CLIMATE ADAPTATION FLAGSHIP
www.csiro.au

Power struggle: Challenges for changing electricity delivery in South East Queensland

Climate Adaptation Flagship Working Paper #15

George Quezada and George Grozev
September 2013

National Library of Australia Cataloguing-in-Publication entry

Title:	Power struggle: Challenges for changing electricity delivery in South East Queensland / George Quezada
ISBN:	978-1-4863-0221-5
Series:	CSIRO Climate Adaptation Flagship working paper series; 15.
Other Authors/Contributors:	Climate Adaptation Flagship George Grozev

Enquiries

Enquiries regarding this document should be addressed to:

George Quezada

CSIRO Ecosystems Sciences

41 Boggo Road, Dutton Park, Queensland 4102

george.quezada@csiro.au

Enquiries about the Climate Adaptation Flagship or the Working Paper series should be addressed to:

Working Paper Coordinator

CSIRO Climate Adaptation Flagship

CAFworkingpapers@csiro.au

Citation

Quezada, G and Grozev, G (2013). Power struggle: Challenges for changing electricity delivery in South East Queensland. CSIRO Climate Adaptation Flagship Working paper No. 15
http://www.csiro.au/en/Organisation-Structure/Flagships/Climate-Adaptation-Flagship/CAF-working-papers.aspx

Copyright and disclaimer

Important disclaimer

The Climate Adaptation Flagship Working Paper series

The CSIRO Climate Adaptation National Research Flagship has been created to address the urgent national challenge of enabling Australia to adapt more effectively to the impacts of climate change and variability.

This working paper series aims to:

- provide a quick and simple avenue to disseminate high-quality original research, based on work in progress
- generate discussion by distributing work for comment prior to formal publication.

The series is open to researchers working with the Climate Adaptation Flagship on any topic relevant to the Flagship's goals and scope.

Copies of Climate Adaptation Flagship Working Papers can be downloaded at:

www.csiro.au/resources/CAF-working-papers

CSIRO initiated the National Research Flagships to provide science-based solutions in response to Australia's major research challenges and opportunities. The eleven Flagships form multidisciplinary teams with industry and the research community to deliver impact and benefits for Australia.

Contents

Figures

Tables

Acknowledgments

We like to thank Ryan McAllister, Michael Kane and Anthony Szatow for their constructive feedback during the preparation of this manuscript. We are also grateful to Energex for access to electricity demand data and for many constructive discussions during several meetings with ENERGEX specialists. This study is partially supported by the South East Queensland Climate Adaptation Research Initiative, a partnership between the Queensland and Australian Governments, the CSIRO Climate Adaptation National Research Flagship, Griffith University, University of the Sunshine Coast and The University of Queensland. The Initiative aims to provide research knowledge to enable the region to adapt and prepare for the impacts of climate change.

Executive summary

South East Queensland's (SEQ's) electricity system is under great pressure to adapt. Climate change and variability along with socio-economic, demographic and technological change is resulting in complex challenges for the region's electricity supply. Distribution networks are particularly impacted with these factors contributing to tremendous peak demand growth, about double the rate of growth in consumption in recent years. This paper examines the risks associated with adapting centralised electricity systems to multiple factors pushing up peak electricity demand. We contextualise the peak demand problem in the SEQ region and use socio-technical transitions theory to understand historical interconnected social and technical dimensions of adaptation at national, state and regional scales.

The paper is structured as follows:

Section 1 discusses the factors contributing to peak demand growth, and reviews the adaptation challenge for centralised electricity systems.

Section 2 introduces the domain of socio-technical transitions theory, which is the theoretical framework applied to the process of adapting Australia's electricity system.

Section 3 presents an historical narrative of the emergence of electricity centralisation in Australia, and draws important links with SEQ's regional context. We also quantify SEQ's peak demand problem and briefly review international literature on adaptation options, and describe today's electricity supply-chain and market structure.

Section 4 analyses the dynamics of adaptation from the year 2000 onwards. Our aim is to trace the interactions between key social groups and their adaptation responses over the past decade.

Section 5 discusses the implications of this analysis, revealing that adaptation has become a contested process between end-users and supply-chain players, as these groups make decisions based on different economic objectives, adaptation needs and capacities. We suggest that the resulting tension shows worrying signs of *maladaptation* of the electricity system; a situation that could lead to increased system-wide vulnerability to climate change.

Section 6 outlines a framework for thinking about how to effectively adapt the electricity system, and we offer suggestions for further research.

Finally, we conclude (Section 7) by recommending that policy makers, regulators and industry consider new investment protocols that evaluate grid versus non-grid investments on the basis of 'whole of system effectiveness', which includes emission reