can be created between utilities and research centres, it may provide benefits to utilities across the value chain.

The paper also suggests that a collaborative mindset is needed to ensure utilities recognise the role they must also play in guiding regulatory reform and driving governments and regulators to accept the uncertainty that future business models must navigate to succeed.

The sixth, and final, paper continues the innovation theme and explores how a high renewable energy penetration can be achieved leveraging existing infrastructure, focusing on the potential benefits that could arise from the broad technological advances in the fields of data analytics and machine learning.

Overall, this doctoral research provides original findings on the barriers, opportunities, customer perceptions, business models, and pricing structures that can facilitate the increased uptake of solar and storage systems in energy markets around the world, and outlines how disruption in the sector can also be leveraged as an opportunity for existing and new entrant energy companies, governments and customers alike.

The research, using the Western Australian energy market as a case-study, fills a gap in the literature and outlines various policy recommendations and strategies for industry participants, regulators and policy makers on how to evolve existing electricity infrastructure and institutions. The findings are as relevant for Western Australian energy market participants as they are for utilities and energy stakeholders around the world, who are eagerly looking for guidance on how to manage their local energy system transitions. In effect, Western Australia has inadvertently become a central player in guiding how energy markets globally will create innovative, sustainable electricity systems of the future.

PUBLICATIONS CONSTITUTING THIS THESIS

Paper 1 - (Published)

Tayal A.D., 2016. Disruptive Forces on the Electricity Industry - A Changing Landscape for Utilities. The Electricity Journal, Volume 29, Issue 7, 13-17.

Paper 2 - (Published)

Tayal A.D., Rauland V., 2016. Barriers and Opportunities for Residential Solar PV and Storage Markets – A Western Australian Case Study. Global Journal of Researches in Engineering, Volume 16, Issue 7, 45-57.

Paper 3 – (Published)

Tayal A.D., Rauland V., 2017. Future Business Models for Western Australian Electricity Utilities. Sustainable Energy Technology Assessments, Volume 19, 59-69.

Paper 4 – (Under Review for Publication)

Tayal A.D. A Behavioural Approach to Sustainable Electricity Pricing. Energy Policy.

Paper 5 – (Published)

Tayal A.D. Leveraging Innovation for Electricity Utilities. The Electricity Journal. Volume 30, Issue 3, 23-29.

Paper 6 – (Published)

Tayal A.D. Achieving high renewable energy penetration in Western Australia using data digitisation and machine learning. Renewable and Sustainable Energy Reviews. Volume 80C, 1537-1543.

Other Publications Arising from this Thesis

Tayal A.D. Newman P., 2017. Five Things the East Coast can learn from WA about Energy. The Conversation [Online]. Available from: http://theconversation.com/five-things-the-east-coast-can-learn-from-wa-about-energy-76398 (Appendix C)

STATEMENT OF CONTRIBUTION

This statement verifies that the greater part of the work in the above-named manuscripts is attributed to the candidate, Anant Dev Tayal, whom under the guidance and supervision of his supervisors, took primary responsibility for the design of each paper, all data collection and analysis, prepared the first draft of each manuscript, and prepared the papers for submission to relevant journals. The co-author, who was also a co-supervisor to the candidate, contributed to the thesis by providing initial guidance on the design of papers.

Anant Dev Tayal (PhD Candidate)

Professor Peter Newman (Primary Supervisor)

Dr Vanessa Rauland (Co-supervisor)

TABLE OF CONTENTS

CHAPTER 1: INTRODUCTION

This doctoral research assesses the impact of technology innovations on the energy sector to understand both the challenges and opportunities being faced by incumbent utilities, energy businesses and policy makers. Using Western Australia (WA) as a case study, the research focuses on the impact of solar photovoltaic (PV) and storage systems on electricity systems, utilising a series of interviews with energy sector participants and an online survey of residential electricity customers. An extensive literature review is also conducted to explore and contrast the findings against existing frameworks and policy recommendations from around the world. The Western Australian electricity market is of global significance, as the adoption of solar PV has proceeded very rapidly in recent years, battery storage is due to follow a similar trajectory, and the sector has reached a point where significant disruption is occurring.

Energy markets are already inherently complex structures. In WA, the complexity is made even more apparent by the State's geographical isolation, preventing any feasible prospect for WA's networks to be connected to neighbouring systems. However, within this challenging environment, WA's unique isolation also presents an opportunity to study the extent to which renewable energy technologies can be utilised to disrupt the conventional, centralised model of our existing systems.

In particular, this thesis focuses on two main energy technologies. The first, rooftop solar PV for the residential and commercial sectors (steadily gaining in operating efficiency and rapidly falling in capital cost), is considered in its most common form – crystalline silicon cells. The second, complimentary, technology considered is battery storage systems, which have the advantage of scalability, and can therefore be deployed from the household scale (kWh) through to grid-scale (MWh and GWh). No restriction to battery chemical composition was made, although during the period of research, lithium-ion batteries achieved the largest cost reductions and remained the most common choice for the small-scale sector. An assessment of these decentralised technologies is then undertaken from a view that they may operate in isolation (either solar PV or storage), in combination (both solar PV and storage), in grid-connected, or in islanded mode, as appropriate to the local contextFrom the perspective of electricity utilities, the increasing uptake of solar and storage can have a significant impact on electricity demand, introduces the need for innovation in metering and pricing (to account for the cost of maintaining the grid and appropriately reward distributed energy), and raises issues for network stability and security. In addition, the energy sector is also heavily influenced by the volatile nature of Federal and State government views on electricity regulation and climate change policy.

From the perspective of small-use consumers (residential households and small businesses reliant on grid-connected utility services), roof-top solar PV panels coupled with storage systems present an opportunity to drive WA towards a resilient, affordable, flexible and secure electricity network – a sustainable future for electricity services. However, to achieve this future, renewable technologies such as solar and storage should not be viewed in isolation, but must be considered as part of a wider transformation of our energy systems and institutions. This is because disruptive technologies such as solar PV and storage essentially create a series of socio-technical transitions, which inherently includes changes in business models to distribute new services and products, consumer behaviour changes, user practices and applications, consumer protections, and broader economic, social and environmental factors, across micro, meso and macro levels (Geels and Shot, 2007). The same future beckons across the globe and hence this thesis is framed to create some global directions that may help other cities and regions, states and nations on this journey.

1.1. Research Objective

The principal thesis of this doctoral research is to investigate:

How solar PV and storage systems can be integrated into electricity networks in a way that aligns the interests of consumers, utilities and government to create a more sustainable energy model.

This problem is addressed by exploring the following questions through a case study assessment of the WA electricity system, providing globally relevant solutions:

1. What are the disruptive forces on the electricity industry and what is driving the sector to change?
2. What are the barriers for solar PV and storage markets and will the rapidly evolving landscape drive potential opportunities?
3. How should utility business models evolve to facilitate the uptake of distributed solar PV and storage systems?
4. How will the continued uptake of solar PV and storage affect electricity pricing and what are the likely impacts and preferences for consumers?
5. Can existing barriers be overcome through technological innovation and what role will innovation play in the strategic development of utilities?
6. How can the electricity industry leverage the innovations in computational capabilities and data analytics to achieve higher penetration of renewable energy?

In answering each question, a discrete, yet interlinked paper was prepared and published in (or submitted to) a peer-reviewed journal. These six papers make up Chapters 5 through 10 of this thesis (see Table 1.1).

Table 1.1: Research Questions by Publication and Thesis Chapter

Paper #	Research Question	Paper Title	Journal Publication	Chapter #
1	What are the disruptive forces on the electricity industry and what is driving the sector to change?	Disruptive Forces on the Electricity Industry - A Changing Landscape for Utilities	The Electricity Journal, Volume 29. Issue 7, 13-17.	5
2	What are the barriers for solar PV and storage markets and will the rapidly evolving landscape drive potential opportunities?	Barriers and Opportunities for Residential Solar PV and Storage Markets – A Western Australian Case Study	Global Journal of Researches in Engineering. Volume 16. Issue 7, 45-57.	6
3	How should utility business models evolve to facilitate the uptake of distributed solar PV and storage systems?	Future Business Models for Western Australian Electricity Utilities	Sustainable Energy Technology Assessments, Volume 19, 59-69.	7
4	How will the continued uptake of solar PV and storage affect electricity pricing and what are the likely impacts and preferences for consumers?	A Behavioural Approach to Sustainable Electricity Pricing	Energy Policy (under review).	8
5	Can existing barriers be overcome through technological innovation and what role will innovation play in the strategic development of utilities?	Leveraging Innovation for Electricity Utilities	The Electricity Journal. Volume 30. Issue 3, 23-29.	9
6	How can the electricity industry leverage the innovations in computational capabilities and data analytics to achieve higher penetration of renewable energy?	Achieving high renewable energy penetration in Western Australia using data digitisation and machine learning	Renewable and Sustainable Energy Reviews. Volume 80C, 1537-1543.	10

Each paper therefore addresses a related aspect of the principal thesis, whilst maintaining a common theme of solar and storage technologies, and a common focus on challenges and opportunities in the sector, using WA's energy market as an example. This provides both a linkage in technology and geography, presenting a contextualised insight for WA businesses, policy makers and customers whilst also highlighting global implications within each paper. Thus, the findings are also designed to be applicable to researchers, policy makers, regulators and utility businesses in comparable energy markets around the world.

Ultimately, this research is driven by the need to address climate change, and the need to fundamentally shift the way an energy system produces and consumes energy, in order to aggressively reduce carbon emissions (Jacobsson and Johnson, 2000). The challenge is therefore in achieving significant carbon emission reductions across the energy sector, without undermining system security - avoiding scenarios that simultaneously raise the risk of black outs and increase electricity prices (Lund, Mikkola and Ypyä, 2015; Newbery, 2016).

A forward-looking response is clearly needed in order to evolve the current energy markets of places like WA, and transform energy systems to deliver across the priority outcomes of a low cost, low-carbon, and secure energy network. It is hoped that this research can be used in practice to contribute towards this evolution – to encourage energy businesses and utilities operating in similar energy markets around the world to utilise solar PV and storage systems in a strategic fashion, to reduce grid congestion, or to remove (or at least defer) the need for network investments and thereby create value for all stakeholders.

This research provides governments and regulators with a series of potential policy and regulatory reform recommendations that can better align utilities' commercial interests with that of consumers and the environment. It should also provide a foundational framework for energy markets around the world to follow in their evolution towards innovative and sustainable electricity networks.

CHAPTER 2: SUMMARY LITERATURE REVIEW

Whilst the published papers that comprise this doctoral dissertation each provide comprehensive coverage of relevant literature and act as stand-alone pieces of research, an overview of the significant literature review findings contained within the subsequent chapters (5 to 10) are presented in this section for completeness, as well as an overview of the structure of the WA electricity market to frame the context of later discussions and findings.

2.1. Background

2.1.1. Updating the Legacy Models

Today's utility business models still largely reflect the legacy design of centralised electricity generation, distribution and transmission. Inherent in this design, is the large upfront capital required to build infrastructure, and the low levels of operating costs and revenues. Naturally, this structure leads to an economically rational motivation for electricity utilities to maximise their revenues through increased production and distribution of electricity through their existing networks of poles and wires. Utilities, therefore, created a traditional service of delivering electricity at price per kilowatt hour (Kind, 2013; Bromley, 2015; Caldecott & McDaniels, 2014).

The pervasive assumption that demand for electricity would always increase, has also contributed to the design of the current electricity system, in regards to network infrastructure planning, system security and control, network regulation, and market dispatch. (Schaltegger et al, 2012; Richter, 2013; Roberts, 2015; Sioshansi, 2014).

Technology developments and improvements notwithstanding, the centralised legacy design of electricity infrastructure has stood the test of time as each enhancement to the system only ever became an incremental improvement – effectively locking the industry into a familiar standard (Nelson & Winter, 1982).

However, as several factors converge across technology, economics and public policy, this standard, legacy design of our electricity systems is now coming under increasing pressure. Over the last ten years, the energy sector in Australia has been dealing with: rapid technology innovation (removing barriers to entry for small players); the falling cost of distributed generation; increased interest in demand side management; slowing trends in demand; shifting government policies on renewable energy incentives; and rising electricity prices across the country (Kind, 2013; e-lab RMI, 2014; Grace, 2014; Bunning, 2011). In combination, these factors are set to fundamentally change the way our electricity systems operate.

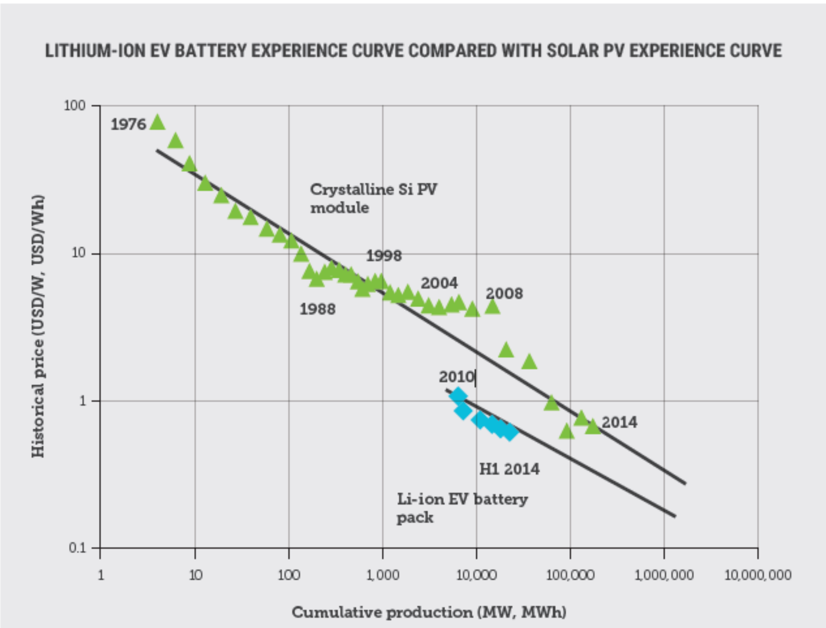
The traditional status quo of the sector and the business models of utilities going forward are being challenged. Not only is this having a direct impact on electricity prices and creating feedback loops towards distributed generation products such as solar PV, but it is also creating major difficulties for governments to continue to subsidise energy costs for residential consumers. The increasing uptake of solar PV and storage, and continuing innovations in intelligent consumer appliances and products will only exacerbate this issue further (Zinaman et al, 2015).

2.2. The Great Disruption

One of the dominant drivers challenging the status quo of traditional electricity systems is solar PV's increasing integration into existing electricity networks. Investment in solar PV is becoming more attractive because, relative to other conventional power plants, solar's long-term power purchase agreements provide insulation from the variability of fuel prices, minimise downside risks from changes to government policies and appeal to both businesses and consumers seeking cleaner sources of electricity generation (Frankel et al, 2014; Oliva, 2015; MIT, 2015; Outhred, 2007).

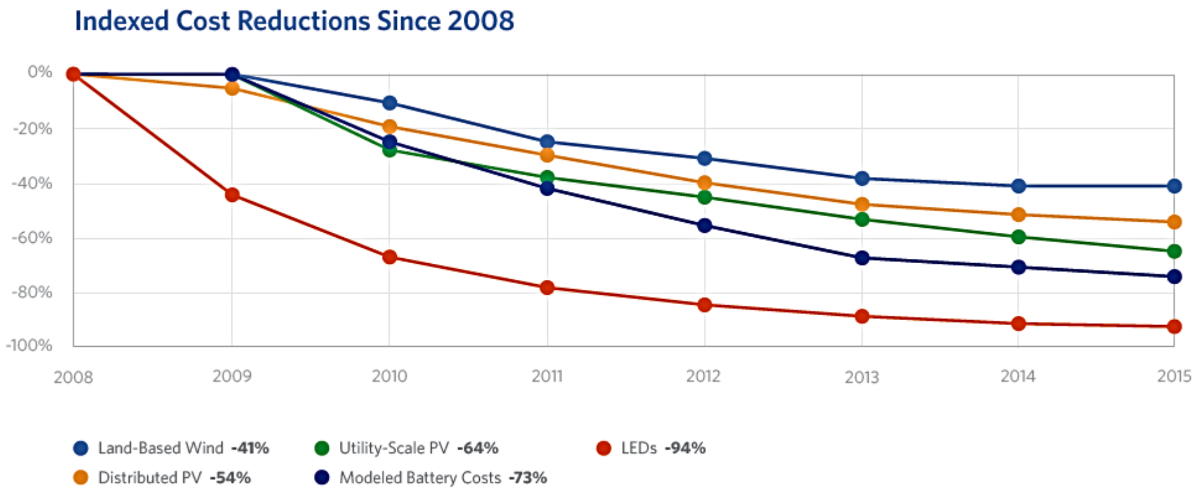
The economic attractiveness of solar PV panels is also improving, driving the rapid uptake of rooftop solar PV around the globe (Fraunhofer, 2015; Frankel, 2014; Grace, 2014). A study by the International Renewable Energy Agency (IRENA, 2015) found that the price of solar PV panels decreased by 75 per cent between 2009 and 2014. However, the competitiveness of solar PV relative to other electricity generation sources depends not just on costs, but also on the value of the generated output within the particular energy market in which it is sold (MIT, 2015; Warshay, 2015). Similarly, battery storage systems are widely predicted to decrease in cost based on their experience curve (see Figure 2.1 and Figure 2.2), a growth in uptake due to the commercialisation of lithium-ion batteries, and the predicted rapid growth in demand expected from electric vehicles The significant changes in the economics of these particular products, and the business model implications driven by their decentralised application provides the basis for focusing this research on the opportunities and challenges they provide, relative to other, more nascent or large-scale, centralised technologies.

Figure 2.1: Cost Reductions in Solar and Lithium Batteries



Source: Adapted from Climate Council, 2015

Figure 2.2: Cost Declines in Key Technologies, 2008 – 2014



Source: Adapted from MIT, 2016

As the MIT study notes, technological advances and cost reductions do not automatically lead to cost-competitiveness in all energy markets, and many distributed technologies such as solar PV combined with battery storage will require subsidy support to compete with legacy, centralised systems on a levelised cost of energy comparison (MIT, 2016).

Nevertheless, numerous energy markets around the world are already grappling with the challenges brought about by increased levels of solar PV on the grid (IEA, 2013; Satchwell, 2015; IMO, 2014). For example in Europe, growth in electricity demand is being challenged, driving down electricity prices and stunting the ability for any further investment in conventional power sources (Richter, 2012; 2013; Overholm, 2015).

In Australia, all states have seen rapid uptake in rooftop solar PV since 2009, with both the Australian Energy Market Operator (AEMO) and the Independent Market Operator (IMO) predicting the strong growth rate to continue for decades to come (AEMO, 2012; IMO, 2014). In dealing with solar PV's integration into the grid, Australian utilities and energy companies can learn from European utilities, who were seen to be slow moving and too reliant on government support, while smaller, independent players led the way (Chowdhury et al., 2014).

A 2013 study of the German energy market by Richter, found that not only were German utilities yet to react to solar, but the majority of managers interviewed saw no future for solar PV within their organisations. This was driven by the view of solar PV as a relatively small scale technology, with relatively high costs and therefore a strong reliance on government subsidies to remain competitive (Richter, 2013).

In contrast, solar PV should be thought of as a ‘disruptive innovation’ given its potential (particularly in combination with residential storage systems) to challenge the entrenched, centralised models of electricity generation and the opportunities it presents to the electricity market going forward.

Research on disruptive technology’s impacts on existing markets has highlighted the inability for incumbent firms to recognise the true nature of threats to existing business models (Christensen, 1997). A study by Christensen and Raynor (2013) found that the primary reason incumbent firms are resistant to innovating products is because of an over-reliance on listening to what customers are asking for. According to the study, the average customer is blind to any potential benefits from new and innovative products prior to their commercialisation, and therefore rather than driving any form of radical innovation, customer preferences simply lead businesses to make gradual improvements on existing products and services (Christensen and Raynor, 2013).

Unsurprisingly then, utilities are yet to adapt to dealing with the disruptive potential that technologies such as solar PV and storage will play in providing a resilient, reliable and renewable source of electricity. While the electricity industry has largely avoided disruptive threats for over a century, components of the existing centralised system are already labeled as stranded assets, and there is a growing need to address this through revised investment criteria (PwC, 2014; Caldecott & McDaniels, 2014). At an extreme, energy analysts describe the situation as the “utility death spiral”, and believe energy generated by solar is threatening the future existence of a grid-based energy systems and business models (Silverstein & Wood, 2014).

2.3. The New Utility Business Model

Within this context of disruptive innovation, for managers of utilities to decide to enter and succeed in solar PV and energy storage markets, they would need to make bold decisions to change their business models and introduce new products, pricing plans, or service offerings, and then be the ones to convince customers of their value (Ratinen, 2014). Utilities moving into this space would also need to either prove their differentiation from existing products and services in the market, or expand the market itself (Richter, 2013).

Put simply, business models are the link between corporate strategies and operational activities, and there are already several examples of organisational efforts to transition towards more sustainable business models (Rauter et al., 2015; Stubbs and Cocklin, 2008). These businesses' strategy and decision making goes beyond maximising shareholder value from a purely economic point of view, and purports to consider additional aspects such as reducing the carbon footprint of products, or taking into consideration wider social implications of their business practices (Matos and Silvestre, 2013; Schaltegger et al., 2012). Underpinning the development of these sustainable business models for the electricity industry, utilities will have to expand beyond the traditional strategy to maximise the volume of electricity sold, and consider additional factors within the social and environmental domains (Schaltegger et al, 2012; Richter, 2013; Ashford, Hall and Ashford, 2012).

These new utility business models cannot be developed and adapted by utilities in a vacuum, whether Government owned or private enterprises (Vanamali, 2015). The transition to new business models will require collaboration and participation across policymakers, regulators, investors, consumers, forward thinking government ministers, as well as technology innovators and entrepreneurs.

Further, any solutions designed to meet the transitioning needs of the energy industry will need to be based on the individual regulatory and market contexts in which they emerge (Crawford, 2015; Hogan, 2014). For instance, utilities in competitive markets will be more directly exposed to the threats that arise from technology innovations such as solar and storage systems, given their ability to reduce electricity use and demand (Kind, 2013).

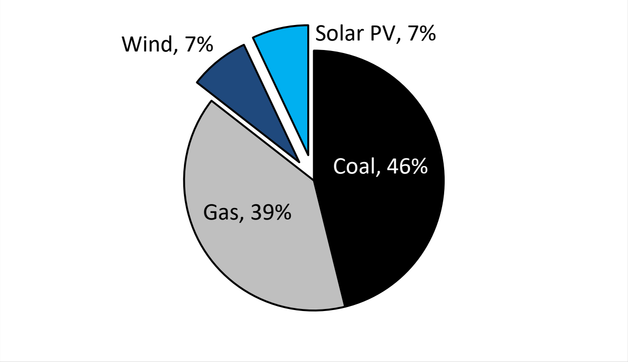
A study by Richter (2013) concludes that the first step in the journey is changing the perspectives of utilities with regards to the opportunities that solar PV brings. The growth potential in the expanding solar market and building new customer relationships would be additional opportunities; and long term contracts for solar PV provided by the utility would also facilitate customer retention. Within this new perspective, solar PV could then be viewed as a stepping stone into promoting other ‘green energy’ initiatives, such as energy efficiency and battery system offerings (Richter, 2013).

2.4. The Western Australian Energy Transition

WA Generation Profile

In Western Australia (WA), the energy sector accounts for around three-quarters of the state’s greenhouse-gas emissions, with just over 40 per cent of this attributed to electricity generation (EPA, 2007; ABS 2012). Resource availability, and the associated politics and economics of fossil fuel supply (with an abundance of gas, oil and coal resource in the state), are major factors that will shape energy market reform and policy going forward (Martin, 2015; Commonwealth of Australia, 2012; Tongia, 2015; Newton and Newman, 2013). This is because electricity generation in WA is still largely reliant on fossil-fuels, which made up over 85 per cent of sent out generation in the market during 2016, according to an assessment of the data released by the market operator (Figure 2.3).

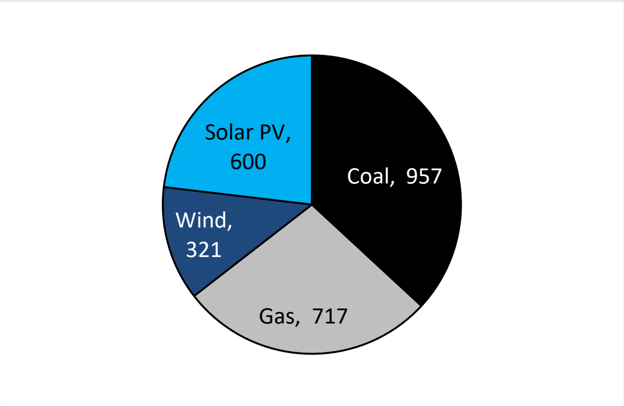
Figure 2.3: WA Energy Market Generation (% of Total MWh) by Fuel Type, 2016



Source: Analysis based on AEMO data, 2016.

The SWIS has a total registered generation capacity of 5,798MW, including around 600 MW of non-scheduled rooftop solar PV generation.

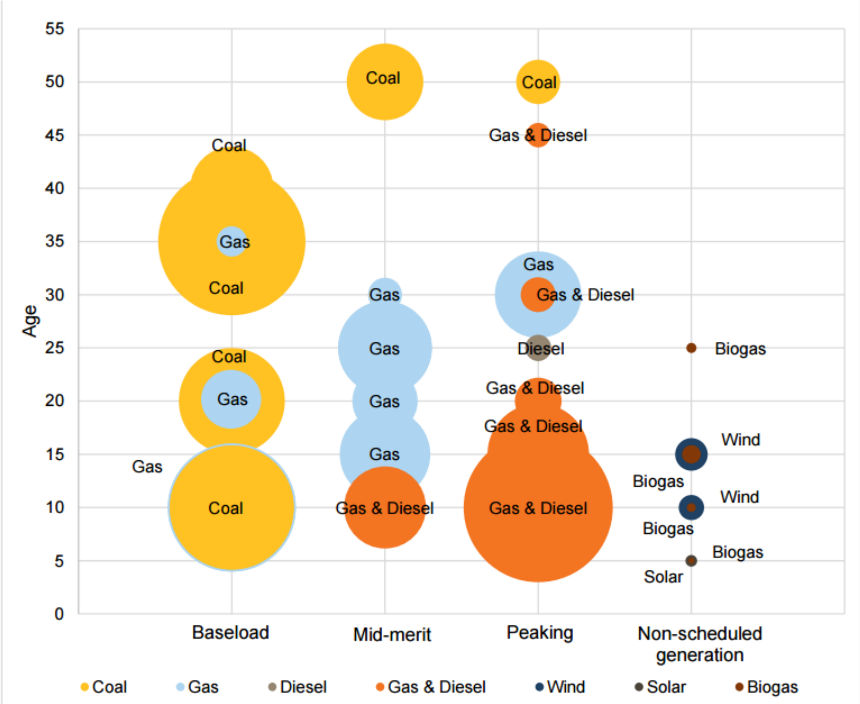
Figure 2.4: WA Energy Market Installed Capacity (MW) by Fuel Type, 2016



Source: Analysis based on AEMO data, 2016.

However, a large proportion of this fossil-fuel fleet is ageing, with over half of baseload generation capacity being older than 20 years (see Figure 2.5).

Figure 2.5: SWIS Facilities by Type, Age and Classification



Source: Adapted from AEMO, 2016

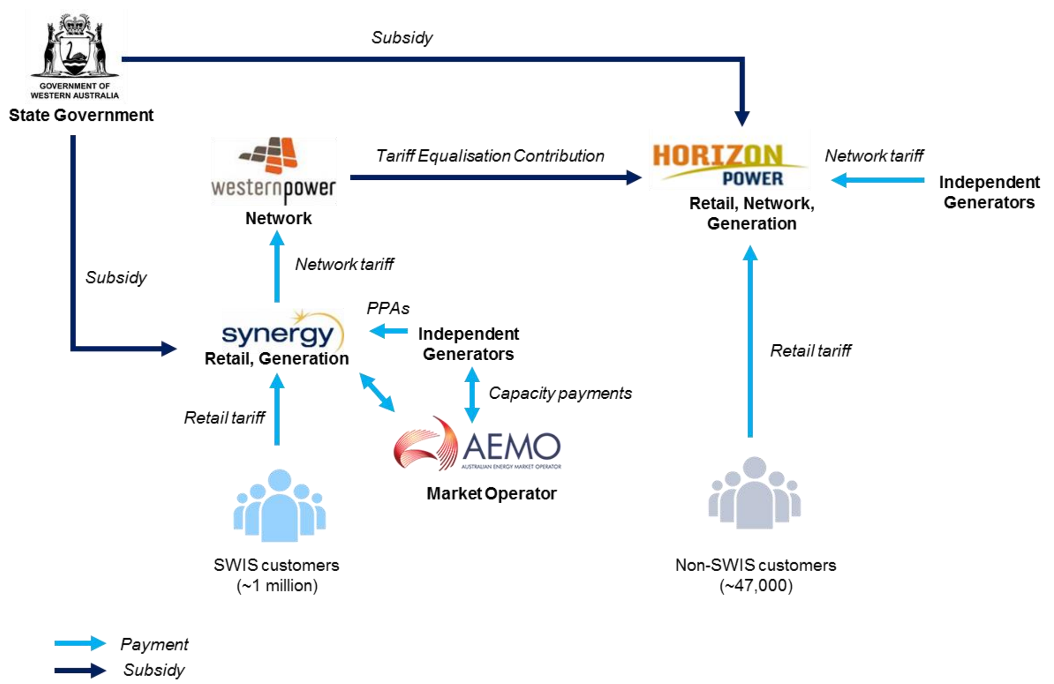
Industry Structure

Unlike the eastern states of Australia comprising the National Electricity Market (NEM), WA's electricity sector predominately consists of state government-owned utilities. The capital, Perth, and its surrounds in the south-west of the State, are part of the South West Interconnected System (the SWIS). The supply chain in the SWIS comprises the government owned gentailer, Synergy, and the transmission and distribution network provider, Western Power, also wholly government owned. There is no retail competition in WA (although the Government has previously signaled its intention to introduce it as part of a wider reform package), so Synergy is the sole retailer to small-use customers in the SWIS – residential households and small businesses using less than 50MWh per annum. On the generation side, Synergy also produces or controls (through long-term contracts) more than 75 per cent of the electricity consumed in the SWIS, with only the remainder supplied by independent, privately owned generators (Government of WA, 2014; Wood and Blowers, 2015).

Both Synergy and Western Power are regulated by an independent regulatory body, the Economic Regulation Authority (ERA). However, retail tariffs in the SWIS for small-use customers are still set and regulated by the state government, with the ERA approving underlying network tariffs, and conducting ad-hoc reviews on the efficiency and performance of the overall market (Government of WA, 2014).

Outside of the SWIS, in the regional and remote areas of WA, electricity is supplied by the vertically integrated (and government-owned) Horizon Power (Figure 2.6). The state has also implemented a 'uniform tariff policy' for these regional areas, where tariffs are equalised across the state for small-use customers, so that even customers in rural areas, with much greater costs to serve, are charged the same rate for electricity as households in the middle of Perth. Therefore, Horizon Power requires an additional subsidy, the tariff equalization contribution (TEC) to remain solvent (Government of WA, 2014).

Figure 2.6: Simplified Structure of WA Energy Market



Note: simplified depiction, which does not include all financial transactions

In addition to this overall structure, several characteristics of the WA market make it an interesting case-study on which to analyse the impact of technology innovation and the transition occurring in the sector.

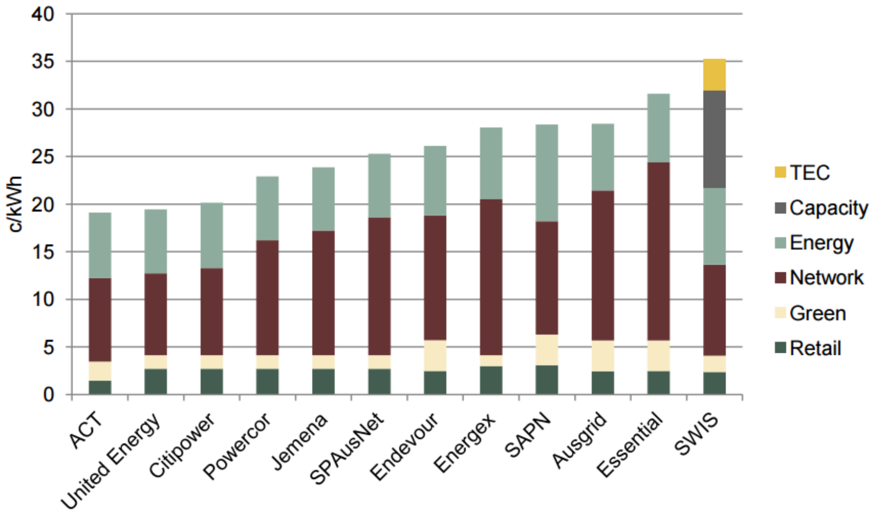
The State's main electricity network, the SWIS, is relatively small in terms of total energy consumption, but occupies an extensive geographic area. Western Power provides electricity services to around one million customers, over a service area of around 255 thousand km^2, and Horizon Power, the regional utility, provides electricity to around 47,000 customers over 2.3 million km^2. These expansive, low-density networks lead to high network capital and operation costs and present significant opportunities for emerging technologies to provide non-network solutions to customers in remote, regional and fringe of grid areas. However, regulatory and institutional barriers will need to be overcome before these network utilities are appropriately incentivised to pursue these non-traditional avenues.

WA Electricity Pricing and Cost Structure

WA is tackling high and increasing costs and charges for electricity services, most evident in the small-use market, where customers cannot choose their retailer and are provided by Synergy's regulated tariffs. These tariffs have increased, on average, by 5.4 per cent per year from 2009 to 2016, and are flagged to increase by another 15 per cent over 2017-2019 (Mercer, 2017). Meanwhile, the cost of providing electricity to these customers has increased by 61 per cent between 2006 and 2014, resulting in substantial increase in government subsidies required by the utilities (Government of WA, 2014). A number of factors contribute to these high and rising costs, detailed below.

Given WA's isolation from the rest of Australia, the SWIS has little potential for interconnection with other electricity networks and must therefore be self-sufficient – i.e. have enough installed generation capacity to meet peak electricity demand in addition to meeting reserve requirements and reliability standards (Government of WA, 2014). WA achieves this through its Capacity Market, which adds an additional cost to the market (see Figure 2.7) by paying for generators to be ‘on standby’ for times of need (i.e. during periods of peak demand), but procures this capacity through set pricing, not via any auction mechanism, shown to be much more efficient in other jurisdictions (Newbery, 2017).

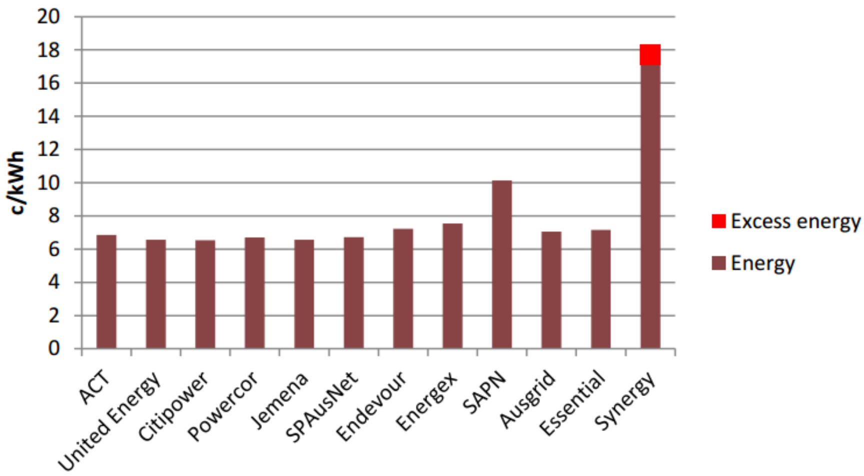
Figure 2.7: Supply Cost Comparison for Residential Customers across Australia, 2014



Source: Adapted from Government of WA, 2014

The cost stacks shown in Figure 2.7 and Figure 2.8 reflect that whilst SWIS transmission and distribution costs are lower than other areas in Australia, the portfolio energy generation cost (wholesale energy plus capacity) is significantly higher (Government of WA, 2014).

Figure 2.8: Wholesale Electricity Cost Comparison, 2014



Source: Adapted from Government of WA, 2014

Whilst some of this difference can be attributable to higher coal fuel costs and a higher proportion of gas-fired generation plant in WA than other states in Australia, the key drivers are the design of WA's energy market itself, which has:

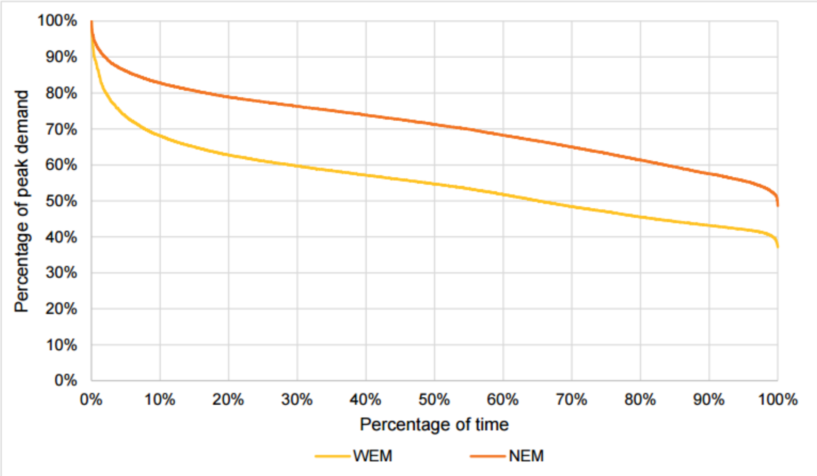
- High capacity costs – which are not charged elsewhere in Australia and not via auction
- High bilateral contract costs – on average more than 85 per cent of generation is traded bilaterally, so has little relation to competitive Short Term Energy Market (STEM) prices (i.e. only the electricity volume that is not already covered by bilateral contracts is traded in the wholesale market)
- Lack of retailer and generator competition due to government regulation (Synergy owns or controls more than 75 per cent of generation in the market).

In effect, this means that wholesale market prices are largely irrelevant for small-use customers in the SWIS, as no other retailer is allowed to compete by buying from the STEM and offering customers lower prices, as in other contestable retail markets. Retail energy costs (or retail energy prices from the perspective of contestable customers) therefore seem to be reliant on the bilateral contracts, and the transfer prices Synergy charges between its generator and retail business units. Clearly, a more competitive market would reduce the influence of one large incumbent utility.

WA Electricity Consumption and Demand

The SWIS must also grapple with its consistently 'peaky' electricity demand, highlighted by a much wider load duration curve produced from market data (see Figure 2.9). Mainly due to consecutive hot summer days, peak demand usually occurs during the summer months. For example, the 2015-16 system peak was 4,013 MW and was observed during the 17:30-18:00 trading interval on 8 February 2016, a week when maximum temperatures exceeded 40 degrees Celsius for four consecutive days (AEMO, 2016). Analysis by the market operator in the SWIS, AEMO, also shows that peak demand has been moving to later in the day, now occurring during late afternoon, when customers return from work or school and start their household air condition units.

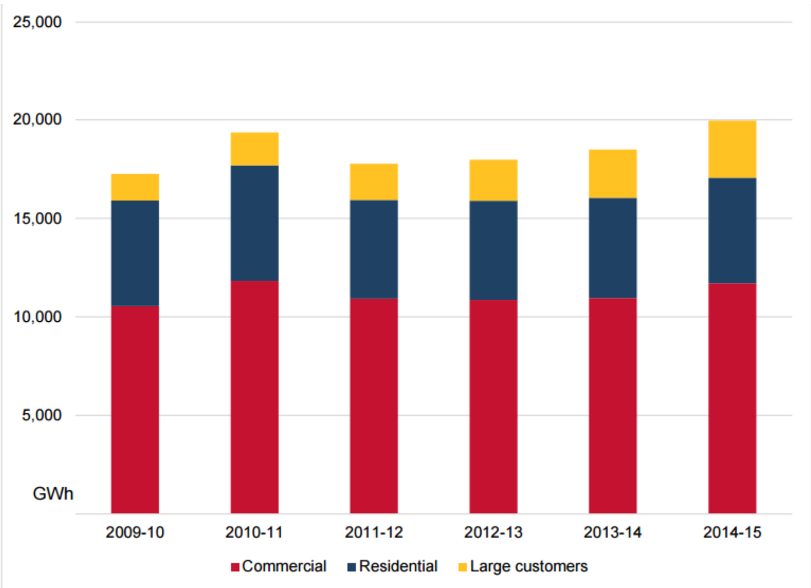
Figure 2.9: Load Duration Curve for WA versus NEM, 2015



Source: Adapted from AEMO data, 2016

Underlying SWIS electricity consumption has continued to grow (driven by increased appliance use and air-conditioning units), although in per connection terms, average consumption has fallen due to the growth in rooftop PV (AEMO, 2016).

Figure 2.10: SWIS Total Operational Consumption, 2009 - 2015



Source: Adapted from AEMO, 2016

New Technologies Driving the WA Transition

At present, more than 210,000 small-use residential and business customers have rooftop solar PV (a penetration level of 14 percent), providing a total installed capacity of around 600 MW, at an installation growth rate of 22 per cent per year (or around 25,000 PV systems per annum). There are also around 300 small-scale battery installations around the SWIS network (Western Power, 2016; Clean Energy Regulator, 2016).

The WA Government has traditionally subsidised the centralised model of electricity generation as a political offering to consumers: in 2014/15, the total subsidy paid to Synergy amounted to more than $500 million (Government of WA, 2015). Now, due to the increased (and growing) uptake of solar PV and storage, and the changing cost structures within the industry itself, the State is facing some of the highest electricity costs in the world (Sandiford, 2016). The Government, media and electricity customers are all acutely aware that this subsidy is unsustainable, but the threat of electricity bill increases remains a contentious issue. Without this subsidy, WA households, even those in central, urban locations, would pay more for electricity than anyone else across the country (Wood and Blowers, 2015). As such, WA should be in a prime position to become an early adopter in the transition towards an electricity system based on renewable, distributed energy, given it has available an abundance of renewable resources (Nahan, 2015; Bromley, 2015; Sayeef, 2012).

Meanwhile, the underlying economics of renewable generation are shifting in favour of the decentralised models of clean technology - as afforded by solar PV and storage, and concerns are already being raised with regards to future industry investment and business decisions for WA energy companies (COAG, 2014; Allen et al., 2009; Grace, 2014).

In acknowledgement of the increasingly challenging and changing energy sector, the Minister for Energy in WA launched a broad based review of the structure, design and regulatory regime of the electricity market in the south west interconnected system (SWIS) in

March 2014. Recognising long-standing industry concerns of various market failures, the Minister committed the Government to review why WA was so susceptible to high network costs and significant subsides, and investigate the major contributions to high (and rising) electricity prices (Government of WA, 2014).

These assessments were made against a 'business as usual' view for the government's electricity businesses. However, when considered in the context of the changing landscape – driven by the need for clean energy and the surge in distributed generation, particularly in the form of solar PV systems plus storage (Denholm, 2007; Katiraei, 2011; Yip, 2013; Newman, Beatley and Boyer, 2009) – this new wave of technical innovation is set to disrupt WA's electricity utility business models, dramatically affect the availability of capital in the industry, and further intensify the issues with the State's electricity market.

Transforming incumbent, legacy utility business models away from conventional, centralised systems towards models based on distributed generation should become the necessary strategy for WA electricity businesses to explore across many parts of the network in the medium term. These businesses will have to undertake extensive planning and development internally and acknowledge the opportunities inherent in new products and services, such as energy efficiency, solar PV and energy storage, which will become future growth opportunities (Poudineh & Jamasb, 2014; Klose et al, 2010).

WA's isolated electricity network and energy market place it in a prime position to leverage the potential that solar PV and battery storage systems can provide. WA is also a market that is undergoing extensive reform: the deregulation of prices, increasing levels of private sector capital, and re-design of capacity markets all provide additional opportunity to consider significant technologically driven structural reform – beyond the incremental improvements to existing models as experienced through decades previous (CSIRO, 2009; Sharma, 1997; Newton and Newman, 2013). Indeed, these reforms and additional services, (e.g. capacity markets) may be used to send price signals to either drive or hinder further uptake of products such as solar PV and storage, or a combination of both. Therefore, policy makers must be aware of where wider initiatives compete with, rather than contribute to achieving the desired outcomes.

WA also presents itself as a region open for trials and demonstrations from new technology companies and increasingly flexible regulations - for the benefit of utilities and energy sector participants looking for guidance on how to manage the transition (Parkinson, 2015). Innovative collaborations between private participants and government owned utilities have already presented useful research outcomes in regards to strata peer to peer trading (White Gum Valley project[1]), microgrid trials (Kalbarri[2], Garden Island[3]), utility scale battery storage (Perenjori[4]), demand management trials (Mandurah[5]), and stand-alone power systems for fringe of grid areas.

Whilst other energy markets around the world (such as Hawaii, California and Germany) are also beginning to contend with increasing pressures of solar disruption, WA is assured of its unique confluence of abundant solar resource, economic prosperity, energy market reforms, and consumer appetite continuing to drive the transition toward future electricity frameworks steadily forward (Parkinson, 2015; Bromley, 2015).

2.5. The Inequities of Misaligned Tariffs

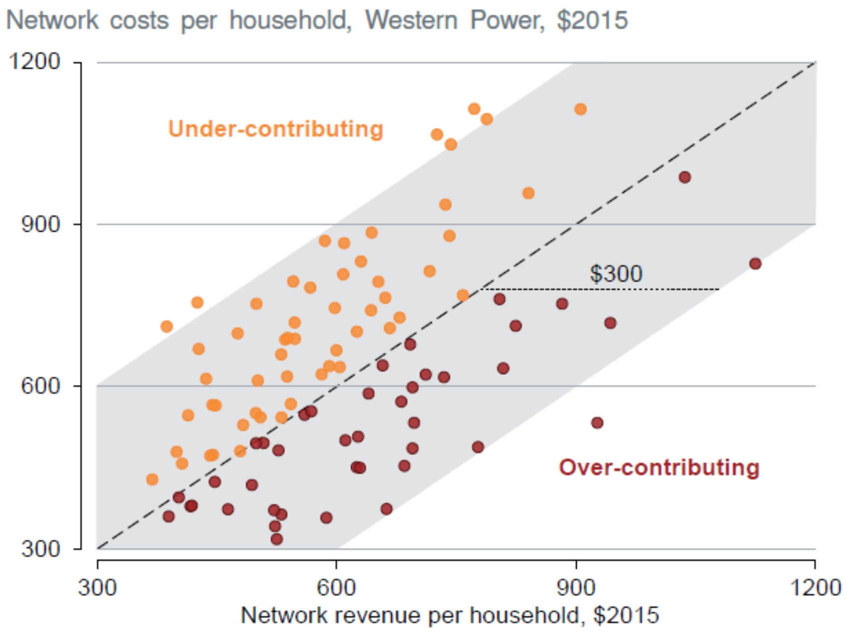
Misaligned pricing structures create additional complexities for utilities as they attempt to recover investments in fixed capital and ongoing operating (variable) costs, as well as plan for future investments. As the MIT Utility of the Future study notes, inefficient and inappropriately structured tariffs results in "skewed incentives", particularly for customers with distributed generation such as rooftop solar PV or battery storage (MIT, 2016).

[1] Gen Y Demonstration Housing Project – White Gum Valley: https://www.landcorp.com.au/genyhouse/
[2] https://www.westernpower.com.au/community/work-in-your-area/kalbarri-microgrid-project/
[3] https://arena.gov.au/project/garden-island-microgrid-project/
[4] https://www.westernpower.com.au/about/media/western-power-to-install-first-utility-scale-battery-in-mid-west/
[5] https://www.westernpower.com.au/about/media/submissions-sought-on-new-approach-to-power-planning/

In WA, tariffs are still regulated and uncontestable for all residential and small business customers and are predominately flat (i.e. do not reflect time of use or peak pricing based on underlying wholesale energy costs). These tariffs may have been appropriate for the traditional model of electricity service provision, where utilities were centrally controlled and provided end-to-end services. Today, however, this model no longer fits (e-lab, 2013).

At present, small-use customers on WA's main electricity grid (the SWIS), have around 10 per cent of their electricity bill attributable to fixed cost charges, yet the actual fixed costs to supply residential customer's accounts for over 75 per cent of the total cost of electricity supply. Clearly the tariff structure in WA does not currently provide appropriate signals about the underlying costs of electricity service. Figure 2.11, highlights this inequity in network pricing by plotting the cost versus revenue contribution of a random sample of 100 households connected to Western Power's grid (Wood and Blowers, 2015).

Figure 2.11: Network Revenue is Misaligned to Underlying Costs



Source: Adapted from Wood and Blowers, 2015

As shown in Figure 2.11, some households pay greater than $300 more than they 'should' to cover the costs they impose on the networks, whilst conversely some households pay up to $300 less than the cost impact they impose.

This structure also results in discriminatory outcomes by allowing customers who can afford solar PV and storage systems to reduce their contribution to the fixed costs of electricity services, whilst still using the services that give rise to these costs (e.g. when the sun is not shining or when systems generate excess energy). Unless tariff structures are re-aligned tor reflect their true, underlying costs, this will ultimately lead to increasingly higher fixed costs for customers who are unable to afford solar or storage systems, predominately lower-income households.

2.6. The Cost Dynamics of Decentralised Energy

As noted above, the transition from centralised to decentralised energy systems is well underway, and is being largely driven by the underlying cost reductions in non-traditional technology solutions such as solar PV, battery storage and other distributed, modular generation. However, it is important to understand the economics of these proposed solutions as they stand today, as well as how they are forecast to change over time. As with any economic decision, this provides utilities and policy makers with clarity on efficient and prudent expenditure, expected returns and pay back periods, as well allowing comparison of new technology options against a business as usual, traditional (centralised) network approach.

For example, some customers are already advocating strongly for going off-grid completely, believing it will provide both cheaper supply and reduced emissions. However, as the MIT 'Utility of the Future' report notes:

> *"off-grid systems would waste plenty of renewable resources, which otherwise could be exported to the grid, thus reducing the cost of the system…the cost is still several*

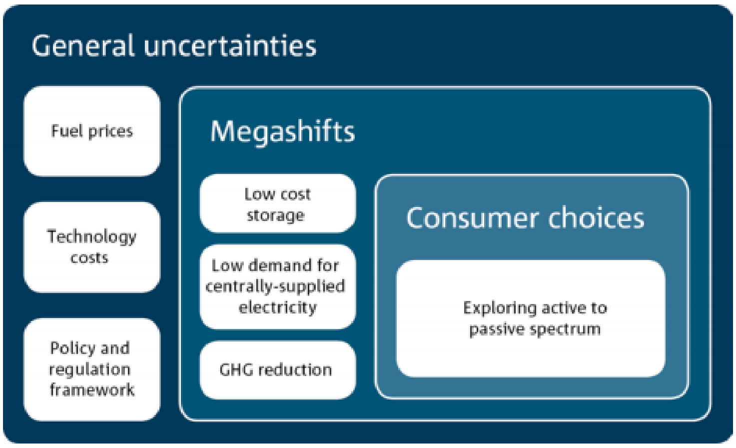
times more expensive than purchasing the power from the grid, and, moreover, the amount of carbon and other pollutant emissions dramatically increases, offsetting the benefits of installing renewables."

(MIT, 2016)

Nevertheless, from a customer standpoint, decisions may still be made to install over-sized solar PV or purchase expensive battery storage systems, even if they are uneconomic, so utilities must prepare to adapt to their uptake based on forecasts that look beyond simply analysing financial metrics.

Australia's main research organisation, the Commonwealth Science and Industrial Research Organisation (CSIRO) assessed this exact issue in its 'Future Grid Forum Report' (Graham, 2013) identifying and forecasting significant changes to the future electricity landscape that would require the industry to respond accordingly (Figure 2.12).

Figure 2.12: CSIRO Scenario Development Framework



Source: Adapted from Graham, 2013

Most notably these included large changes brought about by the rapidly falling costs of supply infrastructure such as photovoltaic systems (PV) and battery storage, as well as increasing levels of customer participation and engagement in the energy supply model (Graham, 2013).

In practice, utilities must begin the journey looking at more expensive parts of their network, for example at the end of long feeder lines where the costs of operating and maintaining the network are much higher than in dense, urban environments at the centre of cities, which already have significant sunk investments in the grid. With large expanses of network service area, low customer density, relatively high fuel costs, an uncompetitive and expensive energy market, and high renewable resource across WA, the state is facing this transition more acutely than many other places around the world.

Horizon Power, the State's regional electricity provider, recognises these challenges, and is beginning to implement a levelised cost of energy model[6] to explore three different energy 'futures' across each of the towns it services:

- Centralised: customers still have a preference for large scale centralised generation systems, but capital costs of network enhancements are relatively low with supportive new grid technologies, and the intermittency of large scale renewables is supported by low cost gas and limited large scale battery storage;
- DER Microgrids: the cost of solar technology and batteries declines rapidly, leading many customers to opt for grid connected solar and storage systems, microgrids become cost competitive and communities implement small scale local energy solutions, reducing the requirement for significant additional investment in network infrastructure, all supported by appropriate flexible regulations;
- Off-grid: motivated by a decline in solar and storage prices, in combination with rising grid-supplied electricity prices, customers invest in individual energy systems and disconnect from the grid.

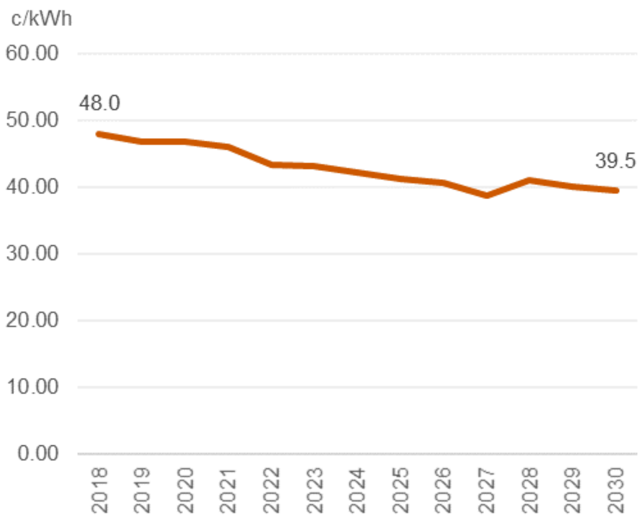
The modelling forecasts that by 2050, around 62 per cent of its systems will be best served by distributed energy resources (DER) microgrids, 12 per cent will be off-grid (stand-alone

[6] Specific characteristics such as demand and long-term fuel prices were also applied to each system to derive the LCOE of each modelling forecast

power systems), with only the remaining 26 per cent still centralised. Today, it classifies 100 per cent of its systems as centralised (Horizon Power, 2015).

Crucially, this outlook is not predicated on the uneconomic addition of renewable technologies and assets, but is based on a cost-competitiveness approach (i.e. lowering overall costs). Indeed, the modelling estimates a reduced cost of supply across Horizon Power's systems from ~50c to ~39c/kWh by 2030, due to the displacement of fossil fuels with solar PV and battery storage (Figure 2.13). Whilst not startling, this reduction is offset by higher gas price assumptions, reflecting that the majority of regional and remote towns have a high proportion of generation capacity in the form of gas plants (Horizon Power, 2015).

Figure 2.13 – Horizon Power Cost to Supply Model Forecast

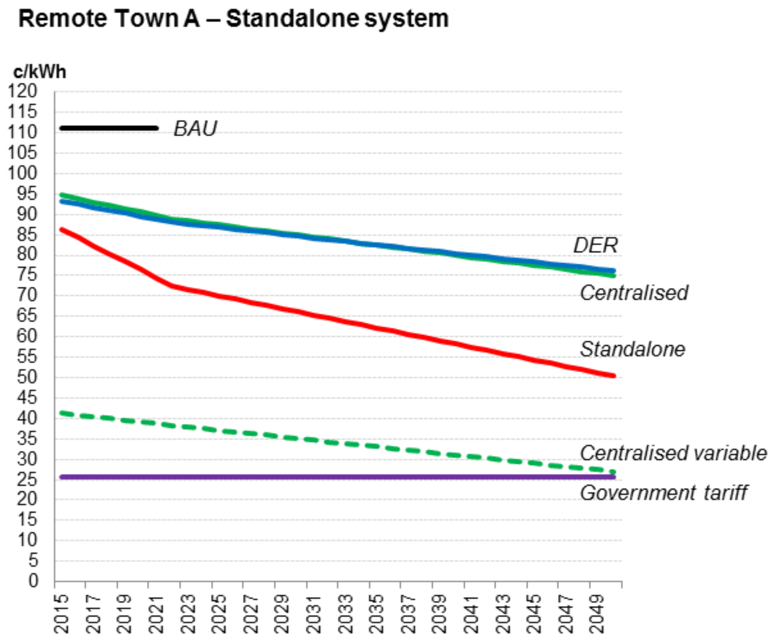


Source: Analysis based on data from Graham, 2013; and Horizon Power, 2015.

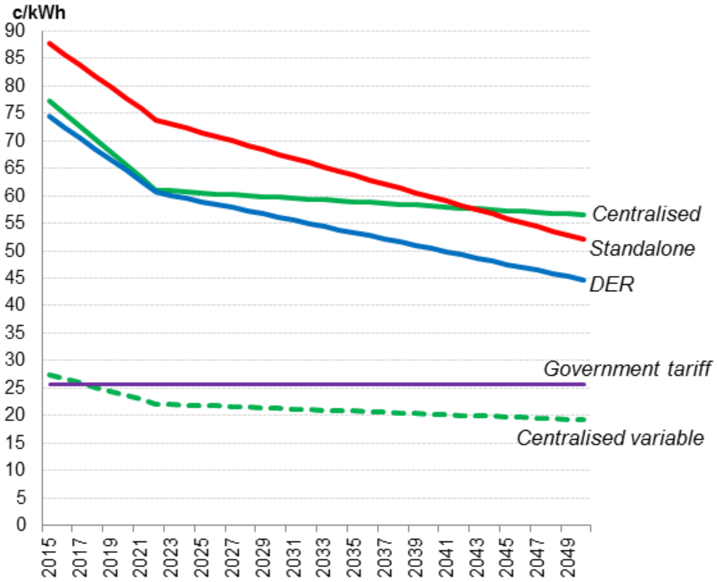
Analysis of the long run costs of electricity service delivery across WA further illustrates the locational factor (Figure 2.14), showing how the capacity mix and technology delivery model can differ dramatically depending on the underlying economics of the local electricity system, load forecasts, generation contracts, fuel prices, and network investment sunk costs for each town. Data published by Horizon Power and the CSIRO has been adapted to produce Figure 2.14, which shows an example of a standalone-system future (Town A), where over time, it is forecast that the most economic delivery model would be to provide customers with individual standalone systems (solar PV, battery storage, and back-up diesel generators), rather than invest in the poles and wires of a centralised electricity network and procure large-scale generation contracts.

In contrast, analysis of Town B suggests a DER microgrid already presents the most efficient economic service provision model today, leveraging customer participation whilst again avoiding major centralised infrastructure upgrades. Similarly, individual models for each town or region within a utility's service area can be constructed to provide the business with an initial view of changing service delivery models, and to assist with formulating and negotiating future generation and supply contracts, pricing tariffs, or drive the roll-out of new products, services and regulatory frameworks required to facilitate the shift.

Figure 2.14 – Long Run Cost Modelling of Electricity Supply Models



Town B – Distributed Energy Resources



Source: Analysis based on data from Graham, 2013; and Horizon Power, 2015.

In both examples in Figure 2.14, the modelling highlights just how much subsidy is required to maintain WA's uniform tariff policy, and that cost-reflective pricing, particularly in these regional areas, has a significant gap (Graham, 2013, Horizon Power, 2015). Nevertheless, technological advances and cost reductions in distributed energy products already provide cost-competitive alternatives to centralised systems in certain areas of WA's grid, highlighting the imperative of utilities to begin exploring the strategic opportunities and new business models required as the transition towards decentralised energy models gains momentum (MIT, 2016).

CHAPTER 3: RESEARCH DESIGN AND METHODOLOGY

Given the rapid pace of innovation and disruptive change currently occurring in the electricity sector, this research was conducted as a series of academic papers, and submitted as a doctoral thesis by publication. As each published paper forming this thesis contains its own detailed data and a full description of the research methodology used, this section contains a brief overview of the overall research design.

A variety of research methods were used in order to gather data, including literature review, interviews and online survey (see Figure 3.1 and Figure 3.2).

Figure 3.1: Research Methodology

Literature Review

- Existing methods, policies and initiatives
- Case-studies of comparable cities with high solar and storage
- Comparisons to countries proposing policy solutions

Interviews

- Semi-structured with relevant stakeholders
- Based on protocol to ensure consistency of topic and discussion
- Conducted with WA energy market participants, policy & regulatory bodies

Survey

- Concise survey of 100 WA residential electricity customers
- Conducted through data research company
- Provided contextualised perceptions of solar, storage, pricing, costs.

Figure 3.2: Research Methodology by Paper

Paper	Research Question	Methodology
01	What are the disruptive forces on the electricity industry?	Literature Review
02	What are the barriers for solar PV and storage in WA?	Literature Review → Interviews
03	How should utility business models evolve?	Literature Review → Interviews
04	How will pricing structures be affected?	Literature Review → Survey
05	What role will innovation play?	Literature Review
06	Can innovations in data analytics assist?	Literature Review

3.1. Literature Review

The first stage of research for each paper involved an extensive review of the literature on each topic, in order to gain an understanding of existing methodologies in the field, to explore case studies of barriers in comparable cities with high solar PV penetration, and to provide a synthesis of solar policy solutions being proposed in other contexts, countries and jurisdiction which are facing comparable energy market disruptions to WA.

To address the specific questions outlined as part of the research objective and to complement the extensive literature review undertaken, this research utilised qualitative analysis, requiring multiple sources of research material including face-to-face interviews with WA market participants, and an online survey with WA customers. Conducting both the interviews and the online survey allowed for a greater understanding of the challenges, issues and barriers being faced by market participants and customers within WA's energy sector, and the responses underpinned many of the policy recommendations and findings that are describe in the papers that comprise this doctoral thesis.

3.2. Interviews

The literature review helped inform the design of a series of semi-structured interviews held with several stakeholders in the WA electricity industry, building on similar approaches used by researchers for other energy markets (Richter, 2013; Overholm, 2015; Rauter; 2015; Ratinen & Lund, 2014).

Semi structured interviews, based on a protocol, were identified as the most relevant method to use to ensure consistency of topic and discussion (Robson, 2002). They involve priming interviewees for responses based on a set of formulated questions, but also provided flexibility for the discussion to involve topics beyond the structured questions.

One important finding was that by framing the interviews as a contribution to research, without unduly impacting any competitive advantages that the participants may otherwise be protecting on behalf of their companies, the interviews were able to achieve a rare level of candor to benefit the research.

Interviews were used in Paper 2 and Paper 3 to identify stakeholder perspectives on the opportunities and threats of solar and storage for utilities, as well as other relevant considerations for the WA energy market going forward. Interviews were conducted with energy market participants in WA, policy and regulatory bodies, academic and research bodies, and consumer representatives (see Table 2.2).

Table 2.2: List of Interview Participants and Affiliations

Interviewees	Affiliation
Participant 1	Senior Manager - Energy Consulting Firm
Participant 2	Managing Director – Independent WA Electricity Retailer
Participant 3	Manager – Network Utility
Participant 4	Manager – Government Electricity Retailer
Participant 5	Director – Government Energy Policy Office
Participant 6 & 7	Directors – WA Local Government
Participant 8	Director – Energy Consulting Firm
Participant 9 & 10	Analysts – Australian Energy Market Operator
Participant 11	Director – Energy Consulting Firm
Participant 12	Director – Non-Government Organisation
Participant 13	Director – Local Electricity Regulatory Authority
Participant 14	Partner – Professional Services Firm
Participant 15	Manager – Metering Firm
Participant 16	Manager – Distribution Network Utility
Participant 17	CEO – Solar Energy Firm
Participant 18	General Manager - Independent WA Electricity Retailer

A wide selection of interview participants was purposefully chosen in order to provide an objective and balanced viewpoint of the issues raised and discussed.

3.3. Online Survey

Paper four used an online survey specifically designed to complement the research into sustainable electricity pricing and assess how electricity tariffs may need to be restructured given the increasing disruption in the sector.

A concise 'three-minute' survey was distributed to 100 participants through a professional data research company (Pureprofile). The survey asked residential electricity consumers in WA about their perceptions of solar PV and battery storage systems, electricity cost drivers, their ability to change consumption behaviour, and their acceptance of various electricity pricing structures (cost-reflective time-of-use and maximum demand pricing). The full list of survey questions is included in the appendix of paper four (pg 146).

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CHAPTER 4: SUMMARY OF RESULTS

This research is presented through six corresponding academic papers on the topic (constituting Chapters 5 to 10 of this thesis). Each paper is summarised below, with details on significant findings and results.

4.1. Disruptive Forces on the Electricity Industry - A Changing Landscape for Utilities

The first paper (Chapter 5) conducts a thorough literature review and outlines the drivers of disruption for electricity utilities. The energy sector has been navigating rapid technology innovation, slowing demand, and rising electricity prices. A steady shift towards renewable energy products is also exacerbating the disruption of utility business models. The paper explores potential risks and opportunities as traditional business models evolve to embrace these disruptions going forward. Government, financial and industry acknowledgement was noted and reviewed, highlighting that even the utilities themselves recognise that their key infrastructure is now at risk.

The research suggests that a long-term view is needed by policy makers to ensure stability and investment certainty can create the appropriate investment environment.

4.2. Barriers and Opportunities for Residential Solar PV and Storage Markets – A Western Australian Case Study

The second paper (Chapter 6) builds on the foundations of paper one, further detailing the barriers and opportunities for residential solar PV and storage in the energy sector. It outlines how solar PV panels coupled with storage systems present an opportunity to move towards a resilient, affordable, flexible and secure electricity network, particularly in Western Australia given the unique set of conditions (isolated network, high solar radiation, and rising electricity prices), but increasingly in all energy markets around the world. However, a number of barriers are still obstructing the transition to renewables, and through a series of interviews with several Western Australian energy market participants, these barriers are identified and qualified.

Three broad groups of barriers were identified and discussed: technological, institutional and financial. The main barriers identified within the technological barrier include: forecasting capability; constraints of existing technology; and network capacity and access. Institutional barriers include: psychological will of people and the reluctance to embrace the new; organisational management and issues associated with listening too closely to customers; the need for Government lobbying and policy reform; and consumer inertia & information blocks. The main financial barriers discussed include: how to deal with sunk network costs; as well as inertia around network design and how to cover the upfront system costs of solar PV and batteries.

The research suggests that the adoption of solar PV and storage systems is still a challenging process and one that requires all stakeholders in the sector – whether they are industry stakeholders, policy makers, local communities or consumers – to participate in the transition. Results also suggest that regulatory and policy reform is what will underpin the removal of other financial, institutional and technological barriers. Without cohesive collaboration and dedicated support for this regulatory and policy reform, the barriers to wider adoption of technology innovations will not be easily overcome. Findings also suggest that over the long-term, it is the efficiency of markets that will drive competition, rather than regulators. Policy makers must recognise the importance of not only identifying and removing any existing regulatory barriers, but creating adaptable and flexible frameworks so that any future barriers can be easily identified, navigated, or mitigated.

4.3. Future Business Models for Western Australian Electricity Utilities

Paper three (Chapter 7) continues the theme of disruption by investigating how utilities can best adapt, exploring how existing business models will need to evolve beyond traditional energy economics. Six critical business model characteristics were identified and discussed: customer focus, community engagement, research and development incubator for innovative technologies, regulatory and policy engagement, participation in distributed generation markets and the transition to energy service providers.

The research identified the inability for large, risk-averse Government bureaucracies to transform business models effectively, and cited the need for more nimble private players and entrepreneurial firms to navigate the transition into new energy market structures.

To counter this, it is recommended that new characteristics and business models be adopted in a modular approach, to ensure capabilities are maintained, costs minimised and customers retained.

4.4. A Behavioural Approach to Sustainable Electricity Pricing

Paper four (Chapter 8) explores why new cost-allocation and tariff-design methodologies are needed in order for electricity prices to better reflect costs based on grid usage. Achievement of cost reflectivity is always going to be difficult, with cross-subsidies across consumer groups and across geographies resulting in winners and losers. In order to drive sustainable policy change, regulators and customers must accept that there will be costs, both financial and involving behavioural change, associated with creating more equitable and transparent pricing arrangements for electricity services.

To test various electricity pricing methodologies, paper four also conducts an online survey of one hundred residential electricity consumers in Western Australia to analyse their perceptions of solar PV and battery storage systems, electricity cost drivers, willingness to change consumption behaviour, and acceptance of various pricing structures. The majority of respondents indicated strong enthusiasm to change their behaviour and reduce electricity usage providing it saves sufficient money on electricity bills and appropriately rewards solar and storage technologies, suggesting there is a real possibility for successful retail tariff reform in the near term in WA, and it could even be customer-led. This is a significant finding, with major implications for Government and policy-makers around the world, as it is in direct contrast to general political and policy hesitation about changing electricity prices, for fear of consumer backlash and resistance.

This paper's findings will have increasing relevance and importance as residential electricity demand increases, global energy market are de-regulated, competition is increased, and new retail products are introduced to provide more cost-reflective price signals.

4.5. Leveraging Innovation for Electricity Utilities

Paper five (Chapter 9) investigates how important technology innovation is to facilitating the transition occurring in the energy sector, and investigates how to best create an environment to remove obstacles and enable innovation in energy products and services. The research outlines that if effective partnerships can be created between utilities and research centres, it may provide benefits to utilities across the value chain.

By embracing new services and products, utilities can capitalise on the innovation occurring and provide enhanced customer service through greater choice and lower costs, whilst maintaining business value. The research suggests that looking forward, we are more likely to see dense microgrids with high penetration of renewable assets, linked virtually through intelligent communications and adaptable to several customer segments in order to drive efficient behaviour.

The paper also suggests that a collaborative mindset is needed to ensure utilities recognise the role they must also play in guiding regulatory reform and driving governments and regulators to accept the uncertainty that future business models must navigate to succeed. Utilities must understand it is their responsibility, on behalf of their shareholders and customers, to drive this regulatory and policy change – through partnerships with universities and research labs in order to drive innovation through the business as well as through the sector as a whole.

4.6. Achieving High Renewable Energy Penetration Using Data Digitisation and Machine Learning

The sixth, and final, paper (Chapter 10) continues the innovation theme and explores how a high renewable energy penetration can be achieved leveraging existing infrastructure, focusing on the potential benefits that could arise from the broad technological advances in the fields of data analytics and machine learning.

Data digitisation and analytics combined with machine learning has already impacted numerous industries, and its influence on the energy sector is inevitable, as computational capabilities increase to manage big data, and as machines develop algorithms to solve the energy challenges of the future.

The research suggests that the future of electricity grids, particularly in WA, could very likely transition towards one of dense microgrids with high penetration of renewable generation sources, linked through intelligent, wireless communications to manage flows and maintain overall system security and stability. Therefore, utilities will need to continue to encourage research and development, undertaking trials, demonstration projects and taking risks in an industry that has historically discouraged risk-taking.

CHAPTER 5: DISRUPTIVE FORCES ON THE ELECTRICITY INDUSTRY – A CHANGING LANDSCAPE FOR UTILITIES

Paper 1: Published

Tayal A.D., 2016. Disruptive Forces on the Electricity Industry - A Changing Landscape for Utilities. The Electricity Journal., 29 (7), 13-17.

Chapter 5 contains the first published paper presented in this thesis. The published form is included in Appendix C of this thesis.

5.1. Abstract

The energy sector has been navigating rapid technology innovation, slowing demand, and rising electricity prices. A steady shift towards renewable energy products is also exacerbating the disruption of utility business models.

This paper outlines the drivers of disruption for electricity utilities, and explores potential risks and opportunities should traditional business models evolve to embrace innovative technologies going forward.

Keywords: Solar, storage, electricity, business models, innovation

5.2. Introduction

5.2.1. The Energy Model Transition

The underlying economics for conventional energy markets and systems have already shifted in favour of the decentralised models of clean technology - as afforded by solar PV and storage at the residential level, and larger renewable projects at the community scale. In effect, this has created excessive uncertainty for existing, 'traditional' energy market participants, and concerns are already being raised with regards to future industry investment and business decisions for energy companies (COAG, 2014; Allen et al., 2009; Grace, 2014).

With the attractiveness of new energy products and services such as solar PV and storage only increasing, the electricity industry is now being regarded as a sector ripe for disruptive potential (Frankel et al, 2014; Roberts, 2013). In particular, this new wave of technical innovation is set to disrupt electricity utility business models, dramatically affect the availability of capital in the industry, and further intensify issues within the electricity markets (Denholm, 2007; Katiraei, 2011; Yip, 2013).

As market dynamics force the hand of electricity utilities globally, changing the business model away from a conventional, grid-based system towards one that embraces distributed solar and storage across the entire network is the only long term solution for electricity businesses (Tayal & Rauland, unpublished). Utilities undertaking future business planning and strategy development should be proactively looking to energy efficiency, solar PV and storage as growth opportunities rather than an existential threat, and acknowledging that their place in the energy system will only grow (Poudineh & Jamasb, 2014; Klose et al, 2010).

Ultimately, all electricity grids share a common goal of achieving a safe, secure, sustainable and affordable service of electricity to customers – and this can only be achieved by first recognising that the old model is no longer suitable.

In the past decade alone, the energy sector has been navigating: rapid technology innovation (removing barriers to entry for small players); the falling cost of distributed generation; increased interest in demand side management; slowing trends in demand; shifting government policies on renewable energy incentives; and rising electricity prices across the country (Kind, 2013; Newcomb et al, 2014; Grace, 2014; Bunning, 2011). In combination, these factors are set to fundamentally change the way our electricity systems operate.

The key for electricity provision may include making industries and systems smaller, as efficiency advocates propound, but it must also require that they are redesigned in a way that replenishes, restores, and nourishes (Braungart & McDonough, 2009). And as Ashford, Hall and Ashford (2012) note, we need to be prepared to challenge ingrained, limiting, and outdated beliefs.

5.3. Background

5.3.1. The old model in a different setting

Traditional business models for utilities reflect the centralised system of electricity generation and network design (Kind, 2013; Bromley, 2015; Caldecott & McDaniels, 2014). This centralised system also drove a standard approach to system security and network planning, economic regulation, and drove the design of wholesale and retail markets and dispatch engines (Schaltegger et al, 2012; Richter, 2013; Roberts, 2015; Sioshansi, 2014).

Recognising this ‘coupling' of volumes and profitability was at a natural tension with the assumption that electricity should be treated as a ‘public good’, the electricity industry most commonly became a natural monopoly (Newcomb et al, 2014).

However, this view of electricity utilities as natural monopolies is now coming under increasing scrutiny due to a convergence of several factors across technology, economics and public policy. Customer impacts are now driving investment trends in the opposite direction (through energy efficiency and distributed generation) and the increasing uptake of solar PV and storage will only exacerbate this trend (Zinaman et al, 2015).

5.4. Methodology

5.4.1. ***Literature Review***

A review of existing literature was carried out over twelve months to gain a broad understanding of the central drivers disrupting the electricity sector as a whole, across major electricity markets around the world.

5.5. Discussion

5.5.1. Existing Barriers

Currently, the interests of utilities (preventing stranded assets, maximising electricity sales, preventing increased competition) are in tension with the interests of consumers and the environmental imperative to decarbonize the electricity sector (Roberts, 2015).

Further, any solutions designed to meet the transitioning needs of the energy industry will need to be based on the individual regulatory and market contexts in which they emerge (Crawford, 2015; Hogan, 2014). For instance, utilities in competitive markets will be more directly exposed to the threats that arise from technology innovations such as solar and storage systems, given their ability to reduce electricity use and demand (Kind, 2013). There are also a series of regulatory, institutional and financial barriers that remain and that inhibit the effective transition of electricity businesses to new ways of operating.

Utilities themselves are also likely to have predisposition to inertia – what transition theory terms ‘path dependency’ – being locked into a particular pathway that inhibits consideration and adoption of innovative ideas (Lee & Gloaguen, 2015). Traditional utilities have been found to rely on traditional forms of research and development (Frankel et al, 2014). This is a significant risk across the industry, given the momentum that new, distributed technologies and ‘big-data’ is gathering. Utilities of the future will be expected to have their own innovation hubs or partnerships, identify new ideas, and leverage the capabilities of other businesses that can provide products and services complimentary to their traditional offering (Tayal & Rauland, unpublished).

> *"Nimble information gathering produces a better foundation for strategic decisions and a more diversified flow of ideas for innovation."*
>
> (Heiligtag, Luczak & Windhagen, 2015, pg 1)

The restructuring of electricity tariffs also creates significant obstacles for Governments and policy makers to overcome. While regulatory frameworks allow for cost recovery in future tariff proposals, existing tariff structures can create the perverse incentive that results in customers without solar PV having to pay the most for lost revenues. As solar penetration increases, this cost recovery structure will only further attract political pressure to undo these cross subsidies, ultimately exposing utilities to the risk of stranded assets – see section 4.4 below (Caldecott & McDaniels, 2014).

5.5.2. The WA Case Study

Western Australia (WA) presents a uniquely challenging environment under the 'traditional' approach to electricity service provision. WA occupies an area equal in size to the United Kingdom, but with a fraction of the population density – with around one million customers as opposed to 73 million (McGoldrik, 2016). This has always created challenges for the government-owned electricity utilities, who rely on millions of dollars of annual subsidies to provide uniform electricity tariffs to residential customers across the state – irrespective of location. Of course, the actual cost of supplying customers in the remote and rural towns scattered across WA is significantly higher than providing electricity to anyone living in the State's capital, Perth – which has established distribution networks, excess capacity, and a reliable distribution network (Government of WA, 2015).

In addition, the maintenance costs for such an expansive network are significant, in and of themselves, with additional threats of bushfires and cyclones preventing the State Government from expecting to move to a cost-reflective centralised service model any time soon. However, with the declining costs in stand-alone power systems – with cheaper solar PV and battery storage components – WA has realised it may need to rethink this traditional centralised model. The outstanding question is what can be done to minimise the pain for these utilities to walk away from billions of dollars of investment in the grid infrastructure.

5.5.3. Banking Sector Acknowledgement

A number of banking institutions have already identified the decentralised electricity system as a necessary transition given the financial impact that would result from maintain existing models, and have adjusted credit and stock ratings of involved electricity businesses accordingly. For example, the financial risks created by disruptive technologies such as solar PV and storage systems include declining utility revenues, increasing costs, and lower profitability potential, particularly over the long-term. Adding the higher costs to integrate increasing penetrations of distributed generation technologies will inevitably result in lowering profitability and, therefore, credit metrics. Failing to address these financial pressures with a restructure of business models would result in a major impact on equity returns, required investor returns, and credit quality (Kind, 2013; UBS, 2015).

Given the increasing pressure on traditional pricing structures and revenue sources, the financial institutions themselves are recommending utilities to develop ‘smarter grids’ by partnering with solar, battery, and smart meter providers in order to leverage their existing relationship with customers (Rader, 2015).

UBS, a leading investment bank and financial analysis firm, is very optimistic about the impact of large (utility) scale solar on energy markets around the world, citing that by 2025, utilities could make up 50 per cent of the solar market across the world (UBS, 2015). The

UBS report (2015) goes on to suggest that utilities will be the ‘lead actors’ in large-solar, replicating the business models of US companies like SolarCity (UBS, 2015).

The table below summarises the views from UBS and three other investment banks on the impact of electricity sector disruption.

Table 5.1: Bank responses to electricity sector disruption

Bank	Comments
UBS	• sees the potential of pairing solar and storage systems (and electric vehicles) with responsive demand as a perfect fit for a smarter grid of the future, with nightly charging smoothing the demand curve.
HSBC	• recommends utilities leverage their relationship with customers and existing assets to become full-spectrum service providers via a smart grid. • utilities could market value-added services to customers or provide backup power.
Citigroup	• utilities have the option of boosting their asset base by investing in storage - alongside vehicles and consumer electronics, sees utilities taking advantage of storage as a pillar of growth.
Morgan Stanley	• similarly highlights the greatest value is gained from a utility integrator model, especially in Europe, to offer energy services including finance, design, and installation of solar-plus-storage solutions. • Addressing central generators, the recommendation was fairly straightforward – invest in renewables since fossil plants will lose out due to fuel costs.

Source: based on Rader, 2015; UBS, HSBC, Citigroup & Morgan Stanley analyst reports, 2015.

5.5.4. Stranded Asset Risk

From an accounting perspective, stranded assets are those that succumb to unanticipated devaluations, early write-downs or are ultimately converted from balance sheet assets to liabilities. Stranded assets come about through a variety of reasons, usually driven by an underlying misunderstanding (and mispricing) of the level of risk involved in the venture, and the assets exposure to that risk (Caldecott & McDaniels, 2014).

In the electricity sector, utility businesses are already witnessing the potential for their assets to become stranded. For example, in Europe, previously high regarded gas peaking gas, operating in markets with excess capacity, have quickly become financially unsustainable due to the lower wholesale price of electricity they receive not covering their marginal cost of generation (Green & Staffell, 2016).

Power stations around the world commonly have business cases reliant on high utilisation rates, built on the assumption that energy demand will continue to increase, or that innovations such as roof-top solar PV and battery storage are still nascent technologies years away from impacting their market share. As this paper discusses, however, a whole series of factors are disrupting these business cases and underlying assumptions.

Ultimately, if the outlook for these power stations is not expected to improve (e.g. through a resurgence in demand, or a significant change in cost structures), than these assets will need to be prematurely mothballed, or retired ahead of schedule. More often than not, this will involve a significant write down of capital costs, leaving asset holders with large sunk costs that will never be recovered from the project itself – the stranded asset (Caldecott & McDaniels, 2014). As more and more assets are gaining the uncoveted 'stranded' status within utilities' portfolios, investment in the sector is being increasingly marginalised.

5.5.5. Disruptive Forces - Lessons from Other Industries

With the increasing prominence of solar PV and storage in the electricity sector, these systems are now commonly referred to as 'disruptive innovations', due to their impact on the entrenched, centralised models of electricity generation and the strategic challenges they present to electricity markets going forward (Richter, 2013).

Originating from an article by Christensen and Bower in 1995, the term 'disruptive innovation' is defined as:

> *"an innovation that helps create a new market and value network, and eventually goes on to disrupt an existing market and value network (over a few years or decades), displacing an earlier technology".*
>
> *(Christensen & Bower, 1995, pg 1)*

The term is now widely used in business and technology literature to expose the vulnerability of existing business models to new innovations in products or services that revolutionise the market. A commonly cited example is of Kodak – a firm previously of the photo films and related supplies market. Kodak, a once dominant, highly profitable company, became a redundant observer as the photo business was transformed by digital technology, before finally filing for bankruptcy in 2012 (Christensen & Raynor, 2013).

From an industry perspective, the telecommunications industry may also provide some insight into the impact disruptive innovation can have, and highlight challenges and opportunities that may face the electric utility industry.

In the late 1970s, the telecommunications industry was price and franchise regulated, with high barriers to entry provided by the capital-intensive nature of the business as well as the protective government regulations in place (Kind, 2013). However, as mobile phone technology developed and become widely adopted, traditional sources of revenue for telecom firms were significantly impacted, and the entire industry underwent regulatory reform to encourage competition. As a result, the businesses operating in the telecommunication sector in the 1970's are not recognisable today.

In the United States, traditional telecommunication companies such as AT&T and Verizon maintained their leadership in wireless telephone services by incorporating a progressive vision in their business models and services to lead development of unregulated networks and update consumer marketing approaches. As a result, they managed to maintain their large shares of the United States telecommunication market and have continued to leverage technology innovation to expand customer offerings (Kind, 2013).

Similarly, technology innovations that enabled broader communication, such as the modem, were a critical enabler for the internet revolution that began in the late 1990s. By purchasing a modem, any consumer with a computer and a telephone line was able to access the digital world, without requiring any further network alterations by the telephone company and encouraged the development of other technology innovations to focus on interconnecting household communication systems with the broader telephone exchange system (Pentland, 2015). It is expected that distributed generation technologies, such as solar PV and storage, will follow similar transitions, reliant on open access protections that facilitate development of systems at the household level.

Shomali and Pinkse (2015) looked at how the introduction of smart grids[7] may present a threat to incumbent utilities, given the potential for new information and communication technology (ICT) firms to enter the energy market. The authors concluded that while incumbent electricity utilities may have strong drivers to innovate their business models to include and embrace smart grids (and also to better integrate renewable energy technologies such as solar PV and storage), there are currently several uncertainties around the threat of new entrants, government support, and consumer engagement acting as barriers to such innovation, on top of the general resistance toward business model innovation for fear of losing current revenue streams (Shomali and Pinkse, 2015; Amit and Zott, 2001).

The electricity industry has largely avoided disruptive threats for over a century due to large customer monopolies and the value derived from economies of scale leading to easy access

[7] Smart grids are defined as “an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users” (IEA, 2011, p.6).

to relatively low-cost capital. However, given the impact that disruptive challenges such as technological innovation, changes to public policy, and consumer preferences may have on electric utilities in terms of their future investment and access to capital (and resultant impacts on consumers), it will be necessary for electric utilities to keep these historical outcomes for other industries in mind, as the industry continues to shift. Business development plans and medium to long term strategies must address disruptive threats and be open to replace their own outdated technology with new products. Tesla’s widely publicised residential and commercial battery announcement on 30 April 2015, will be just one of several announcements that will expedite the transition as new entrants and consumers alike drive momentum towards more innovative services at competitive prices.

5.5.6. Implications of Disruptive Innovation

Traditionally, electricity utilities have increased their revenue earnings by either expanding electricity sales (consumption volumes), or increasing prices charged per unit of sales (higher electricity prices) – the old measures of success. Whilst these levers have provided consistent returns to investors for decades, due to the disruptive technological threats outlined above combined with changing consumption patterns, utilities of the future will need to transform their business models in order to maintain their revenue sources and meet the higher required rates of return for their investors (Kind, 2013; Tayal & Rauland, unpublished).

Given electricity prices are a function of consumption volumes, when electricity sales decline – due to demand management programs, innovations in energy efficient appliances, distributed generation, or other behavior changes – electricity companies will need to increase rates charged across remaining volumes in order to continue to meet the cost of providing service (meet the cost of capital). What this scenario ultimately leads to, however, is what the media has affectionately dubbed the ‘death spiral’, where increasing electricity prices simply drive further reductions in consumption by enhancing the proposition of competing technologies and demand management programs. Grace (2014), modeled this impact on the Western Australian South West Interconnected System, showing how high levels of solar PV uptake would likely result in a cycle of price rises that leave very few customers to support the high costs of the embedded transmission and distribution infrastructure.

Industry analysts are now less fearful of large volumes of customers going off-grid and inducing a death spiral on the incumbent utilities. Even with aggressive estimates for electricity storage technology, given: (a) the concentrations of solar production relative to peak demand; (b) the technical limitations of batteries; and (c) the advantages that distribution networks provide (e.g. buying and selling excess energy between local areas); it is expected that most customers will maintain some form of network connection (UBS, 2015; Nahan, 2015). Rather than threaten the ability of utilities to invest in key infrastructure, the uptake of solar PV systems will drive substantial volumes of intermittent energy and require additional frequency control measures – in effect necessitating substantial investments in smart grids and grid-scale batteries (UBS, 2015). In effect, while utilities may lose some revenue from traditional forms of generation, additional earnings from playing an integral part in the future of smart grids and solar and storage technologies are likely to more than compensate for any losses (UBS, 2015).

5.5.7. Potential Preventative Responses

The electricity industry is very much aware of the increasing pressure to implement actions and prevent a worst case scenario. Strategic actions circulated previously by industry groups for consideration include (Kind, 2013):

- Assess depreciation calculations that utilise a recovery life based on the economic useful life of the investment, to consider the potential for disruptive innovations and loss of customers;

- Disconnection charges to be paid by solar PV customers and/or customers going off-grid to recognise the portion of investment deemed stranded as customers depart;
- More stringent capital expenditure evaluation tools to factor-in potential investment that may be subject to stranded cost risk, including the potential to recover such investment over a shorter depreciable life; and
- New business models and services that can be provided by utilities in order to prevent continued revenue erosion.

Interestingly, the final action regarding the updating of business models was identified as a longer-term initiative by the Edison Electric Institute when it first published its recommendations in 2013. Today, given the pace of technology innovation (Tesla's Powerwall batteries being the prime example), utilities have already begun investigating new business models, products and services to maintain relevance with their existing customers. Meanwhile, a number of the regulatory tariff changes, such as implementing customer service charges and/or disconnection charges, have yet to gain traction amongst most regulatory jurisdictions in Australia; not least Western Australia where Government focus is largely on reducing subsidy to incumbent monopoly providers and transitioning towards a more competitive, transparent market through initiatives such as full retail contestability (Government of WA, 2014).

5.6. Conclusions & Policy Implications

This paper outlined the significant disruption already taking place in the electricity industry, driven by technology innovations such as roof-top solar PV panels coupled with residential storage systems. Government, financial and industry acknowledgement was noted and reviewed, highlighting that even the utilities themselves recognise that their key infrastructure is now at risk.

Amongst this disruption, potential risks, challenges and opportunities were explored and that may become available should traditional business models evolve beyond existing frameworks and embrace new and innovative technologies going forward.

A logical next step would be for utility businesses to embrace these technologies strategically and through a wholesale revision to their existing, traditional business models.

Similarly, this research suggests that a long-term view is needed by policy makers to ensure stability and investment certainty can create the appropriate investment environment.

It is hoped that this research provides additional impetus to encourage utilities, Governments and policy makers around the world to apply a longer-term view of electricity market transformation, to address some of the inherent uncertainty in energy markets driven by this potential for existing frameworks to be disrupted, and to develop flexible regulatory frameworks that will remain relevant in the years to come.

5.7. References

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CHAPTER 6: BARRIERS AND OPPORTUNITIES FOR RESIDENTIAL SOLAR PV AND STORAGE MARKETS – A WESTERN AUSTRALIAN CASE STUDY

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Chapter 6 contains the second published paper presented in this thesis. The published form is included in Appendix C of this thesis

6.1. Abstract

Residents and businesses around the world are increasingly installing solar photovoltaic (PV) panels and battery storage systems, satisfying not just their interest in clean energy, but also taking advantage of reduced technology costs and mitigating against future electricity price rises.

Solar PV panels coupled with storage systems present an opportunity to move towards a resilient, affordable, flexible and secure electricity network.

Western Australia provides a unique set of conditions (isolated network, high solar radiation, and rising electricity prices), which has contributed to the rapid uptake of solar PV's in the state. Yet, a number of issues are still obstructing the transition to renewables.

Using Western Australia as a case study, this paper investigates the barriers inhibiting the network transformation and explores the role that solar PV and storage can play as a disruptive threat to the incumbent, centralised service model of electricity utilities.

These barriers are identified and qualified through a series of interviews with several Western Australian energy market participants.

If policy makers intend to enable widespread adoption of solar PV and storage, they will need to address barriers to support these emerging technologies. In parallel, market participants must work with policy makers to drive flexibility in regulatory frameworks and progress the evolution towards innovative and sustainable electricity networks of the future.

Keywords: Solar; storage; energy; electricity; barriers; network

6.2. Introduction

Western Australia (WA) has inadvertently become a central player in addressing the universal challenges that are inherent in the transition to a renewable, distributed model of electricity networks. The WA Government has traditionally subsidised the centralised model of fossil fuel generation as a political offering to consumers. But this has only artificially reduced prices, and taxpayers ultimately face the impact of non-cost-reflective pricing. As a result, the state is now faced with some of the highest increases to electricity costs in the world, has discovered this subsidy is unsustainable, and is thus seeking to benefit from the some of the best renewable resources available (Nahan, 2015; Bromley, 2015; Sayeef, 2012).

Coupled with these changing economics is the structure of WA's electricity market itself: still highly regulated, dominated by Government-owned entities and currently undergoing a major reform program. Although the WA market is relatively late in considering initiatives such as full retail competition and flexible pricing (Australia's Eastern States implemented similar reforms through the nineties), the industry is now open to consider major structural reforms and market re-design - not just economic improvements to existing models (CSIRO, 2009; Sharma, 1997). For example, WA is now in prime position to consider the impact of increasing penetration of solar PV on the grid and unlock the potential of increasingly cost-competitive battery storage systems. The technology innovations driving battery costs lower will only increase the challenges for utilities and Government, more so for WA's isolated electricity network relative to other states in Australia, or around the world. As such, the authors predict that WA's energy sector and market will become a demonstration site for energy authorities around the world looking for guidance on how to manage the transition (Parkinson, 2015a).

Whilst other markets are also beginning to contend with the pressures of solar disruption (most notably Hawaii, California and Germany), WA has a unique confluence of economic affluence, market reform, network isolation, high solar radiation and consumer demand that has driven enough Government impetus to recognise the urgency in addressing its impacts (Parkinson, 2015; Bromley, 2015).

While change is imminent, there are still a number of barriers. This paper explores what barriers are preventing renewable energy technologies (specifically residential solar PV and battery storage) from transforming the current energy markets of WA to deliver across the priority outcomes of a low cost, low-carbon, and secure energy network.

Through conducting an extensive literature review and analysing a series of interviews with industry stakeholders, key barriers relating to the development and integration of residential solar PV and battery storage in WA are identified. To assist in the identification process, this paper classifies these barriers into three groups: institutional, technological and financial.

It is hoped that this research can be used in practice to encourage energy businesses and utilities operating in WA (and those in similar energy markets around the world), to utilise solar PV and storage systems in a strategic fashion, in order to reduce grid congestion, and/or to remove (or at least defer) the need for network investments, thereby creating value for all stakeholders. This research should also provide valuable insights and recommendations to policymakers currently grappling with an electricity service and delivery model in a state of flux. The authors note that ultimately, all electricity grids share a common goal of achieving a safe, secure, sustainable and affordable service of electricity to customers, and in order to achieve this, leveraging and integrating new technologies into existing grid structures and business models will be inevitable.

6.3. Background

6.3.1. The WA energy transition

Energy markets are inherently complex structures. They have numerous stakeholders constantly lobbying for industry and regulatory reform. In WA, the complexity is made even more apparent by the state’s geographical isolation, preventing any feasible prospect for

WA's networks to be connected to neighbouring systems. However, within this challenging environment, WA's unique isolation also presents an opportunity to study the extent to which renewable energy technologies and distributed generation can be utilised to disrupt the conventional, centralised model of our existing systems.

In WA, the energy sector (retail, distribution and generation of electricity and gas) accounts for around three-quarters of the state's greenhouse-gas emissions, with just over 40 per cent of this attributed to electricity generation (EPA, 2007; ABS 2012). Resource availability, and the associated politics and economics of fossil fuel supply (with an abundance of gas, oil and coal resource in the state), are major factors that will shape energy market reform and policy going forward (Martin, 2015; Commonwealth of Australia, 2012; Tongia, 2015).

The WA Government has remained relatively silent on the issue of climate change, and in particular, its interactions with electricity generation. Meanwhile, the underlying economics of renewable generation have already shifted in favour of the decentralised models of clean technology - as afforded by solar PV and storage, and concerns are already being raised with regards to future industry investment and business decisions for WA energy companies (COAG, 2014; Allen et al., 2009; Grace, 2014).

Recognising the inevitable impact of a changing environment, on 6 March 2014 the Minister for Energy in WA launched a broad based review of the structure, design and regulatory regime of the electricity market in the south west interconnected system (SWIS) of WA. The Minister reflected industry wide-concerns that the electricity market was not functioning as expected and was susceptible to high network costs and the need for significant subsides to maintain downward pressure on costs, contributing to high (and rising) electricity prices (Government of WA, 2014).

These assessments were made against a 'business as usual' view for the government's electricity businesses. However, when considered in the context of the changing landscape – driven by the need for clean energy to address climate change and the surge in distributed generation, particularly in the form of solar PV systems plus storage (Denholm, 2007; Katiraei, 2011; Yip, 2013) – this new wave of technical innovation is set to disrupt WA's electricity utility business models, dramatically affect the availability of capital in the industry, and further intensify the issues with the State's electricity market.

In January 2016, an additional impetus for distributed energy systems was (unfortunately) provided by a destructive fire that damaged or destroyed 873 power poles, 77 transmission poles, 44 transformers and up to 50 kilometres of overhead power lines (Western Power, 2016). In response to criticism of the high expenses involved in restoring the grid, the Minister for Energy in WA outlined that distributed energy options, such as the use of solar and storage micro-grids, were being considered by Western Power (Parkinson, 2016A).

As market dynamics force the hand of electricity utilities globally, changing the business model away from a conventional, grid-based system towards a grid plus distributed solar model across the entire network is forming as a likely solution for WA electricity businesses. Utilities undertaking future business planning and strategy development should be proactively looking to energy efficiency, solar PV and energy storage as growth opportunities rather than an existential threat, and acknowledging that their place in the energy system will only grow (Poudineh & Jamasb, 2014; Klose et al, 2010). The question then remains as to why electricity businesses have not already embraced this change, and what barriers are preventing this transition from occurring.

6.4. Methodology

6.4.1. Interviews

A review of existing literature was carried out over six months to gain a broad understanding of barriers to the increased adoption of solar PV and residential storage systems in electricity networks around the world. This research helped to inform the design of a series of semi-structured interviews held with several stakeholders in the WA electricity industry, to ascertain the specific barriers, obstacles and potential solutions within the Western

Australian context. Semi structured interviews are based on a protocol and were identified as the most relevant method to use to ensure consistency of topic and discussion (Robson, 2002). They involve priming interviewees for responses based on a set of formulated questions (see Table 6.1), but also provide flexibility for the discussion to involve topics beyond the structured questions.

Table 6.1: Semi Structured Interview Questions

No.	*Question*
1	What are your thoughts on the speed of the energy [revolution/evolution] process occurring?
2	Where do you see your businesses' role in the solar PV and/or residential storage market? Are you already/planning/exploring/advising product and service offerings in this space?
3	**Energy storage is often quoted as the most 'disruptive technology', but to what extent is it an opportunity or a challenge for your business?** Do these technologies pose any challenges in maintaining the service of traditional electricity networks? (e.g. expectation for 1 in 10 year service interruptions?), and related to this, what do you see as the biggest threats over the next 2 – 5-10 year time horizons?
4	Are you also considering large-scale solar projects? i.e. once base-load coal and gas generation retires? If not, why not? (UBS released a very optimistic report on the growth prospects of large-scale solar projects for Utilities)
5	How else is your business model changing? Would you consider splitting off 'traditional' energy from renewables (e.g. E.ON in Europe?)
6	What are the remaining barriers, if any, for residential solar PV and storage markets and will the rapidly evolving landscape drive potential opportunities specific to WA?
7	How can existing barriers be overcome? Through regulation and policy change? Technological innovation? Capital investment? Business Model adaptation?
8	Any active measures you and your company are employing over the short term to address these barriers?
9	How will the continued uptake of solar PV and storage affect cost and revenues for utilities and what are the likely impacts for consumers?
10	What is your view on the tariff reform needed going forward? Would you support a demand based network tariff being passed through retailers to more accurately reflect the cost of the system? **How should technologies such as solar and storage best be rolled out at the consumer level, and what role will tariffs play in helping this?**
11	Where do you see WA's energy market relative to the east coast? Other places in the world?
12	What is the best means to transition the grid, as it is now, to one best placed for the future?

Interviewee responses helped to identify how important, in practice, these barriers are in the adoption decision and to gain a greater understanding of the challenges that participants in the electricity industry are having to grapple with, particularly during this disruptive period in the energy sector.

Although the interviews were primarily conducted with Western Australians regarding the local barriers faced, it is expected that they could be considered indicative of issues faced globally across energy markets worldwide. It is also noted that under normal circumstances, this information is often difficult to acquire – as business challenges and potential innovations remain in-house and are rarely published in public material. By framing the interviews as a contribution to research, without unduly impacting any competitive advantages the participants and their respective companies may otherwise be protecting, the interviews were able to achieve a rare level of candor to benefit the study.

6.4.2. Selection process

Various methods were used to identify candidates. These included online databases (e.g. LinkedIn), industry magazines, conferences, news articles, academic literature, and recommendations. They were contacted via email and in total, 40 people were asked to take part in the interviews, of which 45% accepted.[8]

The open nature of semi-structured interviews also allowed for new topics to be discussed, and the guide was tailored to suit the interviewee's experience and background and adapted 'live', depending on what the interviewees said.

Interviewees were identified on the basis of their knowledge and expertise in this area, primarily within the WA electricity sector. Interviewees were predominantly senior executives and directors and represented an eclectic mix of organisations, including: state and local governmental bodies, network generation and retail electricity utilities, private energy

[8] Homogeneity of interview content, structure and participants, and a high degree of expertise of participants offers comprehensive information from smaller interview samples (Guest et al., 2006).

companies, energy consulting firms, associations, non-governmental organisations, academics, and several industry professionals from legal, economic and political backgrounds. The importance of a wide ranging selection across public, private and individual viewpoints was identified in order to obtain more of a balanced and objective account of the current challenges related to distributed generation and barriers being faced in residential solar PV and storage markets.

A summary table of interviewees and their affiliation is included below, which also corresponds as a reference to particular comments and views expressed throughout the text that follows.

Table 6.2: Interview Participant Summary

Interviewees	Affiliation
Participant 1	Senior Manager - Energy Consulting Firm
Participant 2	Managing Director – Independent WA Electricity Retailer
Participant 3	Manager – Network Utility
Participant 4	Manager – Government Electricity Retailer
Participant 5	Director – Government Energy Policy Office
Participant 6 & 7	Directors – WA Local Government
Participant 8	Director – Energy Consulting Firm
Participant 9 & 10	Analysts – Australian Energy Market Operator
Participant 11	Director – Energy Consulting Firm
Participant 12	Director – Non-Government Organisation
Participant 13	Director – Local Electricity Regulatory Authority
Participant 14	Partner – Professional Services Firm
Participant 15	Manager – Metering Firm
Participant 16	Manager – Distribution Network Utility
Participant 17	CEO – Solar Energy Firm
Participant 18	General Manager - Independent WA Electricity Retailer

All interviews were recorded on a phone microphone recording application, with the majority occurring in person. The interviews were largely informal, typically lasting between 45 to 60 minutes.

6.5. Results

6.5.1. Overview of barriers

Research on increasing the adoption of solar PV systems has a long heritage, beginning in the 1980s and with research literature continuing today, profiling the advancement of PV technologies from sociotechnical (Müggenburg et al, 2012; Dewald & Truffer, 2012), economic (Lund, 2011) and political perspectives (Jacobsson & Lauber, 2006). This research shows that the barriers to increased uptake of solar PV typically relates to a similar set of areas including sociotechnical, management, economic, or policy (Karakaya & Sriwannawit, 2015; Balcombe et al, 2014). Although specific research investigating the barriers from a WA context was not found, barriers are expected to be similar, albeit with varying levels of priority, and encompassing issues including cost, environmental concerns, self-generation, policy uncertainty, inertia and inconvenience and aesthetic impacts (Ratinen, 2014; Strupeit, 2015; Balcombe et al, 2014; Sandberg & Aarikka-Stenroos, 2014; Suzuki, 2015; Luthra et al, 2014). For ease of classification, barriers have been re-grouped under three main headings: technological, institutional, and financial.

A summary of the barriers under these three classifications (as reported by stakeholders in interviewees and identified in literature) has been included in Figure 6.1:

Figure 6.1: Summary of barriers to solar PV and storage uptake

Technological:
- Forecasting capability
- Constraints of existing technology
- Network capacity and access

Institutional:
- Psychological will
- Organisational management
- Government lobbying
- Government policy
- Consumer Inertia & Information Blocks

Financial:
- Sunk network costs
- Upfront system costs

Each barrier is discussed in more detail below.

6.5.2. Technological

Forecasting capability

Forecasting inaccuracies are infamously known to drive poor decision-making across any industry, but forecasting has become embedded into the centralised model of electricity provision. In WA, actual demand growth has been far below forecasts made at the time the Wholesale Electricity Market in WA was designed. As a result there is now a substantial excess of capacity in the market, imposing a significant cost to electricity consumers as there is a Capacity Market that pays for the capacity of all generators, even if they simply provide back-up services and are rarely if ever called on to generate electricity. In conjunction, the market mechanism designed to reduce this cost over time is not functioning at all – failing to incentivise generators to mothball or retire redundant capacity. Poor forecasting by the Independent Market Operator (as WA's system operator), Government authorities, and the Economic Regulation Authority, has now resulted in a situation where consumers have to pay for the costly errors and un-needed infrastructure investments in the market (Government of WA, 2015; Parkinson, 2015B).

Whilst the impact of additional costs imposed by poor forecasting might provide residents with additional incentive to go 'off-grid' or install solar PV and storage units, at a business level, electricity generators, networks and retailers have a reduced need for additional capacity and can already secure long term power contracts at long-term average costs (Participant 1, 2016).

Constraints of existing technology

The transformation of electricity systems requires technological innovation in order to implement services and products to consumers in an affordable and accessible way (Suzuki, 2015). The quality and reliability of solar PV and storage systems is therefore critical for their increased adoption and barriers exist relating to the uncertainty of the technical performance of solar and storage systems (Zahedi, 2011; Luthra et al, 2014). Adoption rates in China provide an example where high levels of dissatisfaction with the low performance of solar home systems (whether caused by improper usage or not) has reportedly prevented other potential adopters from purchasing systems (Karakaya & Sriwannawit, 2015; Yuan et al, 2011). Similarly, studies in the US indicated that consumers were also likely to hesitate from adopting solar PV systems due to the perceived risks of unknown technologies and associated complexities (Drury et al, 2012).

As part of the Government led electricity market reforms in WA, the local network utility responsible for grid connections for the SWIS, Western Power, has begun reviewing its processes and technical standards for distributed generation connection in order to reduce system connection costs (Government of WA, 2015).

WA will also require the adoption of smart meters, sensors and advanced communication networks in order to realise the full benefits of new technology such as solar PV and storage systems. For example, new control systems will have to be developed to deal with the bi-directional power flows inherent in a fully developed distributed market. As existing networks evolve to become 'smart grids', utilities will also need to grapple with the complexities of data ownership, cyber security and data privacy (Luthra et al, 2014).

Market participants and smart-meter providers interviewed for this research noted that engaging with incumbent utilities in WA was still a slow and often unsuccessful process, with network utilities (Western Power and Horizon Power) and Government owned retailer (Synergy), still applying existing centralised business models (Participant 15, 2016). Trials being conducted by both companies (e.g. at the Alkimos Beach energy storage trial, a fringe of grid development on the outskirts of Perth)[9], and removal of regulatory barriers may assist in alleviating these technology constraints.

[9] For information on this, see https://www.synergy.net.au/Our-energy/Energy-Storage-Trial-at-Alkimos-Beach

Network capacity and access

Integrating solar PV systems (with or without storage) also raises technical challenges in regards to network stability, reliability and power quality. Western Power is responsible for following technical rules and regulations in order to safeguard and maintain its network assets. Therefore, as the gatekeeper to network access, Western Power is extremely interested in the potential impacts of new connections. While individual residential solar PV customers introducing 1 or 2kW into the system may have only a minor impact, when aggregated across the interconnected system, or when concentrated in areas with existing network constraints or older infrastructure, network impacts may be more pronounced (Participant 3, 2016).

Given the rapid uptake of solar PV that has already occurred across the state, network access barriers appear to have been minimal over the last few years. Going forward may present a different situation, however, particularly as the penetration rates rise from less than 20 per cent of customers on the network to estimates far above 50 per cent in the next decade. The unknown disruptive component in all of this is of course the impact that residential storage systems will play across both supply and demand side management. Although the connection of small-scale residential batteries received a promising start in 2015, when the WA Energy Minister facilitated the removal of regulations prohibiting homes with battery storage from feeding electricity back into the grid (Participant 4, 2016).

6.5.3. Institutional

Psychological will – increasing motivation to embrace innovation

A 2013 study of the German energy market by Richter (2013), found that not only were German utilities yet to react to solar, but the majority of managers interviewed saw no future for solar PV within their organisations (at that time). This was driven by the view of solar PV as a relatively small-scale technology, with relatively high costs and therefore a strong reliance on government subsidies to remain competitive (Richter, 2013). This view may be particularly prevalent for companies without established capabilities in solar or storage technologies (most incumbents), who have a greater reluctance to embrace these technologies than comparable companies with some previous experience (Markard & Truffer, 2006; Stenzel & Frenzel, 2008; Luthra et al, 2014). This places most incumbent electricity utilities (particularly the dominant government-owned entities in WA) in a position where they may be inclined to rely more on their beliefs than facts when formulating business strategies and predicting future market outcomes (Henderson & Clark, 1990). Alternatively, as Storbacka et al. (2009) note, companies may just be 'stuck' in their mindset and identify the structures and players of the energy market as being "given and unchangeable".

In contrast, and three years on, all WA stakeholders interviewed now see solar PV as a 'disruptive innovation' given its potential (particularly in combination with residential storage systems) to challenge the entrenched, centralised models of electricity generation and the opportunities it presents to the electricity market going forward (Participant 1-18, 2016).

Further, the growth potential in the expanding solar market and building new customer relationships would be additional opportunities for utilities; and long-term contracts for solar PV provided by the utility would also facilitate customer retention. Within this new perspective, solar PV could then be viewed as a stepping stone into promoting other 'green energy' initiatives, such as energy efficiency and battery system offerings (Richter, 2013). In the WA context, many stakeholders agreed with the vast opportunities that 'new energy' offerings provide, but various views were expressed on the timing of when these opportunities would be pursued (Participant 1-18, 2016).

Organisational management - is listening to customers a bad thing?

Interviewees also cited a general belief that lack of management expertise has acted as a central barrier to increasing adoption of solar PV and storage systems in WA. Unlike the conventional type of value chains in the centralised energy industry (i.e. generators wholesale to distributors and retailers), in the distributed generation model, participants need to develop different types of business models that cooperates across multiple fronts with multiple actors (Karakaya & Sriwannawit, 2015; Participant 1-18, 2016). The question then becomes how these new models will be developed.

Research on disruptive technology's impacts on existing markets has highlighted the inability for incumbent firms to recognise the true nature of threats to existing business models (Christensen, 1997). A study by Christensen and Raynor (2013) found that the primary reason incumbent firms are resistant to innovating products is because of an over-reliance on listening to what customers are asking for. According to the study, the average customer is blind to any potential benefits from new and innovative products prior to their commercialisation, and therefore rather than driving any form of radical innovation, customer preferences simply lead businesses to make gradual improvements on existing products and services (Christensen and Raynor, 2013).

Apajalahti et al. (2015) identified a further institutional barrier; the inherent complexity faced by utilities attempting to unbundle and split their business units along service offering lines.

Two interviewees also raised the important issue of culture for utility businesses (Participants 8 and 14, 2016), and suggested that whilst in Government hands, WA utilities such as Horizon Power and Western Power would be more resistant to embrace innovation and would inhibit any form of lasting institutional change. One interviewee argued that unless Government-owned enterprises continued to provide secure and stable returns via traditional business models, they would be acting outside their mandate as they could then be seen as first movers and take on the risks of unproven technologies (Participant 14, 2016).

Government led decision making

Another challenge for WA's state-owned electricity companies cited by market participants is overcoming inhibitions to adapt to changing market conditions and surmounting the barriers inherent in bureaucratic decision making processes. As government-owned entities, Synergy, Western Power and Horizon Power have a requirement to obtain not just Board approval, but Ministerial sign-off for all major strategic initiatives. This can be a slow and cumbersome process. Should these businesses remain as public corporations going forward, these restrictive remits will need to be flexible enough to adapt the company's functions and objectives to encourage innovation and repositioning, not hinder it (Participants 1, 4,18, 2016).

Levi-Faur (2003), argues that this relationship with policy makers is so pervasive, that even following privatisation, bundling of interests and ties between government and utilities continues to permeate through all levels of the policy-making process. These ties slow down both the ability for utilities to change their business models, and the innovations occurring across the sector as a whole (Levi-Faur, 2003).

Indeed, utilities across Australia have been primarily interested on protecting their traditional sources of revenue, and several have gone so far as to publicly announce proposals for higher fixed tariffs, specific solar 'charges', and attempt to introduce market rules and regulations to prevent the sale of generation from battery storage connected households – all efforts to dampen the attractiveness of new technologies for customers (Parkinson, 2016B).

Further, the dominant government-owned electricity utilities of WA have previously sought to slow renewable energy development and influence state energy policies (through politically driven point scoring or otherwise), and have taken limited or lagging actions to address or benefit from its increasing relevance to energy markets and networks (Bromley, 2015; Mitchell, 2000; Pehle, 1997; Participants 1, 4, 12, 18, 2016).

Ultimately, these incumbent entities will have to adapt and compete with new services and products entering the market, or face increasing redundancy in an increasingly competitive energy market.

A renewable energy expert and active advocate in WA summarised it as follows:

> *"As long as government retains ownership of those facilities, we will not see innovative suppliers or price competition at market. As a consumer…I had no choice of another retailer to go to who might have offered me a new product, a different product. That is an example of where the lack of the competitive market and the lack of consumer choice means that I am stuck with the decision that one retailer makes."*
>
> (Participant 12, 2016)

Government policy and reform

The Government is often the vilified target for impeding change, and according to energy market participants interviewed, this is arguably justified in the case of policy for renewable energy technologies. The feed-in-tariff policy controversy, whereby the WA Government attempted to remove payments to solar PV customers for surplus electricity exported back to the grid, is a prime example of political uncertainty. It also led to a great deal of scepticism and added to the perception of Government introducing barriers to the adoption of solar PV (Balcombe et al, 2014; Participant 1-18, 2016).

At the federal level, confusing and complicated legislative frameworks and a lack of long term policy certainty is acting as a barrier to renewable energy investment and introducing unnecessary regulatory 'red tape' (Karakaya & Sriwannawit, 2015). Australia has had significant volumes of legislation, regulations, policies and commitments that apply to renewable energy – large and small scale renewable energy targets; renewable energy certificates, carbon pricing schemes, direct action mechanisms – all while enduring competitive pressures of relatively cheap, thermal coal plants (Martin, 2015).

The need to overcome barriers to the adoption of new technologies through the development of "clear and consistent frameworks" was also noted at the meeting of the Council of Australian Governments Energy Council (COAG, 2015).

Removing regulatory barriers was the most consistent theme and highest priority barrier identified by interviewees. As it stands in WA, there is still no reference in the overarching market objectives to any environment effects of energy supply. The WA Government has also remained notably silent on proposing any tariff reform to specifically encourage innovation and consumer investment in renewable or 'clean' technology such as solar PV– citing a preference only to remove market distortions such as eliminating subsidies given to the Government owned electricity retailer, Synergy (WA Government, 2015; Participant 3-5, 2016).

Of course, the issue then becomes how you regulate an evolving area with several unknowns. Comments from an experienced representative of the regulatory environment in Australia hypothesised that unknowns are not necessarily a barrier: "regulations are an iterative process" (Participant 13, 2016). The interviewee used the case of existing electricity market regulations, highlighting that at their early stages, the frameworks were short and concise documents, and as issues were raised, evolved in their level of detail and complexity. A similar evolution is likely already underway for regulatory flexibility to incorporate distributed generation on the WA networks.

Tariff reform was also a central theme that interviewees suggested underpinned the transformation of electricity markets (Participant 9-10, 2016). The current flat-rate electricity tariffs do not incentivise consumers to reduce demand for electricity at peak times, nor do they accurately reflect the true cost of service. Once tariff structures can leverage the capabilities of smart meters and reflect dynamic pricing structures, then the full value of solar PV and battery storage will be unlocked ((Participant 9-10, 2016).

Consumer inertia and information blocks

Related to government involvement is insufficient consumer information contributing to consumer inertia in adopting solar PV and storage systems. UK studies even highlighted a lack of trust for micro-generation system suppliers and installers due to the sharing of previous poor experiences online, or as a result of aggressive marketing and sales promotions (Taylor, 2013).

Other consumer related barriers include uncertainty and information gaps with regards to access requirements and regulations to use and connect solar and storage into the grid. This has prevented many customers from undertaking the required efforts associated with installation of these systems (Strupeit, 2015). Coupled with these uncertainties for consumers is the growing confusion surrounding local council treatment of building aesthetics (i.e. visual impact of panels), strata issues and shading complications resulting from roof-top solar PV panels being effected by neighbouring buildings and trees. These individual issues combined are likely to provide an overall threshold of inconvenience for potential adopters. While interviews with local council planners (Participant 6-7, 2016) re-enforced that there are no local council obstacles in installing the vast majority of residential solar PV or storage systems (as long as they can be considered part of the dwelling structure), the media dramatisation of the rare cases that cause problems can still feed consumer perception (Participant 6-7, 2016).

Arguably, these constraints are less evident in the WA market, where high solar resource and rising electricity prices are driving consumers through any initial or historic inertia and motivating adopters to face the risks, complexities or uncertainties anyway. Further, the expansion of solar PV providers has risen dramatically in WA over recent years, assisting with consumer education regarding price, visual impacts, maintenance requirements, PV reliability and simplifying the installation process (Faiers and Neame, 2006).

6.5.4. Financial

Sunk network costs - network design inertia

Sunk costs in existing network infrastructure are a significant hurdle that is central to the transformation of centralised grids towards more sustainable, distributed platforms for energy trading. A Commonwealth of Australia Governmental led investigation, the Senate's

Select Committee on Electricity Prices (Select Committee, 2012), found that network design, connection and cost barriers were the main impediments to increasing embedded generation in Australia's electricity grids.

As per the current design model, customers pay for the sunk costs of electricity poles and wires (whether they want to use them or not) based on levels of spending pre-approved by economic regulators (in Western Power's case, this has been the Economic Regulation Authority). This model has provided very limited incentive to shift these electricity utilities away from their reliance on the regulated asset base (which allows for a more certain revenue stream). In effect, this model propagates old, centralised electricity service business models which are framed to see residential solar and storage generation units as a threat, rather than as an opportunity for new business (Parkinson, 2015B).

One interviewee suggested the immediate focus should be on:

> *"Applications where it already makes more economic sense to have solar and storage technologies, particularly when considering any large capital heavy projects on the electricity network - such as fringe of grid, new developments, undergrounding power lines, or replacing damaged power lines (e.g. following bushfires)*."
>
> (Participant 1, 2016)

Indeed, for the WA context, this appears to be the approach now being followed by the Government and government-owned utilities. The aforementioned trial in Alkimos beach, combines community scale battery energy storage, high penetration solar PV and energy management, and will test the feasibility of new energy retail models (ARENA, 2016).

Upfront system costs

The high cost of solar PV systems is usually cited as the most common (and largest) economic barrier to increased adoption – specifically the high initial capital costs, high repair costs, and long payback period (Zhang et al, 2012; Balcombe et al, 2014; Allen et al, 2008;

Ravindranath and Balachandra, 2009). It should also be noted that it is important to consider this cost in relation to the cost of substitutable energy sources available (Karakaya & Sriwannawit, 2015; Sarzynski et al, 2012).

However, significantly cheaper levelised cost of energy[10] for solar and storage systems will not automatically result in strong increases in the uptake for solar PV and storage systems (even if this cost falls below the level of the retail price of electricity), as other cost barriers are likely to continue to impinge on the attractiveness of the investment (Elliston, 2010). These barriers include, for example, investment uncertainty and risk, high rates of return, or a lack of access to debt or equity financing, which can all inhibit “an economically rational decision to install PV once prices provide a good rate of return” (Elliston, 2010: pg 8).

This view was confirmed in research by Mountain (2014), who looked at applying traditional project finance analysis to investigate the value that recent renewable energy policies (feed-in tariff payments and renewable energy target certificates) has had on the uptake of solar in Australia from 2010 to 2012. Combining these government incentives with retailer payments and avoided energy purchases, Mountain’s (2014) findings suggested that, on average, households that invested in rooftop PV over the period achieved similar returns to what a utility could have reasonably expected for the same investment. In other words, without these Government incentives in the form of feed-in tariffs and renewable energy certificates, returns would have been strongly negative (Mountain, 2014). Of course, as residential solar and storage technologies continue down the cost curve, these findings will continue to be challenged.

6.6. Discussion

In all interviews undertaken with stakeholders, it was implicit that whilst barriers were often discussed in isolation, it is in fact their interaction and combined impact, which has the most

[10] Levelised cost of energy is a common summary measure of the overall competitiveness of a particular technology and includes capital and fuel costs, operating and maintenance costs, and financing costs, as well as the assumed rate of utilisation.

significant effect on the deployment and uptake of solar PV and storage systems in Western Australia (Participant 1-18, 2016).

Further, some of the barriers identified do not fit neatly into just one category and feed into multiple themes. For example, one interviewee provided a unique insight into a potential barrier that straddles both financial and technological classifications, relating to Australia's relatively small size in the global markets. In their view, since Australia offers a significantly smaller market than those found in Asia, North America and Europe, Australian consumers with strong preferences for solar and storage products will likely be left waiting in line behind the larger markets (Participant 2, 2016). This is likely to be more noticeable in relation to storage products, which have limited supply chains.

Of course, as these products become commoditised (like our mobile phones), then this limiting factor will no longer be an issue for Australian consumers. This 'maturity' of markets is already seen for solar PV systems, which have all but eroded their high capital costs through mass production and technological improvements.

This research highlighted a common occurrence of attributing general market frustrations on a particular entity - a need to blame someone for a lack of progress, regardless of whether the barriers are actual impediments or simply perceived. In the case of impediments to solar PV and storage uptake in WA, the scapegoat appears to be Government and regulators. A common theme that emerged throughout all interviews was the importance of "flexible and forward looking regulatory frameworks". The example of 'uber' and the taxi industry was often cited as a likely and comparable scenario for the energy industry, whereby customers override regulators and established regulatory frameworks once presented with an affordable, efficient and favourable alternative to the status quo.

On the other hand, despite these barriers, there are still enough commercial incentives for new and existing market participants to take risks and conduct trials. The opportunities in WA have already been identified by global technology and energy service companies (e.g.

storage providers: Enphase, Tesla and Redflow), who are working with local governments and electricity businesses to pilot projects such as battery technology trials, innovative pricing structures, demand side management studies and long-term capacity planning methodologies. As the diffusion of these technology innovations grows in the WA energy market, new opportunities will continue to arise for both existing and emerging businesses, and importantly consumers are in line to benefit.

Lastly, the timing uncertainties and the speed at which the energy (r)evolution may occur was a topical theme brought up by most interviewees. The full spectrum of rates of change were voiced across the interviewees, from “yesterday” to “decades away”, with the common understanding that forecasting the speed of innovation is an inherently complex task. Although in relation to timing, one respondent (Participant 1, 2016) highlighted the interesting dynamic of late-movers to storage systems potentially benefiting substantially, arguing that once electric vehicle uptake is at a reasonable level (e.g. in 2030), the secondary market for the vehicle’s batteries to be used as conventional, stationary batteries in residential applications will likely be over supplied and lead to significant downward pressure on battery prices (Participant 1, 2016).

It is outside the scope of this paper to examine in depth the solutions needed to overcome the myriad of barriers inhibiting greater uptake of solar and batteries in the market. Nevertheless, based on the barriers identified in this paper, some potential solutions, which will require further research, may include:

- Improved regulatory frameworks that remove economic and political barriers at the same time as promoting necessary capital investment;
- Customer involvement and education;
- Development of infrastructure – e.g. upgrade to smart grids and bi-directional communication systems;

- Changes to licensing requirements (to allow power purchase agreements) and revision of customer protection frameworks;
- Increased transparency, introduction of performance reporting, and lower cost connection requirements for distributed generation; and
- Exploration of new utility *business models* (e.g. partnership with technology providers and third-party ownership products to shift financial and performance risks away from customers).

6.7. Conclusions & Policy implications

This paper focused on the existing barriers to increased penetration of residential solar PV and storage in WA. Three broad groups of barriers were identified and discussed: technological, institutional and financial. A range of issues were identified under each of these groups, both from existing literature, as well as from interviews with key stakeholders working within the WA energy market.

The main barriers identified within the technological barrier include: forecasting capability; constraints of existing technology; and network capacity and access. Institutional barriers include: psychological will of people and the reluctance to embrace the new; organisational management and issues associated with listening too closely to customers; the need for Government lobbying and policy reform; and consumer inertia & information blocks. The main financial barriers discussed include: how to deal with sunk network costs; as well as inertia around network design and how to cover the upfront system costs of solar PV and batteries.

A collective view of the discussions suggests that the adoption of solar PV and storage systems is still a challenging process and one that requires all stakeholders in the sector – whether they are industry stakeholders, policy makers, local communities or consumers – to participate in the transition towards a more innovative and sustainable electricity networks of the future. Results also suggest that regulatory and policy reform is what will underpin the removal of other financial, institutional and technological barriers. Without cohesive collaboration and dedicated support for this regulatory and policy reform, the barriers to wider adoption of technology innovations will not be easily overcome.

While many countries worldwide are yet to fully embrace or acknowledge the forthcoming disruption to global electricity markets by solar PV and battery storage technology, the WA stakeholders interviewed clearly recognise these as a disruptive innovation that is already having a significant impact on the WA energy network and market.

The unique set of conditions within WA has created a situation and issue which the WA Government can no longer ignore. For this reason, it is expected that WA's isolated electricity network and energy market will become a demonstration site for energy authorities around the world looking for guidance on how to manage the transition and adapt their own regulatory frameworks for the future.

Given the technological and political uncertainty that remains, this paper highlights the importance of firstly creating regulatory transparency to empower a robust, yet flexible policy design, that can then be used to underpin the energy markets that are essential to the sector. Over the long-term, it is the efficiency of markets that will drive competition, rather than regulators. For example, removing barriers to entry for solar PV and storage will facilitate uptake, which will in turn drive innovation and customer choice across retail, network and wholesale markets. Policy makers must recognise the importance of not only identifying and removing any existing regulatory barriers, but creating adaptable and flexible frameworks so that any future barriers can be easily identified, navigated, or mitigated.

Further research is needed to examine the specific solutions that WA may require to address and minimise the negative impact on the network and the market.

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CHAPTER 7: FUTURE BUSINESS MODELS FOR WESTERN AUSTRALIAN ELECTRICITY UTILITIES

Paper 3: Published

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Chapter 7 contains the third published paper presented in this thesis. The published form is included in Appendix C of this thesis

7.1. Abstract

There is growing interest and investment in solar photovoltaic (PV) panels and battery storage systems, driven by the rapidly decreasing technology costs and the movement towards more sustainable energy solutions.

The increasing adoption of solar and storage systems presents both a challenge and an opportunity for electricity utilities amidst wider technological disruption in the sector. This paper investigates how Western Australian utilities can best adapt to this disruption, and in particular, explores how existing business models will need to evolve beyond traditional energy economics. Distinctive characteristics of new business models are classified, before being qualified for appropriateness to the local Western Australian context through interviews with a variety of energy market participants. It is suggested that these characteristics be adopted in a modular approach, to ensure capabilities are maintained, costs minimised and customers retained.

This research aims to fill this gap in existing literature, to inform Western Australian government policy makers and industry participants on how to evolve their existing networks and processes to create innovative and sustainable electricity systems of the future.

Keywords: Solar, storage, electricity, business models, innovation

7.2. Introduction

7.2.1. The Energy Model Transition

Inherently, energy markets are complex and dynamic structures. They usually have a variety of stakeholders, representing different agendas on price, system security and reliability, and environmental issues, who are constantly lobbying governments for regulatory and industry reform. For example, renewable energy developers tout the advantages of clean energy and the need for regulatory reform to encourage more projects to connect. However, for projects to be financially viable in Western Australia (WA), they still rely on Federal subsidy schemes (Large and Small Scale Generation Certificates), if not State support as well (such as generous Power Purchase Agreements and network connection assistance for non-reference services). In contrast, network utilities must manage intermittency and hosting capacity within existing capital constraints and regulatory frameworks, which in WA includes unconstrained access for generators connecting to the network. Therefore, from a utility's perspective, current business models discourage projects that add costs without increasing revenue, particularly in the context of WA's plentiful base-load plant, and within a market that already has excess capacity.

In WA, the complexity is made even more apparent by the state's geographical isolation, preventing any feasible prospect for WA's networks to be connected to neighbouring systems. However, within this challenging environment, WA's unique isolation also presents an opportunity to study the extent to which renewable energy technologies and distributed generation can be utilised to disrupt the conventional, centralised models of our existing systems.

The underlying economics of renewable generation have already shifted in favour of the decentralised models of clean technology - as afforded by solar PV and storage, and concerns are already being raised with regards to future industry investment and business decisions for energy companies (COAG, 2014; Allen et al., 2009; Grace, 2014).

With the attractiveness of these new energy products and services only increasing, the electricity industry is now being regarded as a sector ripe for disruption (Frankel et al, 2014; Roberts, 2013). In particular, this new wave of technical innovation is set to disrupt electricity utility business models, dramatically affect the availability of capital in the industry, and further intensify issues within the electricity markets (Denholm, 2007; Katiraei, 2011; Yip, 2013). For example, as customers drive the uptake of solar PV and storage systems, coupled with smart 'behind-the-meter' appliances, utilities are faced with changing demand patterns, falling revenues, increased requirements to maintain system security, and the threat that any future large infrastructure investments may be undermined by further erosion of revenue and increasing costs.

WA utilities are beginning to be acutely aware of these challenges for future investments. Following destructive bushfires in January 2016 that destroyed up to 50 kilometres of power lines in the South West, Western Power chose not to re-build the network, but determined that distributed energy options, such as stand-alone power systems and micro-grids provided more economical solutions (Western Power, 2016).

As market dynamics force the hand of electricity utilities globally, electricity businesses must start exploring the value of changing business models away from a conventional, grid-based system to new models, such as one that embraces distributed generation and storage across the entire network, as well as new opportunities to provide energy efficiencies services. Failing to change will almost certainly exacerbate the challenges being faced by incumbent businesses (see Section 2.1 below). However, this will require utilities to break from the inherent path dependence and lock-in common to such complex socio-technical structures as the electricity system - irrespective of potential reversal costs (Lee & Gloaguen, 2015). Utilities undertaking future business planning and strategy development should be open to these business model explorations, although this may require a change in mindset to see technology innovations as growth opportunities, rather than as existential threats, acknowledging that innovation is inevitable, and may drive existing business models to become obsolete (Poudineh & Jamasb, 2014; Klose et al, 2010).

Using WA as a case study to explore how these future business models may be implemented in practice, this paper presents a series of evolutionary business models for WA electricity businesses to consider. These models relate particularly to the development and integration of residential solar PV and battery storage and have been identified through an extensive literature review. These models are then validated through a series of semi-structured interviews with WA market participants and stakeholders.

For policymakers and regulators currently grappling with a fluctuating electricity service and delivery model, this research aims to provide valuable insights and recommendations on how to help facilitate the transformation of the electricity system, and overcome the significant inertia of a system when exposed to change (Pierson, 2000).

It is hoped that this research can also be used in practice to encourage energy businesses and utilities operating in WA (and those in similar energy markets around the world), to utilise solar PV and storage systems in a strategic fashion in order to reduce grid congestion, remove (or at least defer) the need for network investments, maintain downward pressure on electricity prices, help to decarbonise the electricity network, and most importantly, to stay relevant in the evolving, highly disrupted energy market.

The authors note that, ultimately, all electricity grids share a common goal of achieving a safe, secure, sustainable and affordable service of electricity to customers. Achieving this will inevitably involve leveraging and integrating new technologies into existing grid structures and business models.

This paper begins by providing some background around traditional business models for electricity generation and supply in Australia before specifically highlighting the opportunity that is being presented in WA. This is followed by an overview of the methodology and analysis used. Results are discussed in terms of existing barriers, new business models and the need for new partnerships and energy companies. This is then examined in relation to how WA could respond to these challenges, and concludes by highlighting some potential policy implications.

7.3. Background

7.3.1. The Old Model in a Changing Landscape

The current business model of utilities reflects the legacy of a centralised electricity generation and distribution design, underpinned by large upfront capital requirements relative to marginal operating costs, driving a natural motivation for electricity utilities to maximise the production and sale of electricity through existing networks (Kind, 2013; Bromley, 2015; Caldecott & McDaniels, 2014).

Historically, electricity demand was thought to be largely inelastic and the main driver of cost was capacity peaks and the resultant infrastructure spend to cater for them. A view of ever-rising peak demand also contributed to a standard approach to power system and security planning, network regulation, and energy market dispatch design. Utilities, therefore, created a traditional service of delivering electricity at price per kilowatt hour (Schaltegger et al, 2012; Richter, 2013; Roberts, 2015; Sioshansi, 2014).

Recognising this ‘coupling' of volumes and profitability was at a natural tension with the assumption from customers that their electricity supply should be treated as a ‘right’, the electricity networks most commonly became a natural monopoly (e-lab RMI, 2014). In WA’s case, the result was a regulatory agreement between government and the government-owned utility (Western Power) to provide affordable, reliable and accessible electricity to all consumers across the State at a uniform price (Government of WA, 2014). This led to a growing gap between the cost of electricity supply and the cost paid by consumers, with the Government absorbing the deficit.

Meanwhile, each technology improvement or institutional enhancement in the system was only ever an incremental development tracing along the same traditional pathway – constrained by previous decisions which effectively 'locked the industry in' (Nelson & Winter, 1982).

However, the standing of electricity utilities as safe and steady businesses is now coming under increasing pressure due to a convergence of several factors across technology, economics and public policy. In the past decade alone, the energy sector in Australia has been navigating: rapid technology innovation (removing barriers to entry for small players); the falling cost of distributed generation; increased interest in demand side management; slowing trends in demand; shifting government policies on renewable energy incentives; and rising electricity prices across the country (Kind, 2013; e-lab, 2014; Grace, 2014; Bunning, 2011). In combination, these factors are set to fundamentally change the way our electricity systems operate.

The very tenets of the status quo 'traditional path' are being challenged. Not only has it become cost prohibitive for the WA Government to continue to subsidise energy costs to consumers, but the impact of rising costs on some customers is now beginning to drive investment trends in the opposite direction for those who can afford it and are motivated enough to analyse their energy costs (through energy efficiency and distributed generation). The increasing uptake of solar PV and storage will only exacerbate this trend (Zinaman et al, 2015).

7.3.2. The WA Opportunity

A variety of unique factors are forcing WA to become an early adopter in the transition to a new electricity network and system based on renewable, distributed energy. Because the WA Government has traditionally subsidised the centralised model of fossil fuel generation as a political offering to consumers, the state is now faced with some of the highest electricity costs in the world (Sandiford, 2016). The Government now admits this subsidy is unsustainable, and is seeking to benefit from the some of the best renewable resources available (Nahan, 2015; Bromley, 2015; Sayeef, 2012).

WA is now is in prime position to unlock the potential of increasingly cost-competitive solar PV and battery storage systems. Coupled with changing economics is the structure of WA's electricity market itself: still highly regulated, dominated by Government-owned entities and currently undergoing a major reform program. Although the WA market is relatively late in considering initiatives such as full retail competition and flexible pricing (Australia's Eastern States implemented similar reforms through the nineties), the industry is now open to consider major structural reforms and market re-design - not just economic improvements to existing models (CSIRO, 2009; Sharma, 1997). However, these technology innovations will only increase the challenges for utilities and Government.

WA's isolated electricity network and energy market can therefore become a demonstration site for utilities and energy sector participants looking for guidance on how to manage the transition (Parkinson, 2015a; Tayal & Rauland, 2016). Already, innovative studies and collaborations between private participants and the monopoly network provider, Western Power, include strata peer to peer trading (White Gum Valley project), microgrid trials (Kalbarri, Garden Island), utility scale battery storage (Perenjori), demand management trials (Mandurah), and the stand-alone power systems following the bushfire damage mentioned above (Ravensthorpe) (McGoldrik, 2016).

Whilst other markets are also beginning to contend with the pressures of solar disruption (most notably Hawaii, California and Germany), WA has a unique confluence of economic affluence, market reform, network isolation, high solar radiation and consumer demand that has driven enough market impetus to recognise the urgency in addressing its impacts (Parkinson, 2015; Bromley, 2015).

7.4. Methodology

A review of existing literature over a twelve month period was undertaken to gain a broad understanding of the various new business models being proposed, trailed or conceptualised for electricity businesses around the world. This research was used to inform the design of interviews subsequently undertaken with various stakeholders within the WA electricity industry.

7.4.1. Interviews

Interviews were conducted with a variety of stakeholders within the electricity industry to ascertain the specific merits of adopting these 'future business models' within the WA context. Interviewee responses also helped to provide a greater understanding of the challenges that electricity businesses are faced with, and what aspects of the existing business models could be enhanced to leverage the future opportunities in the market.

Semi-structured interviews were identified as the most relevant method to use to ensure consistency of topic and adequate fluidity in discussion (Robson, 2002). The semi-structured interviews conducted were purposely open in nature to allow new topics to be discussed, and new information to be gathered, which may not have been identified by particular interview questions. They involved priming interviewees for responses based on a set of formulated questions (see Table 7.1), but also provided flexibility for the discussion to involve topics beyond the structured questions.

Table 7.1: Semi Structured Interview Questions

No.	*Question*
1	What are your thoughts on the speed of the energy [revolution/evolution] process occurring?
2	Where do you see your businesses' role in the solar PV and/or residential storage market? Are you already/planning/exploring/advising product and service offerings in this space?
3	**Energy storage is often quoted as the most 'disruptive technology', but to what extent is it an opportunity or a challenge for your business?**

	Do these technologies pose any challenges in maintaining the service of traditional electricity networks? (e.g. expectation for 1 in 10 year service interruptions?), and related to this, what do you see as the biggest threats over the next 2 – 5-10 year time horizons?
4	Are you also considering large-scale solar projects? i.e. once base-load coal and gas generation retires? If not, why not? (UBS released a very optimistic report on the growth prospects of large-scale solar projects for Utilities)
5	How else is your business model changing? Would you consider splitting off 'traditional' energy from renewables (e.g. E.ON in Europe?)
6	What are the remaining barriers, if any, for residential solar PV and storage markets and will the rapidly evolving landscape drive potential opportunities specific to WA?
7	How can existing barriers be overcome? Through regulation and policy change? Technological innovation? Capital investment? Business Model adaptation?
8	Any active measures you and your company are employing over the short term to address these barriers?
9	How will the continued uptake of solar PV and storage affect cost and revenues for utilities and what are the likely impacts for consumers?
10	What is your view on the tariff reform needed going forward? Would you support a demand based network tariff being passed through retailers to more accurately reflect the cost of the system? **How should technologies such as solar and storage best be rolled out at the consumer level, and what role will tariffs play in helping this?**
11	Where do you see WA's energy market relative to the east coast? Other places in the world?
12	What is the best means to transition the grid, as it is now, to one best placed for the future?

The interviews were conducted with Western Australian experts, to identify the viability of implementing global ideas and commentary on energy market challenges being faced across Australian markets, and worldwide. The appropriateness of solutions and future business models proposed in existing literature was also assessed for its relevance to Western Australian utilities to gain a greater understanding of the challenges that participants in the local WA electricity industry are having to grapple with, particularly during this disruptive period in the energy sector.

It is also noted that under normal circumstances, this information is often difficult to acquire – as business challenges and potential innovations and corporate strategies remain in-house and are rarely published in public material. By framing the interviews as a contribution to research, without unduly impacting any competitive advantages the participants and their respective companies may otherwise be protecting, the interviews achieved a rare level of candor to the advantage of the study.

7.4.2. Selection Process

Candidates were identified using a variety of methods including online databases (e.g. LinkedIn), industry magazines, conferences, news articles, academic literature, and recommendations. They were contacted primarily via email, although a select few were also asked to participate in interviews in person at meetings. Overall, 18 interviews were conducted, which equated to a 45 per cent acceptance rate.[11]

Interviewees were directors or senior executives primarily from the WA electricity sector and were chosen because of their knowledge and expertise in this area. Interviewees were selected from a broad mix of organisations, including: state and local governmental bodies, network generation and retail electricity utilities, private energy companies, energy consulting firms, associations, non-governmental organisations, academics, and several industry professionals from legal, economic and political backgrounds. This wide ranging selection of interviewees representing public, private and individual viewpoints was important to gain more of a balanced and objective overview of the challenges around distributed generation and how future business models could incorporate products and services relating to residential solar PV and storage more effectively.

Table 2 provides the list of the interviewees/participants and their affiliations.

Table 2:

Participant	Affiliation	Role
1	Energy Consulting Firm	Senior Manager
2	Independent WA Electricity Retailer	Managing Director
3	Network Utility	Manager
4	Government Electricity Retailer	Manager
5	Government Energy Policy Office	Director
6 & 7	WA Local Government	Directors
8	Energy Consulting Firm	Director

[11] Homogeneity of interview content, structure and participants, and a high degree of expertise of participants offers comprehensive information from smaller interview samples (Guest et al., 2006).

9 & 10	Australian Energy Market Operator	Analyst
11	Energy Consulting Firm	Director
12	Non-Government Organisation	Director
13	Local Electricity Regulatory Authority	Director
14	Professional Services Firm	Partner
15	Metering Firm	Manager
16	Distribution Network Utility	Manager
17	Solar Energy Firm	Chief Executive Officer (CEO)
18	Independent WA Electricity Retailer	General Manager (GM)

The majority of interviews were undertaken in person, with only two conducted over the phone. All interviews were recorded and typically lasted between 45 minutes to one hour. The interview responses were then transcribed and systematically categorised into five thematic areas based on the specific issue raised to align with the initial literature review: Performance Improvement; Capacity Removal and Divestment; Regulatory Issues; Policy Issues; and Miscellaneous (e.g. electric vehicles, creation of new business units, building partnerships). These areas frame this paper's discussion section (Section 5.3 below), which includes the relevant responses to provide the unique WA context and expand on existing literature, filling the gap in research.

7.5. Results

7.5.1. Existing Barriers

Currently, the interests of utilities (preventing stranded assets, maximising electricity sales, preventing increased competition) are in tension with the interests of consumers and the environmental imperative to decarbonize the electricity sector (Roberts, 2015; Vanamali, 2015; Bromley, 2015).

Further, any solutions designed to meet the transitioning needs of the energy industry will need to be based on the individual regulatory and market contexts in which they emerge (Crawford, 2015; Hogan, 2014). For instance, utilities in competitive markets will be more directly exposed to the threats that arise from technology innovations such as solar and storage systems, given their ability to reduce electricity use and demand (Kind, 2013).

It is widely acknowledged that if utility business models fail to adapt to disruptive potential of distributed generation, components of their old, centralised system will increasingly become stranded assets (PwC, 2014; UBS, 2015; Sioshansi, 2014). As a worst-case scenario, business analysts describe the situation as the “utility death spiral”, citing a “failing utility business model” to explain how energy generated by solar is threatening the future existence of a grid-based energy system (Silverstein & Wood, 2014).

In order to avoid this, a series of regulatory, institutional and financial barriers that inhibit the effective transition of electricity businesses to new ways of operating need to be addressed. After investigating barriers for various Swiss and German utilities in their transformation from largely ‘asset’ businesses to being providers of intangible services and products, Helms (2016) concluded that the central facilitator to this process was the policy makers’ role in supporting the transition for utilities via flexible regulatory frameworks. Gunningham and Sinclair’s (1998) work in relation to environmental regulation provides a useful grounding for how flexible (smart) regulation might be designed for energy markets, outlining the usefulness of multiple, complimentary policy instruments, using less interventionist measures where possible, and empowering third parties to include a broader range of regulatory actors and stakeholders (Gunningham and Sinclair, 1998).

Tayal and Rauland (unpublished) who investigated barriers specific to WA, found a similar argument was common amongst energy sector participants – that forward thinking policy and regulatory flexibility and the removal of government barriers was a necessary pre-condition to the true transition to new business models in the state (Participant 13 & 14, 2016).

The real challenge for WA’s state-owned electricity companies may be in overcoming their inhibitions to adapt to changing market conditions and surmounting the barriers to innovation given their requirement to obtain not just Board approval, but Ministerial sign-off for all major strategic initiatives. This creates tension between government and the utilities, and also facilitates government intervention into the market, confusing what would otherwise be independent commercial decisions in the interests of shareholders or private owners. Should these businesses remain as public corporations going forward, these restrictive remits will need to be flexible enough to adapt the company's functions and objectives to encourage innovation and repositioning, not hinder it (Participant 5 & 13, 2016).

The existing corporate inertia and Board's resistance to change core business functions is also argued to be having a direct impact on current profitability and thus, can no longer be ignored in Western Australia (Participant 14, 2016). Claims that renewables are a risky side-project that will never gain serious market share for their intermittency or cost structures are now also being shown to be increasingly false amongst wider industry groups, financiers and politicians in WA (Participant 8, 2016). As the pressure mounts, however, new policy and strategy announcements are beginning to be heard from the major electricity business in the State. For example, Synergy, the Government-owned monopoly gentailer in WA announced its own solar PV system offering, 'SolarReturn', in May 2016:

> *"Synergy is transforming into a contemporary, responsive and adaptive business that embraces innovative technology and the use of renewable energy sources."*
>
> *(Synergy, 2016)*

Clearly previous rationales for WA utilities to remain indifferent to the threat of residential solar PV and storage systems are no longer accepted and have largely disappeared from the local debate (Participants 1-18, 2016).

The new utility business models that are now urgently required cannot be developed and adapted by the WA utilities in a vacuum, even if they are predominately Government owned (Participant 15, 2016). The transition to new business models will require collaboration and participation across policymakers, regulators, investors, consumers, forward thinking Government Ministers, as well as technology innovators and entrepreneurs.

7.5.2. The New Utility Business Model

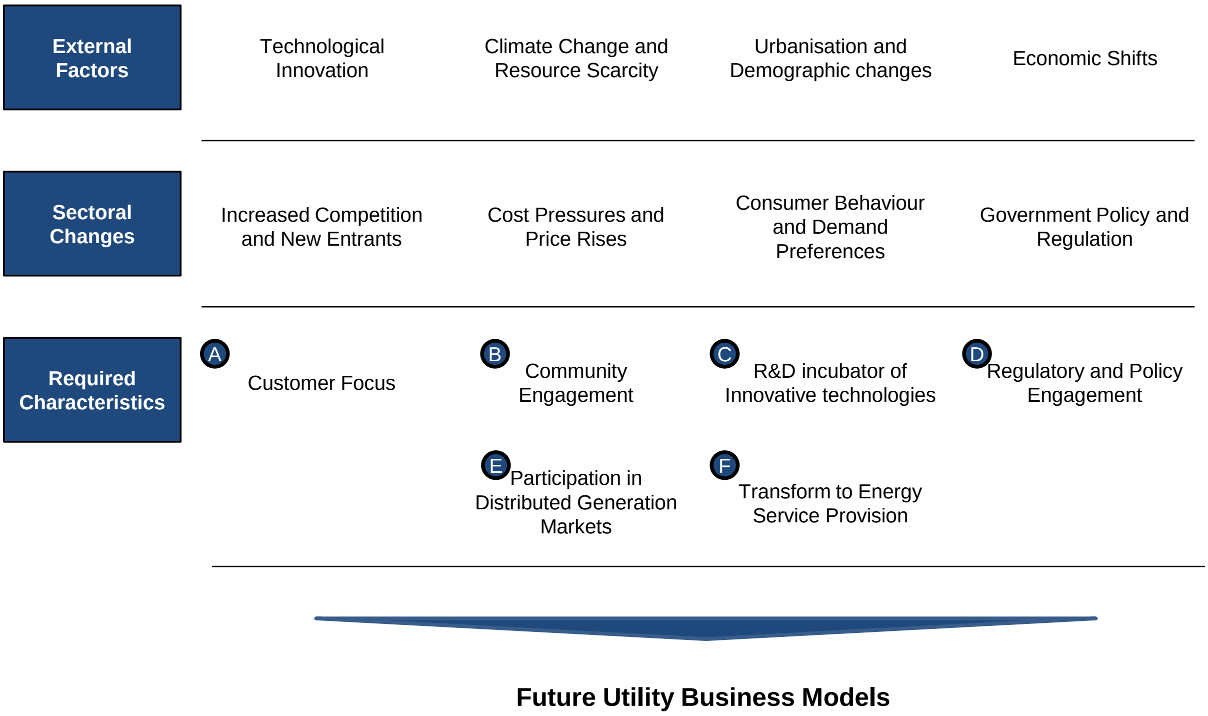
Business models are the link between corporate strategies and operational activities (Rauter et al., 2015). Several examples of organisational efforts to transition towards more sustainable business models already exists (Stubbs and Cocklin, 2008). Some businesses claim to consider more than just shareholder value, citing additional focus on, for example: reducing the ecological footprint of their products; providing service-based products, or on incorporating wider social issues into business strategy (Matos and Silvestre, 2013; Schaltegger et al., 2012). Underpinning the development of these sustainable business models for the electricity industry, is the need for utilities to expand beyond their traditional mantra of delivering 'as much electricity as possible at the highest price allowed' and start considering social and environmental factors (Schaltegger et al, 2012; Richter, 2013; Ashford, Hall and Ashford, 2012).

Within the context of disruptive innovation, managers of utilities deciding to enter and succeed in solar PV and energy storage markets, need to make bold decisions to change their business models and introduce new products, pricing plans, or service offerings, and be able to convince customers of their value (Ratinen, 2014). Utilities moving into this space also need to either prove their differentiation from existing products and services in the market, or expand the market itself (Richter, 2013).

A growing body of research continues to develop a series of essential requirements and characteristics that a next generation electricity utility business will need to incorporate, in order to maintain relevance in the energy market going forward. The characteristics identified (see Figure 7.1 and Table 7.2) can then underpin a full range of potential strategic responses to the competitive 'threat' of solar PV and storage, thus protecting investors and capital availability for the electricity businesses themselves.

Figure 7.1: Drivers and Key Characteristics of Future Utility Business Models

(Based on interviewees with Participants 1-18, 2016)



Following the extensive literature review, and corroborated by industry experts in WA, the six characteristics (A-F in Figure 7.1) that electricity businesses should consider are further expanded upon in Table 7.3. The table provides examples, as well as necessary considerations for each characteristic, with further explanation provided on specific initiatives in the sections below.

Table 3: New Energy Business Model Characteristics

Characteristic	Description & Considerations	Examples
A. **Customer-focus**	○ Utilities have to view their customers as more than simply sources of revenue – increasing customer engagement and intentionally putting customers first, making distributed generation an accessible part of their resource delivery ○ Products and services need to be accessible, fit for purpose, simplified and easy to use ○ Customer retention depends on ability (age and income) and motivation (past action, energy efficiency) ○ Need to target use of mobile, social and web interfaces to provide customers with improved view of energy use and enable greater (and two-way) communication between the utility and customer. ○ Utilities need to improve their ability to test and implement novel services such as customised rate plans based on individual usage patterns and requirements (e.g. lower cost models for those that don't value direct relationships).	○ Utilities in the United States (e.g. AT&T and Verizon Wireless),have started attempts to transform their image into trusted energy advisors. ○ Amory Lovins (RMI, 2014) suggests utilities must sell their customers "hot showers and cold beer", rather than electrons. ○ Behavioral insights for billing (e.g. normative comparison with neighbours) ○ Transition to real time billing platforms - OPower (United States) ○ Lampiris (Belgian retailer) – using social media for customer feedback
B. **Community engagement**	○ Utilities need to engage in job creation, training and education, and awareness programs ○ Recognise that community participants seeking independent energy systems are not necessarily concerned about price ○ Maintain/develop brand awareness and improve customer retention in increasingly competitive energy market	○ Integration with Government led community service schemes for fuel-poverty households ○ Crowdfunding solar programs - Local ownership ○ Ovo Communities (UK Utility)– complimentary community energy solutions
C. **R&D incubator of innovative technologies [hardware]**	○ Utilities currently have limited research expertise - utilities need to emerge from their monopolistic privileges and become leading incubators of new technologies and business strategies. ○ Utilities may not be the lowest cost provider and/or may require significant investment ○ Technologies likely to facilitate higher solar penetration – further cannibalising traditional core business	○ Tesla, Battery technology, electric vehicle charging ○ Investments in home energy management (e.g. smart thermostats) and storage systems that can lend to a wider service offering. ○ Digitisation – i.e. significant increases to supervisory control and data acquisition sensors and related customer data ○ Smart Grids, Smart Homes and advanced metering will help utilities develop granular insights into demand patterns at customer level and have benefits for pricing, dispatch planning, energy efficiency targets and long-term capacity planning.

D. **Regulatory and policy engagement**	○ To insulate from regulatory and policy changes, utilities will have to actively pursue adaptable regulatory frameworks that facilitate technology update, reduce barriers to entry, and embrace the long term view. ○ Acknowledging that there is no single correct solution, utilities need to engage with policy makers and regulators to get the framework right and then let the market and competition drive the solutions ○ New tariff structures (incorporating behavioral economic insights) may be commercially sensible, but often politically unpalatable – this tension needs to be balanced in order to propose pragmatic solutions for Governments	○ Utilities will need to actively pursue new business models that decouple profitability from the volume of energy sold (how traditional utilities function which is inherently unsustainable), and create new models around efficiency of use,. ○ In Australia, businesses need to be flexible about future carbon price introduction, changes to renewable energy targets – based on political parties
E. **Active participation in distributed generation markets**	○ Utilities invest in, acquire, or partner with small and large-scale PV installers, storage providers and renewable energy project developers – noting that incorporating renewable energy assets (e.g. solar leasing) cannibalises sales from traditional core business services ○ Will be reliant on flexible regulatory provisions and open Government policy ○ Utilities in WA lack experience in competitive and crowded markets ○ Need to leverage roof-top solar capabilities with non-residential (grid-scale) solar projects	○ AGL, Synergy, Origin, Perth Energy - solar leasing and installation programs ○ Explore and expand through new financing options (loans, leases, PPAs). ○ Grid scale storage - AES in United States ○ Large-scale solar projects
F. **Transform to energy 'service providers' and increase [software] applications**	○ Utilities need to shift from selling electricity (a commodity differentiated on price) toward selling a comprehensive service (differentiated on quality) offering a package of energy efficient appliances, building improvements, hardware and installation services, and improved software and billing services to meet customer's needs ○ Utility may not be the lowest cost provider and/or may require significant investment (e.g. retraining of staff, develop analytics capability)– exposing rate payers to inefficient pricing ○ Limited longevity of cellular technology (i.e. due to rapid technological improvements) may expose earlier redundancy than utilities are accustomed ○ Utilities need to be aware of the potential for a highly competitive market, with entrants from consumer technology, telecommunication, home security and energy sectors	○ Provision of customer support and billing services to solar PV retailers (e.g. Powershop, Flick – New Zealand) ○ Improve performance and streamline asset base over shorter time-periods ('manage rather than own'). ○ Partnership with telecommunication companies to combine mobile technology services with home energy management systems (e.g. Telefonica in UK, SP AusNET and Telstra in Australia) ○ Combine internet and mobile communication services, big data analytics and cloud computing with smart grids and smart metering to provide real-time price information.

Sources: Vanamali, 2015; RMI, 2014; Bromley, 2015; PwC, 2013; Richter, 2013; Klose et al, 2010; Zinaman et al, 2015; NYU, 2015; UBS, 2015; Roberts, 2015; Farrell, 2015; Sioshansi, 2014; Glickman and Leroi, 2015; Gunningham and Sinclair, 1998; Participants 1-18, 2016

7.6. Discussion

7.6.1. Building Partnerships

Inevitably, there will not be one perfect business model, and each electricity business will need to assess the contextual risks and impacts unique to its position in the market (Kiesling, 2015).

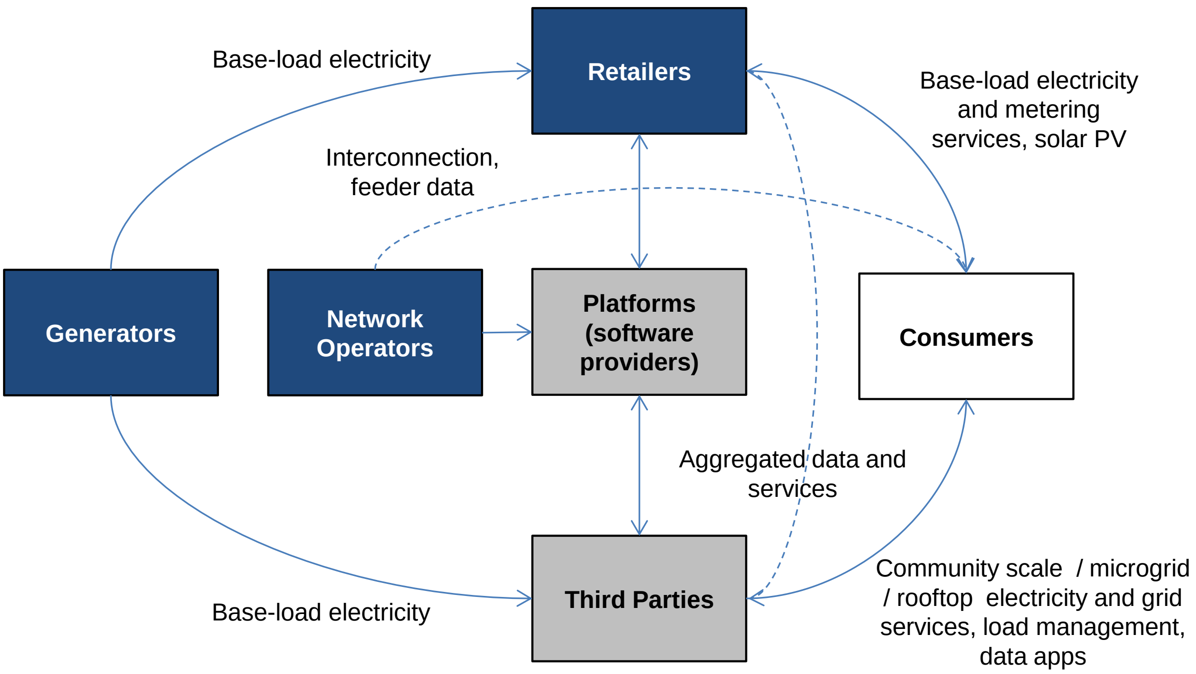
As distributed generation such as residential solar PV and storage penetration grows on electricity networks, new opportunities will arise for both existing and emerging businesses, and consumers are in line to benefit. A key element of this changing landscape is for energy providers to leverage their existing relationships with customers into an enduring partnership aligning with the long life of solar PV systems (common power-purchase agreements in the current market last 15 to 20 years).

Incumbent energy retailers, network operators and generators, like the WA Government-owned Synergy and Western Power, will have to adapt and compete with new services and products, or face increasing redundancy in the market (Participant 4,5, 8, 2016).

Notwithstanding the natural competition of the energy market, a regulatory battle will also be inevitable, to define the boundaries within which traditional retailers and network operators can provide data analytics, energy-efficiency solutions, storage technologies, and other in-home products that consumers of tomorrow will be seeking. As a result, the potential for innovative partnerships with third parties (including software providers) and new information flows also arises, that combine existing customer relationships with these new products and services that currently sit outside the existing domain of centrally planned electricity networks (Participant 3,4, 18, 2016). Figure 7.2 depicts one such future scenario of market participant interactions (Lewis, 2015 and NYU, 2015).

Figure 7.2: Market participant relationships – a future scenario

(adapted from Lewis, 2015 and NYU, 2015)



Establishing external partnerships with other businesses, for example in the solar PV sector, also provides utilities an initial, row-risk entry point into the market and provides access to innovation capabilities (Boscherini et al, 2011). Figure 7.2 depicts how 'Retailers' can choose to interact with consumers directly (as per traditional custom), or alternatively, can partner with 'Platforms (software providers)' and 'Third Parties' such as solar panel and battery technology providers, thereby utilising their experience and contacts and leveraging the established knowledge that these businesses have developed, strengthening the customer engagement model (Pieper & Rubel, 2010).

An existing example of the strategic importance of partnerships is Tesla Motors strong relationship with SolarCity (a solar systems provider), with mutual benefits gained from the development of battery storage systems to seamlessly integrate with electric vehicles and roof top solar PV (McDuling, 2015; Participant 1, 2016). It is easy to imagine similar relationships being built between existing WA energy market players and national, or even international, providers of energy solutions, and several WA market participants expressed confidence that this was already well-underway in the local market, with trials, feasibility studies, and 'sister-company' relationships being set-up between local and global energy service companies (Participants 1, 11 & 18, 2016). However, these opportunities invite an additional condition: that beyond the changes to technology and regulation, such players must also be constantly innovating their business models and corporate strategies to survive in the sector's rapid evolution.

7.6.2. Creating Energy Co's for the Future

Existing literature on business model innovation within the utility sector suggests that utilities would maximise benefits from the new strategies discussed above by adapting their traditional organisational structure and creating a separate and independent business unit to focus on solar PV products and services (Schaltegger et al, 2012; Klose et al, 2010; He et al, 2011; Richter, 2012; Sioshansi, 2014). Establishing a specialised business unit addresses any internal culture and cognitive barriers or conflicts with the core business (e.g. a view that solar cannibalises traditional sales volumes) and allows for a more creative, innovative environment that is empowered to trial new ideas (Bessant et al, 2004).

Several local market participants indicated the appropriateness of this model for WA utilities, citing the uncertainty of traditional generation as a revenue source, and growing customer apathy towards 'dirty generation' as major drivers (Participants 1, 11, 18, 2016).

In Germany, several major utilities have already created new business units to manage renewable energy projects (e.g. E.ON SE) (Anderson, 2014). Similarly in Australia, a number of east-coast retailers operating in the National Electricity Market (NEM) have already progressed with the separation of renewable businesses (e.g. AGL's 'new energy' business unit) that have begun offering customers packages to finance solar PV and battery systems. Other variants include companies initiating 'third-party-ownership' or 'power purchase agreement' (PPA) models where the utilities sign long-term agreements with customers to finance, install and manage the rooftop solar PV installations, whilst the customer buys the electricity that is generated at a pre-determined rate (EPA, 2015; Richter, 2012).

7.6.3. Response Pathways for Western Australia

The lowest risk 'new' utility is the one that will be able to adapt and embrace technology and innovation, and use it to provide a wide suite of energy services at cost-competitive prices that include very high levels of customer service – a future that would no doubt be welcomed by consumers increasingly dissatisfied with the service of their current electricity providers (Zinaman et al, 2015).

In WA, whilst the electricity utilities are no longer vertically integrated, the Government owned gentailer Synergy, and the transmission and distribution network company Western Power still retain a dominant and principal role in the energy system.

Building on the characteristics identified in Table 7.3, four specific responses have been identified as being needed for WA's electricity utilities to maintain their competitiveness and relevance in the changing landscape. These include: Performance Improvement; Capacity Removal and Divestment; Updated Regulatory Framework; and, Long Term Policy Direction (Participants 1, 3, 8-10, 2016).

Performance Improvement

To compete with the lowering costs of renewable energy and the increase of distributed generation on networks, WA's utilities will inevitably need to reduce their costs to remain competitive. They will need to be more flexible and adaptable, focusing on performance improvement measures across the value chain – improving return on invested capital by becoming lean, forward thinking and engaging in product and service partnerships where possible. WA utilities will need to reduce their asset base, which doesn't necessarily have to reduce their profitability (Participant 3 & 5, 2016).

Synergy, the government-owned retailer with a monopoly on residential customers in WA, will need to increase the self-service capabilities for customers without reducing customer service (or increasing churn once full retail competition is introduced). This is where innovations in big data and system optimisation is vital (Participant 15, 2016). Improved data on network performance and big data analytics will need to be incorporated to provide Synergy with real time insight into investment requirements and can include the impact from distributed generation sources (Participant 15, 2016).

Capacity Removal and Divestment

As solar capacity increases globally, energy analysts estimate power generators will start closing their older, thermal fleet (i.e. coal and gas fired power stations) leading to savings for utilities, but spiking electricity prices for consumers – at least in the short term - due to the higher marginal cost for addressing intermittency through peaking plants or large-scale storage. Therefore, in order to maintain security of supply, it is expected that some cash-flow negative plants may remain online in order to provide back-up capacity services (e.g. strategic reserve and ancillary services) (UBS, 2015).

WA already has a problem of excess capacity in the market, which has been a primary contributor to high (and rising) electricity tariff rates due to the state having a reserve capacity market (Participant 1, 5, 8 & 13, 2015). The reserve capacity process, at a high level, requires the market operator to set the capacity requirement for the market largely based on the system reliability requirement and their own demand forecasts. Currently, this creates a perverse situation where unnecessary generators and demand-side management programs are still being paid generously to act as 'back-ups'.

It is acknowledged that forecasting demand (as with all forecasting) is extremely difficult, especially three years into the future as required in the WA Electricity Market's capacity mechanism. Compounding the WA market operator's forecasting complexity is the requirement to include estimates of large new mining loads or "block loads" into the forecast.

These block loads are highly prospective and uncertain. Looking back over the accuracy of the forecasts, it has become evident that actual demand has been far lower than the forecast requirements, resulting in a significant surplus of capacity, which is ultimately paid for by consumers (Participant 8, 2016).

New methods on how to more efficiently procure market capacity and set the reserve capacity price (such as an auction mechanism) are being considered by the Government as part of the Electricity Market Review (Government of WA, 2015). Synergy, also the dominant government owned generator in the South West Interconnected System, is the largest contributor to excess capacity on the system, largely from old, inefficient, coal fired power stations. These have already been identified by WA's Energy Minister as a prime candidate for removing the majority of existing excess capacity, much of which is old, inefficient, coal fired power stations (Nahan, 2015). Electricity businesses must be both adaptable and constantly striving to be efficient and innovative in their generation portfolio (or electricity supply contracts). In reality, this may mean slightly higher premiums or shorter-term contracts to avoid technology lock-in and thus path dependency and preserve medium-to-long-term flexibility in a highly disrupted market (Participant 8, 2016).

Updated Regulatory Framework

Improvements in distributed generation technology and economics are already driving competition at the distribution level – i.e. on local grids within neighbourhoods and communities. This new, distributed world challenges the future role of regulated utilities in WA –they should no longer be assumed to run as regulated monopoly businesses (Participants 1-3, 8, 13-16, 2016). Over the long-term, the efficiency of markets must drive competition in the small non-interconnected electricity sector in WA, rather than regulators (Participant 13, 2016).

To enable the transition to new energy businesses and to establish sufficient conditions required for a truly competitive market, it is vital to have a smart and flexible regulation and policy framework in WA that looks to the future, not the past (Participant 13, 2016). This framework will require the electricity regulator (currently the Economic Regulation Authority) to transition from its traditional ‘gate-keeper’ role, to one in which it can facilitate energy markets and competition. In particular, the Economic Regulation Authority will need to remove the regulatory barriers to the uptake of renewable energy generation, enabling technologies and innovative retail product offerings (Participant 13, 2016). Removing barriers to entry will in turn drive innovation and customer choice, encourage a smaller network size (or defer network augmentation), improve tariff structures and integrate network price signals with energy markets (e.g. locational pricing).

In the National Electricity Market (NEM), the Australian Energy Regulator (AER) has been working on the regulatory framework to make it more resilient and adaptable to change (AER, 2015; Vertigan, 2015), recognising the disruptive potential of solar PV as penetration levels increase across the network. Nevertheless, there is still a need for further refinement to the national regulatory framework, as regulation must continue to evolve to account for issues (applicable on a global scale) such as cost-reflective pricing, structural separation of energy services, demand management initiatives, advanced metering services, and addressing barriers to market entry (Participants 8-10 & 15, 2016).

Notwithstanding these revisions, utility compensation will be a complicated regulatory issue to resolve, and will need to move beyond the current ‘cost of service’ principles, which compensates utilities for incurred costs and investments in physical assets and may incentivise overinvestment in infrastructure at the expense of consumers (Participant 13, 2016). An ‘incentive based’ framework will need to be created that aligns network revenue and performance with customer interests. For example, utilities’ earnings could be linked to metrics such as energy efficiency, clean energy generation and other performance measures that require the utility to deliver a safe, reliable and affordable energy service (Participant 5, 2016). Looking forward, the concept of a utility acting as a natural monopoly should only continue to apply in respect to its services as the load serving ‘provider-of-last-resort' – providing back up in the presence of mature distributed generation and storage markets. Beyond that role, all grid services in WA should be subject to competition (Participant 5 & 13, 2016).

Regulatory transparency is essential for empowering this revised framework for the WA electricity market, whilst robust policy design will also be needed to maintain appropriate consumer protections (Participant 13-15, 2016).

Long Term Policy Direction

Energy policy has substantial impacts on both sides of the Government's budget - income and expenditure. Taxes and tariffs generate revenue, while incentives for decarbonisation and energy efficiency require financial support (Newbery, 2015). In WA, the present pattern of policy has accumulated over time in a haphazard, partisan way and without long-term strategic thinking. Going forward, policy decisions on ambitious renewable energy targets, and continuing feed-in tariffs and other incentive and subsidy schemes (e.g. to foster the development of battery technology) may be an impetus to stimulate the fast growing solar market – at least in the short term where coal and other fossil fuels enjoy largely hidden tax benefits. However, having policy based on short-term political cycles will always remain a risk and create legal and financial uncertainty for participants. Policy uncertainty can be incorporated into project financing, and in WA, financiers should continue to take a conservative approach when incorporating sovereign risk into any risk premiums (Participant 13, 2016).

Longer term, short of gaining bi-partisan support on all new policy directions, participants should seek to utilise market-based contracts where possible, and leverage the transition to more flexible regulatory frameworks to ensure projects have less reliance on legislative provisions and direct subsidies.

For example, increasing the ability for market participants to sign long term power purchase agreements (PPA's) for solar projects will stimulate new revenue streams through the sector and provide longer-term certainty for solar providers.

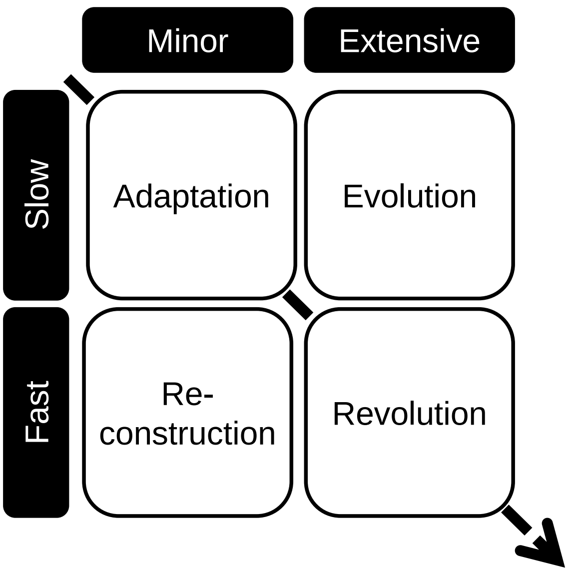
Nevertheless, some policy revisions specific to the WA context will need to address the unique structure of the market and may continue to create uncertainty for participants. For example, the review of Western Power's role and use of the technical rules (i.e. the technical requirements to be met by Western Power on the transmission and distribution systems) to enable greater uptake of renewable resources, the review of the licensing framework to accommodate new retail products (e.g. solar leasing), and the review of the rates offered to residential solar PV generation through feed-in tariffs (Participant 3, 2016).

7.6.4. Implementation

The Change Matrix

The speed at which change occurs, and the magnitude of the change will also have bearing on how utilities will transform their business models. Figure 7.3 illustrates several emerging models across these two axis to provide four quadrants of change:

Figure 7.3: Speed and Extent of Change (adapted from Zinaman et al, 2015)



WA is currently idling at the top-left of the matrix, with market participants showing slow and minor signals of change (‘Adaptation’). Of course, any meaningful transition will have to first overcome the inertia to break from path dependence, particularly prevalent in systems as complex and inter-linked as the energy sector (Lee & Gloaguen, 2015). However, as Pierson (2000) notes:

> *“particular course of action, once introduced, can be almost impossible to reverse; and consequently, political development is punctuated by critical moments or junctions”*
>
> *(pg. 251, Pierson, 2000)*

Industry and Government in WA have both recently signalled that they are acutely aware of an inevitable “junction” in the electricity sector - the potential for the speed and extent of the change to drive a ‘Revolution’.

The Phased Approach

A phased-modular approach is recommended to assist WA’s utilities transition away from their existing, traditional business models, towards future, sustainable business models encapsulating solar PV and associated products and services (as outlined by Characteristic F in Table 7.3). This phased approach will be required to underpin the evolution of WA’s incumbent utilities in order to address the increasing threats to their business models. All four response outlined above will need to be implemented from the top down – with full Board and Executive support and communicated across the business in order to drive the requisite change.

Further, each characteristic identified in Table 7.3 can be seen as a discrete initiative or ‘module’ of initiatives that, whilst inter-related with the overall strategy of transforming the business model, does not necessarily have time bound dependencies with the other initiatives. Each utility in WA will therefore be able to focus on the particular initiatives that are most urgent or relevant to their position in the market, package them as a module to implement, and thereby maintain flexibility for technology developments and instances where the political, economic or regulatory environment changes.

For example, the growth potential in the expanding solar market and building new customer relationships would organically provide additional opportunities for the utilities, while long term contracts for solar PV would also facilitate customer retention. Within this new perspective, solar PV could then be viewed as a stepping stone into other 'green energy' growth markets, such as energy efficiency and storage service offerings.

This approach also allows the utilities to explore various combinations of products and services to maximise profitability per customer. Additionally, it allows utilities to control the speed of implementation (vertical axis of Figure 7.3), depending on the extent and potential impact (horizontal axis of Figure 7.3) of each individual initiative – providing further flexibility and adaptability to manage successful outcomes.

One of the first steps that WA utilities can make (and to an extent what is already occurring) is the expansion of solar PV products and services. This could include providing consulting services through partnerships to customers, right through to the installation and operation of rooftop solar PV systems (including the installation and maintenance of smart meters). It could also include lobbying for more flexible and innovative regulation and policy. Given the availability of technology and the substantial volume and access to customers, this transition is relatively low-risk for utilities to make and thus can be seen as a phased-approach.

A majority of market participants interviewed recommended complimenting any solar energy products and services offered by WA utilities with energy efficiency initiatives to maximise both supply and demand side value in products and services (Participant 1-12 & 14, 2016). This could include dynamic and innovative electricity retail tariffs (once full retail contestability is introduced in the WA market), as well as offerings for demand side management services.

Local utilities may also be positioning themselves to facilitate the adoption of electric cars and the storage capabilities they provide customers, allowing involvement in completely new markets, thus creating new opportunities for growth – whether through partnerships, contracts, or ownership of electric vehicle and battery providers (Participant 16, 2016).

7.7. Conclusions & Policy Implications

This paper focused on the need for electricity businesses to develop and transform their business models to deal with the disruption occurring across the energy sector. Six critical business model characteristics were identified and discussed: customer focus, community engagement, research and development incubator for innovative technologies, regulatory and policy engagement, participation in distributed generation markets and the transition to energy service providers.

A range of issues were identified under each of these groups, both from existing literature, as well as from interviews with key stakeholders working within the WA energy market. The relevance of global challenges and disruptions to energy markets was also assessed in the context of local WA regulatory, political and economic conditions. From this, it was strongly advised that energy businesses should embrace the opportunities presented by emerging technologies such as solar PV and storage, and do so in a modular approach, to ensure capabilities are maintained, costs are minimised and customers are retained.

This research has also reinforced the idea that long-term stability in government policy decisions will require long-term strategic thinking and a bi-partisan policy approach to provide the robustness and investment certainty that the electricity sector requires.

The WA energy market and the current business models of its incumbent utilities sit at a precarious point in history - attempting to manage the increasing disruption to the market. On one hand, WA is well placed to leverage the opportunities created by having the Government acting as both a large energy consumer, as well as the owner of the dominant electricity utilities. This may provide opportunities to explore roof-top solar PV on public housing and other government-owned buildings, further incentivise the use of renewable energy certificates by the Government-owned utilities, and encourage policy flexibility to incorporate technological innovations, such as the use of batteries for streetlights or edge of grid applications. On the other hand, many interviewees identified the inability for the large, risk-averse Government bureaucracies to transform business models effectively, and cited the need for more nimble private players and entrepreneurial firms to navigate the transition into new energy market structures.

The unique set of conditions within WA has made it a place ripe for disruption. It is likely that energy market participants globally will be watching WA to see how the energy market evolves, what new business models emerge and how the utilities cope with the transition. For this reason, it is expected that WA's energy market will become a pilot project site for energy businesses seeking to manage the transition and adapt their own business models necessary to meet the demands of consumers of the future.

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CHAPTER 8: A BEHAVIOURAL APPROACH TO SUSTAINABLE ELECTRICITY PRICING

Paper 4: Under Review for Publication

Tayal A.D. A Behavioural Approach to Sustainable Electricity Pricing. Energy Policy.

Chapter 8 contains the fourth paper (under review for publication) presented in this thesis.

8.1. Abstract

Australia's electricity prices are high, driven by inefficient wholesale market structures, high fuel costs, lack of competition in generation markets, and rising peak demand that is forcing significant levels of infrastructure investment. Compounding this issue, is the fact there are no appropriate or transparent price signals for consumers, with flat pricing structures providing no incentive to change consumption behaviours.

This research surveyed residential electricity consumers in Western Australia on their perceptions of solar PV and battery storage systems, electricity cost drivers, their ability to change consumption behaviour, and their acceptance of various electricity pricing structures (cost-reflective time-of-use and maximum demand pricing).

In contrast to the political and policy hesitation regarding electricity pricing reform, this research reveals a strong willingness of residents to change their behaviour, reduce their electricity usage, and be rewarded for the use of renewable technologies, suggesting the appetite for retail tariff reform is strong and can be customer-driven.

Keywords: Solar; storage; electricity; bills; prices

8.2. Introduction

Rising electricity prices are the bane of many households and businesses. The provision of electricity services has also been a sticking point for many governments around the world, due to the inherent political contention of increasing costs, direct and growing impacts on the environment through greenhouse gas emissions, and the risk of unreliable supply causing the lights to go out. The challenge for policy makers and utilities alike, therefore, is in managing and balancing three equally vital elements: how to provide affordable, reliable and clean electricity to all customers.

This research paper focuses on the affordability limb, whilst recognising that there are natural tensions and overlaps in providing efficiently priced electricity without sacrificing on safety, reliability and environmental priorities. There is also the underlying tension of the utilities themselves driven to maximise profits, to reduce their reliance on Government subsidies, and to remain competitive in a challenging environment.

In Australia, electricity prices are consistently ranked amongst the highest in the world (Sandiford, 2016), a fact widely recognised by media, reluctantly acknowledged by State and Federal governments, and reinforced to customers at every billing cycle. Exactly what drives these high prices is a complex and contentious issue, with a myriad of subsidies, cross-subsidies, welfare payments and regulatory challenges conflating with a sector facing the disruptive challenges brought about by significant technological innovation.

Governments are also held accountable to election cycles, and politicians are reluctant to drive through contentious reforms that will inevitably create a broad spectrum of winners and losers when the status quo changes.

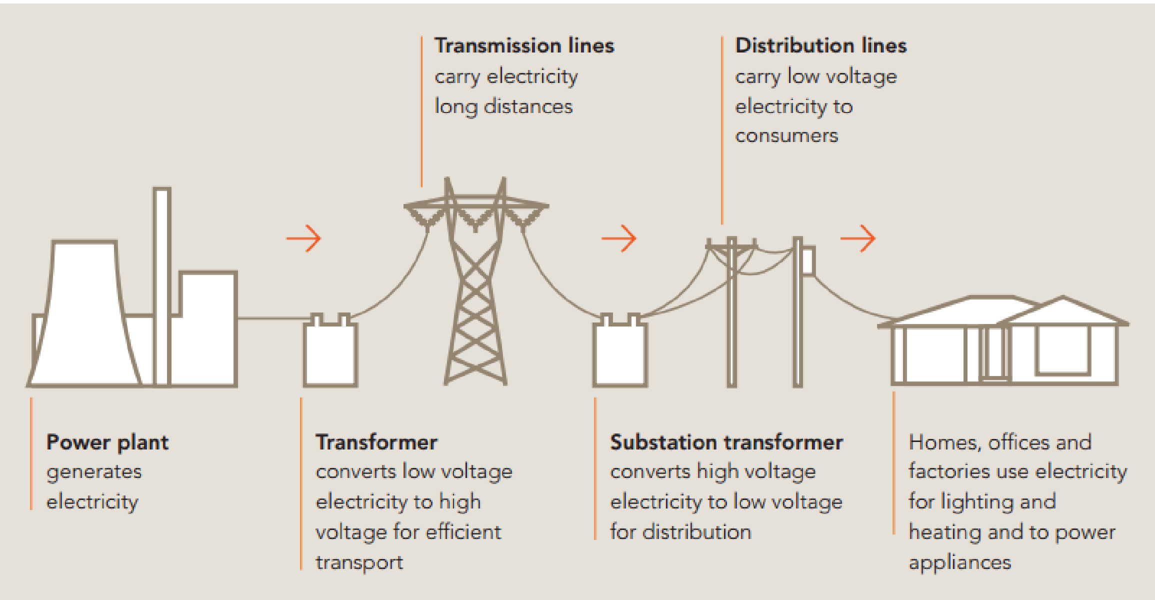
Australia, and Western Australia in particular given its isolation and expansive service area, provides a valuable opportunity to test innovations in electricity pricing models. Through an extensive literature review, coupled with a targeted survey, this paper explores several approaches that decision makers and electricity utilities may want to explore with their customers and constituents going forward. These approaches provide future opportunity to be supported with behavioural insights, in an attempt to unpack some of the psychological barriers that have inhibited effective electricity price reform to date.

8.3. Background

8.3.1. The Traditional Pricing Model

Whilst rapidly changing, the electricity system is still largely based on the same centralised supply model as introduced a century ago (Roberts, 2015). This model sees electricity generation predominantly involve the use of large fossil fuel plants reliant on economies of scale: “the larger the plant, the more efficient and cheaper the electricity generation” (e-Lab, 2013). This electricity is then transported, often over large distances, through a network of poles and wires until it reaches its ultimate destination –households and business customers – see Figure 8.1 below.

Figure 8.1: Traditional Electricity Supply Chain



Source: AEMO, 2015.

Given the significant upfront investment required to construct these large power stations (relative to the low cost of operation), a natural incentive was created for electricity utilities to maximise the production and sale of electricity (Caldecott and McDaniels, 2014).

The cost structure for utilities is therefore calculated according to how much electricity each customer uses over a given period, and driven by the long time frames over which investors can achieve a return of and return on their capital employed. Increasing demand, and maximising the utilisation of all aspects of the electricity supply chain was an assumption in-built to the business cases of utilities, and one that largely stood the test of time over the last century – a service of delivering electricity that was paid for at a price per kilowatt hour. This view of ever-rising demand also pervaded into the standard approach to power system and security planning, network regulation, and energy market dispatch design (Schaltegger et al, 2012; Richter, 2013; Roberts, 2015; Sioshansi, 2014).

Historically, electricity demand was thought to be largely inelastic and the main driver of cost was the specific period of 'peak demand' – when all customers seek to use electricity at the same time. In Australia, this is commonly an evening peak, when customers start returning home from work or school, whilst large commercial and industrial loads are still operating (Leitch, 2016). To cater for this one or two hour period of peak demand (usually the hottest or coldest day of the year driving cooling or heating loads), utilities have to incur the full cost of the infrastructure required, even though for the remainder of the year this infrastructure remains unnecessary.

From a customer perspective, the current 'flat' pricing structure (still used by the majority of electricity utilities around the world) does little to reflect the true cost of service, and gives consumers no incentives to reduce their electricity usage during these infrequent peak times. Instead, unaware customers continue to drive up the level of peak demand, and as a result, utilities are forced to continue increasing their spend on the infrastructure required to service the growing peaks.

From 1990 to 2012, peak demand across Australia grew on average by 50–100 per cent. A large proportion of this growth can be attributed to the increased uptake of air-conditioners by customers, which rose from 30 per cent to 70 per cent over the same period (ABS, 2011; DEWHA, 2008).

A second order issue is the inequity of charging customers who do not contribute to these peak periods the same amount as those that contribute greatly (e.g. those customers that have multiple air conditioners running on hot days are subsidised by those that rely on ceiling fans). This is just one of many existing (and potential) inequities that are created when pricing structures do not reflecting the underlying costs of service provision.

Clearly by incentivising a shift in demand into non-peak periods, utilities will be able to limit further infrastructure requirements and therefore remove major cost pressures on electricity retail tariffs.

However, shifting demand and changing customer behaviour is never a straightforward proposition. Whilst 'price' forms an important factor, research conducted by the AEMC (2012) also recognised "convenience, awareness and understanding", to also have the potential to influence and shape customer's behaviours and decision making in regards to when and how they use electricity.

8.3.2. Disruptive Pressures

Exacerbating the inefficiencies and inequities of the existing pricing structures in electricity service provision is the disruption occurring in the sector due to a convergence of several factors across technology, economics and public policy. In the past decade alone, the energy sector has been navigating rapid technology innovations and the falling cost of distributed generation assets, changes in demand patterns and behaviours, and mixed messages from capricious governmental policies on energy – particularly renewables (Kind, 2013; e-lab, 2013; Grace, 2014; Bunning, 2011). In combination, these factors are set to fundamentally change the way our electricity systems operate and without being addressed, will continue to put upwards pressure on cost structures, and therefore continue to increase inefficiencies and inequities.

The impact of technology innovations will further increase the challenges for utilities and governments, but in particular, WA's isolated electricity networks are already becoming a demonstration site for policy makers around the world due to existing high cost structures (Parkinson, 2015).

Whilst other markets have also been grappling with the pressures of disruptive innovation (e.g. high solar PV penetration rates in Hawaii, California and Germany), WA has an abundant solar resource and consumer demand that has driven Government impetus to recognise the urgency in addressing the impacts of the outdated systems and related pricing structures (Parkinson, 2015; Bromley, 2015).

8.3.3. The Changing Business Model

Amongst this landscape of disruption innovation, electricity utilities will need to make bold decisions to change their business models and introduce new products and services together with innovative pricing plans, and then be the ones to convince customers of their value (Ratinen, 2014). Utilities moving into this space would also need to either prove their differentiation from existing products and services in the market, or expand the market itself (Richter, 2013).

It will not be a straightforward journey and there will not be any one perfect strategy. Developing these new utility business models will require an iterative process, and the utilities cannot be formulating and developing their strategies in a vacuum, whether Government owned or private enterprises (Vanamali, 2015). The transition will also require extensive collaboration and participation across policymakers, regulators, investors, consumers, forward thinking government Ministers, as well as technology innovators and entrepreneurs (Tayal, 2016).

As market dynamics continue to drive these innovations, changing the business models away from a conventional, grid-based system towards a more distributed model forms a leading long term solution for the majority of electricity businesses. Yet many of these technology innovations present a perceived threat of separating a utility from its customers, who may seek to find these new products and services from new entrants and other providers (PWC, 2016). Therefore, utilities undertaking future business planning and strategy development should be proactively looking to incorporate energy efficiency, solar PV and energy storage systems as growth opportunities rather than as existential threats, and making sure these products and services are priced appropriately will be one of the most critical, but complex challenges (Poudineh and Jamasb, 2014; Klose et al, 2010).

8.3.4. The Western Australian Challenge

WA presents a uniquely challenging environment under the traditional approach to electricity service provision. WA has over one million electricity customers who are spread out across millions of kilometers. In contrast, the United Kingdom, which has a similar sized service area, has 73 million customers at a much higher density (McGoldrik, 2016). This creates an immediate cost-pressure and challenge in providing customers with affordable and reliable electricity. Indeed, the government-owned electricity utilities rely on millions of dollars of annual subsidies to provide uniform electricity tariffs to residential customers across the state – irrespective of location. Unsurprisingly, the actual cost of supplying customers in the remote and rural towns scattered across WA is significantly higher than providing electricity to anyone living in the urban centers such as the capital, Perth – which has established distribution networks, excess capacity, and a reliable distribution network (WA Government, 2015).

Whilst infrastructure upgrades and network expansion have always faced tough regulatory investment tests to justify their requirement, the costs for simply maintaining the existing network, given its expanse, are significant. The additional threats of bushfires, cyclones and equipment issues also present considerable challenges for the WA Government and local regulators in providing reliable, secure, yet affordable supply of electricity to all consumers.

However, with the declining costs in stand-alone power systems (with cheaper solar PV and battery storage components) and with ever-increasing subsidies required to sustain current service levels, WA may need to rethink the centralised electricity model and traditional pricing structures.

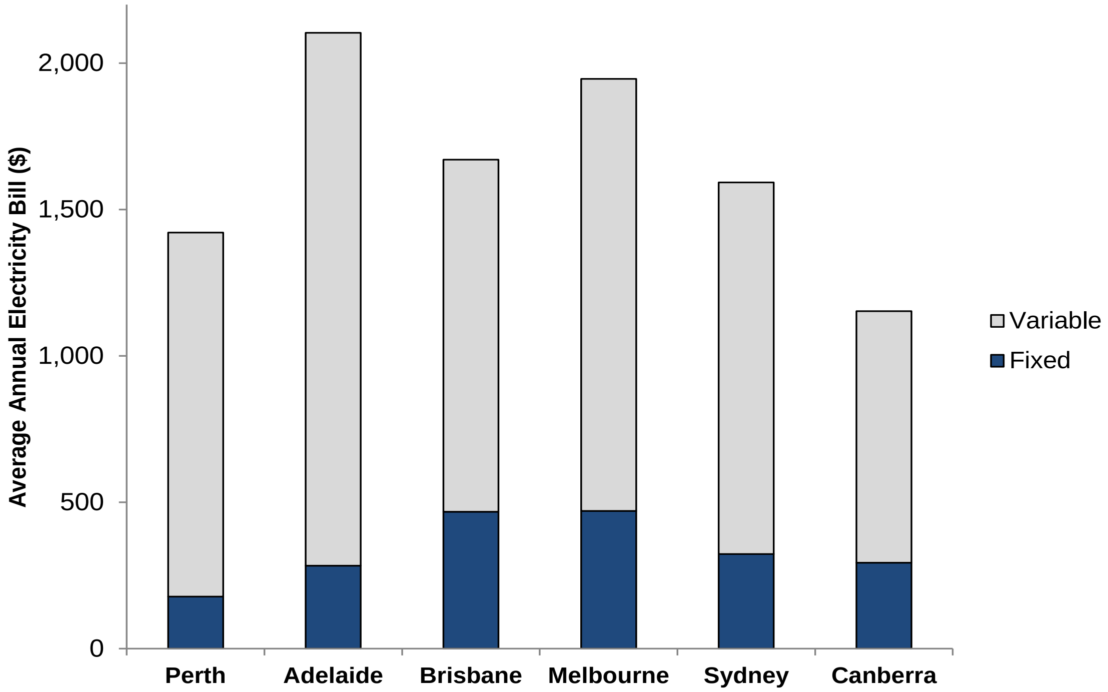
8.3.5. Electricity Costs, Charges and Subsidies

An electricity bill can be split into two major components – fixed charges (a supply charge that remains fixed irrespective of usage) and variable charges (corresponding to usage).

Fixed charges include the costs relating to establishing and maintaining electricity networks and generation capacity, and the fixed costs of the retail service (customer service and billing). These costs do not vary with quantity of electrical energy consumed by a customer. Variable charges relate mainly to the fuel cost and vary directly with the quantity of energy consumed by a customer.

Analysis of electricity tariff structures across Australia reveals that residential customers in Perth, WA pay the lowest fixed charge compared with all other capital cities and appear to have relatively low electricity charges for the average household (Figure 8.2).

Figure 8.2: Average Annual Electricity Bill for Australian Households, $2016



Note: Average bill based on annual consumption of 4,700 kilowatt-hours, using standard market offers provided by major retailers.

Source: Origin Energy, 2016; AGL, 2016. Synergy, 2016.

Although this may appear to contradict the evidence of a costly sparse and regional network, these charges and the price structure should not be interpreted to reflect the idea that electricity is cheaper to supply in WA. Instead, this data highlights the extent of Government subsidies in the State, under a highly regulated model whereby electricity tariffs are set annually (substantially below cost) by Government, not by competitive markets at levels of economic equilibrium (WA Government, 2015).

A study by Wood and Blowers (2015) suggests that without this subsidy, WA customers (even those in urban Perth) would pay significantly more for their electricity than all other States in Australia due to the high underlying costs of the wholesale generation market and reserve capacity market structure (these costs are either non-existent, or much lower in the eastern states).

In WA, household electricity tariffs stayed constant between 1998 and 2008 as a political manoeuvre to avoid agitating constituents. This price freeze remained for the decade despite costs significantly increasing over the same period (WA Government, 2014). Since 2008, the Government has sought to raise tariffs to more cost-reflective levels, but has only had mixed success across regulated business tariffs, with households still heavily subsidised despite tariff increases of over 85 per cent (in aggregate) from 2008 levels.

The subsidy to the State-owned electricity generator and retailer, Synergy, still amounts to around $400 million per year (WA Government, 2015). Led by the Minister for Energy, the State is undergoing an extensive 'Electricity Market Reform' agenda in order to address these cost pressures, reduce subsidies, remove Government risk, and create a more efficient and competitive market (Nahan, 2015). The WA market is still looking to move to full retail competition and flexible pricing, and is actively considering major structural reforms and market re-design - not just economic improvements to existing models (CSIRO, 2009; Sharma, 1997). The opportunity for innovating price structures and creating efficient and competitive electricity markets has never been greater.

Gold-plating

Investment in electricity infrastructure is a warranted process to ensure reliability and security of supply. On the other hand, over-investment, commonly referred to as 'gold-plating', has been argued to be a significant driver behind Australia's high electricity costs.

> *"It's as if, at the beginning of the internet age, Australia invested about $45 billion in fax technology,"*
>
> (Hill, 2015)

> *"There was a perverse incentive in the system for overinvestment in the poles and wires, and that led to dramatic profits for those businesses."*
>
> (Thistlethwaite, 2012)

Based on the traditional regulatory driven cost structure, once a network utility has its infrastructure spend approved by a regulator, it is allowed to recoup those costs through network charges. Under this regulatory model, these network charges are usually wholly passed through to retailers, and ultimately to customers. Should networks be over-invested in by utility businesses, customers will still need to pay for the costs of these unnecessary infrastructure upgrades. Whilst this spend-and-recoup model worked previously, given the evolving technology disruption occurring in the sector, an open question has now arisen for how large capital spend on infrastructure should be assessed going forward. If utilities continue to invest billions of dollars in their poles and wires, they are doing so on the assumption that their customers will continue to have demand for its use and consequently be obliged to pay for it through appropriate network charges for decades into the future. The alternative, would require both significantly reduced infrastructure spend, as well as a substantial write down of the value of network assets.

This is already occurring in the electricity sector in Europe, where gas peaking plants and associated network investments are coming under increasing financial pressure due to excess capacity in energy markets driving wholesale prices below the marginal cost of the infrastructure (Green & Staffell, 2016).

If the demand outlook or cost structure for this electricity infrastructure does not improve, then ultimately generation assets will need to be prematurely mothballed, retired ahead of schedule, or written down, and network assets will need to be revalued. This will necessarily involve a significant write down of capital costs, leaving asset holders with large sunk costs that will never be recovered from the infrastructure itself (Caldecott & McDaniels, 2014). As a greater number of assets are revalued, investment in the sector is being increasingly marginalised or risk premiums are rising as a consequence (Tayal, 2016).

8.3.6. The need for tariff reform and innovative pricing models

Many attributes of pricing innovations are not compatible with the existing regulatory models and associated regulated tariffs for utilities (NYU, 2015; Picciariello et al., 2015). Whilst a number of barriers are responsible for maintaining prevailing tariff structures, the uptake of new technologies is both increasing cost pressures on utilities, and motivating policy makers and regulators to introduce appropriate pricing models that can better reflect the dynamic cost structure of these new networks. It should be noted that in this context, inefficient tariff structures are discussed from the point of view of small-use residential and small-business customers, as larger industrial and commercial users already have flexibility in most markets to negotiate competitive rates with more complex structures directly with retailers.

To create an efficient and equitable tariff system, each residential customer would pay for the services of the network that accurately reflect their share of the underlying costs. However, the traditional structure for tariffs is not well suited to the emerging model of future networks with a high penetration of distributed generation (i.e. non large scale power stations) such as rooftop solar PV and storage. This not only creates inefficiencies in the market, it also creates perverse incentives and cross-subsidies amongst users (e.g. between those with solar and those without), and does not reward distributed generation according to the value it supplies to the system (MIT, 2015; Picciariello et al., 2015; Sioshansi, 2016). It also does little to incentivise customers to change their behaviour and use electricity at 'off-peak' times, to avoid system peaks and reduce costs for all users. More crucially, if these matters are not addressed, they cycle back on themselves and the problem intensifies such that utilities face increasing revenue erosion, or must increase tariffs and drive the uptake of distributed generation more rapidly (Grace, 2014).

This is not just a localised issue, with electricity markets around the world grappling with this increasing divergence between costs and pricing structures. Recognising this, the US Federal Energy Regulatory Commission commenced a review of the wholesale electricity pricing models across the United States (Federal Energy Regulatory Commission, 2014) with the goals of improving pricing models and making these prices available to retail consumers in order to support demand participation and distributed generation. Similarly, Thaler & Sunstein (2008) have previously argued for a policy "nudge" to improve efficiency, whilst a growing body of literature (Faruqui, Hledi and Lessem, 2014; Picciariello et al., 2015; Sakhrani and Parson, 2010; Sioshansi, 2016) recommend a move away from fixed rates by making time varying rates the default policy. The WA Government could build on these frameworks and revise electricity tariffs in the State, not just for cost reflectivity, but to ensure they represent the most efficient energy prices possible.

8.4. Methodology

A literature review was conducted over twelve months to gain a broad understanding of the central drivers of electricity tariffs and why they may need to be restructured given the increasing disruption occurring across the electricity sector. This research helped to inform the design of an online survey which was conducted in January 2017.

8.4.1. Online Survey and Data Analysis

A concise 'three-minute' survey was distributed to 100 participants through a professional data research company (Pureprofile).

The research survey consulted residential electricity consumers in Western Australia on their perceptions of solar PV and battery storage systems, electricity cost drivers, their ability to change consumption behaviour, and their acceptance of various electricity pricing structures (cost-reflective time-of-use and maximum demand pricing). The full list of survey questions is included in Appendix A.

The survey responses were then analysed and substantiated through further review. Survey responses helped to provide a greater understanding of the challenges that governments and utilities face when considering how to align their cost structures with appropriate price incentives for their products and services. The responses underpin a series of policy recommendations outlined in this paper.

An online survey was identified as a useful method with which to access a wide variety of respondents, across a full spectrum of energy sector knowledge, involvement, and concern of the issues.

Although the survey was conducted with West Australian residents, it is expected that similar issues are being faced by utilities nationally, if not across energy markets worldwide. It should also be noted that traditionally, the utilities own marketing departments are likely to commission these surveys, so respondents who typically perceive a conflict of interest should welcome independent research on the topic.

8.4.2. Survey Participant Details

The resulting profile of the survey was 100 participants, with diverse ages, employment, and household income levels. There was a similar representation of males (N=48) and females (N=52), with an average age of 44.2 years old. Over half (N=60) of the participants were employed, with a mix of full-time and part-time employment, allowing for additional insight on bill payment preferences and perspectives.

Table 1: Survey Demographics

Category	Number
Electricity Provider	
Synergy	90
Horizon Power	2
Gender	
Male	48
Female	52
Employment Status	
Full-time	37
Part-time	23
Not in labour force (student, retired)	32
Unemployed	8

Note: *totals may not add up to 100 as not all participants responded to all questions

8.5. Discussion

8.5.1. Survey Analysis

The results of the survey outline the overwhelming perception that customers think they "pay too much for electricity" (N=79), and that the Government (N=16), energy companies (N=21), or both (combined N=21), are to blame. Only one respondent acknowledged that their "own usage" may have an impact on electricity costs (Table 8.2 and Figure 8.3, below).

Table 8.2: Survey Results Summary – Yes/No questions

Question	Yes (%)	No (%)
Do you think you pay too much for electricity?	79	21
Are you happy with your electricity provider?	58	42
Do you have solar panels	35	65
Do you want solar panels - if you don't already have?	50	15*
If you have solar, do you want battery storage?	27	7

Note: *totals may not add up to 100 as not all participants responded to all questions

Figure 8.3: Perceived driver of electricity costs

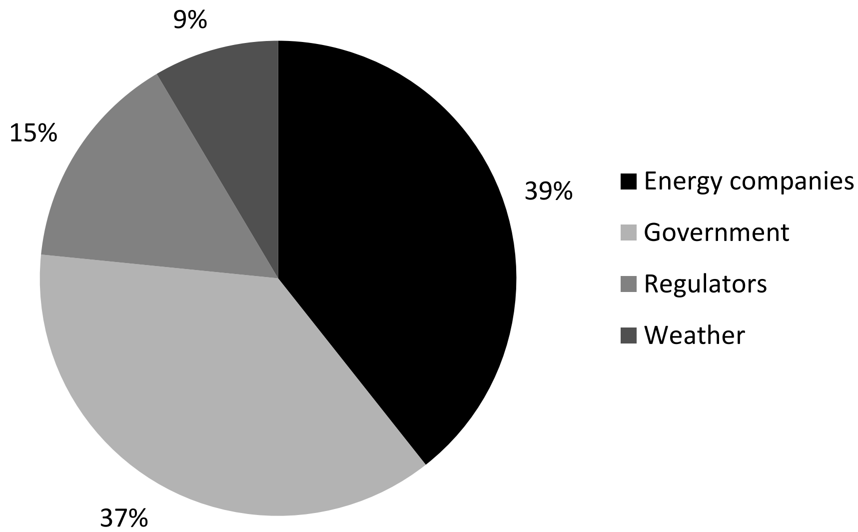


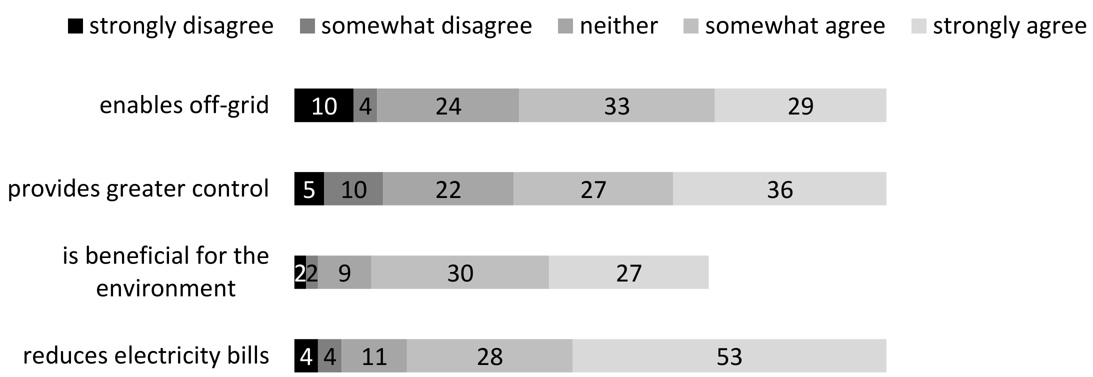
Table 8.3 outlines the most frequent reasons participants cited for unhappiness with their current electricity providers. The most frequent reason cited was the level of costs being too high (N=30), followed by a lack of choice (N=5).

Table 8.3: Perceived unhappiness with current electricity provider (N=39).

Reasons cited	Frequency
Cost – too expensive	30
Lack of choice	5
Corporate structure - CEO	2
Poor service	2

Respondents were consistently favorable towards solar, with significantly over half of all respondents recognising solar panels provide opportunity to reduce electricity bills (strongly agree: N=53; somewhat agree: N=28), and over half agreeing that solar technology can provide greater control, enable off-grid capabilities, and can be beneficial to the environment (see Figure 8.4, below).

Figure 8.4: Survey results – Level of agreement with 'Having solar panels…"



Despite anecdotal evidence and media reports often suggesting otherwise, the majority of respondents were 'probably' (N=33) or 'definitely' (N=44) willing to change their behaviour and reduce their electricity usage if it saved them money (at least $200 worth of savings per year), suggesting the appetite for retail tariff reform is strong in WA (see Figure 8.5 and 8.6 below). Of course further analysis and a more focused exploration of this point would be useful to understand the true value drivers, given the discrepancy often found between willingness to pay revealed in questionnaires, versus that shown in practice – i.e. overestimation (MIT, 2011).

Figure 8.5: Appetite for electricity behaviour change

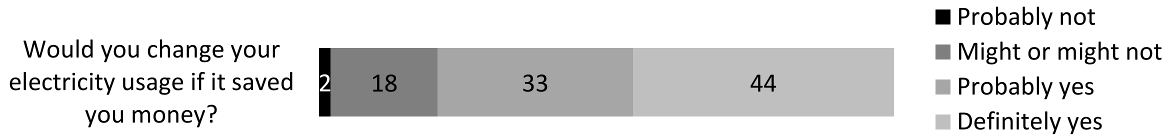
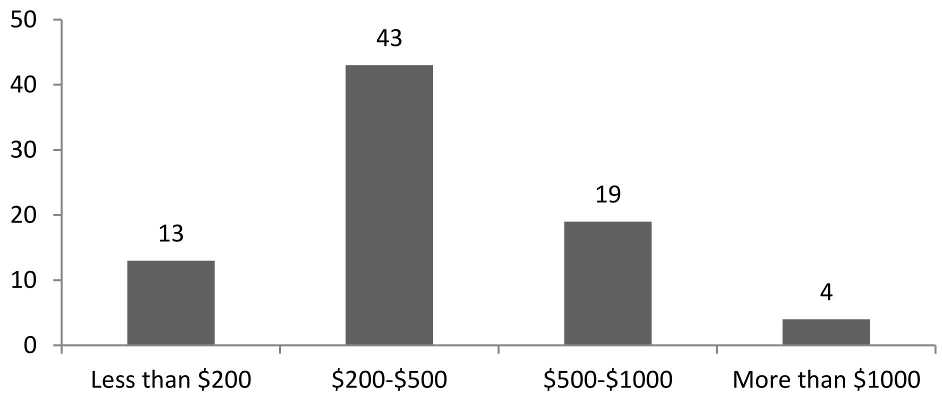
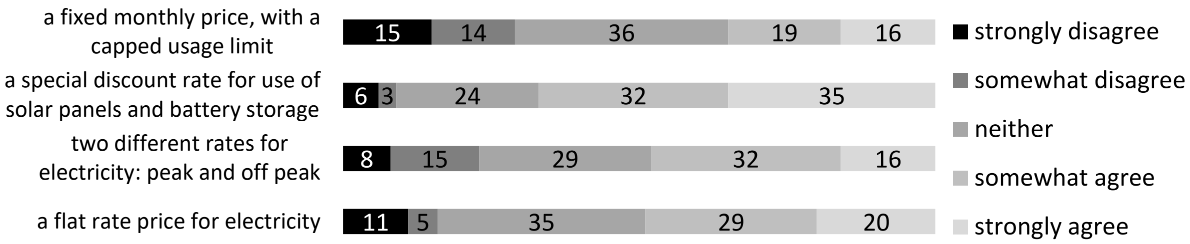


Figure 8.6: Financial incentive (bill saving per year) required for behaviour change



Respondents strongly agreed (N=35) or somewhat agreed (N=32) to special discount rates for using solar and storage technologies, and also had a preference for a simple flat rate price for electricity (N=20 strongly agree; N=29 somewhat agree). This suggested that respondents not only recognised the value that solar and storage technologies can provide to electricity networks (Figure 8.4) but also want to be appropriately incentivised and rewarded for installing residential systems. The large number of undecided responses on pricing structure preferences (Figure 8.7) may have reflected a lack of participant understanding of the various pricing tariffs suggested, such as the maximum demand pricing and peak/off-peak tariffs.

Figure 8.7: Preferences for pricing structures



The data suggests there is an opportunity to leverage customer's price motivations to restructure tariffs in such a way that provides savings opportunities, enables customer choice, incentivises solar and storage systems, drives more efficient behaviour, but also appropriately allocates the cost of the network across customers, without exacerbating cross-subsidies. The challenge then becomes implementing these theoretical ambitions.

8.5.2. How to restructure tariffs – a WA case study

In WA, tariffs are still regulated and uncontestable for all residential and small business customers, and predominately flat (i.e. do not reflect time of use or peak pricing). These tariffs were appropriate for the traditional model of electricity service provision, where utilities were centrally controlled and provided end-to-end services. Today, however, this model no longer fits (e-lab, 2013).

As part of Australia's Federal Government Select Committee inquiry into electricity pricing, several submissions also argued for more cost reflective pricing in order to drive changes in consumer behaviour (Select Committee, 2012).

Introducing more applicable tariff structures is a long term strategy that will require significant political capital and co-operation with retailers to provide innovative pricing products. It can also only be resolved once advanced meters are installed by the majority of the customer base.

This section builds on the work of Sioshansi (2016) and Stoft (2002), which outlined two underlying cost-recovery theorems to identify the pricing structures needed by utilities in order to recover their investment in fixed capital, as well as ongoing operating (variable) costs. Sioshansi (2016) went on to propose that system marginal costs reflect the theoretical price needed to efficiently drive investment and recover capital (assuming an optimal generation mix dispatched in merit order – i.e. lowest cost to highest).

The most common price-based signals used for electricity billing are real time, time of use, and maximum demand pricing. The characteristics and applicability of each are further explored below.

Real time pricing

Actual pass through of wholesale and network costs (and associated ancillary charges) goes some way in addressing the inappropriateness of WA's existing tariff structures.

A major benefit of accurate, real time pricing is the efficiency created by matching the variable costs of generating and transmitting electricity, with the value that distributed generation sources such as solar PV can provide (Sioshansi, 2016; Borenstein, 2005; Schreiber et al., 2015). Having flexible pricing structures also enables a significant reduction in system demand peaks by incentivising customers to shift their demand to off-peak times (Schreiber et al., 2015).

For example, if a household's rooftop solar panels are generating electricity when utility costs are high (e.g. during periods of peak demand when variable generation costs are high), then the household's ability to self-generate holds a high value and the customer receives a clear financial incentive to rely on its own power. Utilities are also more accurately able to model capacity requirements, and customers are provided with real-time signals of when a change in behaviour can have an impact on lowering their electricity bills. All of these advantages ultimately flow through to lower capital requirements on the network, and therefore fixed costs that need to be recovered across all users.

Of course, aside from the metering infrastructure requirements needed to implement such a pricing regime, real time pricing would also have the major consequence of high bill volatility – where customers would be exposed to price spikes and crashes at every interval of the day. This would require complex financial hedging strategies, or effectively deter customers from opting in due to perceived risks, uncertainty and complexity. For these reasons, a real time tariff structure would likely not be appropriate for the majority of WA residential customers.

Time of use tariffs

One early attempt to address the inconsistency between tariff prices and underlying network costs, was the introduction of time-of-use pricing that varied the tariff across the day in blocks, to account for variations in electricity demand and associated costs of supplying electricity during peak periods (Hogan, 2014; Elliston, MacGill and Disendorf, 2010). As with real-time pricing, the prerequisite to this dynamic pricing model is the need for 'advanced meters', which monitor electricity usage in real time. However, in WA, only small proportion of customers that have advanced meters have selected to be on time-of-use tariffs (less than 2 per cent), and WA still has a majority of customers using the old meters that can only measure total household electricity use and that require manual meter reads. This suggests that even if costly advanced meters were rolled out across WA to facilitate more dynamic pricing regimes, there are still several behavioural barriers (e.g. a lack of understanding, awareness, or interest) to address in order to achieve effective implementation.

Even then, as time-of-use pricing does not reflect actual real-time costs of electricity generation and supply, the block prices would need to be constantly adjusted to keep up as greater levels of intermittent sources of renewable energy are incorporated into the grid.

Nevertheless, the principle of more flexibility in tariffs still provides a central link to equitable signals and incentives to change customer behavior and transparently relay the requirements of the network (e-lab, 2013).

WA would not be the first jurisdiction to move to more cost-reflective time-of-use pricing. Similar pricing structures are already employed by several energy providers around the world, such as time-responsive tariffs offered by utilities in the US, time-of-use trial tariffs in the UK, and compulsory time-of-use tariffs for smart meter customers in Italy (Lampard and Aspinall, 2014; Ofgem, 2013).

Maximum demand based pricing

An alternative to aligning electricity bills with underlying cost variability, is to implement maximum demand pricing – akin to what is used in mobile phone plans. A demand charge could be incorporated into the bill that is based on peak demand (net of any self-generation) to incentivise customers to shift their consumption around to stay within a particular maximum threshold (and avoid the price increases of moving up to a higher demand threshold).

Analysis of other recent Australian-based research on maximum demand tariff structures revealed that residential customers were able to shift their consumption and reduce peak demand by up to 40 per cent (AEMC, 2012).

A study by Hall, Jeanneret and Rai (2016) also found that low-consuming households were found to be able to shift their peak load by the same amount as medium- and high-consuming households if the structure of the maximum demand tariff was designed appropriately.

However, there are disadvantages of using demand based pricing relative to a real-time pricing model – such as the failure to encourage energy conservation and efficiency, especially during periods of system peak, and the fact that this model does not protect against the intermittency of distributed renewable energy resources embedded into the network.

To facilitate this could also require the de-regulation of WA's tariffs. As Wood and Blowers (2015) note:

> *"The Government must either hand the regulation of retail tariffs over to an independent body, or fully deregulate retail tariffs and open the market up to competition from prviate retailers".*

Table 8.4: Summary of Tariff Models

Tariff Model	Advantages	Disadvantages
Existing flat-rate	• Simple for customers to understand and utilities to administer via existing billing systems	• Creates cross-subsidies • Does not accurately reflect costs to system (e.g. peak period usage) • Causes higher prices over long term
Time-Of-Use	• Provides opportunity and price signal for customers to shift load (lower network costs and reduce electricity bills) • Reduces system wide costs of network infrastructure upgrades	• Assumes customers have flexibility in shifting demand profiles • Relies on advanced metering infrastructure • Not as accurate as real-time-prices in wholesale market – may not match peak completely
Maximum Demand	• Provides strongest incentives and signals to customers for load shifting • Greatest reduction in network requirements	• Assumes customers have flexibility in shifting demand profiles • Relies on advanced metering infrastructure • Complicated electricity bill structure – will require education and information program • Lower volume charges reduce incentive for overall energy efficiency

Source: Adapted from: Hall , Jeanneret , Rai, 2016; Eid et al, 2016.

8.5.3. The tariff rebalancing proposal

At present, customers in the SWIS have around 10 per cent of their electricity bill attributable to fixed cost charges, yet the actual fixed costs to supply residential customers accounts for over 75 per cent of the total cost of electricity supply. Clearly the tariff structure in WA does not currently provide appropriate signals about the underlying costs of electricity service.

This structure also results in discriminatory outcomes by allowing customers who can afford solar PV and storage systems to reduce their contribution to the fixed costs of electricity services, whilst still using the services that give rise to these costs (e.g. when the sun is not shining or when systems generate excess energy). This will ultimately lead to increasingly higher fixed costs for customers who are unable to afford solar or storage systems, predominately lower-income households.

Mountain and Szuster (2014) propose the best option is to increase the fixed charges that households with distributed generation pay to recognise their continued use of the network (Mountain and Szuster, 2014). This could be achieved in a revenue neutral way by apportioning fixed and variable charges differently for customers with solar PV compared to those without, to reflect the difference in their time of consumption, and hence the cost of supplying the power.

This is supported by research from MIT (2015), which acknowledges that whilst power losses initially decrease as a greater number of people install rooftop solar, once the number of solar installations increases beyond a certain point, network costs start to increase because new investments are required to maintain power quality across the grid.

In Western Australia, a tariff re-structure could involve the Government attributing the total annual electricity tariff increase to the fixed component of residential electricity bills, instead of increasing both the fixed and variable components by a marginal amount. This would allow fixed costs to increase substantially, variable costs to remain unchanged, and the impact on bills to be the same (see Table 8.5).

Table 8.5: Alternative proposal for tariff increases

	Current Residential Tariff[1] (2015-16)	Traditional Tariff Increase	Per cent change	Proposed Restructure	Per cent change
Fixed Cost	48.60 c/day	51.03 c/day	5%	71.30 c/day	47%
Variable Cost	26.47 c/kWh	27.79 c/kWh	5%	26.47 c/kWh	0%
Average bill[2]	$1,653	$1,736	5%	$1,736	5%

Notes: (1) Based on Synergy 2016 Home Plan (A1) tariff. (2) Average bill based on annual consumption of 5,576 kWh

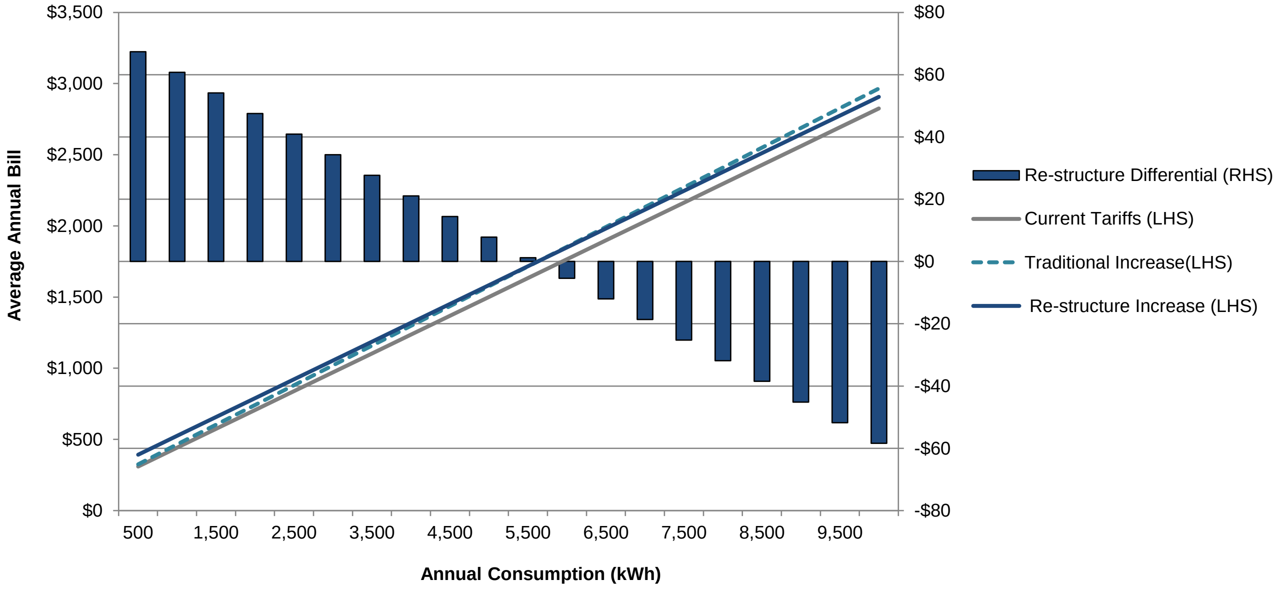
As show in Table 8.5, if the Government decides on a 5 per cent increase to electricity tariffs, the same average annual impact on consumers could be achieved via a fixed cost increase only.

This would be one-step towards providing appropriate signals and incentives to customers to use electricity efficiently, thereby reducing system wide costs and minimising the need for future fixed cost increases. It would also alleviate any unfairness that existing tariffs create by mis-allocating costs between customers.

However, without additional innovations towards more real-time pricing models, it should be recognised that this re-structure would begin to undermine customer’s control, choice and behaviours in how and when they use their electricity to avoid higher variable charges, as the increase in fixed costs would be unavoidable for all customers still connected to the grid. In addition, the price increases highlighted in Table 8.1 are only an average, and the re-structuring of tariffs is inevitably going to cause varying degrees of benefits and costs across customer’s bills, depending on individual consumption patterns.

For example, for customers consuming less than the average, bills would increase by more than 5 per cent, and for those with higher than average consumption, bills would increase by less (see Figure 8.8).

Figure 8.8: Fixed cost re-structure differential against traditional tariff increases



Under the restructured tariff, the average annual bill for customers with:

- an average level of consumption (around 5,500 kWh per annum for residential customers in WA) would effectively increase by the same amount as would have been the case under the traditional approach to increasing electricity tariffs – zero cost differential.
- below average consumption increases more than under a traditional approach, and increases in proportion to the fall in consumption.
- above average consumption increases less than under a traditional approach, again, in proportion to the rise in consumption.

A further complicating factor is the regressive potential of a restructure to tariffs, with a greater proportion of low income households having lower energy consumption.

Various options exist for the WA Government and policy makers to address this, however, such as existing concession and subsidy schemes, and other means-tested allowances available to customers on low incomes to assist with the cost of living.

In time, once the WA market is fully open to retail competition and innovation in products and services no longer have barriers to entry, customers could select pricing plans and advanced products that provide the ability (or eventually even auto-manage) their electricity consumption in order to minimise the variable charges.

Horizon Power Pricing Trial

Following the installation of advanced meters at all customer connection points, WA's regional electricity provider, Horizon Power, has launched a research project to assist in the development of innovative pricing models:

> *"Horizon Power's Power Ahead research pilot is aiming to develop a new, fairer and more sustainable way of charging for electricity that empowers customers to think about when and how they use electricity to reduce their costs."*
>
> (Horizon Power, 2016)

Horizon Power will trial a combination of the 'maximum demand based pricing' and 'time of use pricing' outlined above, using customer's historical demand profiles to nominate individual plans. It is hoped that by offering customers financial incentives ($800 - $1200) to stay within these plans (or reduce their consumption to a lower plan) during peak periods (between 1pm and 8pm), customers will make appropriate behavioural changes and benefit themselves, and the network, by reducing peak demand. As it is a trial, Horizon Power is reluctant to penalise customers from exceeding their maximum demand nominations.

The trial also utilises a specifically built 'app' for customer's phones that can provide real time consumption data, reminders, and warnings when consumption limits are being reached.

Customers with solar PV will also be notified through the app if there is a forecast for hot and cloudy days, so they can be prepared to rely more on the network.

Learnings from Elsewhere

In Germany, regulators are already allowing network utilities to change pricing structures and charge for connection and construction costs, as long as they are "cost oriented, non-discriminatory, transparent, and proportionate". And both German and New Zealand utilities are also able to negotiate specialised tariffs directly with customers who have small-scale generation sources (e.g. rooftop solar PV and storage) or controllable load in order to share the benefits that this distributed generation can provide to the overall network during periods of peak demand (e-lab, 2013; Paul, 2011; Freidrichsen, 2011).

E-lab (2013), a US based electricity body under the auspices of the Rocky Mountain Institute, argues that allowing utilities the flexibility to create these specialised contracts is far easier to implement than other more complicated tariff structures, such as locational pricing.

> *"While locational and temporal pricing is an elegant and logical approach…implementing such pricing regimes would be challenging."*
>
> (e-lab, 2013)

Of course, a fundamental factor that must be considered is the practical implementation potential of any tariff re-structure. This would require thorough assessment and consideration of the level of price signals and incentives offered, as well as customer's willingness and ability to change their behaviour in order to shift or change their consumption. Policy makers should be aware of potential winners and losers, and trials of any scheme would be recommended to ensure customer protection frameworks can be instituted for any groups that may risk an increase in electricity bills.

8.6. Conclusions & Policy Implications

This paper explored why new cost-allocation and tariff-design methodologies are needed in order for electricity prices to better reflect costs based on grid usage. In order for tariffs to be practical, and provide customers with choice in service and flexibility in product, it may be necessary to refine customer groups according to key cost drivers.

A precursor to this transition involves the installation of advanced meters across WA's network. Nevertheless, in whichever way tariffs are adapted, achievement of cost reflectivity is always going to be difficult, with cross-subsidies across consumer groups and across geographies resulting in winners and losers. In order to drive sustainable policy change, regulators and customers must accept that there will be costs, both financial and involving behavioural change, associated with creating more equitable and transparent pricing arrangements for electricity services.

The research was tested against the perceptions of Western Australian residential electricity consumers in regards to solar PV and battery storage systems, electricity cost drivers, consumption behaviour, and various electricity pricing structures (cost-reflective time-of-use and maximum demand pricing).

A significant finding of the research, with major implications for Government and policy-makers around the world, is a willingness from the majority of respondents to change behaviour and reduce electricity usage if it can save them (enough) money and if the value of residential solar and storage systems is recognised and appropriately rewarded through tariffs. In contrast to general political and policy hesitation about changing electricity prices, this research suggests the appetite for retail tariff reform is strong in WA, conditional on the level of savings on offer, and customer understanding of any new, more complex, tariff structures.

While these findings are not immediately generalizable across Australia or in international contexts due to the small sample size, this research still provides critical global insights into customer perceptions as electricity bills and the need for tariff reform becomes more urgent.

This paper's findings have increasing relevance and importance as Western Australian residential electricity demand increases, the market is de-regulated, competition is increased, and new retail products are introduced to provide more cost-reflective price signals.

Future work could conduct correlation analysis on the data to determine whether there are any gender, age or employment factors underlying the responses. Additional research could also investigate the applicability of consumer behaviour theories in assisting with implementation of tariff reform, improving customer knowledge and appetite to adapt to new pricing structures and maximise savings opportunities. For example, the drivers for behaviour change could be investigated beyond simply financial reward, using theories from research in other industries with regards to cues, habits and non-financial incentives. In addition, an expanded quantitative survey across Australia could also be conducted with various sample populations.

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8.8. Appendix – Research Survey

Curtin University

Introduction & Screener

You are invited to complete this short 2 minute survey on energy behaviour as part of a research project at Curtin University.

Your answers will help us understand the energy behaviour of Western Australians, particularly regarding electricity usage.

Consent to participate will be assumed if you continue on and complete the survey.

Curtin University Human Research Ethics Committee (HREC) has approved this study (HREC number RDHU-0816). Should you wish to discuss the study with someone not directly involved, in particular, any matters concerning the conduct of the study or your rights as a participant, or you wish to make a confidential complaint, you may contact the Ethics Officer on (08) 9266 9223 or the Manager, Research Integrity on (08) 9266 7093 or email hrec@curtin.edu.au.

Do you live in Western Australia?

Yes

No

Attitudes toward Electricity Costs

Do you think you pay too much for electricity?

Yes

No

Are you happy with your electricity provider?

Yes

No

Why are you unhappy with your electricity provider?

Which of the following do you think impacts electricity costs? *Please select all that apply.*

Government

Energy companies

Regulators

Weather

Banks

Other

Solar panels

Do you have solar panels?

Yes

No

Do you want solar panels?

Yes

No

As you already have solar panels, do you want battery storage?

Yes

No

I already have battery storage

Please indicate your level of agreement with the following statements.

Having solar panels...

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
Reduces electricity bills	○	○	○	○	○
Is beneficial for the environment	○	○	○	○	○
Provides greater control of energy consumption	○	○	○	○	○
Enables you to be "off-grid"	○	○	○	○	○

Energy behaviour

Would you change your electricity usage if it saved you money?

Definitely yes
Probably yes
Might or might not
Probably not
Definitely not
I don't know

How much money would you need to save per year for you to make changes in your electricity usage? (e.g. turn down air conditioner on hot days)

Less than $200 per year
$200-$500 per year
$500-$1000 per year
More than $1000 per year
I don't know

How much would your bill need to increase per year for you to consider making changes in your electricity usage?

Less than $200 per year
$200-$500 per year
$500-$1000 per year
More than $1000 per year
Cost of electricity would not impact my usage
I don't know

Please indicate your level of agreement with the following statements.

My electricity bill should have...

	Strongly disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Strongly agree
a flat rate price for electricity	○	○	○	○	○
a variable rate that reflects the time of day I use my electricity	○	○	○	○	○
two different rates for electricity: peak and off peak	○	○	○	○	○
a special discount rate for use of solar panels and battery storage	○	○	○	○	○
a fixed monthly price, with a capped usage limit	○	○	○	○	○

Demographics

Finally, just a few questions about you.

Which company provides your electricity?

Synergy

Horizon Power

I don't know

In what year were you born?

What gender are you?

Male

Female

Which of the following best describes your work status?

Employed full-time

Employed part-time

Unemployed

Not in the labour force (e.g. student, home duties, retired)

Which one of the following categories best describes your total household annual gross income (before tax)?

Thank you for participating in our study.

Please press the next button below to submit your answers.

Powered by Qualtrics

CHAPTER 9: LEVERAGING INNOVATION FOR ELECTRICITY UTILITIES

Paper 5: Published

Tayal A.D. Leveraging Innovation for Electricity Utilities. The Electricity Journal, Volume 30. Issue 3, 23-29.

Chapter 9 contains the fifth paper presented in this thesis. The published form is included in Appendix C of this thesis.

9.1. Abstract

The energy industry is undergoing significant disruption. This research outlines that, whilst challenging, this disruption is also a huge opportunity for electricity utilities. Innovations in products and services, facilitated through effective partnerships with research centres, may provide benefits to utilities across the value chain.

Policy implications could be significant in shifting from traditional regulatory models to flexible frameworks that encourage innovation. A collaborative mindset will be needed to ensure utilities recognise the role they must also play in guiding regulatory reform and driving governments and regulators to accept the uncertainty that future business models must navigate to succeed.

Keywords: distributed energy; microgrids; innovation; electricity utilities; solar; storage.

9.2. Introduction

9.2.1. Research and development in the electricity industry

> *'Right now, the world spends only a few billion dollars a year on researching early-stage ideas for zero-carbon energy. It should be investing two or three times that much…because it is a public good.'*
>
> (Nyquist, 2016)

Ever since the electricity grid was developed in the late 1800's, there have been no revolutionary changes to the structure of the system. Today, we still have a centralised grid system, with electrons flowing from generation sources, through transmission and distribution networks, to a final load. There may have been gains from technology innovation incorporated into generation plants, making them more efficient, cheaper, or cleaner. And the safety and reliability of the system has been steadily improving. But the concept and structure of the centralised grid has stood the test of time, and leveraged the economies of scale and existing infrastructure for more than 200 years (King, 2016).

This structure is now under the threat of disruptive innovation. The centralised model is being challenged by new products such as solar PV, battery storage, microgrids and smart meters (Kind, 2013). These technologies and other market led innovations have been slowly entering the sector over the past decade through various trials, pilots and experiments by forward looking commercial enterprises and university led research. They have now entered the lexicon of every day users. Consumers are recognising they no longer need to be passive recipients of electricity at increasingly higher prices, but can become 'prosumers' (producers and consumers) and have independence and control over their consumption and costs. The result so far has been both a reluctance from the large incumbent utilities to acknowledge the threats, and existing regulatory and policy frameworks being too inflexible to manage the transition away from the established, traditional centralised model (Richter, 2013).

The disruption has begun, and even banks and financial institutions have recognised the risk of continued to fund traditional large scale infrastructure to the mould of the centralised model (Caldecott and McDaniels, 2014). Governments and regulators are also facing increasing pressure to manage the cost structure changes.

Financing within the energy sector is already incredibly complex, with a myriad of subsidies, cross-subsidies, incentives and tariffs across market participants, consumers, and utilities. However, in dealing with the evolution of the sector amidst this inevitable disruption, very little funding is directed into the research and development (R&D) of innovative products and services. The International Energy Agency (2015) noted that publicly funded R&D accounted for only four per cent of global research budgets, with renewables less than half of that. This is in contrast to a level of eleven percent in 1981 (IEA, 2015).

This is not just a problem for sustainable energy enthusiasts, but in the medium to long term it is inefficient for utility businesses, and therefore a risk and a cost for participants and consumers as well (Nyquist, 2016). In order to maintain their relevance, and continue to sustain profitable business models, utilities must not simply defend against this disruptive innovation, but must get ahead of the curve and be leading innovators themselves, by re-prioritising their investments in R&D.

9.3. Background

9.3.1. Technology innovation – the role of universities

Whilst research and development is a broad term that can cover several different ideas, in this paper, we use Wonglimpiyarat's (2016) description of 'incubator' to define the process of knowledge transfer and commercialisation:

> "The incubator is an umbrella term referring to a mechanism for technology transfer to promote the growth of innovation and entrepreneurship."
>
> (Wonglimpiyarat, 2016)

There are many studies that have explored the link between businesses and incubators – and how these partnerships can drive technology innovation (Sagar, 2004; Bakouros et al, 2002; Allen and McCluskey, 1990; Acs and Naude, 2011; Smilor and Gill, 1986).

Rubin et al (2015) and Klofsten and Jones-Evans (2000) conducted empirical research into the role and ability of incubators to facilitate entrepreneur's performance and ultimate success. Their findings suggest that, for incubators they studied across Australia and Israel (Rubin et al, 2015) and for entrepreneurs studied in Sweden and Ireland (Klofsten and Jones-Evans, 2000), the collaboration and knowledge shared through the incubation process allowed new start-ups to increase their understanding of financial, technical and market processes and, perhaps most importantly, assisted in the ability for the new businesses to raise capital.

The studies also found that university partnerships and the academic environment also played a vital role in assisting with product development. The research suggests that university based incubators have an important role to play as an intermediary between the academic sector and industry in order to provide the iterative link that allows for effective application and development of university research (Rubin et al, 2015; Fu, 1995; Klofsten and Jones-Evans, 2000).

These findings are consistent with other literature that has outlined how universities around the world are recognising a shift in their traditional role away from providing conventional academic research and educational functions, to one that promotes innovation, knowledge sharing, and commercialisation linked closely with industry developments (Mian, 1997; Youtie and Shapira, 2008; Haoour and Mieville, 2011; Etzkowitz, 2002).

Of course, the concept of incubators to encourage general business development innovation is not new in Australia – technology parks (also known as science, business or research parks) were established across the country throughout the 1970s and 80s to facilitate the flow of knowledge and commercialise research from universities (Phillimore, 1999; Curry, 1985; Monck et al, 1988, Eul, 1985).

Perhaps the most cited example of these parks working with industry is through the telecommunications and information and communications (ICT) space, which was also supported with direct Federal Government funding of over $150 million to promote innovation in the ICT industry and address existing market failures (Garrett-Jones, 2004). However, Australia is still ranked poorly amongst the Organisation for Economic Co-operation and Development (OECD) nations for collaboration between industry and public researchers.

The importance of research and development is becoming increasing relevant to the energy industry, already grappling with understanding and implementing the next wave of technology development. From their perspective, utilities should develop and strengthen partnerships with university and research institutions and recognise the value they can provide as incubators and as a “vehicle for technology and knowledge transfer” (Rothaermel and Thursby, 2005). Not only do external parties provide new points of view to assist with critical thinking and ‘outside-the-box’ brainstorming, but access to this external knowledge base would either have been incredibly difficult and more expensive to drive internally, or unachievable due to institutional lock-in and the mindset to conform to existing methods and practices (Chesbrough, 2003). Whilst potentially new to the energy sector and incumbents within, these advantages are already widely acknowledge in business innovation and entrepreneurship literature (Bollingtoft, 2012; Johannisson, 2000; Lofsten and Lindelof, 2001; West and Bogers, 2014).

9.3.2. Technology Policy

Wider than just the energy sector, Government must recognise that innovation is critical to creating and maintaining growth across all industries and sectors, and therefore coherent and consistent Federal policy is necessary to promote the environment in which this growth can be sustained (Lundvall, 1998; Freeman, 1987). Dalton and Gallachoir (2010) go one step further and suggest that effective technology and innovation policy requires a focus on the creation of user markets to promote technology projects in the short term.

The literature on technology policy also suggest that in order to enable diffusion of the technology innovations, markets as well as 'innovation networks' are a necessary part of the process (Norberg-Bohn, 2002; Sagar and Gallagher, 2006; Zhu and Zou, 2006; Guo et al, 2016).

This policy certainty facilitating the creation of markets is observable from the successful cases of the solar photovoltaic (PV), wind power, and biofuel industries in China, India, and Brazil (Lewis and Wiser, 2007 and Zhang et al., 2009; Ru et al., 2012; Gallagher, 2014).

9.3.3. Case Study: China's Solar Success

Research has shown the rapid success of China as a world leading solar PV manufacturer relies heavily on strong government policy support for technology innovation (Zhang and Gallagher, 2016; Lall and Teubal, 1998; Ockwell et al., 2008; Zhi et al., 2014).

In their research, Zhang and Gallagher (2016) deconstructed the solar PV value chain to analyse the determinative factors that drove China's success in the technology. What they found was a successful strategy that saw the Chinese firms' first acquiring low-cost module manufacturing technologies, before increasing their competitiveness through a step-by-step vertical integration up the value chain.

Success was also contingent on strong Government policy incentives, China's manufacturing market's flexibility, and the globalisation of engineering and research talent that allowed appropriate knowledge transfer to occur (Zhang and Gallagher, 2016).

9.3.4. The WA Opportunity

The challenges facing electricity utilities around the world are the result of a significant innovation disruption – a transition from the centralised model of service delivery to a renewable distributed model of electricity networks. For Western Australia, this disruptive transition is occurring more acutely, due to a market structure that includes Government owned monopoly utilities that rely heavily on subsidies to provide electricity across the state. As a result, the WA Government is now grappling with escalating costs and has recognised the importance that technology innovation will play in allowing the system to take advantage of the renewable resource that is in abundance (Nahan, 2015; Bromley, 2015; Sayeef, 2012).

WA utilities are already exploring how the increasing penetration of solar PV may impact the grid, as well as preparing for the inevitable integration of battery storage systems as they continue to come down the cost curve. And whilst several drivers of this transition are common to markets around the world, such as rapid advancements in technologies, WA is also facing a unique confluence of additional factors – structure market reforms, network size and isolation, high solar radiation, and customer demand - that will only serve to accelerate the process in the region (Parkinson, 2015; Bromley, 2015).

These technology innovations will only increase the challenges for utilities and Government, and WA's isolated electricity network and energy market has already become a demonstration site for energy sector participants around the world looking for guidance on how to manage the transition (Parkinson, 2015). Trials of microgrids, distributed energy generation, behind the meter software and systems, demand side management, stand-alone power systems, and advanced metering infrastructure are just some of the innovative projects that have successfully realised the transition from incubator and R&D labs, to partnering with utilities for implementation opportunities. This paper outlines why these projects form only the start of a wave of innovations needed for utilities.

9.4. Methodology

9.4.1. **Literature Review**

A review of existing literature was carried out to gain a thorough understanding of the existing innovations models being proposed, trailed or conceptualised for electricity utility businesses attempting to create new opportunities, particularly for Western Australia, but with application for utilities around the world.

9.5. Results

9.5.1. Utility 2.0 - New energy business platforms

The delivery business models for electricity companies are being challenged due to the influx of innovative systems and products that will inevitably become part of traditional utility offerings. This is being driven by a convergence of technology innovations, economic conditions, environmental imperatives, and a shift in public policy.

In addition to navigating these innovations and the associated increase in commercial risks, utilities have also been confronted with additional safety and reliability challenges as a result of the increased uptake of customer-driven installations such as distributed renewable generation.

In a scan of companies, conferences, launches and interviews, Reid (2016) identified four potential future business platforms for utilities to explore as part of their future strategies:

Table 9.1: Innovative business platforms for utilities

Model	Description	Existing Examples
1. Pay as you go	Provides customers no obligation for regular billings – allows variety of payment plans and potential for mobile phone payments.	Mobisol, Beegy
2. Software as a service	Companies offer data analytics to customers to improve performance of electricity assets.	Lumeneza, Mercatus
3. Product packages	Utilities combine with electric auto companies, heating or cooling providers with energy agreements	SolarCity & Tesla

4. Optimisation services	Automatically selects cheapest/customised services and products for customers across the value chain– scanning prices across the market	Verivox, Thermondo

Source: Adapted from Reid, 2016.

Whilst Table 9.1 outlines only a selection of potential platforms for utilities to explore and understand, they will also need to make a conscious business decision whether to incorporate or compete against each new product or service – or face losing market share, eroding revenue and increasing irrelevance in the market. To a certain extent, utilities in WA are shielded by strict and cumbersome regulatory barriers, but as the example of 'uber' highlighted, when customers identify an innovative product or service that meets their needs, change will be forced into the industry irrespective of any perceived regulatory barriers.

9.5.2. Big Data

With increasing capabilities in software analytics, smart meters and 'digitisation', the electricity industry is primed to leverage gains in organising, analysing and optimising the data acquired along its electricity networks and systems and take advantage of new business platforms as outlined in Table 9.1.

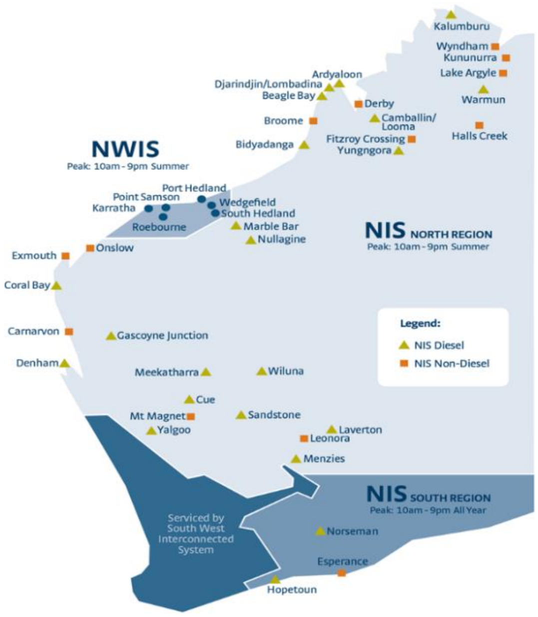
For Western Australian utilities, direct opportunities exist to address the increasing cost of service and reliance on Government subsidy by reducing operational and capital costs and increase efficiencies in the business.

By installing smart meters across its customer base, the regional electricity utility provider in Western Australia, Horizon Power, has already recognised the value that installing intelligent infrastructure can bring to addressing future disruptive forces going forward (Horizon Power, 2016a).

Horizon Power is Government-owned and provides power to over 100,000 customers through 46,000 customer connections across regional and remote Western Australia.

Horizon's service area is more than 2.3 million square kilometres (see Figure 9.1) – twice the area of UK, Germany and France combined (Horizon Power, 2016b).

Figure 9.1: Horizon Power Service Area



Source: Horizon Power, 2016b

Given the sheer size of coverage, immediate advantages of Horizon's investment in these smart meters include the ability to introduce pre-payment products across a hard to serve customer base, electronic billing (saving millions in manual meter readings and testing), increased security and accuracy capabilities, and potential for aggregated system control (in the context of virtual power plants and distributed energy generation assets).

Future benefits, and potential for further collaboration with innovation centres and universities to progress these initiatives, include the opportunity to aggregate customer datasets and combine with weather and system data to improve predictive maintenance and system management capabilities, as well as provide innovative customer engagement platforms to address retention and customer satisfaction (Horizon Power, 2016a).

Hackathons

Utilities should increasingly be looking to participate in innovation initiatives such as hackathons where it may be beneficial to generate creative solutions to new disruptive opportunities – such as those presented by the installation of smart meters.

Hackathons involve groups or teams of self-selected experts, working in a shared space to collaborate around a central idea, dataset, or defined problem. The event is usually limited to days (e.g. over a weekend), to facilitate focused burst of entrepreneurial thinking (Doshi-Velez and Marshall, 2015; Bazilian et al, 2012).

Hackathon participants are traditionally data driven experts such as computer scientists, statisticians, engineers, and other technology specialists who appreciate solving problems and have expertise in computational theory and using complex data-sets (Bazilian et al, 2012). However, utilities should be conscious that, based on historical sessions, only the minority of participants will have direct experience of the energy sector and electricity systems and networks. Therefore, consideration needs to be given to the need for (Doshi-Velez and Marshall, 2015):

a) Well-scoped objectives of the session, but one that encourages creative approaches and unexpected correlations and conclusions;

b) Standardised data sets – for ease of understanding and manipulation; and

c) Attendance by technical staff with energy expertise – to assist with modelling assumptions and problem definitions and boundaries.

By utilising the data generated through smart meters integrated into its network, Horizon Power has a unique opportunity to present hackathon event organisers, such as the university groups outlined in Figure 9.1 above, with an energy event centred on addressing the wider industry disruption. Being a state-owned, vertically integrated power provider, Horizon may also find itself well placed to combine information and learning outcomes across all aspects of the business, for example how customer behaviour may ultimately impact on generation and network requirements.

In Western Australia, opportunities are increasing for companies to partner with existing innovation centres and incubators, or create further networks of experts who already have experience in running hackathons and fostering entrepreneurial ideas.

Table 2 provides a high level scan of what the five major WA universities promote online in regards to their incubators or innovation centres.

Table 9.2: Western Australian University Incubators

University	Centre	Description
University of Western Australia	Innovation Quarter	Building on its rich history of research-led innovation – aims to lead new research efforts in areas like agriculture, resources and medicine that will improve the way we live and help advance WA's prosperity.
Murdoch University	Murdoch University Energy Research and Innovation Group	In association with Innovation Cluster and Atomic Sky, the Start Something program aims to stimulate entrepreneurship among academics, postgraduates and early career researchers at the University – provides enterprise skills, knowledge and contacts in industry to help researchers. Industry engagement is a growing component of the future of public research in Australia, so researchers interacting with industry experts from multiple fields are central to the program.
Edith Cowan University	The Link	A joint initiative between the City of Joondalup and Edith Cowan University - will help to drive innovation and business growth in and around Joondalup. The Link website will enable businesses and investors to access information on business opportunities in the city and connect with ECU research expertise. Includes facilities such as Cyber Security Institute, Electronic Science Research Institute and Health Simulation Centre, ECU will look to drive innovation in the area.
Notre Dame	n/a	Direct health research funding and network with other universities
Curtin University	Cisco Internet of Everything Innovation Centre	Industry and research collaboration centre, established by Cisco, Curtin and Woodside Energy. Over 80 researchers and links to advanced facilities and a global industry network will bring together start-ups, industry experts, developers and researchers to create ground-breaking and innovative solutions that foster growth, provide jobs and help build sustainable economies.

Source: University websites, 2016.

As outlined in Table 9.2, despite the growing body of evidence in the literature of the value that research collaboration provides to underpinning innovation endeavours, Western Australian universities are still at varying stages of implementing incubators and research and development links with industry that could underpin such initiatives as hackathons – particularly on the topic of energy technologies.

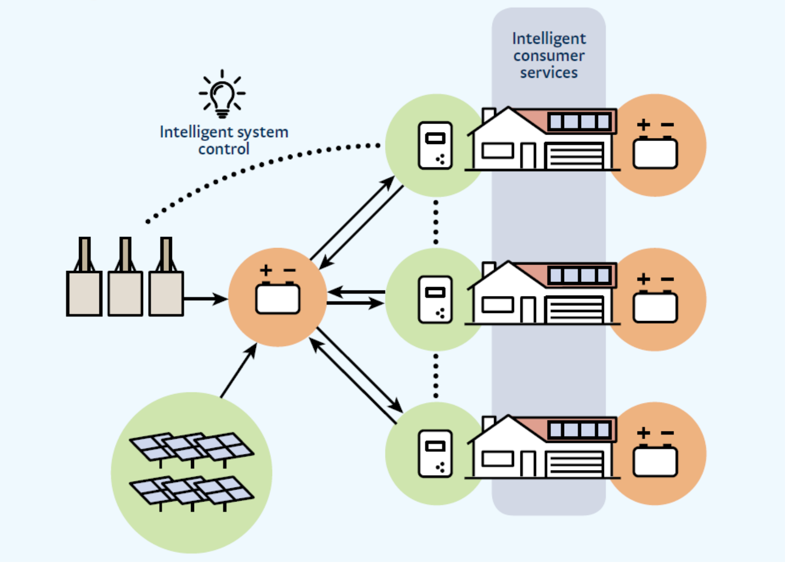
9.5.3. Microgrids

Microgrids, as defined by Prete and Hobbs (2016), are:

> "a group of multiple distributed generation units and loads operating as a coordinated system, connected to the main electric grid at a single point (typically, at the distribution level), and able to function in parallel with the grid or in island mode."
>
> (Prete and Hobbs, 2016)

Remote microgrids are further classified as those microgrids that are not typically interconnected with a reliable grid and therefore operate primarily in island mode. They are also more prone to having high levels of renewable energy (e.g. distributed solar PV), and feature some form of intra-network intelligent control systems to optimise energy flows – see Figure 9.2 below.

Figure 9.2: Distributed Renewable Microgrid



Source: Horizon Power, 2016a.

In contrast to the disruption and increasing competitive pressure on traditional network businesses, the microgrid market is expected to continue its rapid growth as technology innovations and price reductions shift emphasis from a centralised supply model to one predicated on distributed generation.

North America leads the world as a market for microgrids, and has over 65 per cent of total global capacity (Prete and Hobbs, 2016; Lidula and Rajapakse, 2011).

Western Australia's regional areas are also presenting themselves as attractive test-beds for renewable energy microgrid applications – with 2016 alone presenting various wind, wave and solar trails across the State (Parkinson, 2016).

9.5.4. Innovations in customer engagement

Existing technical, financial and institutional barriers still need to be overcome in order to transition to future energy networks (Tayal, 2016), and facilitating new forms of customer engagement is critical in achieving this transition (Accenture, 2016).

Impelled by the recent developments in technology, as well as a common apathy for traditional utility companies, customers now have a different perspective than previously - with higher expectations for service, personalised products, meaningful experiences, as well as pushing for the ability to explore new ways of contributing and participating through their own distributed energy investments (Accenture, 2016).

As forecast by the Australian Energy Market Operator, Australia's system operator for electricity and gas markets, the future electricity supply chain is expected to slowly but steadily be shared more evenly between utilities and their customers (see Table 9.3).

Table 9.3: Percentage of rooftop PV relative to underlying grid consumption

	Queensland	New South Wales	South Australia	Victoria	Tasmania
2014-15	5.7	2.4	8.4	2.7	3.0
2017-18	9.1	3.7	11.9	4.4	4.9
2024-25	16.0	6.3	22.1	8.6	11.0
2034-25	20.2	9.3	28.5	13.7	17.4

Source: AEMO, 2015

The initial challenge for grid-owners and policy makers is in breaking down barriers that seek to protect the traditional structures and impinge on the necessary competition for new products and services (Tayal, 2016). The secondary challenge, is how to leverage these changing perspectives and continue to make whole-of-network efficient decisions, which becomes increasingly difficult once the shift away from centralised networks starts to gain momentum. No longer will utilities be able to have teams of network planners and system operators providing ten year forecasts of required network investment. Customers will relieve investment pressures by investing in electricity assets at both a household and commercial level. But this will not remove system security and reliability requirements from the utilities responsibility. Instead, it will simply change their focus to ensuring grids are flexible, can accommodate the fluctuating input from intermittent sources such as solar and wind generators, and can provide the level of service that customers of the future will be expecting.

9.5.5. Electricity economics - the traditional approach

Traditionally, pricing for electricity is largely driven by a return on investment approach for each aspect of the supply chain that makes of the electricity system. Whilst only some parts of that supply chain are regulated – in Australia the network component – the same economic approach applies to investments in retail and generation components (AER, 2014).

For example, those who have invested in assets require a return of capital, return on capital (i.e. a reward for taking risk), and any other allowances and operating cash flows in order to maintain and run the assets. This concept applies down to marginal costs as well - generators are provided returns for any fuel used, and retailers are paid a margin to compensate them for taking market risks (AER, 2014).

In the traditional model, an electricity network is very capital intensive, and increased utilisation provides a more economically efficient outcome through lower costs per unit for providers, and therefore users. However, as distributed energy generation assets increase their penetration across the grid, different mechanisms will be required to ensure these assets are still utilised effectively.

9.5.6. Electricity economics – incorporating innovation

Given the substantial disruption now occurring in electricity markets, utilities need to be transitioning their business modes away from traditional economic approaches, or at least recognise the impending risk of stranded assets declining revenues (Caldecott and McDaniels, 2014).

Utilities will need to be aware of these constraints, and develop new platforms that can combine with intelligent communications, smart meters, and distributed renewable sources of generation whilst still maintaining lowest possible costs for the system. This may even necessitate providing incentives for customers to invest in specific energy assets, at specific locations to provide benefits to both utilities and customers. The system could then leverage these distributed resources to increase asset utilisation, improve resilience and ultimate transform the electricity supply chain to one that operates through less capital employed and therefor lower electricity prices.

Similar to the economic principles that underpin conventional electricity systems, as distributed renewable generation increases, microgrids gain further prominence, and renewable energy technologies increase penetration levels, several economic approaches will need to be maintained.

For example, even if investment requirements are smaller, distributed across multiple locations or aggregated through numerous investors, any capital invested will still be expected to generate returns over the life of the asset. Therefore, from an economic point of view, the benefits of the transition away from centralised power systems still reside in improving network value and providing the additional customer benefits mentioned earlier. Core to this transition, is ensuring economic efficiency – across networks, retail businesses and future investments.

However, in managing this transition, overall system value still need to be maintained, to ensure that the pendulum does not swing too far the other way, losing economies of scale and disregarding the value of electricity as a tradeable good. For example, system-wide solutions at the distribution level (and smaller) should still be considered to ensure that users are not forced to over-capitalise on capacity (e.g. over-sized PV panels and battery systems), or through acquiring and installing large back-up generating units instead of considering a lower cost, system-wide trading platform or microgrid.

Incentivising market behaviours

The economic business case for utilities of the future will need to ensure that it incorporates system-wide benefits in any value assessment of infrastructure upgrades, in order to maximise the efficiency of the investment. The question then becomes how policy makers can translate these efficiencies into appropriate incentives to encourage market participation and drive competition across energy markets, to the benefit of Governments and customers.

Given the utility's ability to identify the need and benefits associated with network and system investments, it is proposed that in the first instance, it is the utility's responsibility to provide the right incentives – through market-based mechanisms to its customers. One example would be a utility providing discounted batteries or installing advanced meters and incentivising its customers to institute demand side response behaviours during peak demand periods, in order to avoid additional investment. Of course such approaches also require the cooperation of Governments and regulators to ensure the flexibility of regulations, as well as having appropriate customer protection frameworks in place.

Properly designed, a market platform by which customers can utilise the network (and other infrastructure) to exchange services with others would also enhance the value of the network beyond the single dimension of transporting power, helping increase value for both utilities and consumers. It is predicted to improve customer retention, through improved opportunity to increase their own autonomy, investment returns, and ability to respond to price impacts.

By using the means to drive innovative outcomes as identified earlier (e.g. hackathons and research collaborations with universities), utilities can decouple the complex interactions between electricity, system operators, customers, and (increasingly) customer assets. Ideally, utilities would be able to design these interactions to happen automatically, and respond to specific price signals to provide maximum benefit to customers.

Utilities will also need to leverage customer behaviours to ensure that the network is utilised most efficiently – e.g. through changing consumption patterns. One emerging example is the aggregation of individual distributed generation sources, such as small-scale storage at the residential level, but with utilities using a central control system and 'intelligent' communications to make the distributed storage available to address peak demand situations – a form of virtual power plant.

Virtual power plants

Leading the Australian market, AGL Energy (in partnership with Sunverge) announced in August 2016 (AGL, 2016) its development plans for "the world's largest battery storage virtual power plant" in South Australia. The trial includes 1,000 customers installing battery storage with a combined capacity of 5 MW, with each battery system controlled centrally through a 'cloud connected intelligent control system' to provide wider distribution grid stability and assist in the management of peak demand. In effect, the aggregated batteries will act as the equivalent to a peaking plant.

South Australia was chosen as the location given it leads Australia in the penetration of renewable energy, and no longer has any large centralised coal powered fire stations available for generation (AGL, 2016).

Therein lies a challenge to pursue strategic projects of this nature that are fundamentally opposite to traditional electricity revenue streams of centralised generation and distribution. AGL, through this trial, appears to be taking the first step into a distributed energy future - with the opportunity to test, and even control, how distributed energy can be used to benefit customers (lowering power bills and reducing emission) as well as utilities (maximising grid utilisation and providing system security in an efficient way).

Hopefully, regulators and policy makers take note of these ongoing technology trials and ensure frameworks are adapted and are flexible enough to encourage further innovations.

Similarly, embracing these opportunities and facilitating their development will need to become a regular component of utilities business models going forward.

9.6. Conclusions & Policy Implications

With the increasing prominence of technology innovations including distributed renewable generation assets, smart meters, battery storage and intelligent software and communication systems, utilities will need to recognise these disruptive threats to their traditional business models and adapt.

By embracing new services and products, utilities can transform these threats into opportunities, and provide enhanced customer service through greater choice and lower costs, whilst maintaining business value. Looking forward, we are more likely to see dense microgrids with high penetration of renewable assets, linked virtually through intelligent communications and adaptable to several customer segments in order to drive efficient behaviour.

Of course, several barriers will need to be overcome, not least an archaic and inappropriate form of electricity pricing, rigid regulatory framework, and instability in long-term government policy direction. But the economic drivers in support of innovation in the sector are forcing the hand of regulators and governments around the world.

Collaboratively, utilities, governments, policy makers and regulators need to create the right culture and institutional frameworks that don't stymie risk taking but actually facilitate failure – such that iteration can drive successful solutions and create further value. The question remains on how to do this in an inherently risk averse industry, business environment, and largely government controlled ownership model.

Regulatory regimes, established to encourage long-term economically efficient investments by the utility, will need to adapt to recognise the contribution that non-utility-owned assets play in economic efficiency. Utilities will also need to understand it is their responsibility, on behalf of their shareholders and customers, to drive this regulatory and policy change – through partnerships with universities and research labs (and other entrepreneurial means like hackathons) in order to drive innovation through the business as well as through the sector as a whole.

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CHAPTER 10: ACHIEVING HIGH RENEWABLE ENERGY PENETRATION IN WESTERN AUSTRALIA USING DATA DIGITISATION AND MACHINE LEARNING

Paper 6: Published

Tayal A.D. Achieving high renewable energy penetration in Western Australia using data digitisation and machine learning. Renewable and Sustainable Energy Reviews. Volume 80C, 1537-1543.

Chapter 10 contains the sixth paper presented in this thesis. The published form is included in Appendix C of this thesis.

10.1. Abstract

The energy industry is undergoing significant disruption. This research outlines that, whilst challenging, this disruption is also an emerging opportunity for electricity utilities.

One such opportunity is leveraging the developments in data analytics and machine learning. As the uptake of renewable energy technologies and complimentary control systems increases, electricity grids will likely transform towards dense microgrids with high penetration of renewable generation sources, rich in network and customer data, and linked through intelligent, wireless communications.

Data digitisation and analytics has already impacted numerous industries, and its influence on the energy sector is growing, as computational capabilities increase to manage big data, and as machines develop algorithms to solve the energy challenges of the future.

The objective of this paper is to address how far the uptake of renewable technologies can go given the constraints of existing grid infrastructure, and provides a qualitative assessment of how higher levels of renewable energy penetration can be facilitated by incorporating even broader technological advances in the fields of data analytics and machine learning. Western Australia is used as a contextualised case-study, given its abundance and diverse renewable resources (solar, wind, biomass, and wave) and isolated networks, making a high penetration of renewables a feasible target for policy makers over coming decades.

Keywords: renewable penetration; data; innovation; solar; storage.

10.2. Introduction

10.2.1. Disruption in the electricity industry

The electricity network and grid system in use today still largely resembles the original structure of the system that was initially developed in the late 19th century. Electricity infrastructure around the world is predominately based on a centralised system whereby electrons are generated by large thermal plants, before being transported through a large network of transmission and distribution lines to a final customer load.

This centralised structure of the electricity grid has stood the test of time because it best leveraged the economies of scale that thermal plant technologies provided (King, 2006). However, these traditional technologies – the coal and gas fired power stations - are now becoming increasingly challenged by new products and innovations in the energy sector that are being integrated into the existing infrastructure, most notably smaller, distributed energy generation sources such as solar photovoltaic cells (i.e. rooftop solar panels), battery storage systems, and complimentary data and communication tools, such as smart meters, wireless communications, and intelligent inverters (Kind, 2013).

Electricity customers, from households to large businesses, are also increasingly aware of their newfound ability to choose electricity products that better match their load profiles, have less impact on the environment, and perhaps most importantly, reduce their electricity bills.

The energy sector is in the midst of a technological disruption that is challenging existing grid infrastructure, energy institutions, regulations, policy markets and financiers alike. New technological innovations continue to come down the cost curve, improve their efficiencies, and adapt their services to better satiate the increasing expectations of consumers.

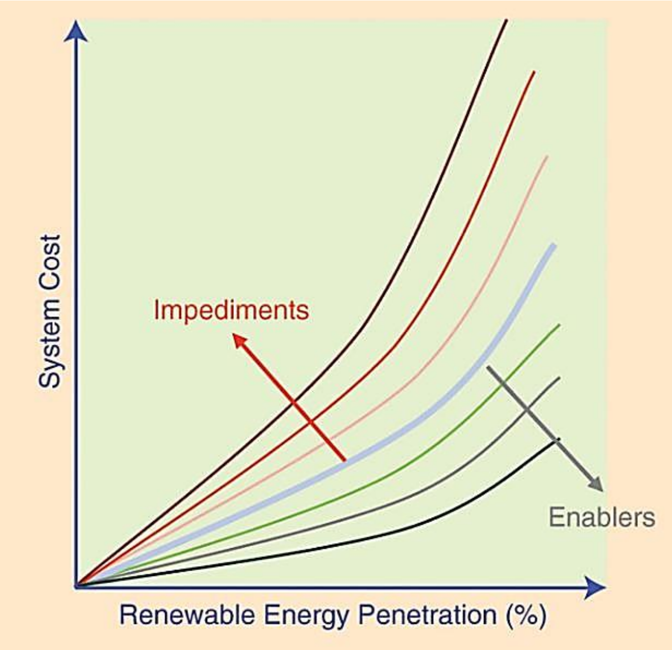
10.3. Background

10.3.1. Barriers to renewable energy

Renewable energy is steadily becoming the new centre point for electricity generation – replacing conventional fossil fuel sources at increasing rates. Global energy statistics show that renewable sources are already providing almost 20 per cent of global consumption, and in 2014 accounted for more than half (59 per cent) of all new energy plants added to grids around the world (Ren21, 2015). This growth captures both developing countries appetite for wind and solar sources above fossil fuel and nuclear capacity, and also suggests that globally, the transition to integrating high penetrations of renewable energies into existing grids has already begun (Elliston, Riesz and MacGill, 2016; International Energy Agency, 2015).

Whilst there are no theoretical limits to continue connecting renewables to the grid, as the penetration level of renewables increases, it becomes exceedingly challenging (Auer and Haas, 2016). In particular, technical and financial limits must be overcome: technical limits on equipment – such as hosting capacity – need to be adhered in order to maintain system security, stability and reliability; and financial limits inhibit high penetration levels, as after a threshold point (see Figure 1 below), the cost to connect increasing levels of renewables also increases, at an exponential rate (Piwko et al., 2012).

Figure 10.1: Limits to high penetration of distributed renewable energy systems



Source: Piwko et al, 2012

As shown conceptually in Figure 10.1, the marginal system cost increases as renewable penetration increases. This marginal cost represents total integration costs, which include, for example (Piwko et al, 2012):

- Increased requirements for ancillary services;
- Higher unit costs for remaining 'traditional' thermal generation plant;
- Higher operating and maintenance costs for traditional plant due to increased cycling and ramping; and
- Increased curtailment costs for both renewable and traditional plant.

Notwithstanding these financial challenges and 'impediments', benefits are also accrued as the penetration level of renewables increases – reduced fuel requirements, lower greenhouse gas emissions, and greater community participation and customer choice, to name a few. By accurately identifying and incentivising these benefits, they become 'enablers', driving total system costs downwards, even whilst renewable penetration levels increase.

However, there are also several significant institutional, regulatory and psychological barriers that need to be overcome by renewable proponents, as outlined by Tayal (2016), in the context of increasing solar and storage in the Western Australian market. However, these are barriers that exist at all levels of renewable integration, even low levels, so this paper will concentrate on innovative technical solutions that focus on overcoming the technical and financial limits specifically. Therefore, this research provides policy-makers, utility executives, and consumers with initial grounding and reinforces the opportunities that our existing electricity grids can have from utilising advances in data analytics. For example, through the application of technical innovations, utilities could ultimately be able to forecast wind speed and solar radiation, increase the flexibility of their traditional (fossil-fuel) plant, and in the future, explore how demand side management and ancillary service markets can leverage machine learning to facilitate the uptake of increased renewables, whilst minimising impacts on total system costs.

Tackling increased renewable energy in parallel with lowering cost is not just a problem for sustainable energy enthusiasts, but in the medium to long term it is inefficient for utility businesses, and therefore a risk and a cost for participants and consumers as well (Nyquist, 2016). Governments and regulators are also facing increasing pressure to manage the cost of structural changes to energy markets being driven by the uptake of renewables. In order to maintain and continue to sustain profitable business models and provide cost-efficient electricity service provision, utilities must address these barriers that are limiting higher penetration of renewables (e.g. beyond current levels of 30-40 percent), and leverage the growing body of knowledge and technical expertise being created in the 'internet of things' sector[12]. Ideally, utilities will get ahead of the curve and be leading innovators themselves, but this will also require regulatory and political support.

[12] Internet of Things: sensors and actuators are embedded in physical objects that are then linked through wired and wireless networks, often using the same Internet Protocol (IP) that connects the Internet. These networks churn out huge volumes of data that flow to computers for analysis (Chui, Löffler, and Roberts, 2010).

10.3.2. The WA Opportunity

Western Australia (WA) is one region that is already beginning to explore how higher penetration levels of rooftop solar may impact the grid, and whilst several drivers of this transition are common to markets around the world (such as rapid advancements in technologies and significant reduction in costs), WA is facing a unique confluence of additional factors – structural reforms to markets and institutions, expansive network size and isolation, high solar radiation, and customer demand - that will only serve to accelerate the process in the region (Parkinson, 2015; Bromley, 2015).

The WA generation mix is still currently dominated by fossil fuels, with around 50 per cent of generation in 2015-16 coming from coal, and another 20 per cent from gas (AEMO, 2015). This provides a realistic baseline from which high renewable transition scenarios can be modelled, such as studies conducted by Elliston, Riesz and Macgill (2016) for Australia's National Electricity Market. As such, the WA energy market provides a useful contextualised study given its abundance of diverse renewable resources (solar, wind, biomass, and wave).

WA has the highest solar radiation levels in Australia, and is the third-windiest region in the world (with average coastal wind speeds of 27km/hr). It also has an extensive 12,9000km coastline – providing significant wave and tidal energy potential. This makes a high penetration of renewables on WA's networks a technical, economic and politically pragmatic target for policy makers over coming decades (Energy2029, 2013).

An additional advantage is WA's electricity market, which is still highly regulated, dominated by Government-owned entities and currently undergoing a major reform program independent from the rest of Australia given its isolation in both network infrastructure and political dependency. This separation means there is little prospect for an interconnector to the national grid and market, meaning there is even greater urgency to outline cost-effective solutions for delivering reliable, secure and clean energy without drawing on the back-up generation of other networks (Tayal and Newman, 2017). Although the WA market is relatively late in considering initiatives such as full retail competition and flexible pricing (Australia's Eastern States implemented similar reforms through the nineties), the industry has therefore become more open to consider major structural reforms and market re-design - not just economic improvements to existing models (CSIRO, 2009; Sharma, 1997).

WA also has a natural abundance of isolated microgrids (over 30 across the State – the largest concentration in Australia), and has already become the centre for trials and pilots of various system network control methods, which will become necessary as these grids attempt to incorporate ever higher levels of distributed renewable energy from solar panels and other sources (Horizon Power, 2017).

As a result, WA is primed to embrace new approaches that facilitate lower costs and increased efficiencies in order to meet the challenges of electricity service provision going forward. Inevitably, the transition to the future state of electricity networks will be underpinned by utilities recognising that technology innovation and high penetration levels of renewable technologies will play a central role in the WA grids of the future (Nahan, 2015; Bromley, 2015; Sayeef, 2012).

WA's isolated electricity network and energy market has already become a demonstration site for energy sector participants around the world looking for how best to manage the transition within their own markets and networks (Parkinson, 2016). Indeed, some markets are still facing barriers of a political, rather than technical nature, whereby the utilities themselves are fighting advances in renewable energy initiatives at the policy and regulatory level. Examples include Arizona Public Service and the Denver-based Xcel Energy, both utilities in the United States attempting to reverse or repeal progressive energy and climate change policy through strong lobbying and fear mongering about the risks (and costs) from higher penetration levels of renewables (Dickinson, 2016; Gunther, 2013).

Meanwhile, WA appears to be getting on with it. trials of microgrids, distributed energy generation, behind the meter software and systems, demand side management, stand-alone power systems, and advanced metering infrastructure are just some of the innovations that are currently embedded on parts of the WA network. This paper outlines why these projects form only the start of a wave of innovations, and will inevitably be expanded to include complimentary innovations in the communications and data analytics sectors as well.

10.4. Methodology

A review of existing literature was carried out to gain a thorough understanding of the challenges in integrating higher penetration levels of renewable technologies and to ascertain what solutions are currently being proposed around the world as various energy markets strive for increasingly ambitious renewable energy targets. Three of these solutions are presented as case-studies in the 'Results' section that follows, to provide clear, practical examples of energy initiatives that provide a useful contextual demonstration of the challenges and opportunities found in attempting to increase the penetration of renewable energy technologies within existing electricity infrastructure. The three case-studies were selected to highlight a diverse range of energy markets (Belgium, China and South Australia), with each receiving significant media and political attention as part of the implementation phase due to their novel and leading application of technology, and therefore subsequent analysis by researchers to understand the processes and learning outcomes.

The review of academic literature was conducted under a qualitative analysis framework outlined by Onwuegbuzie, Leech and Collins (2012), and more specifically described by the authors as a 'Theme Analysis' that searched for relationships among domains (i.e. data digitisation and machine learning) as well as how these relationships link to the overall context of the research question (i.e. achieving higher levels of renewable energy penetration).

This analysis was then used to identify a gap in existing literature with regards to challenges and opportunities contextualised for Western Australia, given the unique market structure and network requirements described above.

10.5. Results

Several papers outline a comprehensive list of constraints presented by the increasing levels of renewables (i.e. over 30 per cent penetration level) and the challenges in integrating them into existing power systems (a summary is provided in Table 10.1).

Table 10.1: Potential challenges in integration of high levels of renewable energy

Issue	*Challenges*
1. Intermittency	– Fluctuations from renewable resources are directly translated into variations in electricity frequency and output, and therefore impact power quality and reliability – Intermittency is hard to model and forecast – increasing reserve capacity requirements and complicating balance of supply for system management
2. System Complexity	– Reliance on battery storage or smart inverter / controller components create additional system costs and complexities for both home management systems and system operators (e.g. voltage smoothing) – System management dispatch systems will likely need to be adapted/upgraded to deal with increasing quantities of distributed renewable resources (beyond 30 per cent penetration levels) – through updated software/trading/data platforms
3. Costs	– High capital costs and lower recovery factors for back-bone network assets (e.g. transmission infrastructure, transfomers) – Higher balance of system costs – Higher fuel costs for peaking plants or back-up generators
4. Threat of power supply interruptions / black-outs	– Reduction in wholesale prices may lead to less base-load generators, increasing susceptibility to blackouts during equipment failure, extreme climate events, or attacks

Source: Adapted from Rodrigues et al, 2014; Denholm and Hand, 2011; Lund, 2005; Hedegaard et al, 2012; IRENA, 2012.

Some of these challenges will be able to be addressed through technology solutions - such as grid-scale battery storage systems (with virtual operability), heat pumps, and electric vehicles, but others will require more advanced control systems, greater flexibility in regulatory and policy settings, updated financial markets and incentive structures, as well as psychological shifts by incumbent energy market participants in order to drive behaviour change and minimise peak demand events that could otherwise be avoided through shifting consumption.

There are numerous technical studies that have investigated some of the solutions to these challenges of integrating renewable energy resources into existing grids. Specifically, these studies have explored how to minimise system instability caused by high penetration of renewables through the use of demand and supply side initiatives (Alizadeh et al, 2016; Morlok and Chang, 2004; Meibom et al, 2007; Ela, Milligan and O'Malley, 2011; Florita, Hodge and Orwig, 2013; Wan, 2012; Lannoye, Flynn and O'Malley, 2011; Lew et al, 2012). These initiatives include greater prioritisation of, and increased incentivisation within demand-side response programs to focus on changing consumption behaviours in order to adapt load requirements to better align with supply outputs, as well as exploring how greater response flexibility in existing plant infrastructure can be achieved (e.g. by increasing the ramping rates of plant output using updated software or incorporating different fuel types).

The studies also reference greater utilisation of 'smart grids'(a traditional electricity grid that has been enhanced through the inclusion of sensors, communication capabilities, computational ability and remote controls) in order to leverage technological solutions that can lead to an improved functionality of the overall electricity grid system as it incorporates increased renewable generation (Gellings, 2009; Siano, 2014).

Three case-studies (focusing on the markets of Belgium, China and South Australia) are explored in detail below, to further outline the practical implications and barriers to initiatives that attempt to connect high volumes of renewable energy sources to existing electricity infrastructure.

10.5.1. Background Case Study A: Belgium

The challenges of increasing renewable penetration have gained prominence in European electricity networks, with studies highlighting the need for flexibly controlled demand and generation in order to maintain system security. A case study of Belgium networks, by Van den Berg et al (2015), highlights the impact and challenges created by the commissioning of over 800 MW of offshore wind farms, outlining transmission grid congestion issues and difficulties imposed on a coastal network not originally designed for a large capacity of offshore, intermittent generation sources.

The authors identify three main issues to address in the Belgium context. First, loop flows (or unintended power flows caused by injections and withdrawals in other parts of the grid) increase the complexity of managing the grid system. Loop flows are particularly relevant in highly interconnected electricity networks such as the European power system. But they may also be significant as Western Australia develops embedded microgrids within its regional networks.

Second, the authors note system management requirements and costs increase for already congested areas of the network seeking to continue to connect additional renewable generation sources. The Belgium example highlighted the issues on coastal networks, but for Western Australia, this could also apply to electricity distribution and transmission lines connecting growing demand loads with the areas best suited to renewable generation plant (e.g. areas with high wind and solar resource such as through the Mid-West of the state). This mismatch between infrastructure capability and electricity requirement would inevitably create new network constraints that would seek further technical solutions.

Last, the research suggests that the back-up security criterion (commonly referred to as ‘N-1’ which refers to having one level of redundancy in the system) may create unnecessary barriers to renewable integration, and costs would be significantly reduced if this criterion is relaxed from being a prescriptive requirement to one that looks at parts of the network on a case-by-case approach. For Western Australia, a broader view of technical rules and system requirements such as the relaxation of a strict security criterion based on location or generation characteristics may also be useful in order to better optimise across system security, reliability, and affordability goals.

10.5.2. Background Case Study B: China

China also provides a useful contextual demonstration of the challenges and opportunities presented by increasing integration of renewable energy technologies. From 2005 to 2010, largely driven by concessional laws and State incentives, China's (land-based) wind capacity doubled every year to reach 44 GW. The Government has still further plans for total wind generation capacity to reach 150 GW by 2020 and is continuing to encourage large-scale wind farms, many of which have capacities greater than 100 MW (Piwko, 2012).

The rapid uptake and integration of these large-scale wind farms is challenging in itself, but Chinese utilities must also deal with the concentration of much of this wind generation capacity within particular areas. Conceptually, this increased challenge makes sense – average renewable penetration across an entire country or State may only be 5 – 10 per cent, but particular locations within the same system could be facing much higher penetration levels (50-100 per cent) at specific intervals – causing more direct technical and operation challenges. For example, in China, the remote Western Inner Mongolian region already has more than 10 GW, despite its isolation, small local consumption requirements at the customer level, and grid infrastructure that is not designed for larger quantities of power transmission.

Further, there were initially no mandatory technical codes and rules for developers to follow to facilitate the secure and safe integration of these wind farms. Grid code features common to other countries to specify generation connection requirements and maintain stable system operation such as reactive power controls, voltage regulation, and fault ride-through requirements were noticeably absent. A lack of grid code resulted in poor operational outcomes, low output efficiencies, and caused frequent voltage collapse and cascaded tripping during system instabilities, which might have otherwise been easily avoided by instituting a standard technical code with mandatory connection requirements. Following several system events, the State-owned grid utility finally issued a grid code in late 2009 with stringent rules on active and reactive power control, voltage regulation and fault ride-through requirements. The code also includes stringent rules testing, wind power forecasting and grid compliance. By 2011, the regulators had finally instituted regulations to ensure new wind turbines be tested for compliance to grid requirements before being granted grid access, with measures also being sought to be applied retrospectively to the initial, problematic wind farms (Piwko et al, 2012).

10.5.3. Background Case Study C: South Australia

South Australia provides another useful example of how the transition to increased renewable energy penetration is progressing – reinforcing the transition is all but straightforward to implement. On 28 September 2016, the State succumbed to one of Australia's worst black-outs, resulting in months of strong debate on energy policy, system security and the role of renewable energy targets.

The event itself was initiated by an extreme weather event (a large storm front with high winds), which caused the loss of three transmission lines, tripped generators offline, and saw the output of the State's wind farms significantly reduce (or cease) over a short period, increasing reliance on the interconnector with the neighbouring State of Victoria. In a matter of milliseconds following the last wind farm that reduced its output, the interconnector itself then tripped offline and South Australia became an islanded network system, causing the entire State to be blacked out due to a "sever supply/demand imbalance" around 3.50pm (AEMO, 2016). The blackout affected most parts of the State's network for over 5 hours, with full restoration occurring overnight.

The significance of a State-wide black-out led to an intense media debate and a wider review was implemented by the Federal Australian Government to understand and assess the implications and issues related to the changing generation mix across the energy networks in Australia. As the Australian Energy Market Operator (AEMO), the market and system operator of the Australian energy sector stated at the time:

> *"The generation mix now includes more non-synchronous and inverter-connected plant, which has different characteristics to conventional plant and uses active control systems to ride through disturbances."*
>
> *(AEMO, 2016)*

Non-synchronous and inverter connected plant are the technical terms for distributed renewable energy generation sources – such as the large-scale wind farms, or rooftop solar PV systems at the residential level. Whilst not problems in and of themselves, the changing characteristics of the generation mix is requiring a change in how the grid is managed and operated, and as AEMO discovered in South Australia, will also require new technical requirements and processes to be implemented.

As the proportion of renewables in the grid increases, technical challenges such as low inertia (a lack of large base-load generating plant supporting the grid) and resilience to extreme events such as that experienced by South Australia will need to be considered and managed. Ultimately, these technical challenges can be overcome, but must also be supported by effective regulations and market mechanism that encourage efficient investment (e.g. consideration of non-network solutions before spending on network assets occurs) and facilitate the transition to increased renewables, rather than prevent and ignore it. These regulations and mechanisms are yet to be defined in Australia, and therein lies and opportunity for utilities to work together with regulators to facilitate how regulatory frameworks of the future will need to evolve. The collaborative approach has gained traction in recent years, with the most influence coming from Australia's leading research organisation, CSIRO, which partnered with the Electricity Networks Association (the peak body representing Australia's energy utilities) to conduct a deep dive into the future of the country's electricity grids, and released several transformative reports and roadmaps, such as its latest Low Emissions Technology Roadmap (Campey et al, 2017).

> *"Recognising that the transformation of the energy system cannot be 'engineered' by any single player, collaboration with participants across the energy supply chain is critical to the progress of the Roadmap."*
>
> (Campey et al, 2017)

What these case-studies all show, is that the energy sector is no longer simply about building electricity network infrastructure – future solutions to electricity service provision challenges will need to come from advances in computational capabilities and machine learning, and researchers have already started exploring how data analytics can be applied to better manage our grid, to assist with the challenges and complexities outlined above as the transition to increased quantities of renewables continues.

10.5.4. Data Digitisation

The accumulation of 'big data'[13] continues at an unprecedented scale, with information flowing from online platforms, mobile applications, wireless appliances, meters and sensors, being stored at increasingly large data facilities at increasingly cheaper cost. Analysts now have enormous computational power with which to sift, sort and synthesize these data, and are leveraging data digitisation and devising increasingly sophisticated algorithms to also embrace machine learning to assist with the challenge (Henke et al, 2016).

> *"Data have swept into every industry and business function and are now an important factor of production, alongside labor and capital."*
>
> (Manyika et al, 2011)

[13] Big data is the term used for extremely large data sets (there is no defined quantity) that can be structured and analysed for patterns, trends and information, especially relating to human behaviour.

A review of existing research in the field of big data reveals four ways in which big data creates significant value for businesses that can harness it (Manyika et al, 2011; Bughin, Livingston, Marwaha, 2011; Court, 2015; Buluswar, 2016):

1. It makes information transparent and enables it to be used at a greater frequency;
2. It increases the accuracy, detail and quality of data across all forms and levels (e.g. product inventory, employee rosters), exposing variability, fluctuations and providing performance improvement potential and analysis to drive better management decisions;
3. It provides for a greater level of customer segmentation and the potential to tailor specific products and services at the individual customer level; and
4. It provides a platform for the next generation of products and services and enables further innovation (e.g. proactive maintenance before failures actually occur).

Across almost every industry, businesses will need to leverage data-driven analytics and decision making to remain relevant, to innovate, stay competitive and to capture the value on offer from the enormous quantity of new information on offer. However, challenges remain in addressing issues related to information security, data access, consumer privacy and intellectual property rights in the emerging big data sector.

Nevertheless, as outlined by Manyika et al (2011), the significant increase in the volume and resolution of information captured by smart meters and smart appliances, combined with the rise of social and multi medias will drive exponential growth in the recognition of the importance of data analysis for most companies, and particularly for utilities and energy market participants going forward. Specifically, data analytic capabilities will allow analysis of both external factors to utility business operations, such as forecasting weather and high demand events, and internal, operational factors such as network loads and stresses, with the analysis further enabling efficient electricity use at the network and household level. By incorporating the advantages of big data, renewable energy penetration can overcome the outstanding technical and financial barriers. For example, big data may provide analysis to reinforce the business case for non-network solutions, highlighting that further optimisation of existing generation with forecast load can be done in a way that drives improved efficiency of existing assets. Ultimately, big data should allow utilities to drive better decision making and influence customer behaviour with appropriate incentives.

10.5.5. Machine Learning

Machine learning is a related aspect of the future of analytics (part of cognitive science and the field of artificial intelligence) that makes optimized output predictions using algorithms based on historical data as inputs. Machine learning can be used to compliment data digitisation and big data, providing a scalability aspect to data science and leveraging computational capabilities to build predictive systems and solve complex analytics problems (Wang et al, 2013).

One method of machine learning gaining increasing prominence is artificial neural networks (ANN), being used to solve a variety of tasks such as speech recognition that is too complex for ordinary rule-based programming. The ANN method replicates the human brain to process information and creates complex relationships between inputs and outputs.

The inherent complexity of balancing energy generation and consumption in real time, and forecasting demand and planning for energy system requirements in the future creates an enormous opportunity for machine learning and methods such as ANN within the energy sector (Setaiwan, Koprinksa and Agelidis, 2009; Pai and Hong, 2005).

As technology innovations (e.g. smart meters, smart appliances, inverters and control systems) increases both the volume and the ability for data collection and analysis, and as renewable penetration increases the complexity of grid management due to volatile climatic factors, system noise, line losses and behind the meter loads and generation, ANN algorithms are beginning to provide researchers with potential solutions that can underpin intelligent energy management and forecasting systems (Wang et al, 2010; Su, Liu, Stay, 1999; Liang, 1999). The ability to mine and identify the value in large data sets is a challenge, but big data tools provided by machine learning are already allowing innovative researchers and companies to overcome these challenges at rapid rates (Wu et al, 2014).

In their 'big data' research paper, Rahman, Esmailpour and Zhao (2016) propose a big data forecasting model using machine learning to train the electricity dispatch and operation system for more effective prediction of demand and supply outcomes that achieved a 99 per cent accuracy rate. Using similar machine learning methods in combination with geospatial modelling, a study by Assouline, Mohajeri and Scartezzine (2017) was able to estimate the upper penetration level potential of solar PV in urban areas of Switzerland, taking into account shading effects, solar radiation, roof slopes and aspects and available roof surface area. And as the volume of data being stored, shared and uploaded to the internet continues to exponentially expand, Google is seeking to develop in-house big data and machine learning expertise – through its artificial intelligence group 'DeepMind' – that is tasked by studying the patterns in Google's data centre operations in order to increase energy efficiencies (Kahn, 2016).

10.5.6. Incorporating 'big data' in the WA energy sector

As capabilities in software and data analytics increases, the electricity sector can start leveraging the functionality provided by smart meters, in order to analyse and optimise what electricity customers' need, when they need it and how energy products and services can best deliver it. Fundamental to recognising this value is a shift away from the traditional models of utilities, towards business models that facilitate innovation, encourage research and innovation, and maintain flexibility going forward, as outlined by Tayal and Rauland (2017).

For WA utilities, opportunities already exist to lower the cost of service and reduce the reliance on Government subsidy by leveraging innovative technologies and increasing efficiencies in the business. For example, by installing 47,000 smart meters across its customer base[14]), Horizon Power (the regional electricity utility provider in WA) is in prime position to understand how the next generation of energy technologies can optimise the provision of electricity services across its service area (Horizon Power, 2016).

Smart meters provide a range of advantages to electricity utilities - through electronic billing (avoiding the need for manual meter readings and testing), increased accuracy of consumption data, and the potential for connectivity across meters, which could provide opportunities for trials in aggregated system control (in the context of virtual power plants and distributed energy generation assets).

Yet it is the data that these smart meters generate that could prove most useful for energy participants seeking to understand how to manage the transition to penetration levels of renewables 30 per cent and beyond. Smart meters provide extensive, real time customer consumption datasets, which can combine with weather and network system data to assist system management functions in managing intermittent loads and generation sources – directly address both the technical and financial limits to higher penetration of solar PV and storage technologies (Horizon Power, 2016).

The extensive microgrids within Horizon Power's regional networks, in particular, are also more prone to having high levels of renewable energy (e.g. distributed solar PV well beyond 50 per cent penetration levels), and can therefore greatly benefit from some form of intra-network (between microgrids) intelligent control systems to optimise energy flows.

[14] Smart meters (also referred to as 'advanced meters') were upgraded for all Horizon Power customers on a mandatory basis to provide electronic billing, 15 min metering cycles, and remote communication capabilities.

For example, building on the three time-frame energy cycle concept and leveraging data analytics can assist in planning and improve the ability to meet balancing requirements for energy supply to meet energy demand:

1. Long-term planning helps to prepare the electricity system for extreme events such as peak demand or large troughs in supply (years/months ahead);
2. Continuous balancing (days/minutes ahead) ensures supply equals demand irrespective of generation source; and
3. Controlling frequency instantaneously (seconds after) assists in resolving frequency deviations caused by contingency events and forecasting errors.

Combining advances in battery storage and inverter products through ongoing trials, pilots, partnerships and demonstration projects will also provide opportunities for WA utilities to transition to new energy technologies and high penetration of renewables. Peer to peer trading (customers selling electricity amongst themselves), virtual net metering (netting off excess electricity generation from one bill, and transferring it to neighbouring customers) and network credits (customers receiving a share of the financial benefit from avoiding network upgrades) are just some of the emerging innovative ideas that will create new data sources, and may require complex data analytics (e.g. predicting which loads will need electricity where and when) in order to operate successfully and maintain network security and reliability and customer satisfaction.

10.5.7. Identifying the Opportunity

Evergen and Reposit Power are two new Australian energy technology start-ups, already trialling how the innovative use of data can benefit customers, by combining consumption patterns with weather forecasting data to ascertain when best to consume rooftop solar Evergen and Reposit Power are two new Australian energy technology start-ups, already trialling how the innovative use of data can benefit customers, by analysing electricity consumption patterns alongside weather forecasting data to ascertain when customers should consume rooftop solar power, when to store it, and when to sell it back to the grid based on price and energy usage preferences (Vorrath, 2016).

Redback Technologies, based in Queensland, is another company seeking to encourage the use of ‘smart’ inverters and metering that uses wireless communication between solar panels, batteries and major home appliances such as air-conditioners and washing machines, to optimise and manage energy consumption at the household level - ‘behind-the-meter’ (Redback, 2016).

These companies, and their innovative products, provide an insight into the novel applications that ‘smart’ energy technologies can provide, leveraging inter-technology communications that not only drive efficiency for network utilities at the grid-level (providing grid stability, support and alternatives to traditional methods of network asset investment), but have potential to also result in more cost-effective outcomes for customers, particularly as electricity tariffs become more cost-reflective and adapt to incentivise reduced consumption during periods of peak demand. The Western Australian Government, in particular, has signalled an acute awareness for the need for electricity tariffs to reflect their underlying costs, recognising that ongoing (and increasing) subsidy levels are untenable (Mercer, Emerson and Wearne, 2017). Increasing electricity tariffs will provide even further incentive for consumers to install solar PV and storage systems, even as solar feed-in-tariff schemes reduce payment rates or come to expire across Australia in the coming years.

As the electricity service model continues to change, the entire sector is being disrupted by new technology and new entrants, non-traditional utility start-up companies that are securing the interest and the funds from various venture capital and financial backers to develop the future of high penetration renewable energy grids. For example, Sunverge received $37 million in funding from AGL and Mitsui in February 2016, to develop grid automation technologies, BitStew Systems received $153 million in funding from GE Digital in June 2016 to deliver ‘edge computing’ services, and BuildingiQ received $20 million by AS IP and Aster Capital in December 2015.

10.6. Conclusions & Policy Implications

One scenario for the future of electricity grids, particularly in WA, could be a transition towards one of distributed microgrids with high levels of renewable generation sources (over 50 per cent), linked through intelligent, wireless communications to manage flows and maintain overall system security and stability. Data digitisation and analytics combined with machine learning is already impacting the transport and health sectors, and the influence of data analyses in the energy sector is also likely to gain momentum, as computational capabilities increase to manage big data, and as machines develop algorithms to solve the energy challenges of the future.

Of course, this vision is predicated on the assumption that both technical and financial barriers are overcome through the appropriate application of new energy technologies and innovations, such as smart inverters and distributed battery storage systems. And several institutional barriers will also need to be overcome, such as the removal of redundant regulatory frameworks that fail to incentivise non-network solutions. But the transition to more flexible regulatory and economic models has already begun, and as innovation continues in the sector, it will continue to drive the transition forward, and regulators, policy makers and innovators within industry and governments alike will need to ensure they stay up-to-date and do not intentionally, or unintentionally, block the development of these new products and services that will become part of electricity service provision.

Utilities will need to continue to encourage research and development, undertaking trials, demonstration projects and taking risks in an industry that has historically discouraged risk-taking. The evolution of the electricity industry has commenced a process of creative-destruction, where new products and services and new entrants will compete with traditional, incumbent utility business models. Big data, analytics and machine learning are only three examples of technology innovations that are assisting in driving this evolution forward. Ultimately, the transition to increased renewables within our electricity grids is not one that should be feared or resisted, but instead should be recognised as an opportunity for something that can generate financial and customer choice benefits for both users and service providers.

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CHAPTER 11: DISCUSSION AND CONCLUSIONS

The Western Australian electricity market is gaining increasing global significance due to the rapid adoption of solar PV, growing interest in battery storage and resultant disruption that is occurring in the energy sector. As the preceding six papers have shown, WA has inadvertently become a central player in addressing the universal challenges that are inherent in the transition to a renewable, distributed model of electricity networks.

Combined with these technology disruptions, the structure of WA's electricity market itself (currently dominated by Government-owned entities) is also undergoing a major reform program that is actively considering a move to full retail competition and coordinated regulation. The industry appears open to consider major structural reforms and market re-design - not just economic improvements to existing models. For example, WA is now in prime position to consider the impact of increasing penetration of solar PV on the grid and unlock the potential of the increasingly cost-competitive battery storage systems. These technology innovations will only increase the challenge for utilities and Government, and WA's isolated electricity network and energy market will become a demonstration site for energy authorities around the world looking for guidance on how to manage the transition.

The unique set of conditions within WA has made it a place ripe for disruption. Globally, energy businesses will be closely monitoring how the WA energy market evolves, to observe what new business models emerge and how the utilities cope with the transition. For this reason, it is expected that WA's energy market will become a pilot project site for energy businesses seeking to manage the transition and adapt their own business models necessary to meet the demands of consumers of the future.

Indeed, the opportunities in WA have already been identified by global technology and energy service companies (e.g. storage providers: Enphase, Tesla and Redflow), who are working with local governments and electricity businesses to pilot projects such as battery technology trials, innovative pricing structures, and long-term capacity planning methodologies. As the diffusion of these technology innovations grows in the WA energy market, new opportunities will continue to arise for both existing and emerging businesses, and importantly consumers are in line to benefit.

11.1. Significance and Originality

Although research on increasing the adoption of solar PV systems has a long heritage, beginning in the 1980s and with research literature continuing today, contextualised studies seeking to explore disruptive innovations and impacts on electricity utility business models, pricing regimes, and research and development priorities are all still nascent areas of academic research.

This research aims to fill this gap in existing literature, leveraging learnings from the WA market to inform governments and industry participants around the world on how to evolve their existing networks, models and processes.

Therefore, whilst this research uses a localised contextual study to analyse barriers, challenges, opportunities, risks and future developments specific to the WA energy market, the research findings will be relevant to energy companies and utilities around the world. These stakeholders are already grappling with similar challenges within their own markets, and are looking for assistance on how best to manage these system disruptions and transitions.

The research expands beyond the current body of knowledge to explore appropriate solutions, and model new pathways of the energy market transformation that will inevitably be occurring on a global scale.

All electricity grids share a common goal of achieving a safe, secure, sustainable and affordable service of electricity to customers. Achieving this will involve integrating new technologies into existing grid structures and business models, as well as creating the need for completely new business models going forward.

This research can therefore be viewed as a critical addition to the global energy debate, providing suggestions, findings and recommendations and enabling future research of these issues. WA, whilst isolated, remote and relatively small in the context of global energy markets, is already being recognised as a significant player in trialling new technologies and regulatory frameworks that will guide all policy makers, utility strategists and regulators on how to create our future electricity networks.

11.2. Research Findings

This doctoral research has sought to fill a gap in the existing literature and provide insight for utility managers, policy makers, government and customers to inform decision making going forward – both in WA and in world utility management. It aims to provide valuable insights and recommendations on how to help facilitate the transformation of the electricity system, and overcome the significant inertia of a system when exposed to change.

The research has led to several original findings and recommendations underlying the principal research question:

> *How solar PV and storage systems can be integrated into electricity networks in a way that aligns with the interests of consumers, utilities and government to create a more sustainable energy model.*

The six sub-questions identified as research objectives underpinned the six peer-reviewed papers. This section summarises the main research findings and conclusions within each. It is anticipated the findings will have implications within both global and local communities, as an increasing number of energy markets reach the disruptive threshold seen in WA.

1. *What are the disruptive forces on the electricity industry and what is driving the sector to change?*

The energy sector is facing significant disruptive pressures – challenges created by global carbon emission concerns, technology innovations and price reductions, slowing demand,

and infrastructure requirements. The commerciality of conventional, centralised generation and transmission networks is also rapidly being challenged by the decentralised models of clean technology such as residential solar PV and battery storage. This has been illustrated very clearly in fringe of grid and regional towns across WA, and there is very little published research that can readily assist. There is no perfect answer in how utilities will manage this transition, and with solar penetration rates continuing to increase, there is currently no template to follow. In practice, achieving this transition may require a complete overhaul of the strategy employed by utilities, rather than simply rely on incremental changes (Paper 1).

2. *What are the barriers for solar PV and storage markets and will the rapidly evolving landscape drive potential opportunities?*

Policy makers who intend to enable widespread adoption of solar PV and storage will first need to overcome several barriers in order to support these emerging technologies. These barriers can be grouped into three classifications:

- Technological (forecasting capability, constraints of existing technology, network capacity and access);
- Institutional (Psychological will, organisational management, government policy and lobbying, consumer inertia and information blocks); and
- Financial (sunk network costs, upfront system costs).

To assist in addressing these barriers, this research suggests that market participants must work with policy makers to drive flexibility in regulatory frameworks and progress the evolution towards innovative and sustainable electricity networks (Paper 2). In particular, utilities should: actively pursue adaptable regulatory frameworks that facilitate technology update, reduce barriers to entry, and embrace the long term view; engage with policy makers and regulators to get the framework right and then let the market and competition drive the solutions; and provide pragmatic solutions for Government, recognising that commercial solutions may be untenable based on political appetite (Paper 3).

3. *How should utility business models evolve to facilitate the uptake of distributed solar PV and storage systems?*

The real challenge for utilities is overcoming inhibitions to adapt to changing market conditions and surmounting the barriers to innovation. This is illustrated in WA's utilities by their requirement to obtain Ministerial approval, as well as Board approval, for all major strategic initiatives. Should these businesses remain as public corporations going forward, these restrictive remits will need to be flexible enough to adapt the company's functions and objectives to encourage innovation and repositioning, not hinder it. This research suggests that incumbent energy utilities will therefore have to adapt and compete with new services and products, or face increasing redundancy in the market. These challenges are already being faced by WA's state owned companies, and similar challenges are expected to arise increasingly for energy companies around the world.

This research also suggests that a collaborative mindset is needed to ensure utilities recognise the role they must play in guiding regulatory reform and driving governments and regulators to accept the uncertainty that future business models must navigate to succeed. Findings from the research suggest that energy businesses should do this in an iterative, phased approach. For example, businesses should embrace the opportunities presented by emerging technologies (such as solar PV and storage), but do so in a modular fashion, to ensure capabilities are maintained, costs are minimised and customers are retained (Paper 3).

4. *How will the continued uptake of solar PV and storage affect electricity pricing and what are the likely impacts and preferences for consumers?*

Another finding of this research is that WA residents (and potentially global residents) are very open to change electricity consumption behaviour, and they recognise the value that solar and storage systems provide to enable cost reductions in electricity bills. However, customers also perceive that electricity prices are too high, and want a special rate for solar and storage technologies to assist in bringing down this cost. These findings will have increasing relevance around the world as residential electricity demand increases, markets are de-regulated, competition is increased, and new retail products are introduced to provide more cost-reflective price signals. This trade-off and circularity between the need to drive behaviour change and the need to provide cost-reflective pricing is the same issue for all utilities and policy-makers around the world (Paper 4).

5. *Can existing barriers be overcome through technological innovation and what role will innovation play in the strategic development of utilities?*

Investigation of technology innovation (and appropriate environments to facilitate ongoing innovation) suggests that research, development and innovation is critical to the evolution of incumbent utilities and will enable barriers to be overcome. For example, regulatory regimes, established to encourage long-term economically efficient investments by the utility, will need to adapt to recognise the contribution that non-utility-owned assets play in economic efficiency. Utilities will also need to understand they share the burden of responsibility, on behalf of their shareholders and customers, to drive regulatory and policy change – through partnerships with universities and research labs (and other entrepreneurial means like hackathons) in order to enable innovation through the business as well as through the sector as a whole. This research outlines that these partnerships between companies, research institutions and entrepreneurs will likely form a major component of electricity business models going forward (Paper 5).

6. *How can the electricity industry leverage the innovations in computational capabilities and data analytics to achieve higher penetration of renewable energy?*

Finally, the research explores how greater levels of renewable energy can be integrated into existing grids by utilising technology developments in data analytics and machine learning. These areas provide the computational power and sophisticated algorithms needed to synthesise and comprehend information from the endless streams of data ('big data') flowing from new online platforms, meters, and sensors.

Research findings suggest that as the uptake of distributed renewable generation increases, electricity utilities around the world will need to incorporate advanced control systems and leverage big data analytics and machine learning in order to appropriately manage future intelligent grids.

11.3. Limitations and Future Work

While this thesis predominately focused on the WA energy market as a case study from which to derive findings, there is a common foundation of electricity infrastructure, customer behaviour and new technology innovations that are applicable globally. Therefore, this research provides critical insight to encourage energy businesses and utilities operating in similar energy markets around the world to utilise solar PV and storage systems in a strategic fashion in order to reduce grid congestion, remove (or at least defer) the need for network investments, maintain downward pressure on electricity prices, help to decarbonise the electricity network, and most importantly, to stay relevant in the evolving, highly disrupted energy market.

Future work could investigate the applicability of consumer behaviour theories in assisting with implementation of tariff reform, improving customer's knowledge and appetite to adapt to new pricing structures, technology systems and to maximise savings opportunities. For example, the drivers for behaviour change could be investigated beyond simply financial reward, using theories from other industries with regards to cues, habits and non-financial incentives. In addition, an expanded quantitative survey across Australia or in similar energy markets around the world could also be conducted with various sample populations.

Further research is also needed to examine the specific solutions that may be required to address and minimise the negative impact on the network and the market during a re-structure process. For example, how losers of tariff reform will be compensated or protected, or how those customers without solar or storage systems may also be able to realise benefits and participate in sustainable, renewable, smart grids of the future. This is highly relevant to utilities around the world seeking guidance within their own markets.

Financial analysis could also be undertaken to further explore the value that solar and storage systems provide, in an attempt to assist policy makers with quantifying the level of subsidy or incentives that electricity customers might fairly seek in response to assisting the avoidance of network augmentation.

11.4. Concluding Remarks

This thesis is part of the journey being taken by most communities around the world towards a renewable energy future. It has shown that dramatic changes are underway, due mostly to solar PV and battery storage, and that WA provides a valuable case study about where and how to proceed on this journey.

Ultimately, it is hoped that this research provides a basis to formulate ongoing discussions and continue exploring these critical energy issues. If the findings of this research can be built on through further work, it will promote a nexus between the electricity industry, consumers and governments, and lay a foundational framework for other energy markets to follow in their own evolution towards innovative and sustainable electricity networks of the future.

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Under initial guidance from supervisors, I took primary responsibility for the design, data collection, analysis and drafting of each manuscript, and prepared the papers for submission to relevant journals.

Anant Dev Tayal

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Disruptive forces on the electricity industry: A changing landscape for utilities

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ABSTRACT

The energy sector has been navigating rapid technology innovation, slowing demand, and rising electricity prices. A steady shift towards renewable energy products is also exacerbating the disruption of utility business models. This article outlines the drivers of disruption for electricity utilities, and explores potential risks and opportunities should traditional business models evolve to embrace innovative technologies going forward.

1. Introduction

1.1. The energy model transition

The underlying economics for conventional energy markets and systems have already shifted in favor of the decentralized models of clean technology – as afforded by solar PV and storage at the residential level, and larger renewable projects at the community scale. In effect, this has created excessive uncertainty for existing, 'traditional' energy market participants, and concerns are already being raised with regards to future industry investment and business decisions for energy companies (COAG, 2014; Allen et al., 2009; Grace, 2014).

With the attractiveness of new energy products and services such as solar PV and storage only increasing, the electricity industry is now regarded as ripe for disruptive potential (Frankel et al., 2014; Roberts, 2013). In particular, this new wave of technical innovation is set to disrupt electricity utility business models, dramatically affect the availability of capital in the industry, and further intensify issues within the electricity markets (Denholm and Margolis, 2007; Katiraei and Agüero, 2011; Yip, 2013).

As market dynamics force the hand of electricity utilities globally, changing the business model away from a conventional, grid-based system towards one that embraces distributed solar and storage across the entire network is the only long-term solution for electricity businesses (Tayal & Rauland, unpublished). Utilities undertaking future business planning and strategy development should be proactively looking to energy efficiency, solar PV, and storage as growth opportunities rather than as an existential threat, and acknowledging that their place in the energy system will only grow (Poudineh and Jamasb, 2014; Klose et al., 2010).

Ultimately, all electricity grids share a common goal of achieving a safe, secure, sustainable and affordable service of electricity to customers – and this can only be achieved by first recognizing that the old model is no longer suitable.

In the past decade alone, the energy sector has been navigating: rapid technology innovation (removing barriers to entry for small players); the falling cost of distributed generation; increased interest in demand-side management; slowing trends in demand; shifting government policies on renewable energy incentives; and rising electricity prices (Kind, 2013; Newcomb et al., 2014; Grace, 2014; Bunning, 2011). In combination, these factors are set to fundamentally change the way our electricity systems operate.

The key for electricity provision may include making industries and systems smaller, as efficiency advocates propound, but it must also require that they are redesigned in a way that replenishes, restores, and nourishes (Braungart and McDonough, 2002). And as Ashford et al. (2012) note, we need to be prepared to challenge ingrained, limiting, and outdated beliefs.

2. Background

2.1. The old model in a different setting

Traditional business models for utilities reflect the centralized system of electricity generation and network design (Kind, 2013; Bromley, 2015; Caldecott and McDaniels, 2014). This centralized system also drove a standard approach to system security and network planning, economic regulation, and underpinned the design of wholesale and retail markets and dispatch engines

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(Schaltegger et al., 2012; Richter, 2013; Roberts, 2015; Sioshansi, 2014).

Recognizing this "coupling" of volumes and profitability was at a natural tension with the assumption that electricity should be treated as a "public good," the electricity industry most commonly became a natural monopoly (Newcomb et al., 2014).

However, this view of electricity utilities as natural monopolies is now coming under increasing scrutiny due to a convergence of several factors across technology, economics, and public policy. Customer impacts are now driving investment trends in the opposite direction (through energy efficiency and distributed generation) and the increasing uptake of solar PV and storage will only exacerbate this trend (Zinaman et al., 2015).

3. Methodology

3.1. Literature review

A review of existing literature was carried out over 12 months to gain a broad understanding of the central drivers disrupting the electricity sector as a whole, across major electricity markets around the world.

4. Discussion

4.1. Existing barriers

Currently, the interests of utilities (preventing stranded assets, maximizing electricity sales, preventing increased competition) are in tension with the interests of consumers and the environmental imperative to decarbonize the electricity sector (Roberts, 2015).

Further, any solutions designed to meet the transitioning needs of the energy industry will need to be based on the individual regulatory and market contexts in which they emerge (Crawford, 2015; Hogan, 2014). For instance, utilities in competitive markets will be more directly exposed to the threats that arise from technology innovations such as solar and storage systems, given their ability to reduce electricity use and demand (Kind, 2013). There are also a series of regulatory, institutional, and financial barriers that remain and that inhibit the effective transition of electricity businesses to new ways of operating.

Utilities themselves are also likely to have a predisposition to inertia – what transition theory terms "path dependency" – being locked into a particular pathway that inhibits consideration and adoption of innovative ideas (Lee and Gloaguen, 2015). Traditional utilities have been found to rely on traditional forms of research and development (Frankel et al., 2014). This is a significant risk across the industry, given the momentum that new, distributed technologies and "big data" is gathering. Utilities of the future will be expected to have their own innovation hubs or partnerships, identify new ideas, and leverage the capabilities of other businesses that can provide products and services complimentary to their traditional offering.

> *Nimble information gathering produces a better foundation for strategic decisions and a more diversified flow of ideas for innovation* (Heiligtag et al., 2015).

The restructuring of electricity tariffs also creates significant obstacles for governments and policymakers to overcome. While regulatory frameworks allow for cost recovery in future tariff proposals, existing tariff structures can create the perverse incentive that results in customers without solar PV having to pay the most for lost revenues. As solar penetration increases, this cost recovery structure will only further attract political pressure to undo these cross subsidies, ultimately exposing utilities to the risk of stranded assets – see Section 4.4 below (Caldecott and McDaniels, 2014).

4.2. The Western Australia case study

Western Australia (WA) presents a uniquely challenging environment under the "traditional" approach to electricity service provision. WA occupies an area equal in size to the United Kingdom, but with a fraction of the population density – with around 1 million customers as opposed to 73 million (McGoldrik, 2016). This has always created challenges for the government-owned electricity utilities, which rely on millions of dollars of annual subsidies to provide uniform electricity tariffs to residential customers across the state, irrespective of location. Of course, the actual cost of supplying customers in the remote and rural towns scattered across WA is significantly higher than providing electricity to anyone living in the state's capital, Perth – which has established distribution networks, excess capacity, and a reliable distribution network (Government of WA, 2014).

In addition, the maintenance costs for such an expansive network are significant, in and of themselves, with additional threats of bushfires and cyclones preventing the state government from expecting to move to a cost-reflective centralized service model any time soon. However, with the declining costs in stand-alone power systems – with cheaper solar PV and battery storage components – WA has realized it may need to rethink this traditional centralized model. The outstanding question is what can be done to minimize the pain for these utilities to walk away from billions of dollars of investment in the grid infrastructure.

4.3. Banking sector acknowledgement

A number of banking institutions have already identified the decentralized electricity system as a necessary transition given the financial impact that would result from maintain existing models, and have adjusted credit and stock ratings of involved electricity businesses accordingly. For example, the financial risks created by disruptive technologies such as solar PV and storage systems include declining utility revenues, increasing costs, and lower profitability potential, particularly over the long term. Adding the higher costs to integrate increasing penetrations of distributed generation technologies will inevitably result in lowering profitability and, therefore, credit metrics. Failing to address these financial pressures with a restructure of business models would result in a major impact on equity returns, required investor returns, and credit quality (Kind, 2013; UBS, 2014).

Given the increasing pressure on traditional pricing structures and revenue sources, the financial institutions themselves are recommending utilities to develop "smarter grids" by partnering with solar, battery, and smart meter providers in order to leverage their existing relationship with customers (Rader, 2015).

UBS, a leading investment bank and financial analysis firm, is very optimistic about the impact of large (utility) scale solar on energy markets around the world, citing that by 2025, utilities could make up 50% of the solar market across the world (UBS, 2015). The UBS report (2015) goes on to suggest that utilities will be the "lead actors" in large-scale solar, replicating the business models of U.S. companies like SolarCity (UBS, 2015).

Table 1 summarizes the views from UBS and three other investment banks on the impact of electricity sector disruption.

4.4. Stranded asset risk

From an accounting perspective, stranded assets are those that succumb to unanticipated devaluations, early write-downs or are ultimately converted from balance sheet assets to liabilities.

Table 1
Bank responses to electricity sector disruption.

Bank	Comments
UBS	• sees the potential of pairing solar and storage systems (and electric vehicles) with responsive demand as a perfect fit for a smarter grid of the future, with nightly charging smoothing the demand curve.
HSBC	• recommends utilities leverage their relationship with customers and existing assets to become full-spectrum service providers via a smart grid. • utilities could market value-added services to customers or provide backup power.
Citigroup	• utilities have the option of boosting their asset base by investing in storage – alongside vehicles and consumer electronics, sees utilities taking advantage of storage as a pillar of growth.
Morgan Stanley	• similarly highlights the greatest value is gained from a utility integrator model, especially in Europe, to offer energy services including finance, design, and installation of solar-plus-storage solutions. • Addressing central generators, the recommendation was fairly straightforward – invest in renewables since fossil plants will lose out due to fuel costs.

Source: based on Rader, 2015; UBS, HSBC, Citigroup & Morgan Stanley analyst reports, 2015.

Stranded assets come about through a variety of reasons, usually driven by an underlying misunderstanding (and mispricing) of the level of risk involved in the venture, and the assets exposure to that risk (Caldecott and McDaniels, 2014).

In the electricity sector, utility businesses are already witnessing the potential for their assets to become stranded. For example, in Europe, previously highly regarded peaking gas, operating in markets with excess capacity, have quickly become financially unsustainable due to the lower wholesale price of electricity they receive not covering their marginal cost of generation (Green and Staffell, 2016).

Power stations around the world commonly have business cases reliant on high utilization rates, built on the assumption that energy demand will continue to increase, or that innovations such as rooftop solar PV and battery storage are still nascent technologies years away from impacting their market share. As this article discusses, however, a whole series of factors are disrupting these business cases and underlying assumptions.

Ultimately, if the outlook for these power stations is not expected to improve (e.g. through a resurgence in demand, or a significant change in cost structures), than these assets will need to be prematurely mothballed, or retired ahead of schedule. More often than not, this will involve a significant write-down of capital costs, leaving asset holders with large sunk costs that will never be recovered from the project itself – the stranded asset (Caldecott and McDaniels, 2014). As more and more assets are gaining the uncoveted "stranded" status within utilities' portfolios, investment in the sector is being increasingly marginalized.

4.5. Disruptive forces: lessons from other industries

With the increasing prominence of solar PV and storage in the electricity sector, these systems are now commonly referred to as "disruptive innovations," due to their impact on the entrenched, centralized models of electricity generation and the strategic challenges they present to electricity markets going forward (Richter, 2013).

Originating from an article by Christensen and Bower in 1995, disruptive innovation is defined as:

> *. . . an innovation that helps create a new market and value network, and eventually goes on to disrupt an existing market and value network (over a few years or decades), displacing an earlier technology.*

The term is now widely used in business and technology literature to expose the vulnerability of existing business models to new innovations in products or services that revolutionize the market. A commonly cited example is Eastman Kodak (Kodak). Once a dominant, highly profitable marketer of photo film and related supplies, Kodak became a redundant observer as the photo business was transformed by digital technology, before finally filing for bankruptcy in 2012 (Christensen and Raynor, 2013).

From an industry perspective, the telecommunications industry may also provide some insight into the impact disruptive innovation can have, and highlight challenges and opportunities that may face the electric utility industry.

In the late 1970s, the telecommunications industry was price- and franchise-regulated, with high barriers to entry provided by the capital-intensive nature of the business as well as the protective government regulations in place (Kind, 2013). However, as mobile phone technology developed and become widely adopted, traditional sources of revenue for telecom firms were significantly impacted, and the entire industry underwent regulatory reform to encourage competition. As a result, the businesses operating in the telecommunication sector in the 1970s are not recognizable today.

In the United States, traditional telecommunication companies such as AT&T and Verizon maintained their leadership in wireless telephone services by incorporating a progressive vision in their business models and services to lead development of unregulated networks and update consumer marketing approaches. As a result, they managed to maintain their large shares of the United States telecommunication market and have continued to leverage technology innovation to expand customer offerings (Kind, 2013).

Similarly, technology innovations that enabled broader communication, such as the modem, were a critical enabler for the Internet revolution that began in the late 1990s. By purchasing a modem, any consumer with a computer and a telephone line was able to access the digital world, without requiring any further network alterations by the telephone company and encouraged the development of other technology innovations to focus on interconnecting household communication systems with the broader telephone exchange system (Pentland, 2015). It is expected that distributed generation technologies, such as solar PV and storage, will follow similar transitions, reliant on open access protections that facilitate development of systems at the household level.

Shomali and Pinkse (2015) looked at how the introduction of smart grids[1] may present a threat to incumbent utilities, given the potential for new information and communication technology (ICT) firms to enter the energy market. The authors concluded that while incumbent electricity utilities may have strong drivers to

[1] Smart grids are defined as "an electricity network that uses digital and other advanced technologies to monitor and manage the transport of electricity from all generation sources to meet the varying electricity demands of end-users" (IEA, 2016, p.6).

innovate their business models to include and embrace smart grids (and also to better integrate renewable energy technologies such as solar PV and storage), there are currently several uncertainties around the threat of new entrants, government support, and consumer engagement acting as barriers to such innovation, on top of the general resistance toward business model innovation for fear of losing current revenue streams (Shomali and Pinkse, 2015; Amit and Zott, 2001).

The electricity industry has largely avoided disruptive threats for over a century due to large customer monopolies and the value derived from economies of scale leading to easy access to relatively low-cost capital. However, given the impact that disruptive challenges such as technological innovation, changes to public policy, and consumer preferences may have on electric utilities in terms of their future investment and access to capital (and resultant impacts on consumers), it will be necessary for electric utilities to keep these historical outcomes for other industries in mind, as the industry continues to shift. Business development plans and medium to long-term strategies must address disruptive threats and be open to replace their own outdated technology with new products. Tesla's widely publicized residential and commercial battery announcement on April 30, 2015, will be just one of several announcements that will expedite the transition as new entrants and consumers alike drive momentum towards more innovative services at competitive prices.

4.6. Implications of disruptive innovation

Traditionally, electricity utilities have increased their revenue earnings by either expanding electricity sales (consumption volumes) or increasing prices charged per unit of sales (higher electricity prices) – the old measures of success. Whilst these levers have provided consistent returns to investors for decades, due to the disruptive technological threats outlined above combined with changing consumption patterns, utilities of the future will need to transform their business models in order to maintain their revenue sources and meet the higher required rates of return for their investors (Kind, 2013; Tayal and Rauland, unpublished).

Given electricity prices are a function of consumption volumes, when electricity sales decline – due to demand management programs, innovations in energy efficient appliances, distributed generation, or other behavior changes – electricity companies will need to increase rates charged across remaining volumes in order to continue to meet the cost of providing service (meet the cost of capital). What this scenario ultimately leads to, however, is what the media has luridly dubbed the "death spiral," where increasing electricity prices simply drive further reductions in consumption by enhancing the proposition of competing technologies and demand management programs. Grace (2014) modeled this impact on the Western Australian South West Interconnected System, showing how high levels of solar PV uptake would likely result in a cycle of price rises that leave very few customers to support the high costs of the embedded transmission and distribution infrastructure.

Industry analysts are now less fearful of large volumes of customers going off-grid and inducing a death spiral on the incumbent utilities. Even with aggressive estimates for electricity storage technology, given: (a) the concentrations of solar production relative to peak demand; (b) the technical limitations of batteries; and (c) the advantages that distribution networks provide (e.g. buying and selling excess energy between local areas); it is expected that most customers will maintain some form of network connection (UBS, 2015; Nahan, 2015). Rather than threaten the ability of utilities to invest in key infrastructure, the uptake of solar PV systems will drive substantial volumes of intermittent energy and require additional frequency control measures – necessitating substantial investments in smart grids and grid-scale batteries (UBS, 2015). In effect, while utilities may lose some revenue from traditional forms of generation, additional earnings from playing an integral part in the future of smart grids and solar and storage technologies are likely to more than compensate for any losses (UBS, 2015).

4.7. Potential preventative responses

The electricity industry is very much aware of the increasing pressure to implement actions and prevent a worst-case scenario. Strategic actions circulated previously by industry groups for consideration include (Kind, 2013):

- Assess depreciation calculations that utilize a recovery life based on the economic useful life of the investment, to consider the potential for disruptive innovations and loss of customers;
- Disconnection charges to be paid by solar PV customers and/or customers going off-grid to recognize the portion of investment deemed stranded as customers depart;
- More stringent capital expenditure evaluation tools to factor in potential investment that may be subject to stranded cost risk, including the potential to recover such investment over a shorter depreciable life; and
- New business models and services that can be provided by utilities in order to prevent continued revenue erosion.

Interestingly, the final action regarding the updating of business models was identified as a longer-term initiative by the Edison Electric Institute when it first published its recommendations in 2013. Today, given the pace of technology innovation (Tesla's Powerwall batteries being the prime example), utilities have already begun investigating new business models, products, and services to maintain relevance with their existing customers. Meanwhile, a number of the regulatory tariff changes, such as implementing customer service charges and/or disconnection charges, have yet to gain traction amongst most regulatory jurisdictions in Australia; not least Western Australia where government focus is largely on reducing subsidy to incumbent monopoly providers and transitioning towards a more competitive, transparent market through initiatives such as full retail contestability (Government of WA, 2014).

5. Conclusions and policy implications

This article outlined the significant disruption taking place in the electricity industry, driven by technology innovations such as rooftop solar PV panels coupled with residential storage systems. Government, financial, and industry acknowledgement was noted and reviewed, highlighting that even the utilities themselves recognize that their key infrastructure is now at risk.

Amongst this disruption, potential risks, challenges, and opportunities were explored and may become available should traditional business models evolve beyond existing frameworks and embrace new and innovative technologies going forward.

A logical next step would be for utility businesses to embrace these technologies strategically and through a wholesale revision to their existing, traditional business models.

Similarly, this research suggests that a long-term view is needed by policymakers to ensure stability and investment certainty can create the appropriate investment environment.

It is hoped that this research provides additional impetus to encourage utilities, governments and policymakers around the world to apply a longer-term view of electricity market transformation, to address some of the inherent uncertainty in energy markets driven by this potential for existing frameworks to be disrupted, and to develop flexible regulatory frameworks that will remain relevant in the years to come.

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Barriers and Opportunities for Residential Solar PV and Storage Markets – A Western Australian Case Study

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Abstract- Residents and businesses around the world are increasingly installing solar photovoltaic (PV) panels and battery storage systems, satisfying not just their interest in clean energy, but also taking advantage of reduced technology costs and mitigating against future electricity price rises.

Solar PV panels coupled with storage systems present an opportunity to move towards a resilient, affordable, flexible and secure electricity network.

Western Australia provides a unique set of conditions (isolated network, high solar radiation, and rising electricity prices), which has contributed to the rapid uptake of solar PV's in the state. Yet, a number of issues are still obstructing the transition to renewables.

Using Western Australia as a case study, this paper investigates the barriers inhibiting the network transformation and explores the role that solar PV and storage can play as a disruptive threat to the incumbent, centralised service model of electricity utilities.

These barriers are identified and qualified through a series of interviews with several Western Australian energy market participants.

If policy makers intend to enable widespread adoption of solar PV and storage, they will need to address barriers to support these emerging technologies. In parallel, market participants must work with policy makers to drive flexibility in regulatory frameworks and progress the evolution towards innovative and sustainable electricity networks of the future.

Keywords: solar; storage; energy; electricity; barriers; network.

I. Introduction

Western Australia (WA) has inadvertently become a central player in addressing the universal challenges that are inherent in the transition to a renewable, distributed model of electricity networks. The WA Government has traditionally subsidised the centralised model of fossil fuel generation as a political offering to consumers. But this has only artificially reduced prices, and taxpayers ultimately face the impact of non-cost-reflective pricing. As a result, the state is now faced with some of the highest increases to electricity costs in the world, has discovered this subsidy is unsustainable, and is thus seeking to benefit from the some of the best renewable resources available (Nahan, 2015; Bromley, 2015; Sayeef, 2012).

Coupled with these changing economics is the structure of WA's electricity market itself: still highly regulated, dominated by Government-owned entities and currently undergoing a major reform program. Although the WA market is relatively late in considering initiatives such as full retail competition and flexible pricing (Australia's Eastern States implemented similar reforms through the nineties), the industry is now open to consider major structural reforms and market re-design - not just economic improvements to existing models (CSIRO, 2009; Sharma, 1997). For example, WA is now in prime position to consider the impact of increasing penetration of solar PV on the grid and unlock the potential of increasingly cost-competitive battery storage systems. The technology innovations driving battery costs lower will only increase the challenges for utilities and Government, more so for WA's isolated electricity network relative to other states in Australia, or around the world. As such, the authors predict that WA's energy sector and market will become a demonstration site for energy authorities around the world looking for guidance on how to manage the transition (Parkinson, 2015a).

Whilst other markets are also beginning to contend with the pressures of solar disruption (most notably Hawaii, California and Germany), WA has a unique confluence of economic affluence, market reform, network isolation, high solar radiation and consumer demand that has driven enough Government impetus to recognise the urgency in addressing its impacts (Parkinson, 2015; Bromley, 2015).

While change is imminent, there are still a number of barriers. This paper explores what barriers are preventing renewable energy technologies (specifically residential solar PV and battery storage) from transforming the current energy markets of WA to deliver across the priority outcomes of a low cost, low-carbon, and secure energy network.

Through conducting an extensive literature review and analysing a series of interviews with industry stakeholders, key barriers relating to the development and integration of residential solar PV and battery storage in WA are identified. To assist in the

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identification process, this paper classifies these barriers into three groups: institutional, technological and financial.

It is hoped that this research can be used in practice to encourage energy businesses and utilities operating in WA (and those in similar energy markets around the world), to utilise solar PV and storage systems in a strategic fashion, in order to reduce grid congestion, and/or to remove (or at least defer) the need for network investments, thereby creating value for all stakeholders. This research should also provide valuable insights and recommendations to policymakers currently grappling with an electricity service and delivery model in a state of flux. The authors note that ultimately, all electricity grids share a common goal of achieving a safe, secure, sustainable and affordable service of electricity to customers, and in order to achieve this, leveraging and integrating new technologies into existing grid structures and business models will be inevitable.

II. Background

a) *The WA energy transition*

Energy markets are inherently complex structures. They have numerous stakeholders constantly lobbying for industry and regulatory reform. In WA, the complexity is made even more apparent by the state's geographical isolation, preventing any feasible prospect for WA's networks to be connected to neighbouring systems. However, within this challenging environment, WA's unique isolation also presents an opportunity to study the extent to which renewable energy technologies and distributed generation can be utilised to disrupt the conventional, centralised model of our existing systems.

In WA, the energy sector (retail, distribution and generation of electricity and gas) accounts for around three-quarters of the state's greenhouse-gas emissions, with just over 40 per cent of this attributed to electricity generation (EPA, 2007; ABS 2012). Resource availability, and the associated politics and economics of fossil fuel supply (with an abundance of gas, oil and coal resource in the state), are major factors that will shape energy market reform and policy going forward (Martin, 2015; Commonwealth of Australia, 2012; Tongia, 2015).

The WA Government has remained relatively silent on the issue of climate change, and in particular, its interactions with electricity generation. Meanwhile, the underlying economics of renewable generation have already shifted in favour of the decentralised models of clean technology - as afforded by solar PV and storage, and concerns are already being raised with regards to future industry investment and business decisions for WA energy companies (COAG, 2014; Allen et al., 2009; Grace, 2014).

Recognising the inevitable impact of a changing environment, on 6 March 2014 the Minister for Energy in WA launched a broad based review of the structure, design and regulatory regime of the electricity market in the south west interconnected system (SWIS) of WA. The Minister reflected industry wide-concerns that the electricity market was not functioning as expected and was susceptible to high network costs and the need for significant subsides to maintain downward pressure on costs, contributing to high (and rising) electricity prices (Government of WA, 2014).

These assessments were made against a 'business as usual' view for the government's electricity businesses. However, when considered in the context of the changing landscape – driven by the need for clean energy to address climate change and the surge in distributed generation, particularly in the form of solar PV systems plus storage (Denholm, 2007; Katiraei, 2011; Yip, 2013) – this new wave of technical innovation is set to disrupt WA's electricity utility business models, dramatically affect the availability of capital in the industry, and further intensify the issues with the State's electricity market.

In January 2016, an additional impetus for distributed energy systems was (unfortunately) provided by a destructive fire that damaged or destroyed 873 power poles, 77 transmission poles, 44 transformers and up to 50 kilometres of overhead power lines (Western Power, 2016). In response to criticism of the high expenses involved in restoring the grid, the Minister for Energy in WA outlined that distributed energy options, such as the use of solar and storage micro-grids, were being considered by Western Power (Parkinson, 2016A).

As market dynamics force the hand of electricity utilities globally, changing the business model away from a conventional, grid-based system towards a grid plus distributed solar model across the entire network is forming as a likely solution for WA electricity businesses. Utilities undertaking future business planning and strategy development should be proactively looking to energy efficiency, solar PV and energy storage as growth opportunities rather than an existential threat, and acknowledging that their place in the energy system will only grow (Poudineh &Jamasb, 2014; Klose et al, 2010). The question then remains as to why electricity businesses have not already embraced this change, and what barriers are preventing this transition from occurring.

III. Methodology

a) *Interviews*

A review of existing literature was carried out over six months to gain a broad understanding of barriers to the increased adoption of solar PV and residential storage systems in electricity networks around the world. This research helped to inform the design of a series of semi-structured interviews held with several stakeholders in the WA electricity industry, to ascertain the specific barriers, obstacles and potential solutions within the Western Australian context. Semi structured interviews are based on a protocol and were identified as the most relevant method to use to ensure consistency of topic and discussion (Robson, 2002).They involve priming interviewees for responses based on a set of formulated questions (see Table 1), but also provide flexibility for the discussion to involve topics beyond the structured questions.

Table 1: Semi Structured Interview Questions

No.	Question
1	What are your thoughts on the speed of the energy [revolution/evolution] process occurring?
2	Where do you see your businesses' role in the solar PV and/or residential storage market? Are you already/planning/exploring/advising product and service offerings in this space?
3	Energy st orage is often quoted as the most 'disruptive technology', but to what extent is it an opportunity or a challenge for your business? Do these technologies pose any challenges in maintaining the service of traditional electricity networks? (e.g. expectation for 1 in 10 year service interruptions?), and related to this, what do you see as the biggest threats over the next 2 – 5-10 year time horizons?
4	Are you also considering large-scale solar projects? i.e. once base-load coal and gas generation retires? If not, why not? (UBS released a very optimistic report on the growth prospects of large-scale solar projects for Utilities)
5	How else is your business model changing? Would you consider splitting off 'traditional' energy from renewables (e.g. E.ON in Europe?)
6	What are the remaining barriers, if any, for residential solar PV and storage markets and will the rapidly evolving landscape drive potential opportunities specific to WA?
7	How can existing barriers be overcome? Through regulation and policy change? Technological innovation? Capital investment? Business Model adaptation?
8	Any active measures you and your company are employing over the short term to address these barriers?
9	How will the continued uptake of solar PV and storage affect cost and revenues for utilities and what are the likely impacts for consumers?
10	What is your view on the tariff reform needed going forward? Would you support a demand based network tariff being passed through retailers to more accurately reflect the cost of the system? How should technologies such as solar and storage best be rolled out at the consumer level, and what role will tariffs play in helping this?
11	Where do you see WA's energy market relative to the east coast? Other places in the world?
12	What is the best means to transition the grid, as it is now, to one best placed for the future?

Interviewee responses helped to identify how important, in practice, these barriers are in the adoption decision and to gain a greater understanding of the challenges that participants in the electricity industry are having to grapple with, particularly during this disruptive period in the energy sector.

Although the interviews were primarily conducted with Western Australians regarding the local barriers faced, it is expected that they could be considered indicative of issues faced globally across energy markets worldwide. It is also noted that under normal circumstances, this information is often difficult to acquire – as business challenges and potential innovations remain in-house and are rarely published in public material. By framing the interviews as a contribution to research, without unduly impacting any competitive advantages the participants and their respective companies may otherwise be protecting, the interviews were able to achieve a rare level of candor to benefit the study.

b) Selection process

Various methods were used to identify candidates. These included online databases (e.g. LinkedIn), industry magazines, conferences, news articles, academic literature, and recommendations. They were contacted via email and in total, 40 people were asked to take part in the interviews, of which 45% accepted.[1]

The open nature of semi-structured interviews also allowed for new topics to be discussed, and the guide was tailored to suit the interviewee's experience and background and adapted 'live', depending on what the interviewees said.

Interviewees were identified on the basis of their knowledge and expertise in this area, primarily within the WA electricity sector. Interviewees were predominantly senior executives and directors and represented an

[1] Homogeneity of interview content, structure and participants, and a high degree of expertise of participants offers comprehensive information from smaller interview samples (Guest et al., 2006).

eclectic mix of organisations, including: state and local governmental bodies, network generation and retail electricity utilities, private energy companies, energy consulting firms, associations, non-governmental organisations, academics, and several industry professionals from legal, economic and political backgrounds. The importance of a wide ranging selection across public, private and individual viewpoints was identified in order to obtain more of a balanced and objective account of the current challenges related to distributed generation and barriers being faced in residential solar PV and storage markets.

A summary table of interviewees and their affiliation is included below, which also corresponds as a reference to particular comments and views expressed throughout the text that follows.

Table 2: Interview Participant Summary

Interviewees	Affiliation
Participant 1	Senior Manager - Energy Consulting Firm
Participant 2	Managing Director – Independent WA Electricity Retailer
Participant 3	Manager – Network Utility
Participant 4	Manager – Government Electricity Retailer
Participant 5	Director – Government Energy Policy Office
Participant 6 & 7	Directors – WA Local Government
Participant 8	Director – Energy Consulting Firm
Participant 9 & 10	Analysts – Australian Energy Market Operator
Participant 11	Director – Energy Consulting Firm
Participant 12	Director – Non-Government Organisation
Participant 13	Director – Local Electricity Regulatory Authority
Participant 14	Partner – Professional Services Firm
Participant 15	Manager – Metering Firm
Participant 16	Manager – Distribution Network Utility
Participant 17	CEO – Solar Energy Firm
Participant 18	General Manager - Independent WA Electricity Retailer

All interviews were recorded on a phone microphone recording application, with the majority occurring in person. The interviews were largely informal, typically lasting between 45to 60 minutes.

IV. Results

a) Overview of barriers

Research on increasing the adoption of solar PV systems has a long heritage, beginning in the 1980s and with research literature continuing today, profiling the advancement of PV technologies from socio technical (Müggenburg et al, 2012; Dewald &Truffer, 2012), economic (Lund, 2011) and political perspectives (Jacobsson & Lauber, 2006).This research shows that the barriers to increased uptake of solar PV typically relates to a similar set of areas including socio technical, management, economic, or policy (Karakaya & Sriwannawit, 2015; Balcombe et al, 2014). Although specific research investigating the barriers from a WA context was not found, barriers are expected to be similar, albeit with varying levels of priority, and encompassing issues including cost, environmental concerns, self-generation, policy uncertainty, inertia and inconvenience and aesthetic impacts (Ratinen, 2014; Strupeit, 2015; Balcombe et al, 201 4; Sandberg & Aarikka-Stenroos, 2014; Suzuki, 2015; Luthra et al, 2014).For ease of classification, barriers have been re-grouped under three main headings: technological, institutional, and financial.

A summary of the barriers under these three classifications (as reported by stakeholders in interviewees and identified in literature) has been included in Figure 1:

Figure 1: Summary of barriers to solar PV and storage uptake

Each barrier is discussed in more detail below.

b) Technological

i. *Fore casting capability*

Forecasting inaccuracies are infamously known to drive poor decision-making across any industry, but forecasting has become embedded into the centralised model of electricity provision. In WA, actual demand growth has been far below forecasts made at the time the Wholesale Electricity Market in WA was designed. As a result there is now a substantial excess of capacity in the market, imposing a significant cost to electricity consumers as there is a Capacity Market that pays for the capacity of all generators, even if they simply provide back-up services and are rarely if ever called on to generate electricity. In conjunction, the market mechanism designed to reduce this cost over time is not functioning at all – failing to incentivise generators to mothball or retire redundant capacity. Poor forecasting by the Independent Market Operator (as WA's system operator), Government authorities, and the Economic Regulation Authority, has now resulted in a situation where consumers have to pay for the costly errors and un-needed infrastructure investments in the market (Government of WA, 2015; Parkinson, 2015B).

Whilst the impact of additional costs imposed by poor forecasting might provide residents with additional incentive to go 'off-grid' or install solar PV and storage units, at a business level, electricity generators, networks and retailers have a reduced need for additional capacity and can already secure long term power contracts at long-term average costs (Participant 1, 2016).

ii. *Constraints of existing technology*

The transformation of electricity systems requires technological innovation in order to implement services and products to consumers in an affordable and accessible way (Suzuki, 2015).The quality and reliability of solar PV and storage systems is therefore critical for their increased adoption and barriers exist relating to the uncertainty of the technical performance of solar and storage systems (Zahedi, 2011; Luthra et al, 2014). Adoption rates in China provide an example where high levels of dissatisfaction with the low performance of solar home systems (whether caused by improper usage or not) has reportedly prevented other potential adopters from purchasing systems (Karakaya & Sriwannawit, 2015; Yuan et al, 2011). Similarly, studies in the US indicated that consumers were also likely to hesitate from adopting solar PV systems due to the perceived risks of unknown technologies and associated complexities (Drury et al, 2012).

As part of the Government led electricity market reforms in WA, the local network utility responsible for grid connections for the SWIS, Western Power, has begun reviewing its processes and technical standards for distributed generation connection in order to reduce system connection costs (Government of WA, 2015).

WA will also require the adoption of smart meters, sensors and advanced communication networks in order to realise the full benefits of new technology such as solar PV and storage systems. For example, new control systems will have to be developed to deal with the bi-directional power flows inherent in a fully developed distributed market. As existing networks evolve to become 'smart grids', utilities will also need to grapple with the complexities of data ownership, cyber security and data privacy (Luthra et al, 2014).

Market participants and smart-meter provider sinter viewed for this research noted that engaging with incumbent utilities in WA was still a slow and often unsuccessful process, with network utilities (Western Power and Horizon Power) and Government owned retailer (Synergy), still applying existing centralised business models (Participant 15, 2016). Trials being conducted by both companies (e.g. at the Alkimos Beach energy storage trial, a fringe of grid development on the outskirts of Perth)[2], and removal of regulatory barriers may assist in alleviating these technology constraints.

[2] For information on this, see https://www.synergy.net.au/Our-energy/Energy-Storage-Trial-at-Alkimos-Beach

iii. *Network capacity and access*

Integrating solar PV systems (with or without storage) also raises technical challenges in regards to network stability, reliability and power quality. Western Power is responsible for following technical rules and regulations in order to safeguard and maintain its network assets. Therefore, as the gatekeeper to network access, Western Power is extremely interested in the potential impacts of new connections. While individual residential solar PV customers introducing 1 or 2kW into the system may have only a minor impact, when aggregated across the interconnected system, or when concentrated in areas with existing network constraints or older infrastructure, network impacts may be more pronounced (Participant 3, 2016).

Given the rapid uptake of solar PV that has already occurred across the state, network access barriers appear to have been minimal over the last few years. Going forward may present a different situation, however, particularly as the penetration rates rise from less than 20 per cent of customers on the network to estimates far above 50 per cent in the next decade. The unknown disruptive component in all of this is of course the impact that residential storage systems will play across both supply and demand side management. Although the connection of small-scale residential batteries received a promising start in 2015, when the WA Energy Minister facilitated the removal of regulations prohibiting homes with battery storage from feeding electricity back into the grid (Participant 4, 2016).

c) *Institutional*

i. *Psychological will –increasing motivation to embrace innovation*

A 2013 study of the German energy market by Richter (2013), found that not only were German utilities yet to react to solar, but the majority of managers interviewed saw no future for solar PV within their organisations (at that time). This was driven by the view of solar PV as a relatively small-scale technology, with relatively high costs and therefore a strong reliance on government subsidies to remain competitive (Richter, 2013). This view may be particularly prevalent for companies without established capabilities in solar or storage technologies (most incumbents), who have a greater reluctance to embrace these technologies than comparable companies with some previous experience (Markard & Truffer, 2006; Stenzel & Frenzel, 2008; Luthra et al, 2014).This places most incumbent electricity utilities (particularly the dominant government-owned entities in WA) in a position where they may be inclined to rely more on their beliefs than facts when formulating business strategies and predicting future market outcomes (Henderson & Clark, 1990).Alternatively, as Storbacka et al. (2009) note, companies may just be 'stuck' in their mindset and identify the structures and players of the energy market as being "given and unchangeable".

In contrast, and three years on, all WA stakeholders interviewed now see solar PV as a 'disruptive innovation' given its potential (particularly in combination with residential storage systems) to challenge the entrenched, centralised models of electricity generation and the opportunities it presents to the electricity market going forward (Participant 1-18, 2016).

Further, the growth potential in the expanding solar market and building new customer relationships would be additional opportunities for utilities; and long-term contracts for solar PV provided by the utility would also facilitate customer retention. Within this new perspective, solar PV could then be viewed as a stepping stone into promoting other 'green energy' initiatives, such as energy efficiency and battery system offerings (Richter, 2013). In the WA context, many stakeholders agreed with the vast opportunities that 'new energy' offerings provide, but various views were expressed on the timing of when these opportunities would be pursued (Participant 1-18, 2016).

ii. *Organisational management - is listening to customers a bad thing?*

Interviewees also cited a general belief that lack of management expertise has acted as a central barrier to increasing adoption of solar PV and storage systems in WA. Unlike the conventional type of value chains in the centralised energy industry (i.e. generators wholesale to distributors and retailers), in the distributed generation model, participants need to develop different types of business models that cooperates across multiple fronts with multiple actors (Karakaya & Sriwannawit, 2015; Participant 1-18, 2016). The question then becomes how these new models will be developed.

Research on disruptive technology's impacts on existing markets has highlighted the inability for incumbent firms to recognise the true nature of threats to existing business models (Christensen, 1997). A study by Christensen and Raynor (2013) found that the primary reason incumbent firms are resistant to innovating product sis because of an over-reliance on listening to what customers are asking for. According to the study, the average customer is blind to any potential benefits from new and innovative products prior to their commercialisation, and therefore rather than driving any form of radical innovation, customer preferences simply lead businesses to make gradual improvements on existing products and services (Christensen and Raynor, 2013).

Apajalahti et al. (2015) identified a further institutional barrier; the inherent complexity faced by utilities attempting to unbundle and split their business units along service offering lines.

Two interviewees also raised the important issue of culture for utility businesses (Participants 8 and 14, 2016),and suggested that whilst in Government hands, WA utilities such as Horizon Power and Western Power would be more resistant to embrace innovation and would inhibit any form of lasting institutional change. One interviewee argued that unless Government-owned enterprises continued to provide secure and stable returns via traditional business models, they would be acting outside their mandate as they could then be seen as first movers and take on the risks of unproven technologies(Participant 14, 2016).

iii. *Government led decision making*

Another challenge for WA's state-owned electricity companies cited by market participants is overcoming inhibitions to adapt to changing market conditions and surmounting the barriers inherent in bureaucratic decision making processes. As government-owned entities, Synergy, Western Power and Horizon Power have a requirement to obtain not just Board approval, but Ministerial sign-off for all major strategic initiatives. This can be a slow and cumbersome process. Should these businesses remain as public corporations going forward, these restrictive remits will need to be flexible enough to adapt the company's functions and objectives to encourage innovation and repositioning, not hinder it(Participants1, 4,18, 2016).

Levi-Faur (2003), argues that this relationship with policy makers is so pervasive, that even following privatisation, bundling of interests and ties between government and utilities continues to permeate through all levels of the policy-making process. These ties slow down both the ability for utilities to change their business models, and the innovations occurring across the sector as a whole (Levi-Faur, 2003).

Indeed, utilities across Australia have been primarily interested on protecting their traditional sources of revenue, and several have gone so far as to publicly announce proposals for higher fixed tariffs, specific solar 'charges', and attempt to introduce market rules and regulations to prevent the sale of generation from battery storage connected households – all efforts to dampen the attractiveness of new technologies for customers (Parkinson, 2016B).

Further, the dominant government-owned electricity utilities of WA have previously sought to slow renewable energy development and influence state energy policies (through politically driven point scoring or otherwise), and have taken limited or lagging actions to address or benefit from its increasing relevance to energy markets and networks (Bromley, 2015; Mitchell, 2000; Pehle, 1997; Participants 1, 4, 12, 18, 2016).

Ultimately, these incumbent entities will have to adapt and compete with new services and products entering the market, or face increasing redundancy in an increasingly competitive energy market.

A renewable energy expert and active advocate in WA summarised it as follows:

> *"As long as government retains ownership of those facilities, we will not see innovative suppliers or price competition at market. As a consumer…I had no choice of another retailer to go to who might have offered me a new product, a different product. That is an example of where the lack of the competitive market and the lack of consumer choice means that I am stuck with the decision that one retailer makes."*

(Participant 12, 2016)

iv. *Government policy and reform*

The Government is often the vilified target for impeding change, and according to energy market participants interviewed, this is arguably justified in the case of policy for renewable energy technologies. The feed-in-tariff policy controversy, whereby the WA Government attempted to remove payments to solar PV customers for surplus electricity exported back to the grid, is a prime example of political uncertainty. It also led to a great deal of scepticism and added to the perception of Government introducing barriers to the adoption of solar PV (Balcombe et al, 2014; Participant 1-18, 2016).

At the federal level, confusing and complicated legislative frameworks and a lack of long term policy certainty is acting as a barrier to renewable energy investment and introducing unnecessary regulatory 'red tape' (Karakaya & Sriwannawit, 2015). Australia has had significant volumes of legislation, regulations, policies and commitments that apply to renewable energy – large and small scale renewable energy targets; renewable energy certificates, carbon pricing schemes, direct action mechanisms – all while enduring competitive pressures of relatively cheap, thermal coal plants (Martin, 2015).

The need to overcome barriers to the adoption of new technologies through the development of "clear and consistent frameworks" was also noted at the meeting of the Council of Australian Governments Energy Council (COAG, 2015).

Removing regulatory barriers was the most consistent theme and highest priority barrier identified by interviewees. As it stands in WA, there is still no reference in the overarching market objectives to any environment effects of energy supply. The WA Government has also remained notably silent on proposing any tariff reform to specifically encourage innovation and consumer investment in renewable or 'clean' technology such as solar PV– citing a preference only to remove market distortions such as eliminating subsidies given to the Government owned electricity retailer, Synergy (WA Government, 2015; Participant 3-5, 2016).

Of course, the issue then becomes how you regulate an evolving area with several unknowns. Comments from an experienced representative of the regulatory environment in Australia hypothesised that unknowns are not necessarily a barrier: "regulations are an iterative process" (Participant 13, 2016). The interviewee used the case of existing electricity market regulations, highlighting that at their early stages, the frameworks were short and concise documents, and as issues were raised, evolved in their level of detail and complexity. A similar evolution is likely already underway for regulatory flexibility to incorporate distributed generation on the WA networks.

Tariff reform was also a central theme that interviewees suggested underpinned the transformation of electricity markets (Participant 9-10, 2016). The current flat-rate electricity tariffs do not incentivise consumers to reduce demand for electricity at peak times, nor do they accurately reflect the true cost of service. Once tariff structures can leverage the capabilities of smart meters and reflect dynamic pricing structures, then the full value of solar PV and battery storage will be unlocked ((Participant 9-10, 2016).

v. *Consumer inertia and information blocks*

Related to government involvement is insufficient consumer information contributing to consumer inertia in adopting solar PV and storage systems. UK studies even highlighted a lack of trust for micro-generation system suppliers and installers due to the sharing of previous poor experiences online, or as a result of aggressive marketing and sales promotions (Taylor, 2013).

Other consumer related barriers include uncertainty and information gaps with regards to access requirements and regulations to use and connect solar and storage into the grid. This has prevented many customers from undertaking the required efforts associated with installation of these systems (Strupeit, 2015). Coupled with these uncertainties for consumers is the growing confusion surrounding local council treatment of building aesthetics (i.e. visual impact of panels), strata issues and shading complications resulting from roof-top solar PV panels being effected by neighbouring buildings and trees. These individual issues combined are likely to provide an overall threshold of inconvenience for potential adopters. While interviews with local council planners (Participant 6-7, 2016)re-enforced that there are no local council obstacles in installing the vast majority of residential solar PV or storage systems (as long as they can be considered part of the dwelling structure), the media dramatisation of the rare cases that cause problems can still feed consumer perception (Participant 6-7, 2016).

Arguably, these constraints are less evident in the WA market, where high solar resource and rising electricity prices are driving consumers through any initial or historic inertia and motivating adopters to face the risks, complexities or uncertainties anyway. Further, the expansion of solar PV providers has risen dramatically in WA over recent years, assisting with consumer education regarding price, visual impacts, maintenance requirements, PV reliability and simplifying the installation process (Faiers and Neame, 2006).

d) *Financial*

i. *Sunk network costs- network design inertia*

Sunk costs in existing network infrastructure are a significant hurdle that is central to the transformation of centralised grids towards more sustainable, distributed platforms for energy trading. A Commonwealth of Australia Governmental led investigation, the Senate's Select Committee on Electricity Prices (Select Committee, 2012), found that network design, connection and cost barriers were the main impediments to increasing embedded generation in Australia's electricity grids.

As per the current design model, customers pay for the sunk costs of electricity poles and wires (whether they want to use them or not) based on levels of spending pre-approved by economic regulators (in Western Power's case, this has been the Economic Regulation Authority). This model has provided very limited incentive to shift these electricity utilities away from their reliance on the regulated asset base (which allows for a more certain revenue stream). In effect, this model propagates old, centralised electricity service business models which are framed to see residential solar and storage generation units as a threat, rather than as an opportunity for new business (Parkinson, 2015B).

One interviewee suggested the immediate focus should be on:

> *"Applications where it already makes more economic sense to have solar and storage technologies, particularly when considering any large capital heavy projects on the electricity network - such as fringe of grid, new developments, undergrounding power lines, or replacing damaged power lines (e.g. following bushfires)*."

(Participant 1, 2016)

Indeed, for the WA context, this appears to be the approach now being followed by the Government and government-owned utilities. The aforementioned trial in Alkimosbeach, combines community scale battery energy storage, high penetration solar PV and energy management, and will test the feasibility of new energy retail models (ARENA, 2016).

ii. Upfront system costs

The high cost of solar PV systems is usually cited as the most common (and largest) economic barrier to increased adoption – specifically the high initial capital costs, high repair costs, and long payback period (Zhang et al, 2012; Balcombe et al, 2014; Allen et al, 2008; Ravindranath and Balachandra, 2009). It should also be noted that it is important to consider this cost in relation to the cost of substitutable energy sources available (Karakaya & Sriwannawit, 2015; Sarzynski et al, 2012).

However, significantly cheaper levelised cost of energy[3] for solar and storage systems will not automatically result in strong increases in the uptake for solar PV and storage systems (even if this cost falls below the level of the retail price of electricity), as other cost barriers are likely to continue to impinge on the attractiveness of the investment (Elliston, 2010). These barriers include, for example, investment uncertainty and risk, high rates of return, or a lack of access to debt or equity financing, which can all inhibit "an economically rational decision to install PV once prices provide agood rate of return" (Elliston, 2010: pg 8).

This view was confirmed in research by Mountain (2014), who looked at applying traditional project finance analysis to investigate the value that recent renewable energy policies (feed-in tariff payments and renewable energy target certificates) has had on the uptake of solar in Australia from 2010 to 2012. Combining these government incentives with retailer payments and avoided energy purchases, Mountain's (2014) findings suggested that, on average, households that invested in rooftop PV over the period achieved similar returns to what a utility could have reasonably expected for the same investment. In other words, without these Government incentives in the form of feed-in tariffs and renewable energy certificates, returns would have been strongly negative (Mountain, 2014). Of course, as residential solar and storage technologies continue down the cost curve, these findings will continue to be challenged.

V. Discussion

In all interviews undertaken with stakeholders, it was implicit that whilst barriers were often discussed in isolation, it is in fact their interaction and combined impact, which has the most significant effect on the deployment and uptake of solar PV and storage systems in Western Australia (Participant 1-18, 2016).

Further, some of the barriers identified do not fit neatly into just one category and feed into multiple themes. For example, one interviewee provided a unique insight into a potential barrier that straddles both financial and technological classifications, relating to Australia's relatively small size in the global markets. In their view, since Australia offers a significantly smaller market than those found in Asia, North America and Europe, Australian consumers with strong preferences for solar and storage products will likely be left waiting in line behind the larger markets(Participant 2, 2016). This is likely to be more noticeable in relation to storage products, which have limited supply chains.

Of course, as these products become commoditised (like our mobile phones), then this limiting factor will no longer be an issue for Australian consumers. This 'maturity' of markets is already seen for solar PV systems, which have all but eroded their high capital costs through mass production and technological improvements.

This research highlighteda common occurrence of attributing general market frustrations on a particular entity - a need to blame someone for a lack of progress, regardless of whether the barriersare actual impediments or simply perceived. In the case of impediments to solar PV and storage uptake in WA, the scapegoat appears to be Government and regulators. A common theme that emerged throughout all interviews was the importance of "flexible and forward looking regulatory frameworks". The example of 'uber' and the taxi industry was often cited as a likely and comparable scenario for the energy industry, whereby customers override regulators and established regulatory frameworks once presented with an affordable, efficient and favourable alternative to the status quo.

On the other hand, despite these barriers, there are still enough commercial incentives for new and existing market participants to take risks and conduct trials. The opportunitiesin WA have already been identified by global technology and energy service companies (e.g. storage providers: Enphase, Tesla and Red flow), who are working with local governments and electricity businesses to pilot projects such as battery technology trials, innovative pricing structures, demand side management studies and long-term capacity planning methodologies. As the diffusion of these technology innovations grows in the WA energy market, new opportunities will continue to arise for both existing and emerging businesses, and importantly consumers are in line to benefit.

Lastly, the timing uncertainties and the speed at which the energy (r) evolution may occur was a topical theme brought up by most interviewees. The full spectrum of rates of change were voiced across the interviewees, from "yesterday" to "decades away", with the common understanding that forecasting the speed of innovation is an inherently complex task. Although in relation to timing, one respondent (Participant 1, 2016) highlighted the interesting dynamic of late-movers to storage systems potentially benefiting substantially, arguing that once electric vehicle uptake is at a reasonable level (e.g. in 2030), the secondary market for the vehicle's batteries to be used as conventional, stationary batteries in residential applications will likely

[3] Levelised cost of energy is a common summary measure of the overall competitiveness of a particular technology and includes capital and fuel costs, operating and maintenance costs, and financing costs, as well as the assumed rate of utilisation.

be over supplied and lead to significant downward pressure on battery prices (Participant 1, 2016).

It is outside the scope of this paper to examine in depth the solutions needed to overcome the myriad of barriers inhibiting greater uptake of solar and batteries in the market. Nevertheless, based on the barriers identified in this paper, some potential solutions, which will require further research, may include:

- Improved regulatory frameworks that remove economic and political barriers at the same time as promoting necessary capital investment;
- Customer involvement and education;
- Development of infrastructure – e.g. upgrade to smart grids and bi-directional communication systems;
- Changes to licensing requirements (to allow power purchase agreements) and revision of customer protection frameworks;
- Increased transparency, introduction of performance reporting, and lower cost connection requirements for distributed generation; and
- Exploration of new utility *business models* (e.g. partnership with technology providers and third-party ownership products to shift financial and performance risks away from customers).

VI. Conclusions & Policy Implications

This paper focused on the existing barriers to increased penetration of residential solar PV and storage in WA. Three broad groups of barriers were identified and discussed: technological, institutional and financial. A range of issues were identified under each of these groups, both from existing literature, as well as from interviews with key stakeholders working within the WA energy market.

The main barriers identified within the technological barrier include: forecasting capability; constraints of existing technology; and network capacity and access. Institutional barriers include: psychological will of people and the reluctance to embrace the new; organisational management and issues associated with listening too closely to customers; the need for Government lobbying and policy reform; and consumer inertia& information blocks. The main financial barriers discussed include: how to deal with sunk network costs; as well as inertia around network design and how to cover the upfront system costs of solar PV and batteries. A collective view of the discussions suggests that the adoption of solar PV and storage systems is still a challenging process and one that requires all stakeholders in the sector – whether they are industry stakeholders, policy makers, local communities or consumers – to participate in the transition towards a more innovative and sustainable electricity networks of the future. Results also suggest that regulatory and policy reform is what will underpin the removal of other financial, institutional and technological barriers. Without cohesive collaboration and dedicated support for this regulatory and policy reform, the barriers to wider adoption of technology innovations will not be easily overcome.

While many countries worldwide are yet to fully embrace or acknowledge the forthcoming disruption to global electricity markets by solar PV and battery storage technology, the WA stakeholders interviewed clearly recognise these as a disruptive innovation that is already having a significant impact on the WA energy network and market.

The unique set of conditions within WA (i.e. economic affluence, imminent market reform, network isolation and increased consumer demand for solar and, increasingly, batteries) has created a situation and issue which the WA Government can no longer ignore. For this reason, it is expected that WA's isolated electricity network and energy market will become a demonstration site for energy authorities around the world looking for guidance on how to manage the transition and adapt their own regulatory frameworks for the future.

Given the technological and political uncertainty that remains, this paper highlights the importance of firstly creating regulatory transparency to empower a robust, yet flexible policy design, that can then be used to underpin the energy markets that are essential to the sector. Over the long-term, it is the efficiency of markets that will drive competition, rather than regulators. For example, removing barriers to entry for solar PV and storage will facilitate uptake, which will in turn drive innovation and customer choice across retail, network and wholesale markets. Policy makers must recognise the importance of not only identifying and removing any existing regulatory barriers, but creating adaptable and flexible frameworks so that any future barriers can be easily identified, navigated, or mitigated.

Further research is needed to examine the specific solutions that WA may require to address and minimise the negative impact on the network and the market.

Highlights:

- Several barriers to residential solar PV and storage remain in Western Australia
- Barriers are qualified through a series of interviews with Western Australian energy market participants
- Common scapegoat appears to be Government and regulators
- Flexible and adaptable regulatory frameworks are important for innovation

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Future business models for Western Australian electricity utilities

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ABSTRACT

There is growing interest and investment in solar photovoltaic (PV) panels and battery storage systems, driven by the rapidly decreasing technology costs and the movement towards more sustainable energy solutions.

The increasing adoption of solar and storage systems presents both a challenge and an opportunity for electricity utilities amidst wider technological disruption in the sector. This paper investigates how Western Australian utilities can best adapt to this disruption, and in particular, explores how existing business models will need to evolve beyond traditional energy economics. Distinctive characteristics of new business models are classified, before being qualified for appropriateness to the local Western Australian context through interviews with a variety of energy market participants. For Western Australian utilities, it is suggested that these characteristics be adopted in a modular approach, to ensure capabilities are maintained, costs minimised and customers retained.

This research aims to fill this local context gap in existing literature, to inform Western Australian Government policy makers and industry participants on how to evolve their existing networks and processes to create innovative and sustainable electricity systems of the future.

Introduction

The energy model transition

Inherently, energy markets are complex and dynamic structures. They usually have a variety of stakeholders, representing different agendas on price, system security and reliability, and environmental issues, who are constantly lobbying governments for regulatory and industry reform. For example, renewable energy developers tout the advantages of clean energy and the need for regulatory reform to encourage more projects to connect. However, for projects to be financially viable in Western Australia (WA), they still rely on Federal subsidy schemes (Large and Small Scale Generation Certificates), if not State support as well (such as generous Power Purchase Agreements and network connection assistance for non-reference services). In contrast, network utilities must manage intermittency and hosting capacity within existing capital constraints and regulatory frameworks, which in WA includes unconstrained access for generators connecting to the network. Therefore, from a utility's perspective, current business models discourage projects that add costs without increasing revenue, particularly in the context of WA's plentiful base-load plant, and within a market that already has excess capacity.

In WA, the complexity is made even more apparent by the state's geographical isolation, preventing any feasible prospect for WA's networks to be connected to neighbouring systems. However, within this challenging environment, WA's unique isolation also presents an opportunity to study the extent to which renewable energy technologies and distributed generation can be utilised to disrupt the conventional, centralised models of our existing systems.

The underlying economics of renewable generation have already shifted in favour of the decentralised models of clean technology – as afforded by solar PV and storage, and concerns are already being raised with regards to future industry investment and business decisions for energy companies [9,1,19].

With the attractiveness of these new energy products and services only increasing, the electricity industry is now being regarded as a sector ripe for disruption [15,64]. In particular, this new wave of technical innovation is set to disrupt electricity utility business models, dramatically affect the availability of capital in the industry, and further intensify issues within the electricity markets [12,25]; [80]. For example, as customers drive the uptake of solar PV and storage systems, coupled with smart 'behind-the-meter' appliances, utilities are faced with changing demand patterns, falling revenues, increased requirements to maintain

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system security, and the threat that any future large infrastructure investments may be undermined by further erosion of revenue and increasing costs.

WA utilities are beginning to be acutely aware of these challenges for future investments. Following destructive bushfires in January 2016 that destroyed up to 50 km of power lines in the South West, Western Power chose not to re-build the network, but determined that distributed energy options, such as standalone power systems and micro-grids provided more economical solutions [79].

As market dynamics force the hand of electricity utilities globally, electricity businesses must start exploring the value of changing business models away from a conventional, grid-based system to new models, such as one that embraces distributed generation and storage across the entire network, as well as new opportunities to provide energy efficiencies services. Failing to change will almost certainly exacerbate the challenges being faced by incumbent businesses (see section 'The old model in a changing landscape' below). However, this will require utilities to break from the inherent path dependence and lock-in common to such complex socio-technical structures as the electricity system – irrespective of potential reversal costs [28]. Utilities undertaking future business planning and strategy development should be open to these business model explorations, although this may require a change in mindset to see technology innovations as growth opportunities, rather than as existential threats, acknowledging that innovation is inevitable, and may drive existing business models to become obsolete [58,26].

Using WA as a case study to explore how these future business models may be implemented in practice, this paper presents a series of evolutionary business models for WA electricity businesses to consider. These models relate particularly to the development and integration of residential solar PV and battery storage and have been identified through an extensive literature review. These models are then validated through a series of semi-structured interviews with WA market participants and stakeholders.

For policymakers and regulators currently grappling with a fluctuating electricity service and delivery model, this research aims to provide valuable insights and recommendations on how to help facilitate the transformation of the electricity system, and overcome the significant inertia of a system when exposed to change [57].

It is hoped that this research can also be used in practice to encourage energy businesses and utilities operating in WA (and those in similar energy markets around the world), to utilise solar PV and storage systems in a strategic fashion in order to reduce grid congestion, remove (or at least defer) the need for network investments, maintain downward pressure on electricity prices, help to decarbonise the electricity network, and most importantly, to stay relevant in the evolving, highly disrupted energy market.

The authors note that, ultimately, all electricity grids share a common goal of achieving a safe, secure, sustainable and affordable service of electricity to customers. Achieving this will inevitably involve leveraging and integrating new technologies into existing grid structures and business models.

This paper begins by providing some background around traditional business models for electricity generation and supply in Australia before specifically highlighting the opportunity that is being presented in WA. This is followed by an overview of the methodology and analysis used. Results are discussed in terms of existing barriers, new business models and the need for new partnerships and energy companies. This is then examined in relation to how WA could respond to these challenges, and concludes by highlighting some potential policy implications.

Background

The old model in a changing landscape

The current business model of utilities reflects the legacy of a centralised electricity generation and distribution design, underpinned by large upfront capital requirements relative to marginal operating costs, driving a natural motivation for electricity utilities to maximise the production and sale of electricity through existing networks [27,6,8].

Historically, electricity demand was thought to be largely inelastic and the main driver of cost was capacity peaks and the resultant infrastructure spend to cater for them. A view of ever-rising peak demand also contributed to a standard approach to power system and security planning, network regulation, and energy market dispatch design. Utilities, therefore, created a traditional service of delivering electricity at price per kilowatt hour [69,63,65,72].

Recognising this 'coupling' of volumes and profitability was at a natural tension with the assumption from customers that their electricity supply should be treated as a 'right', the electricity networks most commonly became a natural monopoly (e-lab [13]. In WA's case, the result was a regulatory agreement between government and the government-owned utility (Western Power) to provide affordable, reliable and accessible electricity to all consumers across the State at a uniform price [17]. This led to a growing gap between the cost of electricity supply and the cost paid by consumers, with the Government absorbing the deficit.

Meanwhile, each technology improvement or institutional enhancement in the system was only ever an incremental development tracing along the same traditional pathway – constrained by previous decisions which effectively 'locked the industry in' [33].

However, the standing of electricity utilities as safe and steady businesses is now coming under increasing pressure due to a convergence of several factors across technology, economics and public policy. In the past decade alone, the energy sector in Australia has been navigating: rapid technology innovation (removing barriers to entry for small players); the falling cost of distributed generation; increased interest in demand side management; slowing trends in demand; shifting government policies on renewable energy incentives; and rising electricity prices across the country [27]; e-lab, 2014; [19,7]. In combination, these factors are set to fundamentally change the way our electricity systems operate.

The very tenets of the status quo 'traditional path' are being challenged. Not only has it become cost prohibitive for the WA Government to continue to subsidise energy costs to consumers, but the impact of rising costs on some customers is now beginning to drive investment trends in the opposite direction for those who can afford it and are motivated enough to analyse their energy costs (through energy efficiency and distributed generation). The increasing uptake of solar PV and storage will only exacerbate this trend [81].

The WA opportunity

A variety of unique factors are forcing WA to become an early adopter in the transition to a new electricity network and system based on renewable, distributed energy. Because the WA Government has traditionally subsidised the centralised model of fossil fuel generation as a political offering to consumers, the state is now faced with some of the highest electricity costs in the world [67]. The Government now admits this subsidy is unsustainable, and is seeking to benefit from the some of the best renewable resources available [32,6,68].

WA is now is in prime position to unlock the potential of increasingly cost-competitive solar PV and battery storage systems. Coupled with changing economics is the structure of WA's electricity market itself: still highly regulated, dominated by Government-owned entities and currently undergoing a major reform program. Although the WA market is relatively late in considering initiatives such as full retail competition and flexible pricing (Australia's Eastern States implemented similar reforms through the nineties), the industry is now open to consider major structural reforms and market re-design – not just economic improvements to existing models [11,70]. However, these technology innovations will only increase the challenges for utilities and Government.

WA's isolated electricity network and energy market can therefore become a demonstration site for utilities and energy sector participants looking for guidance on how to manage the transition [36,75]. Already, innovative studies and collaborations between private participants and the monopoly network provider, Western Power, include strata peer to peer trading (White Gum Valley project), microgrid trials (Kalbarri, Garden Island), utility scale battery storage (Perenjori), demand management trials (Mandurah), and the stand-alone power systems following the bushfire damage mentioned above (Ravensthorpe) [31].

Whilst other markets are also beginning to contend with the pressures of solar disruption (most notably Hawaii, California and Germany), WA has a unique confluence of economic affluence, market reform, network isolation, high solar radiation and consumer demand that has driven enough market impetus to recognise the urgency in addressing its impacts [37,6].

Methodology

A review of existing literature over a twelve month period was undertaken to gain a broad understanding of the various new business models being proposed, trailed or conceptualised for electricity businesses around the world. This research was used to inform the design of interviews subsequently undertaken with various stakeholders within the WA electricity industry.

Interviews

Interviews were conducted with a variety of stakeholders within the electricity industry to ascertain the specific merits of adopting these 'future business models' within the WA context. Interviewee responses also helped to provide a greater understanding of the challenges that electricity businesses are faced with, and what aspects of the existing business models could be enhanced to leverage the future opportunities in the market.

Semi-structured interviews were identified as the most relevant method to use to ensure consistency of topic and adequate fluidity in discussion [66]. The semi-structured interviews conducted were purposely open in nature to allow new topics to be discussed, and new information to be gathered, which may not have been identified by particular interview questions. They involved priming interviewees for responses based on a set of formulated questions (see Table 1), but also provided flexibility for the discussion to involve topics beyond the structured questions.

The interviews were conducted with Western Australian experts, to identify the viability of implementing global ideas and commentary on energy market challenges being faced across Australian markets, and worldwide. The appropriateness of solutions and future business models proposed in existing literature was also assessed for its relevance to Western Australian utilities to gain a greater understanding of the challenges that participants in the local WA electricity industry are having to grapple with, particularly during this disruptive period in the energy sector.

Table 1
Semi structured interview questions.

No.	*Question*
1	What are your thoughts on the speed of the energy [revolution/ evolution] process occurring?
2	Where do you see your businesses' role in the solar PV and/or residential storage market? Are you already/planning/exploring/advising product and service offerings in this space?
3	Energy storage is often quoted as the most 'disruptive technology', but to what extent is it an opportunity or a challenge for your business? Do these technologies pose any challenges in maintaining the service of traditional electricity networks? (e.g. expectation for 1 in 10 year service interruptions?), and related to this, what do you see as the biggest threats over the next 2–5–10 year time horizons?
4	Are you also considering large-scale solar projects? i.e. once base-load coal and gas generation retires? If not, why not? (UBS released a very optimistic report on the growth prospects of large-scale solar projects for Utilities)
5	How else is your business model changing? Would you consider splitting off 'traditional' energy from renewables (e.g. E.ON in Europe?)
6	What are the remaining barriers, if any, for residential solar PV and storage markets and will the rapidly evolving landscape drive potential opportunities specific to WA?
7	How can existing barriers be overcome? Through regulation and policy change? Technological innovation? Capital investment? Business Model adaptation?
8	Any active measures you and your company are employing over the short term to address these barriers?
9	How will the continued uptake of solar PV and storage affect cost and revenues for utilities and what are the likely impacts for consumers?
10	What is your view on the tariff reform needed going forward? Would you support a demand based network tariff being passed through retailers to more accurately reflect the cost of the system? How should technologies such as solar and storage best be rolled out at the consumer level, and what role will tariffs play in helping this?
11	Where do you see WA's energy market relative to the east coast? Other places in the world?
12	What is the best means to transition the grid, as it is now, to one best placed for the future?

It is also noted that under normal circumstances, this information is often difficult to acquire – as business challenges and potential innovations and corporate strategies remain in-house and are rarely published in public material. By framing the interviews as a contribution to research, without unduly impacting any competitive advantages the participants and their respective companies may otherwise be protecting, the interviews achieved a rare level of candor to the advantage of the study.

Selection process

Candidates were identified using a variety of methods including online databases (e.g. LinkedIn), industry magazines, conferences, news articles, academic literature, and recommendations. They were contacted primarily via email, although a select few were also asked to participate in interviews in person at meetings. Overall, 18 interviews were conducted, which equated to a 45 per cent acceptance rate.[1]

Interviewees were directors or senior executives primarily from the WA electricity sector and were chosen because of their knowledge and expertise in this area. Interviewees were selected from a broad mix of organisations, including: state and local governmental bodies, network generation and retail electricity utilities, private energy companies, energy consulting firms, associations,

[1] Homogeneity of interview content, structure and participants, and a high degree of expertise of participants offers comprehensive information from smaller interview samples [20].

non-governmental organisations, academics, and several industry professionals from legal, economic and political backgrounds. This wide ranging selection of interviewees representing public, private and individual viewpoints was important to gain more of a balanced and objective overview of the challenges around distributed generation and how future business models could incorporate products and services relating to residential solar PV and storage more effectively.

The majority of interviews were undertaken in person, with only two conducted over the phone. All interviews were recorded and typically lasted between 45 min to one hour. The interview responses were then transcribed and systematically categorised into five thematic areas based on the specific issue raised to align with the initial literature review: Performance Improvement; Capacity Removal and Divestment; Regulatory Issues; Policy Issues; and Miscellaneous (e.g. electric vehicles, creation of new business units, building partnerships). These areas frame this paper's discussion section (see section 'Response pathways for Western Australia' below), which includes the relevant responses to provide the unique WA context and expand on existing literature, filling the gap in research.

Results

Existing barriers

Currently, the interests of utilities (preventing stranded assets, maximising electricity sales, preventing increased competition) are in tension with the interests of consumers and the environmental imperative to decarbonize the electricity sector [65,77,6].

Further, any solutions designed to meet the transitioning needs of the energy industry will need to be based on the individual regulatory and market contexts in which they emerge [10,24]. For instance, utilities in competitive markets will be more directly exposed to the threats that arise from technology innovations such as solar and storage systems, given their ability to reduce electricity use and demand [27].

It is widely acknowledged that if utility business models fail to adapt to disruptive potential of distributed generation, components of their old, centralised system will increasingly become stranded assets [59,76,72]. As a worst-case scenario, business analysts describe the situation as the "utility death spiral", citing a "failing utility business model" to explain how energy generated by solar is threatening the future existence of a grid-based energy system [71].

In order to avoid this, a series of regulatory, institutional and financial barriers that inhibit the effective transition of electricity businesses to new ways of operating need to be addressed. After investigating barriers for various Swiss and German utilities in their transformation from largely 'asset' businesses to being providers of intangible services and products, Helm [23] concluded that the central facilitator to this process was the policy makers' role in supporting the transition for utilities via flexible regulatory frameworks. Gunningham and Sinclair's [21] work in relation to environmental regulation provides a useful grounding for how flexible (smart) regulation might be designed for energy markets, outlining the usefulness of multiple, complimentary policy instruments, using less interventionist measures where possible, and empowering third parties to include a broader range of regulatory actors and stakeholders [21].

Tayal and Rauland [75] who investigated barriers specific to WA, found a similar argument was common amongst energy sector participants – that forward thinking policy and regulatory flexibility and the removal of government barriers was a necessary precondition to the true transition to new business models in the state [50,51].

The real challenge for WA's state-owned electricity companies may be in overcoming their inhibitions to adapt to changing market conditions and surmounting the barriers to innovation given their requirement to obtain not just Board approval, but Ministerial sign-off for all major strategic initiatives. This creates tension between government and the utilities, and also facilitates government intervention into the market, confusing what would otherwise be independent commercial decisions in the interests of shareholders or private owners. Should these businesses remain as public corporations going forward, these restrictive remits will need to be flexible enough to adapt the company's functions and objectives to encourage innovation and repositioning, not hinder it [42,50].

The existing corporate inertia and Board's resistance to change core business functions is also argued to be having a direct impact on current profitability and thus, can no longer be ignored in Western Australia [51]. Claims that renewables are a risky side-project that will never gain serious market share for their intermittency or cost structures are now also being shown to be increasingly false amongst wider industry groups, financiers and politicians in WA [45]. As the pressure mounts, however, new policy and strategy announcements are beginning to be heard from the major electricity business in the State. For example, Synergy, the Government-owned monopoly gentailer in WA announced its own solar PV system offering, 'SolarReturn', in May 2016:

> "Synergy is transforming into a contemporary, responsive and adaptive business that embraces innovative technology and the use of renewable energy sources."
>
> [Synergy [74]]

Clearly previous rationales for WA utilities to remain indifferent to the threat of residential solar PV and storage systems are no longer accepted and have largely disappeared from the local debate [38,55].

The new utility business models that are now urgently required cannot be developed and adapted by the WA utilities in a vacuum, even if they are predominately Government owned [52]. The transition to new business models will require collaboration and participation across policymakers, regulators, investors, consumers, forward thinking Government Ministers, as well as technology innovators and entrepreneurs.

The new utility business model

Business models are the link between corporate strategies and operational activities [61]. Several examples of organisational efforts to transition towards more sustainable business models already exists [73]. Some businesses claim to consider more than just shareholder value, citing additional focus on, for example: reducing the ecological footprint of their products; providing service-based products, or on incorporating wider social issues into business strategy [29,69]. Underpinning the development of these sustainable business models for the electricity industry, is the need for utilities to expand beyond their traditional mantra of delivering 'as much electricity as possible at the highest price allowed' and start considering social and environmental factors [69,63,3].

Within the context of disruptive innovation, managers of utilities deciding to enter and succeed in solar PV and energy storage markets, need to make bold decisions to change their business models and introduce new products, pricing plans, or service offerings, and be able to convince customers of their value [60]. Utilities moving into this space also need to either prove their differentiation from existing products and services in the market, or expand the market itself [63].

A growing body of research continues to develop a series of essential requirements and characteristics that a next generation electricity utility business will need to incorporate, in order to maintain relevance in the energy market going forward. The characteristics identified (see Fig. 1 and Table 2) can then underpin a full range of potential strategic responses to the competitive 'threat' of solar PV and storage, thus protecting investors and capital availability for the electricity businesses themselves.

Following the extensive literature review, and corroborated by industry experts in WA, the six characteristics (A-F in Fig. 1) that electricity businesses should consider are further expanded upon in Table 3. The table provides examples, as well as necessary considerations for each characteristic, with further explanation provided on specific initiatives in the sections below.

Discussion

Building partnerships

Inevitably, there will not be one perfect business model, and each electricity business will need to assess the contextual risks and impacts unique to its position in the market [13].

As distributed generation such as residential solar PV and storage penetration grows on electricity networks, new opportunities will arise for both existing and emerging businesses, and consumers are in line to benefit. A key element of this changing landscape is for energy providers to leverage their existing relationships with customers into an enduring partnership aligning with the long life of solar PV systems (common power-purchase agreements in the current market last 15–20 years).

Incumbent energy retailers, network operators and generators, like the WA Government-owned Synergy and Western Power, will have to adapt and compete with new services and products, or face increasing redundancy in the market [41,42,45].

Notwithstanding the natural competition of the energy market, a regulatory battle will also be inevitable, to define the boundaries within which traditional retailers and network operators can provide data analytics, energy-efficiency solutions, storage technologies, and other in-home products that consumers of tomorrow will be seeking. As a result, the potential for innovative partnerships with third parties (including software providers) and new information flows also arises, that combine existing customer relationships with these new products and services that currently sit outside the existing domain of centrally planned electricity networks [40,41,55]. Fig. 2 depicts one such future scenario of market participant interactions [35].

Establishing external partnerships with other businesses, for example in the solar PV sector, also provides utilities an initial, row-risk entry point into the market and provides access to innovation capabilities [5]. Fig. 2 depicts how 'Retailers' can choose to interact with consumers directly (as per traditional custom), or alternatively, can partner with 'Platforms (software providers)' and 'Third Parties' such as solar panel and battery technology providers, thereby utilising their experience and contacts and leveraging the established knowledge that these businesses have developed, strengthening the customer engagement model [56].

An existing example of the strategic importance of partnerships is Tesla Motors strong relationship with SolarCity (a solar systems provider), with mutual benefits gained from the development of battery storage systems to seamlessly integrate with electric vehicles and roof top solar PV [30,38]. It is easy to imagine similar relationships being built between existing WA energy market players and national, or even international, providers of energy solutions, and several WA market participants expressed confidence that this was already well-underway in the local market, with trials, feasibility studies, and 'sister-company' relationships being set-up between local and global energy service companies [38,48,55]. However, these opportunities invite an additional condition: that beyond the changes to technology and regulation, such players must also be constantly innovating their business models and corporate strategies to survive in the sector's rapid evolution.

Creating energy Co's for the future

Existing literature on business model innovation within the utility sector suggests that utilities would maximise benefits from the new strategies discussed above by adapting their traditional organisational structure and creating a separate and independent business unit to focus on solar PV products and services [69,26,22,62,72]. Establishing a specialised business unit addresses any internal culture and cognitive barriers or conflicts with the core business (e.g. a view that solar cannibalises traditional sales volumes) and allows for a more creative, innovative environment that is empowered to trial new ideas (bessant et al., 2004).

Several local market participants indicated the appropriateness of this model for WA utilities, citing the uncertainty of traditional generation as a revenue source, and growing customer apathy towards 'dirty generation' as major drivers [38,48,55].

In Germany, several major utilities have already created new business units to manage renewable energy projects (e.g. E.ON SE) [2]. Similarly in Australia, a number of east-coast retailers operating in the National Electricity Market (NEM) have already progressed with the separation of renewable businesses (e.g. AGL's 'new energy' business unit) that have begun offering customers packages to finance solar PV and battery systems. Other variants include companies initiating 'third-party-ownership' or 'power purchase agreement' (PPA) models where the utilities sign long-term agreements with customers to finance, install and manage the rooftop solar PV installations, whilst the customer buys the electricity that is generated at a pre-determined rate [14,62].

Response pathways for Western Australia

The lowest risk 'new' utility is the one that will be able to adapt and embrace technology and innovation, and use it to provide a wide suite of energy services at cost-competitive prices that include very high levels of customer service – a future that would no doubt be welcomed by consumers increasingly dissatisfied with the service of their current electricity providers [81].

In WA, whilst the electricity utilities are no longer vertically integrated, the Government owned gentailer Synergy, and the transmission and distribution network company Western Power still retain a dominant and principal role in the energy system.

Building on the characteristics identified in Table 3, four specific responses have been identified as being needed for WA's electricity utilities to maintain their competitiveness and relevance in the changing landscape. These include: Performance Improvement; Capacity Removal and Divestment; Updated Regulatory Framework; and, Long Term Policy Direction [38,40,45–47].

Performance improvement

To compete with the lowering costs of renewable energy and the increase of distributed generation on networks, WA's utilities will inevitably need to reduce their costs to remain competitive. They will need to be more flexible and adaptable, focusing on performance improvement measures across the value chain – improving return on invested capital by becoming lean, forward thinking and engaging in product and service partnerships where possible.

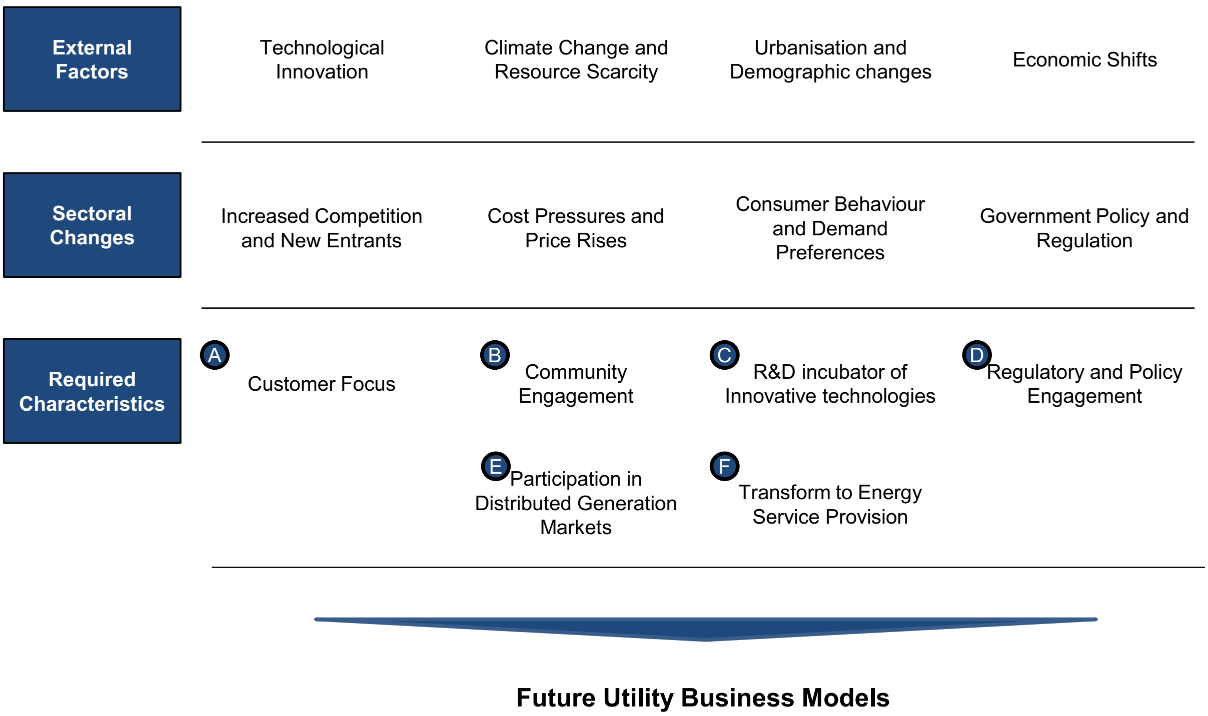

Fig. 1. Drivers and key characteristics of future utility business models. (Based on interviewees with Participants [38–55]).

Table 2
Provides the list of the interviewees/participants and their affiliations.

Participant	Affiliation	Role
1	Energy Consulting Firm	Senior Manager
2	Independent WA Electricity Retailer	Managing Director
3	Network Utility	Manager
4	Government Electricity Retailer	Manager
5	Government Energy Policy Office	Director
6 & 7	WA Local Government	Directors
8	Energy Consulting Firm	Director
9 & 10	Australian Energy Market Operator	Analyst
11	Energy Consulting Firm	Director
12	Non-Government Organisation	Director
13	Local Electricity Regulatory Authority	Director
14	Professional Services Firm	Partner
15	Metering Firm	Manager
16	Distribution Network Utility	Manager
17	Solar Energy Firm	Chief Executive Officer (CEO)
18	Independent WA Electricity Retailer	General Manager (GM)

WA utilities will need to reduce their asset base, which doesn't necessarily have to reduce their profitability [40,42].

Synergy, the government-owned retailer with a monopoly on residential customers in WA, will need to increase the self-service capabilities for customers without reducing customer service (or increasing churn once full retail competition is introduced). This is where innovations in big data and system optimisation is vital [52]. Improved data on network performance and big data analytics will need to be incorporated to provide Synergy with real time insight into investment requirements and can include the impact from distributed generation sources [52].

Capacity removal and divestment

As solar capacity increases globally, energy analysts estimate power generators will start closing their older, thermal fleet (i.e. coal and gas fired power stations) leading to savings for utilities, but spiking electricity prices for consumers – at least in the short term – due to the higher marginal cost for addressing intermittency through peaking plants or large-scale storage. Therefore, in order to maintain security of supply, it is expected that some cash-flow negative plants may remain online in order to provide back-up capacity services (e.g. strategic reserve and ancillary services) [76].

WA already has a problem of excess capacity in the market, which has been a primary contributor to high (and rising) electricity tariff rates due to the state having a reserve capacity market [38,40,45,50]. The reserve capacity process, at a high level, requires the market operator to set the capacity requirement for the market largely based on the system reliability requirement and their own demand forecasts. Currently, this creates a perverse situation where unnecessary generators and demand-side management programs are still being paid generously to act as 'back-ups'.

It is acknowledged that forecasting demand (as with all forecasting) is extremely difficult, especially three years into the future as required in the WA Electricity Market's capacity mechanism. Compounding the WA market operator's forecasting complexity is the requirement to include estimates of large new mining loads or "block loads" into the forecast. These block loads are highly prospective and uncertain. Looking back over the accuracy of the forecasts, it has become evident that actual demand has been far lower than the forecast requirements, resulting in a significant surplus of capacity, which is ultimately paid for by consumers [45].

New methods on how to more efficiently procure market capacity and set the reserve capacity price (such as an auction mechanism) are being considered by the Government as part of the Electricity Market Review [18]. Synergy, also the dominant government owned generator in the South West Interconnected System, is the largest contributor to excess capacity on the system, largely

Table 3
New energy business model characteristics.

Characteristic	Description & considerations	Examples
A. Customer-focus	• Utilities have to view their customers as more than simply sources of revenue – increasing customer engagement and intentionally putting customers first, making distributed generation an accessible part of their resource delivery and fostering relationship with existing customer base • Products and services need to be accessible, fit for purpose, simplified and easy to use • Customer retention depends on ability (age and income) and motivation (past action, energy efficiency) • Need to target use of mobile, social and web interfaces to provide customers with improved view of energy use and enable greater (and two-way) communication between the utility and customer • Utilities need to improve their ability to test and implement novel services such as customised rate plans based on individual usage patterns and requirements (e.g. lower cost models for those that don't value direct relationships)	• Utilities in the United States (e.g. AT&T and Verizon Wireless), have started attempts to transform their image into trusted energy advisors. • Amory Lovins [13] suggests utilities must sell their customers "hot showers and cold beer", rather than electrons • Behavioral insights for billing (e.g. normative comparison with neighbours) • Transition to real time billing platforms - OPower (United States) • Lampiris (Belgian retailer) – using social media for customer feedback
B. Community engagement	• Utilities need to engage in job creation, training and education, and awareness programs • Recognise that community participants seeking independent energy systems are not necessarily concerned about price • Maintain/develop brand awareness and improve customer retention in increasingly competitive energy market	• Integration with Government led community service schemes for fuel-poverty households • Crowdfunding solar programs - Local ownership • Ovo Communities (UK Utility)– complimentary community energy solutions
C. R&D incubator of innovative technologies [hardware]	• Utilities currently have limited research expertise - utilities need to emerge from their monopolistic privileges and become leading incubators of new technologies and business strategies • Utilities may not be the lowest cost provider and/or may require significant investment • Technologies likely to facilitate higher solar penetration – further cannibalising traditional core business	• Tesla, Battery technology, electric vehicle charging • Investments in home energy management (e.g. smart thermostats) and storage systems that can lend to a wider service offering • Digitisation – i.e. significant increases to supervisory control and data acquisition sensors and related customer data • Smart Grids, Smart Homes and advanced metering will help utilities develop granular insights into demand patterns at customer level and have benefits for pricing, dispatch planning, energy efficiency targets and long-term capacity planning
D. Regulatory and policy engagement	• To insulate from regulatory and policy changes, utilities will have to actively pursue adaptable regulatory frameworks that facilitate technology update, reduce barriers to entry, and embrace the long term view • Acknowledging that there is no single correct solution, utilities need to engage with policy makers and regulators to get the framework right and then let the market and competition drive the solutions • New tariff structures (incorporating behavioral economic insights) maybe commercially sensible, but often politically unpalatable – this tension needs to be balanced in order to propose pragmatic solutions for Governments	• Utilities will need to actively pursue new business models that decouple profitability from the volume of energy sold (how traditional utilities function which is inherently unsustainable), and create new models around efficiency of use • In Australia, businesses need to be flexible about future carbon price introduction, changes to renewable energy targets – based on political parties
E. Active participation in distributed generation markets	• Utilities invest in, acquire, or partner with small and large-scale PV installers, storage providers and renewable energy project developers – noting that incorporating renewable energy assets (e.g. solar leasing) cannibalises sales from traditional core business services • Will be reliant on flexible regulatory provisions and open Government policy • Utilities in WA lack experience in competitive and crowded markets • Need to leverage roof-top solar capabilities with non-residential (grid-scale) solar projects	• AGL, Synergy, Origin, Perth Energy - solar leasing and installation programs • Explore and expand through new financing options (loans, leases, PPAs) • Grid scale storage - AES in United States • Large-scale solar projects
F. Transform to energy 'service providers' and increase [software] applications	• Utilities need to shift from selling electricity (a commodity differentiated on price) towards selling a comprehensive service (differentiated on quality) offering a package of energy efficient appliances, building improvements, hardware and installation services, and improved software and billing services to meet customer's needs • Utility may not be the lowest cost provider and/or may require significant investment (e.g. retraining of staff, develop analytics capability)– exposing rate payers to inefficient pricing • Limited longevity of cellular technology (i.e. due to rapid technological improvements) may expose earlier redundancy than utilities are accustomed • Utilities need to be aware of the potential for a highly competitive market, with entrants from consumer technology, telecommunication, home security and energy sectors	• Provision of customer support and billing services to solar PV retailers (e.g. Powershop, Flick – New Zealand) • Improve performance and streamline asset base over shorter time-periods ('manage rather than own'). • Partnership with telecommunication companies to combine mobile technology services with home energy management systems (e.g. Telefonica in UK, SP AusNET and Telstra in Australia) • Combine internet and mobile communication services, big data analytics and cloud computing with smart grids and smart metering to provide real-time price information.

Sources: [77,13,6,59,63,26,81,35,76,65]; Farrell, 2015; [72,16,21,38–55]

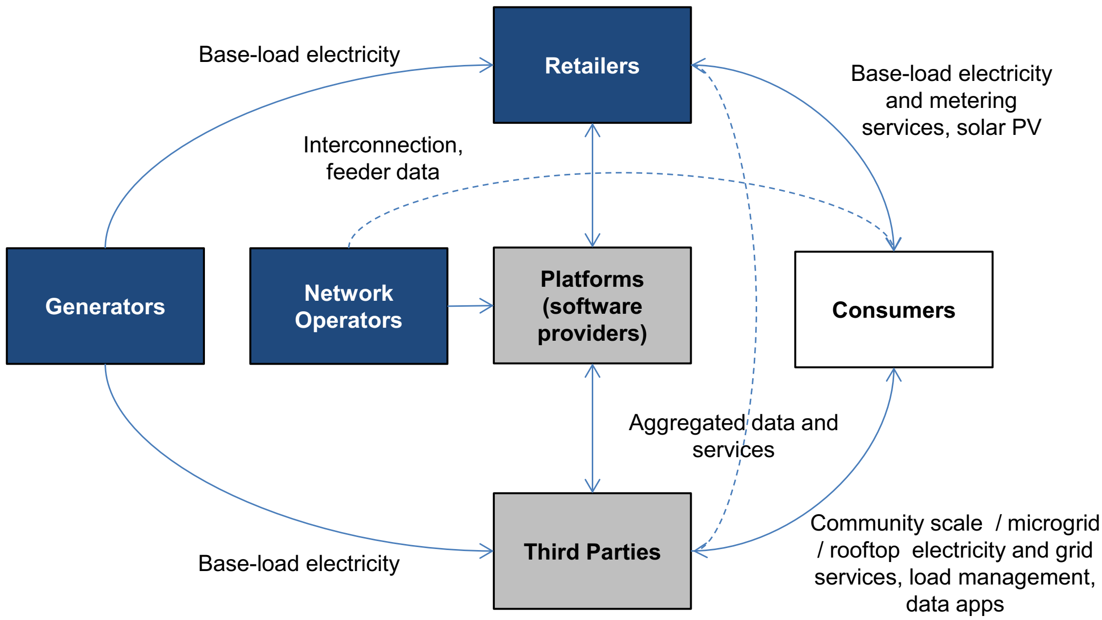

Fig. 2. Market participant relationships – a future scenario adapted from [13].

from old, inefficient, coal fired power stations. These have already been identified by WA's Energy Minister as a prime candidate for removing the majority of existing excess capacity, much of which is old, inefficient, coal fired power stations [32]. Electricity businesses must be both adaptable and constantly striving to be efficient and innovative in their generation portfolio (or electricity supply contracts). In reality, this may mean slightly higher premiums or shorter-term contracts to avoid technology lock-in and thus path dependency and preserve medium-to-long-term flexibility in a highly disrupted market [45].

Updated regulatory framework

Improvements in distributed generation technology and economics are already driving competition at the distribution level – i.e. on local grids within neighbourhoods and communities. This new, distributed world challenges the future role of regulated utilities in WA –they should no longer be assumed to run as regulated monopoly businesses [38,40,45,50–53]. Over the long-term, the efficiency of markets must drive competition in the small non-interconnected electricity sector in WA, rather than regulators [50].

To enable the transition to new energy businesses and to establish sufficient conditions required for a truly competitive market, it is vital to have a smart and flexible regulation and policy framework in WA that looks to the future, not the past [50]. This framework will require the electricity regulator (currently the Economic Regulation Authority) to transition from its traditional 'gatekeeper' role, to one in which it can facilitate energy markets and competition. In particular, the Economic Regulation Authority will need to remove the regulatory barriers to the uptake of renewable energy generation, enabling technologies and innovative retail product offerings [50]. Removing barriers to entry will in turn drive innovation and customer choice, encourage a smaller network size (or defer network augmentation), improve tariff structures and integrate network price signals with energy markets (e.g. locational pricing).

In the National Electricity Market (NEM), the Australian Energy Regulator (AER) has been working on the regulatory framework to make it more resilient and adaptable to change [4,78], recognising the disruptive potential of solar PV as penetration levels increase across the network. Nevertheless, there is still a need for further refinement to the national regulatory framework, as regulation must continue to evolve to account for issues (applicable on a global scale) such as cost-reflective pricing, structural separation of energy services, demand management initiatives, advanced metering services, and addressing barriers to market entry [45–47,52].

Notwithstanding these revisions, utility compensation will be a complicated regulatory issue to resolve, and will need to move beyond the current 'cost of service' principles, which compensates utilities for incurred costs and investments in physical assets and may incentivise overinvestment in infrastructure at the expense of consumers [50]. An 'incentive based' framework will need to be created that aligns network revenue and performance with customer interests. For example, utilities' earnings could be linked to metrics such as energy efficiency, clean energy generation and other performance measures that require the utility to deliver a safe, reliable and affordable energy service [42]. Looking forward, the concept of a utility acting as a natural monopoly should only continue to apply in respect to its services as the load serving 'pro vider-of-last-resort' – providing back up in the presence of mature distributed generation and storage markets. Beyond that role, all grid services in WA should be subject to competition [42,50].

Regulatory transparency is essential for empowering this revised framework for the WA electricity market, whilst robust policy design will also be needed to maintain appropriate consumer protections [50–52].

Long term policy direction

Energy policy has substantial impacts on both sides of the Government's budget – income and expenditure. Taxes and tariffs generate revenue, whilst incentives for decarbonisation and energy efficiency require financial support [34]. In WA, the present pattern of policy has accumulated over time in a haphazard, partisan way and without long-term strategic thinking. Going forward, policy decisions on ambitious renewable energy targets, and continuing feed-in tariffs and other incentive and subsidy schemes (e.g. to foster the development of battery technology) may be an impetus to stimulate the fast growing solar market – at least in the short term where coal and other fossil fuels enjoy largely hidden tax benefits. However, having policy based on short-term political cycles will always remain a risk and create legal and financial uncertainty for participants. Policy uncertainty can be incorporated into project financing, and in WA, financiers should continue to take a conservative approach when incorporating sovereign risk into any risk premiums [50].

Longer term, short of gaining bi-partisan support on all new policy directions, participants should seek to utilise market-based contracts where possible, and leverage the transition to more flexible regulatory frameworks to ensure projects have less reliance on legislative provisions and direct subsidies.

For example, increasing the ability for market participants to sign long term power purchase agreements (PPA's) for solar projects will stimulate new revenue streams through the sector and provide longer-term certainty for solar providers.

Nevertheless, some policy revisions specific to the WA context will need to address the unique structure of the market and may continue to create uncertainty for participants. For example, the review of Western Power's role and use of the technical rules (i.e. the technical requirements to be met by Western Power on the transmission and distribution systems) to enable greater uptake of renewable resources, the review of the licensing framework to accommodate new retail products (e.g. solar leasing), and the review of the rates offered to residential solar PV generation through feed-in tariffs [40].

Implementation

The change matrix

The speed at which change occurs, and the magnitude of the change will also have bearing on how utilities will transform their business models. Fig. 3 illustrates several emerging models across these two axis to provide four quadrants of change:

WA is currently idling at the top-left of the matrix, with market participants showing slow and minor signals of change ('Adaptation'). Of course, any meaningful transition will have to first overcome the inertia to break from path dependence, particularly prevalent in systems as complex and inter-linked as the energy sector [28]. However, as Pierson [57] notes:

> "particular course of action, once introduced, can be almost impossible to reverse; and consequently, political development is punctuated by critical moments or junctions"
>
> [pg. 251, Pierson [57]]

Industry and Government in WA have both recently signalled that they are acutely aware of an inevitable "junction" in the electricity sector – the potential for the speed and extent of the change to drive a 'Revolution'.

The phased approach

A phased-modular approach is recommended to assist WA's utilities transition away from their existing, traditional business models, towards future, sustainable business models encapsulating solar PV and associated products and services (as outlined by Characteristic F in Table 3). This phased approach will be required to underpin the evolution of WA's incumbent utilities in order to address the increasing threats to their business models. All four response outlined above will need to be implemented from the top down – with full Board and Executive support and communicated across the business in order to drive the requisite change.

Further, each characteristic identified in Table 3 can be seen as a discrete initiative or 'module' of initiatives that, whilst interrelated with the overall strategy of transforming the business model, does not necessarily have time bound dependencies with the other initiatives. Each utility in WA will therefore be able to focus on the particular initiatives that are most urgent or relevant to their position in the market, package them as a module to implement, and thereby maintain flexibility for technology developments and instances where the political, economic or regulatory environment changes.

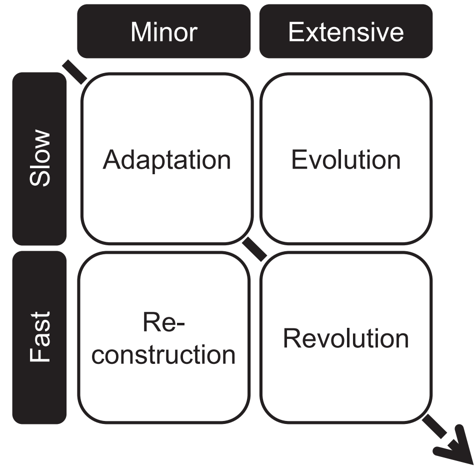

Fig. 3. Speed and extent of change adapted from Zinaman [81].

For example, the growth potential in the expanding solar market and building new customer relationships would organically provide additional opportunities for the utilities, whilst long term contracts for solar PV would also facilitate customer retention. Within this new perspective, solar PV could then be viewed as a stepping stone into other 'green energy' growth markets, such as energy efficiency and storage service offerings.

This approach also allows the utilities to explore various combinations of products and services to maximise profitability per customer. Additionally, it allows utilities to control the speed of implementation (vertical axis of Fig. 3), depending on the extent and potential impact (horizontal axis of Fig. 3) of each individual initiative – providing further flexibility and adaptability to manage successful outcomes.

One of the first steps that WA utilities can make (and to an extent what is already occurring) is the expansion of solar PV products and services. This could include providing consulting services through partnerships to customers, right through to the installation and operation of rooftop solar PV systems (including the installation and maintenance of smart meters). It could also include lobbying for more flexible and innovative regulation and policy. Given the availability of technology and the substantial volume and access to customers, this transition is relatively low-risk for utilities to make and thus can be seen as a phased-approach.

A majority of market participants interviewed recommended complimenting any solar energy products and services offered by WA utilities with energy efficiency initiatives to maximise both supply and demand side value in products and services [38,51]. This could include dynamic and innovative electricity retail tariffs (once full retail contestability is introduced in the WA market), as well as offerings for demand side management services.

Local utilities may also be positioning themselves to facilitate the adoption of electric cars and the storage capabilities they provide customers, allowing involvement in completely new markets, thus creating new opportunities for growth – whether through partnerships, contracts, or ownership of electric vehicle and battery providers [53].

Conclusions & policy implications

This paper focused on the need for WA electricity businesses to develop and transform their business models to deal with the disruption occurring across the local energy sector. Six critical business model characteristics were identified and discussed: customer focus, community engagement, research and development incubator for innovative technologies, regulatory and policy engagement, participation in distributed generation markets and the transition to energy service providers.

A range of issues were identified under each of these groups, both from existing literature, as well as from interviews with key stakeholders working within the WA energy market. The relevance of global challenges and disruptions to energy markets was also assessed in the context of local WA regulatory, political and economic conditions. From this, it was strongly advised that WA energy businesses should embrace the opportunities presented by emerging technologies such as solar PV and storage, and do so in a modular approach, to ensure capabilities are maintained, costs are minimised and customers are retained.

This research has also reinforced the idea that long-term stability in WA Government policy decisions will require long-term strategic thinking and a bi-partisan policy approach to provide the robustness and investment certainty that the electricity sector requires.

The WA energy market and the current business models of its incumbent utilities sit at a precarious point in history – attempting to manage the increasing disruption to the market. On one hand, WA is well placed to leverage the opportunities created by having the Government acting as both a large energy consumer, as well as the owner of the dominant electricity utilities. This may provide opportunities to explore roof-top solar PV on public housing and other government-owned buildings, further incentivise the use of renewable energy certificates by the Government-owned utilities, and encourage policy flexibility to incorporate technological innovations, such as the use of batteries for streetlights or edge of grid applications. On the other hand, many interviewees identified the inability for the large, risk-averse Government bureaucracies to transform business models effectively, and cited the need for more nimble private players and entrepreneurial firms to navigate the transition into new energy market structures.

The unique set of conditions within WA (i.e. economic affluence, imminent market reform, network isolation and increased consumer demand for solar and, increasingly, batteries) has made it a place ripe for disruption. It is likely that energy market participants globally will be watching WA to see how the energy market evolves, what new business models emerge and how the utilities cope with the transition. For this reason, it is expected that WA's energy market will become a pilot project site for energy businesses seeking to manage the transition and adapt their own business models necessary to meet the demands of consumers of the future.

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ABSTRACT

Innovations in energy products and services, facilitated through effective partnerships with research centers, may provide benefits to utilities across the value chain. Policy implications could be significant in shifting from traditional regulatory models to flexible frameworks that encourage innovation. A collaborative mindset will be needed to ensure utilities recognize the role they must also play in guiding regulatory reform.

1. Introduction

1.1. Research and development in the electricity industry

> Right now, the world spends only a few billion dollars a year on researching early-stage ideas for zero-carbon energy. It should be investing two or three times that much . . . because it is a public good.

Ever since the electricity grid was developed in the late 1800s, there have been no revolutionary changes to the structure of the system. Today, we still have a centralized grid system, with electrons flowing from generation sources, through transmission and distribution networks, to a final load. There may have been gains from technology innovation incorporated into generation plants, making them more efficient, cheaper, or cleaner. And the safety and reliability of the system has been steadily improving. But the concept and structure of the centralized grid has stood the test of time, and leveraged the economies of scale and existing infrastructure for more than 200 years (King, 2016).

This structure is now under the threat of disruptive innovation. The centralized model is being challenged by new products such as solar photovoltaic (PV), battery storage, microgrids, and smart meters (Kind, 2013). These technologies and other market led innovations have been slowly entering the sector over the past decade through various trials, pilots, and experiments by forward-looking commercial enterprises and university led research. They have now entered the lexicon of every day users. Consumers are recognizing they no longer need to be passive recipients of electricity at increasingly higher prices, but can become "prosumers" (producers and consumers) and have independence and control over their consumption and costs. The result so far has been both a reluctance from the large incumbent utilities to acknowledge the threats, and existing regulatory and policy frameworks being too inflexible to manage the transition away from the established, traditional centralized model (Richter, 2013).

The disruption has begun, and even banks and financial institutions have recognized the risk of continued to fund traditional large-scale infrastructure in the mold of the centralized model (Caldecott and McDaniels, 2014). Governments and regulators are also facing increasing pressure to manage the cost structure changes.

Financing within the energy sector is already incredibly complex, with a myriad of subsidies, cross-subsidies, incentives, and tariffs across market participants, consumers, and utilities. However, in dealing with the evolution of the sector amidst this inevitable disruption, very little funding is directed into the research and development (R&D) of innovative products and services. The International Energy Agency (2015) noted that publicly funded R&D accounted for only 4% of global research budgets, with renewables less than half of that. This is in contrast to a level of 11% in 1981 (IEA, 2015).

This is not just a problem for sustainable-energy enthusiasts, but in the medium to long term it is inefficient for utility businesses, and therefore a risk and a cost for participants and consumers as well (Nyquist, 2016). In order to maintain their relevance, and continue to sustain profitable business models, utilities must not simply defend against this disruptive innovation, but must get ahead of the curve and be leading innovators themselves, by re-prioritizing their investments in R&D.

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2. Background

2.1. Technology innovation: the role of universities

While research and development is a broad term that can cover several different ideas, in this article, we use Wonglimpiyarat's (2016) description of "incubator" to define the process of knowledge transfer and commercialization:

> The incubator is an umbrella term referring to a mechanism for technology transfer to promote the growth of innovation and entrepreneurship.

There are many studies that have explored the link between businesses and incubators – and how these partnerships can drive technology innovation (Sagar, 2004; Bakouros et al., 2002; Allen and McCluskey, 1990; Acs and Naude, 2011; Smilor and Gill, 1986). Rubin et al. (2015) and Klofsten and Jones-Evans (2000) conducted empirical research into the role and ability of incubators to facilitate entrepreneurs' performance and ultimate success. Their findings suggest that, for incubators they studied across Australia and Israel (Rubin et al., 2015) and for entrepreneurs studied in Sweden and Ireland (Klofsten and Jones-Evans, 2000), the collaboration and knowledge shared through the incubation process allowed new startups to increase their understanding of financial, technical, and market processes and, perhaps most importantly, assisted in the ability for the new businesses to raise capital.

The studies also found that university partnerships and the academic environment also played a vital role in assisting with product development. The research suggests that university-based incubators have an important role to play as an intermediary between the academic sector and industry in order to provide the iterative link that allows for effective application and development of university research (Rubin et al., 2015; Fu, 1995; Klofsten and Jones-Evans, 2000).

These findings are consistent with other literature that has outlined how universities around the world are recognizing a shift in their traditional role away from providing conventional academic research and educational functions, to one that promotes innovation, knowledge sharing, and commercialization linked closely with industry developments (Youtie and Shapira, 2008; Haoour and Mieville, 2011; Etzkowitz, 2002).

Of course, the concept of incubators to encourage general business development innovation is not new in Australia – technology parks (also known as science, business, or research parks) were established across the country throughout the 1970s and 1980s to facilitate the flow of knowledge and commercialize research from universities (Phillimore, 1999; Currie, 1985; Monck et al., 1988; Eul, 1985).

Perhaps the most cited example of these parks working with industry is through the telecommunications and information and communications (ICT) space, which was also supported with direct federal government funding of over $150 million to promote innovation in the ICT industry and address existing market failures (Garrett-Jones, 2004). However, Australia is still ranked poorly amongst the Organisation for Economic Co-operation and Development (OECD) nations for collaboration between industry and public researchers.

The importance of research and development is becoming increasing relevant to the energy industry, already grappling with understanding and implementing the next wave of technology development. From their perspective, utilities should develop and strengthen partnerships with university and research institutions and recognize the value they can provide as incubators and as a "vehicle for technology and knowledge transfer" (Rothaermel and Thursby, 2005). Not only do external parties provide new points of view to assist with critical thinking and "outside-the-box" brainstorming, but access to this external knowledge base would either have been incredibly difficult and more expensive to drive internally, or unachievable due to institutional lock-in and the mindset to conform to existing methods and practices (Chesbrough, 2003). Whilst potentially new to the energy sector and incumbents within, these advantages are already widely acknowledged in business innovation and entrepreneurship literature (Bøllingtoft, 2012; Johannisson, 2000; Lofsten and Lindelof, 2001; West and Bogers, 2014).

2.2. Technology policy

Wider than just the energy sector, government must recognize that innovation is critical to creating and maintaining growth across all industries and sectors, and therefore coherent and consistent federal policy is necessary to promote the environment in which this growth can be sustained (Lundvall, 1998; Freeman, 1987). Dalton and Gallachoir (2010) go one step further and suggest that effective technology and innovation policy requires a focus on the creation of user markets to promote technology projects in the short term.

The literature on technology policy also suggests that in order to enable diffusion of the technology innovations, markets as well as "innovation networks" are a necessary part of the process (Norberg-Bohm, 2002; Sagar and Gallagher, 2006; Zhu and Zou, 2006; Guo et al., 2016).

This policy certainty facilitating the creation of markets is observable from the successful cases of the solar PV, wind power, and biofuel industries in China, India, and Brazil (Lewis and Wiser, 2007; Zhang and Gallagher, 2016).

2.3. Case study: China's solar success

Research has shown the rapid success of China as a world leading solar PV manufacturer relies heavily on strong government policy support for technology innovation (Zhang and Gallagher, 2016; Lall and Teubal, 1998; Ockwell et al., 2008; Zhi et al., 2014).

In their research, Zhang and Gallagher (2016) deconstructed the solar PV value chain to analyze the determinative factors that drove China's success in the technology. What they found was a successful strategy that saw the Chinese firms' first acquiring low-cost module manufacturing technologies, before increasing their competitiveness through a step-by-step vertical integration up the value chain.

Success was also contingent on strong government policy incentives, China's manufacturing market's flexibility, and the globalization of engineering and research talent that allowed appropriate knowledge transfer to occur (Zhang and Gallagher, 2016).

2.4. The Western Australia opportunity

The challenges facing electricity utilities around the world are the result of a significant innovation disruption – a transition from the centralized model of service delivery to a renewable distributed model of electricity networks. For Western Australia, this disruptive transition is occurring more acutely, due to a market structure that includes government-owned monopoly utilities that rely heavily on subsidies to provide electricity across the state. As a result, the WA government is now grappling with escalating costs and has recognized the importance that technology innovation will play in allowing the system to take advantage of the renewable resource that is in abundance (Nahan, 2015; Bromley, 2015).

WA utilities are already exploring how the increasing penetration of solar PV may impact the grid, as well as preparing for the inevitable integration of battery storage systems as they continue to come down the cost curve. And while several drivers of this transition are common to markets around the world, such as rapid advancements in technologies, WA is also facing a unique confluence of additional factors – structural market reforms, network size and isolation, high solar radiation, and customer demand – that will only serve to accelerate the process in the region (Parkinson, 2016; Bromley, 2015).

These technology innovations will only increase the challenges for utilities and government, and WA's isolated electricity network and energy market has already become a demonstration site for energy sector participants around the world looking for guidance on how to manage the transition (Parkinson, 2015). Trials of microgrids, distributed energy generation, behind-the-meter software and systems, demand-side management, stand-alone power systems, and advanced metering infrastructure are just some of the innovative projects that have successfully realized the transition from incubator and R&D labs, to partnering with utilities for implementation opportunities. This article outlines why these projects form only the start of a wave of innovations needed for utilities.

3. Methodology

3.1. Literature review

A review of existing literature was carried out to gain a thorough understanding of the existing innovations models being proposed, trailed or conceptualized for electricity utility businesses attempting to create new opportunities, particularly for Western Australia, but with application for utilities around the world.

4. Results

4.1. Utility 2.0 – new energy business platforms

The delivery business models for electricity companies are being challenged due to the influx of innovative systems and products that will inevitably become part of traditional utility offerings. This is being driven by a convergence of technology innovations, economic conditions, environmental imperatives, and a shift in public policy.

In addition to navigating these innovations and the associated increase in commercial risks, utilities have also been confronted with additional safety and reliability challenges as a result of the increased uptake of customer-driven installations such as distributed renewable generation.

In a scan of companies, conferences, launches, and interviews, Reid (2016) identified four potential future business platforms for utilities to explore as part of their future strategies (Table 1).

Whilst Table 1 outlines only a selection of potential platforms for utilities to explore and understand, they will also need to make a conscious business decision whether to incorporate or compete against each new product or service – or face losing market share, eroding revenue, and increasing irrelevance in the market. To a certain extent, utilities in WA are shielded by strict and cumbersome regulatory barriers, but as the example of Uber highlighted, when customers identify an innovative product or service that meets their needs, change will be forced into the industry irrespective of any perceived regulatory barriers.

4.2. Big data

With increasing capabilities in software analytics, smart meters and “digitization,” the electricity industry is primed to leverage gains in organizing, analysing, and optimizing the data acquired along its electricity networks and systems and take advantage of new business platforms, as outlined in Table 1.

For Western Australian utilities, direct opportunities exist to address the increasing cost of service and reliance on government subsidy by reducing operational and capital costs and increase efficiencies in the business.

By installing smart meters across its customer base, the regional electricity utility provider in Western Australia, Horizon Power, has already recognized the value that installing intelligent infrastructure can bring to addressing future disruptive forces going forward (Horizon Power, 2016a).

Horizon Power is government-owned and provides power to over 100,000 customers through 46,000 customer connections across regional and remote Western Australia.

Horizon's service area is more than 2.3 million square kilometers (Fig. 1) – twice the area of UK, Germany, and France combined (Horizon Power, 2016b).

Given the sheer size of coverage, the immediate advantages of Horizon's investment in these smart meters include the ability to introduce pre-payment products across a hard-to-serve customer base, electronic billing (saving millions in manual meter readings and testing), increased security and accuracy capabilities, and potential for aggregated system control (in the context of virtual power plants and distributed energy generation assets).

Future benefits, and potential for further collaboration with innovation centers and universities to progress these initiatives, include the opportunity to aggregate customer datasets and combine with weather and system data to improve predictive maintenance and system management capabilities, as well as provide innovative customer engagement platforms to address retention and customer satisfaction (Horizon Power, 2016a).

4.2.1. Hackathons

Utilities should increasingly be looking to participate in innovation initiatives such as hackathons where it may be beneficial to generate creative solutions to new disruptive opportunities – such as those presented by the installation of smart meters.

Table 1
Innovative business platforms for utilities.

Model	Description	Existing Examples
Pay as you go	Provides customers no obligation for regular billings – allows variety of payment plans and potential for mobile phone payments.	Mobisol, Beegy
Software as a service	Companies offer data analytics to customers to improve performance of electricity assets.	Lumeneza, Mercatus
Product packages	Utilities combine with electric auto companies, heating or cooling providers with energy agreements	SolarCity, Tesla
Optimization services	Automatically selects cheapest/customized services and products for customers across the value chain – scanning prices across the market	Verivox, Thermondo

Source: Adapted from Reid (2016).

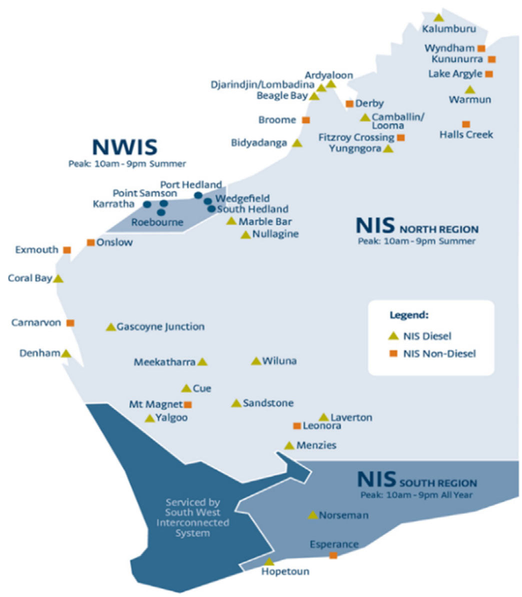

Fig. 1. Horizon Power service area.
Source: Horizon Power (2016b).

Hackathons involve groups or teams of self-selected experts, working in a shared space to collaborate around a central idea, dataset, or defined problem. The event is usually limited to days (e.g. over a weekend), to facilitate a focused burst of entrepreneurial thinking (Doshi-Velez and Marshall, 2015; Bazilian et al., 2012).

Hackathon participants are traditionally data-driven experts such as computer scientists, statisticians, engineers, and other technology specialists who appreciate solving problems and have expertise in computational theory and using complex datasets (Bazilian et al., 2012). However, utilities should be conscious that, based on historical sessions, only the minority of participants will have direct experience of the energy sector and electricity systems and networks. Therefore, consideration needs to be given to the need for (Doshi-Velez and Marshall, 2015):

(a) Well-scoped objectives of the session, but one that encourages creative approaches and unexpected correlations and conclusions;
(b) Standardized datasets – for ease of understanding and manipulation; and
(c) Attendance by technical staff with energy expertise, to assist with modeling assumptions and problem definitions and boundaries.

By utilizing the data generated through smart meters integrated into its network, Horizon Power has a unique opportunity to present hackathon event organizers, such as the university groups outlined in Fig. 1, with an energy event centered on addressing the wider industry disruption. Being a state-owned, vertically integrated power provider, Horizon may also find itself well placed to combine information and learning outcomes across all aspects of the business, for example how customer behavior may ultimately impact on generation and network requirements.

In Western Australia, opportunities are increasing for companies to partner with existing innovation centers and incubators, or create further networks of experts who already have experience in running hackathons and fostering entrepreneurial ideas.

Table 2 provides a high-level scan of what the five major WA universities promote online in regards to their incubators or innovation centers.

As outlined in Table 2, despite the growing body of evidence in the literature of the value that research collaboration provides to underpinning innovation endeavors, Western Australian universities are still at varying stages of implementing incubators and research and development links with industry that could underpin such initiatives as hackathons – particularly on the topic of energy technologies.

4.3. Microgrids

Microgrids, as defined by Prete and Hobbs (2016), are:

. . . a group of multiple distributed generation units and loads operating as a coordinated system, connected to the main electric grid at a single point (typically, at the distribution level), and able to function in parallel with the grid or in island mode.

Remote microgrids are further classified as those microgrids that are not typically interconnected with a reliable grid and therefore operate primarily in island mode. They are also more prone to having high levels of renewable energy (e.g. distributed solar PV), and feature some form of intra-network intelligent control systems to optimize energy flows, as shown in Fig. 2.

Table 2
Western Australian University incubators.

University	Centre	Description
University of Western Australia	Innovation Quarter	Building on its rich history of research-led innovation – aims to lead new research efforts in areas like agriculture, resources and medicine that will improve the way we live and help advance WA's prosperity.
Murdoch University	Murdoch University Energy Research and Innovation Group	In association with Innovation Cluster and Atomic Sky, the Start Something program aims to stimulate entrepreneurship among academics, postgraduates and early career researchers at the University – provides enterprise skills, knowledge and contacts in industry to help researchers. Industry engagement is a growing component of the future of public research in Australia, so researchers interacting with industry experts from multiple fields are central to the program.
Edith Cowan University	The Link	A joint initiative between the City of Joondalup and Edith Cowan University – will help to drive innovation and business growth in and around Joondalup. The Link website will enable businesses and investors to access information on business opportunities in the city and connect with ECU research expertise. Includes facilities such as Cyber Security Institute, Electronic Science Research Institute and Health Simulation Centre, ECU will look to drive innovation in the area.
Notre Dame	n/a	Direct health research funding and network with other universities
Curtin University	Cisco Internet of Everything Innovation Centre	Industry and research collaboration centre, established by Cisco, Curtin and Woodside Energy. Over 80 researchers and links to advanced facilities and a global industry network will bring together startups, industry experts, developers and researchers to create ground-breaking and innovative solutions that foster growth, provide jobs and help build sustainable economies.

Source: University websites (2016).

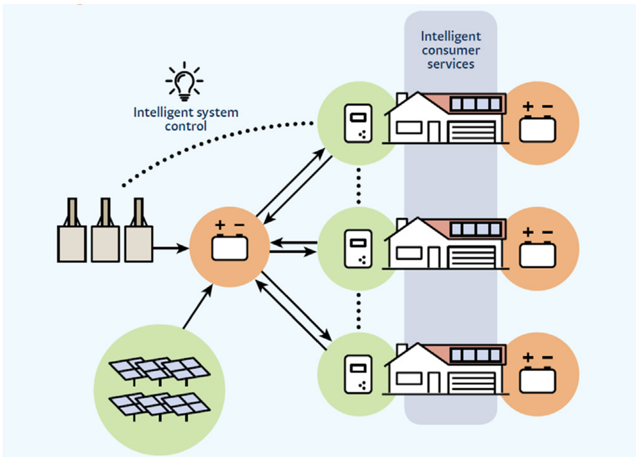

Fig. 2. Distributed renewable microgrid.
Source: Horizon Power (2016a).

In contrast to the disruption and increasing competitive pressure on traditional network businesses, the microgrid market is expected to continue its rapid growth as technology innovations and price reductions shift emphasis from a centralized supply model to one predicated on distributed generation.

North America leads the world as a market for microgrids, and has over 65% of total global capacity (Prete and Hobbs, 2016; Lidula and Rajapakse, 2011).

Western Australia's regional areas are also presenting themselves as attractive test-beds for renewable energy microgrid applications – with 2016 alone presenting various wind, wave, and solar trails across the State (Parkinson, 2016).

4.4. Innovations in customer engagement

Existing technical, financial, and institutional barriers still need to be overcome in order to transition to future energy networks (Tayal, 2016), and facilitating new forms of customer engagement is critical in achieving this transition (Accenture, 2016).

Impelled by the recent developments in technology, as well as a common apathy for traditional utility companies, customers now have a different perspective than previously – with higher expectations for service, personalized products, meaningful experiences, as well as pushing for the ability to explore new ways of contributing and participating through their own distributed energy investments (Accenture, 2016).

As forecast by the Australian Energy Market Operator, Australia's system operator for electricity and gas markets, the future electricity supply chain is expected to slowly but steadily be shared more evenly between utilities and their customers (Table 3). The initial challenge for grid owners and policymakers is in breaking down barriers that seek to protect the traditional structures and impinge on the necessary competition for new products and services (Tayal, 2016). The secondary challenge is how to leverage these changing perspectives and continue to make whole-of-network efficient decisions, which becomes increasingly difficult once the shift away from centralized networks starts to gain momentum. No longer will utilities be able to have teams of network planners and system operators providing 10-year forecasts of required network investment. Customers will relieve investment pressures by investing in electricity assets at both a household and commercial level. But this will not remove system security and reliability requirements from the utilities responsibility. Instead, it will simply change their focus to ensuring grids are flexible, can accommodate the fluctuating input from intermittent sources such as solar and wind generators, and can provide the level of service that customers of the future will be expecting.

Table 3
Percentage of rooftop PV relative to underlying grid consumption.

	Queensland	New South Wales	South Australia	Victoria	Tasmania
2014–15	5.7	2.4	8.4	2.7	3.0
2017–18	9.1	3.7	11.9	4.4	4.9
2024–25	16.0	6.3	22.1	8.6	11.0
2034–25	20.2	9.3	28.5	13.7	17.4

Source: AEMO (2015).

4.5. Electricity economics: the traditional approach

Traditionally, pricing for electricity is largely driven by a return on investment approach for each aspect of the supply chain that makes of the electricity system. While only some parts of that supply chain are regulated – in Australia, the network component – the same economic approach applies to investments in retail and generation components (AER, 2014).

For example, those who have invested in assets require a return of capital, return on capital (i.e. a reward for taking risk), and any other allowances and operating cash flows in order to maintain and run the assets. This concept applies down to marginal costs as well – generators are provided returns for any fuel used, and retailers are paid a margin to compensate them for taking market risks (AER, 2014).

In the traditional model, an electricity network is very capital-intensive, and increased utilization provides a more economically efficient outcome through lower costs per unit for providers, and therefore users. However, as distributed energy generation assets increase their penetration across the grid, different mechanisms will be required to ensure these assets are still utilized effectively.

4.6. Electricity economics: incorporating innovation

Given the substantial disruption now occurring in electricity markets, utilities need to be transitioning their business modes away from traditional economic approaches, or at least recognize the impending risk of stranded assets declining revenues (Caldecott and McDaniels, 2014).

Utilities will need to be aware of these constraints, and develop new platforms that can combine with intelligent communications, smart meters, and distributed renewable sources of generation while still maintaining lowest possible costs for the system. This may even necessitate providing incentives for customers to invest in specific energy assets, at specific locations to provide benefits to both utilities and customers. The system could then leverage these distributed resources to increase asset utilization, improve resilience and ultimately transform the electricity supply chain to one that operates through less capital employed and therefore lower electricity prices.

Similarly to the economic principles that underpin conventional electricity systems, as distributed renewable generation increases, microgrids gain further prominence, and renewable energy technologies increase penetration levels, several economic approaches will need to be maintained.

For example, even if investment requirements are smaller, distributed across multiple locations or aggregated through numerous investors, any capital invested will still be expected to generate returns over the life of the asset. Therefore, from an economic point of view, the benefits of the transition away from centralized power systems still reside in improving network value and providing the additional customer benefits mentioned earlier. Core to this transition, is ensuring economic efficiency – across networks, retail businesses, and future investments.

However, in managing this transition, overall system value still need to be maintained, to ensure that the pendulum does not swing too far the other way, losing economies of scale and disregarding the value of electricity as a tradeable good. For example, system-wide solutions at the distribution level (and smaller) should still be considered to ensure that users are not forced to over-capitalize on capacity (e.g. oversized PV panels and battery systems), or through acquiring and installing large backup generating units instead of considering a lower-cost, system-wide trading platform or microgrid.

4.6.1. Incentivizing market behaviors

The economic business case for utilities of the future will need to ensure that it incorporates system-wide benefits in any value assessment of infrastructure upgrades, in order to maximize the efficiency of the investment. The question then becomes how policymakers can translate these efficiencies into appropriate incentives to encourage market participation and drive competition across energy markets, to the benefit of governments and customers.

Given the utility's ability to identify the need and benefits associated with network and system investments, it is proposed that in the first instance, it is the utility's responsibility to provide the right incentives – through market-based mechanisms to its customers. One example would be a utility providing discounted batteries or installing advanced meters and incentivizing its customers to institute demand-side response behaviors during peak demand periods, in order to avoid additional investment. Of course such approaches also require the cooperation of governments and regulators to ensure the flexibility of regulations, as well as having appropriate customer protection frameworks in place.

Properly designed, a market platform by which customers can utilize the network (and other infrastructure) to exchange services with others would also enhance the value of the network beyond the single dimension of transporting power, helping increase value for both utilities and consumers. It is predicted to improve customer retention, through improved opportunity to increase their own autonomy, investment returns, and ability to respond to price impacts.

By using the means to drive innovative outcomes as identified earlier (e.g. hackathons and research collaborations with universities), utilities can decouple the complex interactions among electricity, system operators, customers, and (increasingly) customer assets. Ideally, utilities would be able to design these interactions to happen automatically, and respond to specific price signals to provide maximum benefit to customers.

Utilities will also need to leverage customer behaviors to ensure that the network is utilized most efficiently – e.g. through changing consumption patterns. One emerging example is the aggregation of individual distributed generation sources, such as small-scale storage at the residential level, but with utilities using a central control system and “intelligent” communications to make the distributed storage available to address peak demand situations – a form of virtual power plant.

4.6.2. Virtual power plants

Leading the Australian market, AGL Energy (in partnership with Sunverge) announced in August 2016 (AGL, 2016) its development plans for “the world's largest battery storage virtual power plant” in South Australia. The trial includes 1,000 customers installing battery storage with a combined capacity of 5 MW, with each battery system controlled centrally through a “cloud connected intelligent control system” to provide wider distribution grid stability and assist in the management of peak demand. In effect, the aggregated batteries will act as the equivalent to a peaking plant.

South Australia was chosen as the location given it leads Australia in the penetration of renewable energy, and no longer has any large centralized coal-powered fire stations available for generation (AGL, 2016).

Therein lies a challenge to pursue strategic projects of this nature that are fundamentally opposite to traditional electricity revenue streams of centralized generation and distribution. AGL, through this trial, appears to be taking the first step into a distributed energy future – with the opportunity to test, and even control, how distributed energy can be used to benefit customers (lowering power bills and reducing emission) as well as utilities (maximizing grid utilization and providing system security in an efficient way).

Hopefully, regulators and policymakers take note of these ongoing technology trials and ensure frameworks are adapted and are flexible enough to encourage further innovations.

Similarly, embracing these opportunities and facilitating their development will need to become a regular component of utilities business models going forward.

5. Conclusions and policy implications

With the increasing prominence of technology innovations including distributed renewable generation assets, smart meters, battery storage and intelligent software and communication systems, utilities will need to recognize these disruptive threats to their traditional business models and adapt.

By embracing new services and products, utilities can transform these threats into opportunities, and provide enhanced customer service through greater choice and lower costs, while maintaining business value. Looking forward, we are more likely to see dense microgrids with high penetration of renewable assets, linked virtually through intelligent communications and adaptable to several customer segments in order to drive efficient behavior.

Of course, several barriers will need to be overcome, not least an archaic and inappropriate form of electricity pricing, rigid regulatory framework, and instability in long-term government policy direction. But the economic drivers in support of innovation in the sector are forcing the hand of regulators and governments around the world.

Collaboratively, utilities, governments, policymakers, and regulators need to create the right culture and institutional frameworks that do not stymie risk taking but actually facilitate failure – such that iteration can drive successful solutions and create further value. The question remains on how to do this in an inherently risk averse industry, business environment, and largely government-controlled ownership model.

Regulatory regimes, established to encourage long-term economically efficient investments by the utility, will need to adapt to recognize the contribution that non-utility-owned assets play in economic efficiency. Utilities will also need to understand it is their responsibility, on behalf of their shareholders and customers, to drive this regulatory and policy change – through partnerships with universities and research labs (and other entrepreneurial means like hackathons) in order to drive innovation through the business as well as through the sector as a whole.

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THE CONVERSATION
Academic rigour, journalistic flair

Five things the east coast can learn from WA about energy

April 26, 2017 5.54am AEST

Western Australia's largest private solar array covers the roof of this food distribution centre in Perth's south. AAP Image/Bidvest

It's an interesting time to be involved in energy policy. Thanks to the east coast energy crisis, the closure of Hazelwood power station and South Australia's blackouts, the broadsheet-reading public suddenly finds itself conversant with all sorts of esoteric concepts, from gas peaking to five-minute price settlements.

Amid all the disruption, it's perhaps not surprising that a long-term, coherent national energy policy remains as elusive as ever. Instead we see piecemeal announcements like pumped hydro and battery storage, none of which is itself a panacea. Some innovations can hinge on a single tweet which, while exciting, hardly gives the impression of joined-up policymaking.

Despite its name, the much-maligned National Electricity Market doesn't extend to Western Australia, which means that federal energy policy discussions don't always reach across the Nullarbor.

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But we suggest looking west for inspiration. In our view, WA is well placed to research, develop and deploy the energy solutions that the whole country could ultimately use. Here are five reasons why.

1. An appetite for change

WA electricity customers have long recognised the advantages that energy innovations provide. More than 200,000 homes have solar panels (rapidly closing in on the penetration levels of Queensland and South Australia), and the appetite for residential battery storage is steadily growing.

This is due to a combination of factors. First, there's the consistently sunny weather. Then there's the fact that WA customers cannot yet choose their electricity retailer, meaning that households are more motivated to shop for solar panels to gain independence from government owned monopoly utilities, and can't simply rely on the innovative price deals of the more nimble retailers found over east.

The vast distance and separation from the rest of Australia's network means the WA grid won't be joined to the NEM any time soon, meaning it will need to address the issues for itself, hopefully aided by a newly elected state government with the political capital to reform energy markets.

2. Micro grids, maximum resilience

To move successfully away from the traditional, centralised model of electricity generation, you need to maintain one of its cornerstone qualities: resilience. Being so far from literally everywhere else on the planet has embedded these traits into WA's energy network, but has also reinforced the need to incorporate "microgrids" into network planning.

Microgrids are best thought of as small electricity sub-grids, able to function in concert with the main grid or in isolation if necessary. This increases the entire network's resilience – you can't have a state-wide blackout if you have plenty of microgrids.

WA currently has over 30 isolated microgrids, and is in prime position to be a test bed for more complex systems of network control, which will become necessary as these grids attempt to incorporate ever higher levels of distributed renewable energy from solar panels and other sources.

3. Trials and tests beat reviews and reports

The forthcoming Finkel Review of the National Electricity Market is clearly necessary and welcome. But while the media and political circus focuses on it, the utilities in WA are already out there testing the solutions.

The government-owned retailer Synergy and network operators Western Powerhave helped to investigate a range of innovations, such as strata peer-to-peer electricity trading, microgrids, utility-scale battery storage, demand-management, and standalone power systems for fringe-of-grid areas.

Meanwhile, the state-owned regional provider Horizon Power provides several valuable test case opportunities to understand how future grids and networks will need to operate in more remote areas. For example, it has successfully installed advanced metering infrastructure ('smart meters') for every one of its 47,000 customers, spread over 2.3 million square kilometres, no less.

4. Skilled labour is plentiful

During WA's decade-long mining boom, technical skills were in high demand and short supply. It's fair to say the opposite is now the case. Meanwhile, the state government has committed to removing 380 megawatts of fossil-fuel generation capacity from the WA energy market, most of which is situated around Collie, south of Perth.

If this pledge leads to greater opportunities for new renewable energy infrastructure it would provide welcome relief for a job market awash with underemployed technical experts, still reeling from the mining downturn.

WA's world-leading reserves of lithium ore also offer a significance chance to join in the burgeoning battery storage industry.

With the recent closure of Hazelwood's ancient coal-fired power station, Victoria's Latrobe valley will no doubt be investigating similar opportunities, and the coal regions of Queensland and New South Wales should not be too far behind.

5. Strong links between government and experts

For WA, the disruptive transition in the energy sector is more acute, partly because its market is dominated by government-owned monopoly utilities that rely heavily on subsidies to ensure consistent power prices. But mostly because in WA there is a very direct link between power prices and politics, and electricity is always a hot topic at state elections.

Because of its physical isolation, WA's energy policies are also largely independent from the rest of the COAG Energy Council.

As described in point 3 above, utilities will need to be prepared to spend significantly on research and development if they want to survive. WA's utilities already rely heavily on state government support for technology innovation, but also have strong networks of local experts that are able to bridge the silos across academia, industry and government and keep the momentum going in WA's smaller markets and grids.

So that was five reasons, among many more, why we think WA has a chance for not just Australian, but global leadership in the renewable power transition. As the rest of the country grapples with its energy headaches, it should consider looking west once in a while.

Electricity Solar power Western Australia Resources National Electricity Market Solar panels resources boom Distributed energy solar PV electricity grid

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Achieving high renewable energy penetration in Western Australia using data digitisation and machine learning

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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

The energy industry is undergoing significant disruption. This research outlines that, whilst challenging, this disruption is also an emerging opportunity for electricity utilities.

One such opportunity is leveraging the developments in data analytics and machine learning. As the uptake of renewable energy technologies and complimentary control systems increases, electricity grids will likely transform towards dense micrograds with high penetration of renewable generation sources, rich in network and customer data, and linked through intelligent, wireless communications.

Data digitisation and analytics has already impacted numerous industries, and its influence on the energy sector is growing, as computational capabilities increase to manage big data, and as machines develop algorithms to solve the energy challenges of the future.

The objective of this paper is to address how far the uptake of renewable technologies can go given the constraints of existing grid infrastructure, and provides a qualitative assessment of how higher levels of renewable energy penetration can be facilitated by incorporating even broader technological advances in the fields of data analytics and machine learning. Western Australia is used as a contextualised case-study, given its abundance and diverse renewable resources (solar, wind, biomass, and wave) and isolated networks, making a high penetration of renewables a feasible target for policy makers over coming decades.

1. Introduction

1.1. Disruption in the electricity industry

The electricity network and grid system in use today still largely resembles the original structure of the system that was initially developed in the late 19th century. Electricity infrastructure around the world is predominately based on a centralised system whereby electrons are generated by large thermal plants, before being transported through a large network of transmission and distribution lines to a final customer load.

This centralised structure of the electricity grid has stood the test of time because it best leveraged the economies of scale that thermal plant technologies provided ([28]). However, these traditional technologies – the coal and gas fired power stations – are now becoming increasingly challenged by new products and innovations in the energy sector that are being integrated into the existing infrastructure, most notably smaller, distributed energy generation sources such as solar photovoltaic cells (i.e. rooftop solar panels), battery storage systems, and complimentary data and communication tools, such as smart meters, wireless communications, and intelligent inverters [27].

Electricity customers, from households to large businesses, are also increasingly aware of their newfound ability to choose electricity products that better match their load profiles, have less impact on the environment, and perhaps most importantly, reduce their electricity bills.

The energy sector is in the midst of a technological disruption that is challenging existing grid infrastructure, energy institutions, regulations, policy markets and financiers alike. New technological innovations continue to come down the cost curve, improve their efficiencies, and adapt their services to better satiate the increasing expectations of consumers.

2. Background

2.1. Barriers to renewable energy

Renewable energy is steadily becoming the new centre point for electricity generation – replacing conventional fossil fuel sources at increasing rates. Global energy statistics show that renewable sources are already providing almost 20 per cent of global consumption, and in 2014 accounted for more than half (59 per cent) of all new energy

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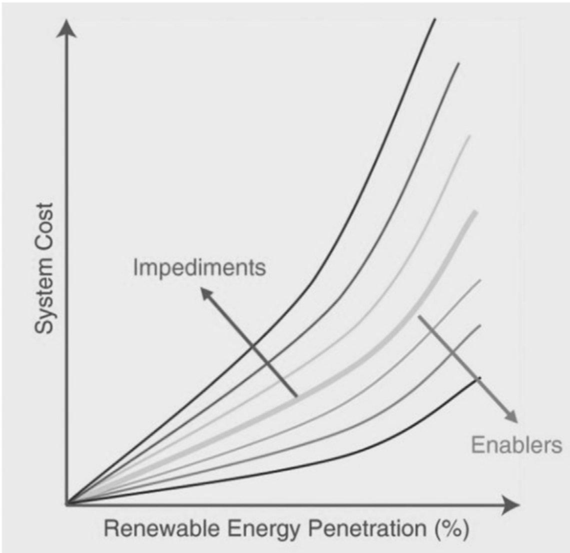

Fig. 1. Limits to high penetration of distributed renewable energy systems. Source [42].

plants added to grids around the world [45]. This growth captures both developing countries appetite for wind and solar sources above fossil fuel and nuclear capacity, and also suggests that globally, the transition to integrating high penetrations of renewable energies into existing grids has already begun [15,24].

Whilst there are no theoretical limits to continue connecting renewables to the grid, as the penetration level of renewables increases, it becomes exceedingly challenging [5]. In particular, technical and financial limits must be overcome: technical limits on equipment – such as hosting capacity – need to be adhered in order to maintain system security, stability and reliability; and financial limits inhibit high penetration levels, as after a threshold point (see Fig. 1 below), the cost to connect increasing levels of renewables also increases, at an exponential rate [42].

As shown conceptually in Fig. 1, the marginal system cost increases as renewable penetration increases. This marginal cost represents total integration costs, which include, for example [42]:

- Increased requirements for ancillary services;
- Higher unit costs for remaining 'traditional' thermal generation plant;
- Higher operating and maintenance costs for traditional plant due to increased cycling and ramping; and
- Increased curtailment costs for both renewable and traditional plant.

Notwithstanding these financial challenges and 'impediments', benefits are also accrued as the penetration level of renewables increases – reduced fuel requirements, lower greenhouse gas emissions, and greater community participation and customer choice, to name a few. By accurately identifying and incentivising these benefits, they become 'enablers', driving total system costs downwards, even whilst renewable penetration levels increase.

However, there are also several significant institutional, regulatory and psychological barriers that need to be overcome by renewable proponents, as outlined by [51], in the context of increasing solar and storage in the Western Australian market. However, these are barriers that exist at all levels of renewable integration, even low levels, so this paper will concentrate on innovative technical solutions that focus on overcoming the technical and financial limits specifically. Therefore, this research provides policy-makers, utility executives, and consumers with initial grounding and reinforces the opportunities that our existing electricity grids can have from utilising advances in data analytics. For example, through the application of technical innovations, utilities could ultimately be able to forecast wind speed and solar radiation, increase the flexibility of their traditional (fossil-fuel) plant, and in the future, explore how demand side management and ancillary service markets can leverage machine learning to facilitate the uptake of increased renewables, whilst minimising impacts on total system costs.

Tackling increased renewable energy in parallel with lowering cost is not just a problem for sustainable energy enthusiasts, but in the medium to long term it is inefficient for utility businesses, and therefore a risk and a cost for participants and consumers as well [37]. Governments and regulators are also facing increasing pressure to manage the cost of structural changes to energy markets being driven by the uptake of renewables. In order to maintain and continue to sustain profitable business models and provide cost-efficient electricity service provision, utilities must address these barriers that are limiting higher penetration of renewables (e.g. beyond current levels of 30–40%), and leverage the growing body of knowledge and technical expertise being created in the 'internet of things' sector.[1] Ideally, utilities will get ahead of the curve and be leading innovators themselves, but this will also require regulatory and political support.

2.2. The WA opportunity

Western Australia (WA) is one region that is already beginning to explore how higher penetration levels of rooftop solar may impact the grid, and whilst several drivers of this transition are common to markets around the world (such as rapid advancements in technologies and significant reduction in costs), WA is facing a unique confluence of additional factors – structural reforms to markets and institutions, expansive network size and isolation, high solar radiation, and customer demand – that will only serve to accelerate the process in the region [40,6].

The WA generation mix is still currently dominated by fossil fuels, with around 50 per cent of generation in 2015–16 coming from coal, and another 20 per cent from gas [1]. This provides a realistic baseline from which high renewable transition scenarios can be modelled, such as studies conducted by [15] for Australia's National Electricity Market. As such, the WA energy market provides a useful contextualised study given its abundance of diverse renewable resources (solar, wind, biomass, and wave).

WA has the highest solar radiation levels in Australia, and is the third-windiest region in the world (with average coastal wind speeds of 27 km/h). It also has an extensive 12,9000 km coastline – providing significant wave and tidal energy potential. This makes a high penetration of renewables on WA's networks a technical, economic and politically pragmatic target for policy makers over coming decades [16].

An additional advantage is WA's electricity market, which is still highly regulated, dominated by Government-owned entities and currently undergoing a major reform program independent from the rest of Australia given its isolation in both network infrastructure and political dependency. This separation means there is little prospect for an interconnector to the national grid and market, meaning there is even greater urgency to outline cost-effective solutions for delivering reliable, secure and clean energy without drawing on the back-up generation of other networks [52]. Although the WA market is relatively late in considering initiatives such as full retail competition and flexible pricing (Australia's Eastern States implemented similar reforms through the nineties), the industry has therefore become more open to consider major structural reforms and market re-design – not just economic improvements to existing models ([11]; Sharma, 1997).

[1] Internet of Things: sensors and actuators are embedded in physical objects that are then linked through wired and wireless networks, often using the same Internet Protocol (IP) that connects the Internet. These networks churn out huge volumes of data that flow to computers for analysis [9].

Table 1
Potential challenges in integration of high levels of renewable energy.
Source: Adapted from [46,12], Lund, 2005, [20,25].

Issue	*Challenges*
1. Intermittency	– Fluctuations from renewable resources are directly translated into variations in electricity frequency and output, and therefore impact power quality and reliability – Intermittency is hard to model and forecast – increasing reserve capacity requirements and complicating balance of supply for system management
2. System complexity	– Reliance on battery storage or smart inverter/controller components create additional system costs and complexities for both home management systems and system operators (e.g. voltage smoothing) – System management dispatch systems will likely need to be adapted/upgraded to deal with increasing quantities of distributed renewable resources (beyond 30 per cent penetration levels) – through updated software/trading/data platforms
3. Costs	– High capital costs and lower recovery factors for back-bone network assets (e.g. transmission infrastructure, transfomers) – Higher balance of system costs – Higher fuel costs for peaking plants or back-up generators
4. Threat of power supply interruptions/ black-outs	– Reduction in wholesale prices may lead to less base-load generators, increasing susceptibility to blackouts during equipment failure, extreme climate events, or attacks

WA also has a natural abundance of isolated microgrids (over 30 across the State – the largest concentration in Australia), and has already become the centre for trials and pilots of various system network control methods, which will become necessary as these grids attempt to incorporate ever higher levels of distributed renewable energy from solar panels and other sources [23].

As a result, WA is primed to embrace new approaches that facilitate lower costs and increased efficiencies in order to meet the challenges of electricity service provision going forward. Inevitably, the transition to the future state of electricity networks will be underpinned by utilities recognising that technology innovation and high penetration levels of renewable technologies will play a central role in the WA grids of the future [36,6,47].

WA's isolated electricity network and energy market has already become a demonstration site for energy sector participants around the world looking for how best to manage the transition within their own markets and networks [41]. Indeed, some markets are still facing barriers of a political, rather than technical nature, whereby the utilities themselves are fighting advances in renewable energy initiatives at the policy and regulatory level. Examples include Arizona Public Service and the Denver-based Xcel Energy, both utilities in the United States attempting to reverse or repeal progressive energy and climate change policy through strong lobbying and fear mongering about the risks (and costs) from higher penetration levels of renewables [13,19].

Meanwhile, WA appears to be getting on with it. trials of micro-grids, distributed energy generation, behind the meter software and systems, demand side management, stand-alone power systems, and advanced metering infrastructure are just some of the innovations that are currently embedded on parts of the WA network. This paper outlines why these projects form only the start of a wave of innovations, and will inevitably be expanded to include complimentary innovations in the communications and data analytics sectors as well.

3. Methodology

A review of existing literature was carried out to gain a thorough understanding of the challenges in integrating higher penetration levels of renewable technologies and to ascertain what solutions are currently being proposed around the world as various energy markets strive for increasingly ambitious renewable energy targets. Three of these solutions are presented as case-studies in the 'Results' section that follows, to provide clear, practical examples of energy initiatives that provide a useful contextual demonstration of the challenges and opportunities found in attempting to increase the penetration of renewable energy technologies within existing electricity infrastructure. The three case-studies were selected to highlight a diverse range of energy markets (Belgium, China and South Australia), with each receiving significant media and political attention as part of the implementation phase due to their novel and leading application of technology, and therefore subsequent analysis by researchers to understand the processes and learning outcomes.

The review of academic literature was conducted under a qualitative analysis framework outlined by [38], and more specifically described by the authors as a 'Theme Analysis' that searched for relationships among domains (i.e. data digitisation and machine learning) as well as how these relationships link to the overall context of the research question (i.e. achieving higher levels of renewable energy penetration).

This analysis was then used to identify a gap in existing literature with regards to challenges and opportunities contextualised for Western Australia, given the unique market structure and network requirements described above.

4. Results

Several papers outline a comprehensive list of constraints presented by the increasing levels of renewables (i.e. over 30 per cent penetration level) and the challenges in integrating them into existing power systems (a summary is provided in Table 1).

Some of these challenges will be able to be addressed through technology solutions - such as grid-scale battery storage systems (with virtual operability), heat pumps, and electric vehicles, but others will require more advanced control systems, greater flexibility in regulatory and policy settings, updated financial markets and incentive structures, as well as psychological shifts by incumbent energy market participants in order to drive behaviour change and minimise peak demand events that could otherwise be avoided through shifting consumption.

There are numerous technical studies that have investigated some of the solutions to these challenges of integrating renewable energy resources into existing grids. Specifically, these studies have explored how to minimise system instability caused by high penetration of renewables through the use of demand and supply side initiatives [3,35,33,14,17,56,29,30]. These initiatives include greater prioritisation of, and increased incentivisation within demand-side response programs to focus on changing consumption behaviours in order to adapt load requirements to better align with supply outputs, as well as exploring how greater response flexibility in existing plant infrastructure can be achieved (e.g. by increasing the ramping rates of plant output using updated software or incorporating different fuel types).

The studies also reference greater utilisation of 'smart grids'(a traditional electricity grid that has been enhanced through the inclusion of sensors, communication capabilities, computational ability and remote controls) in order to leverage technological solutions that can lead to an improved functionality of the overall electricity grid system as it incorporates increased renewable generation [18,48].

Three case-studies (focusing on the markets of Belgium, China and South Australia) are explored in detail below, to further outline the practical implications and barriers to initiatives that attempt to connect high volumes of renewable energy sources to existing electricity infrastructure.

4.1. Background case study A: Belgium

The challenges of increasing renewable penetration have gained prominence in European electricity networks, with studies highlighting the need for flexibly controlled demand and generation in order to maintain system security. A case study of Belgium networks, by Van den Berg et al. [54], highlights the impact and challenges created by the commissioning of over 800 MW of offshore wind farms, outlining transmission grid congestion issues and difficulties imposed on a coastal network not originally designed for a large capacity of offshore, intermittent generation sources.

The authors identify three main issues to address in the Belgium context. First, loop flows (or unintended power flows caused by injections and withdrawals in other parts of the grid) increase the complexity of managing the grid system. Loop flows are particularly relevant in highly interconnected electricity networks such as the European power system. But they may also be significant as Western Australia develops embedded microgrids within its regional networks.

Second, the authors note system management requirements and costs increase for already congested areas of the network seeking to continue to connect additional renewable generation sources. The Belgium example highlighted the issues on coastal networks, but for Western Australia, this could also apply to electricity distribution and transmission lines connecting growing demand loads with the areas best suited to renewable generation plant (e.g. areas with high wind and solar resource such as through the Mid-West of the state). This mismatch between infrastructure capability and electricity requirement would inevitably create new network constraints that would seek further technical solutions.

Last, the research suggests that the back-up security criterion (commonly referred to as 'N-1' which refers to having one level of redundancy in the system) may create unnecessary barriers to renewable integration, and costs would be significantly reduced if this criterion is relaxed from being a prescriptive requirement to one that looks at parts of the network on a case-by-case approach.

4.2. Background case study B: China

China also provides a useful contextual demonstration of the challenges and opportunities presented by increasing integration of renewable energy technologies. From 2005 to 2010, largely driven by concessional laws and State incentives, China's (land-based) wind capacity doubled every year to reach 44 GW. The Government has still further plans for total wind generation capacity to reach 150 GW by 2020 and is continuing to encourage large-scale wind farms, many of which have capacities greater than 100 MW [42].

The rapid uptake and integration of these large-scale wind farms is challenging in itself, but Chinese utilities must also deal with the concentration of much of this wind generation capacity within particular areas. Conceptually, this increased challenge makes sense – average renewable penetration across an entire country or State may only be 5–10 per cent, but particular locations within the same system could be facing much higher penetration levels (50–100 per cent) at specific intervals – causing more direct technical and operation challenges. For example, in China, the remote Western Inner Mongolian region already has more than 10 GW, despite its isolation, small local consumption requirements at the customer level, and grid infrastructure that is not designed for larger quantities of power transmission.

Further, there were initially no mandatory technical codes and rules for developers to follow to facilitate the secure and safe integration of these wind farms. Grid code features common to other countries to specify generation connection requirements and maintain stable system operation such as reactive power controls, voltage regulation, and fault ride-through requirements were noticeably absent. A lack of grid code resulted in poor operational outcomes, low output efficiencies, and caused frequent voltage collapse and cascaded tripping during system instabilities, which might have otherwise been easily avoided by instituting a standard technical code with mandatory connection requirements. Following several system events, the State-owned grid utility finally issued a grid code in late 2009 with stringent rules on active and reactive power control, voltage regulation and fault ride-through requirements. The code also includes stringent rules testing, wind power forecasting and grid compliance. By 2011, the regulators had finally instituted regulations to ensure new wind turbines be tested for compliance to grid requirements before being granted grid access, with measures also being sought to be applied retrospectively to the initial, problematic wind farms [42].

4.3. Background case study C: South Australia

South Australia provides another useful example of how the transition to increased renewable energy penetration is progressing – reinforcing the transition is all but straightforward to implement. On 28 September 2016, the State succumbed to one of Australia's worst black-outs, resulting in months of strong debate on energy policy, system security and the role of renewable energy targets.

The event itself was initiated by an extreme weather event (a large storm front with high winds), which caused the loss of three transmission lines, tripped generators offline, and saw the output of the State's wind farms significantly reduce (or cease) over a short period, increasing reliance on the interconnector with the neighbouring State of Victoria. In a matter of milliseconds following the last wind farm that reduced its output, the interconnector itself then tripped offline and South Australia became an islanded network system, causing the entire State to be blacked out due to a "sever supply/demand imbalance" around 3.50 p.m. [2]. The blackout affected most parts of the State's network for over 5 h, with full restoration occurring overnight.

The significance of a State-wide black-out led to an intense media debate and a wider review was implemented by the Federal Australian Government to understand and assess the implications and issues related to the changing generation mix across the energy networks in Australia. As the Australian Energy Market Operator (AEMO), the market and system operator of the Australian energy sector stated at the time:

> *"The generation mix now includes more non-synchronous and inverter-connected plant, which has different characteristics to conventional plant and uses active control systems to ride through disturbances."*
>
> *AEMO* [2]

Non-synchronous and inverter connected plant are the technical terms for distributed renewable energy generation sources – such as the large-scale wind farms, or rooftop solar PV systems at the residential level. Whilst not problems in and of themselves, the changing characteristics of the generation mix is requiring a change in how the grid is managed and operated, and as AEMO discovered in South Australia, will also require new technical requirements and processes to be implemented.

As the proportion of renewables in the grid increases, technical challenges such as low inertia (a lack of large base-load generating plant supporting the grid) and resilience to extreme events such as that experienced by South Australia will need to be considered and managed. Ultimately, these technical challenges can be overcome, but must also be supported by effective regulations and market mechanism that encourage efficient investment (e.g. consideration of non-network solutions before spending on network assets occurs) and facilitate the transition to increased renewables, rather than prevent and ignore it.

These regulations and mechanisms are yet to be defined in Australia, and therein lies and opportunity for utilities to work together with regulators to facilitate how regulatory frameworks of the future will need to evolve.

What these case-studies all show, is that the energy sector is no longer simply about building electricity network infrastructure – future solutions to electricity service provision challenges will need to come from advances in computational capabilities and machine learning, and researchers have already started exploring how data analytics can be applied to better manage our grid, to assist with the challenges and complexities outlined above as the transition to increased quantities of renewables continues.

4.4. Data digitisation

The accumulation of 'big data'[2] continues at an unprecedented scale, with information flowing from online platforms, mobile applications, wireless appliances, meters and sensors, being stored at increasingly large data facilities at increasingly cheaper cost. Analysts now have enormous computational power with which to sift, sort and synthesize these data, and are leveraging data digitisation and devising increasingly sophisticated algorithms to also embrace machine learning to assist with the challenge [21].

> *"Data have swept into every industry and business function and are now an important factor of production, alongside labor and capital."*
>
> Manyika et al. [32]

A review of existing research in the field of big data reveals four ways in which big data creates significant value for businesses that can harness it [10,32,7,8]:,

1. It makes information transparent and enables it to be used at a greater frequency;
2. It increases the accuracy, detail and quality of data across all forms and levels (e.g. product inventory, employee rosters), exposing variability, fluctuations and providing performance improvement potential and analysis to drive better management decisions;
3. It provides for a greater level of customer segmentation and the potential to tailor specific products and services at the individual customer level; and
4. It provides a platform for the next generation of products and services and enables further innovation (e.g. proactive maintenance before failures actually occur).

Across almost every industry, businesses will need to leverage data-driven analytics and decision making to remain relevant, to innovate, stay competitive and to capture the value on offer from the enormous quantity of new information on offer. However, challenges remain in addressing issues related to information security, data access, consumer privacy and intellectual property rights in the emerging big data sector.

Nevertheless, as outlined by [32], the significant increase in the volume and resolution of information captured by smart meters and smart appliances, combined with the rise of social and multi medias will drive exponential growth in the recognition of the importance of data analysis for most companies, and particularly for utilities and energy market participants going forward. Specifically, data analytic capabilities will allow analysis of both external factors to utility business operations, such as forecasting weather and high demand events, and internal, operational factors such as network loads and stresses, with the analysis further enabling efficient electricity use at the network and household level. By incorporating the advantages of big data, renewable energy penetration can overcome the outstanding technical and financial barriers. For example, big data may provide analysis to reinforce the business case for non-network solutions, highlighting that further optimisation of existing generation with forecast load can be done in a way that drives improved efficiency of existing assets. Ultimately, big data should allow utilities to drive better decision making and influence customer behaviour with appropriate incentives.

4.5. Machine learning

Machine learning is a related aspect of the future of analytics (part of cognitive science and the field of artificial intelligence) that makes optimized output predictions using algorithms based on historical data as inputs. Machine learning can be used to compliment data digitisation and big data, providing a scalability aspect to data science and leveraging computational capabilities to build predictive systems and solve complex analytics problems [57].

One method of machine learning gaining increasing prominence is artificial neural networks (ANN), being used to solve a variety of tasks such as speech recognition that is too complex for ordinary rule-based programming. The ANN method replicates the human brain to process information and creates complex relationships between inputs and outputs.

The inherent complexity of balancing energy generation and consumption in real time, and forecasting demand and planning for energy system requirements in the future creates an enormous opportunity for machine learning and methods such as ANN within the energy sector [49,39].

As technology innovations (e.g. smart meters, smart appliances, inverters and control systems) increases both the volume and the ability for data collection and analysis, and as renewable penetration increases the complexity of grid management due to volatile climatic factors, system noise, line losses and behind the meter loads and generation, ANN algorithms are beginning to provide researchers with potential solutions that can underpin intelligent energy management and forecasting systems [31,50,58]. The ability to mine and identify the value in large data sets is a challenge, but big data tools provided by machine learning are already allowing innovative researchers and companies to overcome these challenges at rapid rates [59].

In their 'big data' research paper [43], propose a big data forecasting model using machine learning to train the electricity dispatch and operation system for more effective prediction of demand and supply outcomes that achieved a 99 per cent accuracy rate. Using similar machine learning methods in combination with geospatial modelling, a study by Assouline et al. [4] was able to estimate the upper penetration level potential of solar PV in urban areas of Switzerland, taking into account shading effects, solar radiation, roof slopes and aspects and available roof surface area. And as the volume of data being stored, shared and uploaded to the internet continues to exponentially expand, Google is seeking to develop in-house big data and machine learning expertise – through its artificial intelligence group 'DeepMind' – that is tasked by studying the patterns in Google's data centre operations in order to increase energy efficiencies [26].

4.6. Incorporating 'big data' in the WA energy sector

As capabilities in software and data analytics increases, the electricity sector can start leveraging the functionality provided by smart meters, in order to analyse and optimise what electricity customers' need, when they need it and how energy products and services can best deliver it. Fundamental to recognising this value is a shift away from the traditional models of utilities, towards business models that facilitate innovation, encourage research and innovation, and maintain flexibility going forward, as outlined by [53].

For WA utilities, opportunities already exist to lower the cost of

[2] Big data is the term used for extremely large data sets (there is no defined quantity) that can be structured and analysed for patterns, trends and information, especially relating to human behaviour.

service and reduce the reliance on Government subsidy by leveraging innovative technologies and increasing efficiencies in the business. For example, by installing 47,000 smart meters across its customer base[3]), Horizon Power (the regional electricity utility provider in WA) is in prime position to understand how the next generation of energy technologies can optimise the provision of electricity services across its service area [22].

Smart meters provide a range of advantages to electricity utilities – through electronic billing (avoiding the need for manual meter readings and testing), increased accuracy of consumption data, and the potential for connectivity across meters, which could provide opportunities for trials in aggregated system control (in the context of virtual power plants and distributed energy generation assets).

Yet it is the data that these smart meters generate that could prove most useful for energy participants seeking to understand how to manage the transition to penetration levels of renewables 30 per cent and beyond. Smart meters provide extensive, real time customer consumption datasets, which can combine with weather and network system data to assist system management functions in managing intermittent loads and generation sources – directly address both the technical and financial limits to higher penetration of solar PV and storage technologies [22].

The extensive microgrids within Horizon Power's regional networks, in particular, are also more prone to having high levels of renewable energy (e.g. distributed solar PV well beyond 50 per cent penetration levels), and can therefore greatly benefit from some form of intra-network (between microgrids) intelligent control systems to optimise energy flows.

For example, building on the three time-frame energy cycle concept and leveraging data analytics can assist in planning and improve the ability to meet balancing requirements for energy supply to meet energy demand:

1. Long-term planning helps to prepare the electricity system for extreme events such as peak demand or large troughs in supply (years/months ahead);
2. Continuous balancing (days/minutes ahead) ensures supply equals demand irrespective of generation source; and
3. Controlling frequency instantaneously (seconds after) assists in resolving frequency deviations caused by contingency events and forecasting errors.

Combining advances in battery storage and inverter products through ongoing trials, pilots, partnerships and demonstration projects will also provide opportunities for WA utilities to transition to new energy technologies and high penetration of renewables. Peer to peer trading (customers selling electricity amongst themselves), virtual net metering (netting off excess electricity generation from one bill, and transferring it to neighbouring customers) and network credits (customers receiving a share of the financial benefit from avoiding network upgrades) are just some of the emerging innovative ideas that will create new data sources, and may require complex data analytics (e.g. predicting which loads will need electricity where and when) in order to operate successfully and maintain network security and reliability and customer satisfaction.

4.7. Identifying the opportunity

Evergen and Reposit Power are two new Australian energy technology start-ups, already trialling how the innovative use of data can benefit customers, by analysing electricity consumption patterns alongside weather forecasting data to ascertain when customers should consume rooftop solar power, when to store it, and when to sell it back to the grid based on price and energy usage preferences [55].

Redback Technologies, based in Queensland, is another company seeking to encourage the use of 'smart' inverters and metering that uses wireless communication between solar panels, batteries and major home appliances such as air-conditioners and washing machines, to optimise and manage energy consumption at the household level – 'behind-the-meter' [44].

These companies, and their innovative products, provide an insight into the novel applications that 'smart' energy technologies can provide, leveraging inter-technology communications that not only drive efficiency for network utilities at the grid-level (providing grid stability, support and alternatives to traditional methods of network asset investment), but have potential to also result in more cost-effective outcomes for customers, particularly as electricity tariffs become more cost-reflective and adapt to incentivise reduced consumption during periods of peak demand. The Western Australian Government, in particular, has signalled an acute awareness for the need for electricity tariffs to reflect their underlying costs, recognising that ongoing (and increasing) subsidy levels are untenable [34]. Increasing electricity tariffs will provide even further incentive for consumers to install solar PV and storage systems, even as solar feed-in-tariff schemes reduce payment rates or come to expire across Australia in the coming years.

As the electricity service model continues to change, the entire sector is being disrupted by new technology and new entrants, non-traditional utility start-up companies that are securing the interest and the funds from various venture capital and financial backers to develop the future of high penetration renewable energy grids. For example, Sunverge received $37 million in funding from AGL and Mitsui in February 2016, to develop grid automation technologies, BitStew Systems received $153 million in funding from GE Digital in June 2016 to deliver 'edge computing' services, and BuildingiQ received $20 million by AS IP and Aster Capital in December 2015.

5. Conclusions and policy implications

One scenario for the future of electricity grids, particularly in WA, could be a transition towards one of distributed microgrids with high levels of renewable generation sources (over 50 per cent), linked through intelligent, wireless communications to manage flows and maintain overall system security and stability. Data digitisation and analytics combined with machine learning is already impacting the transport and health sectors, and the influence of data analyses in the energy sector is also likely to gain momentum, as computational capabilities increase to manage big data, and as machines develop algorithms to solve the energy challenges of the future.

Of course, this vision is predicated on the assumption that both technical and financial barriers are overcome through the appropriate application of new energy technologies and innovations, such as smart inverters and distributed battery storage systems. And several institutional barriers will also need to be overcome, such as the removal of redundant regulatory frameworks that fail to incentivise non-network solutions. But the transition to more flexible regulatory and economic models has already begun, and as innovation continues in the sector, it will continue to drive the transition forward, and regulators, policy makers and innovators within industry and governments alike will need to ensure they stay up-to-date and do not intentionally, or unintentionally, block the development of these new products and services that will become part of electricity service provision.

Utilities will need to continue to encourage research and development, undertaking trials, demonstration projects and taking risks in an industry that has historically discouraged risk-taking. The evolution of the electricity industry has commenced a process of creative-destruction, where new products and services and new entrants will compete with traditional, incumbent utility business models. Big data, analytics and machine learning are only three examples of technology innovations that are assisting in driving this evolution forward. Ultimately,

[3] Smart meters (also referred to as 'advanced meters') were upgraded for all Horizon Power customers on a mandatory basis to provide electronic billing, 15min metering cycles, and remote communication capabilities.

the transition to increased renewables within our electricity grids is not one that should be feared or resisted, but instead should be recognised as an opportunity for something that can generate financial and customer choice benefits for both users and service providers.

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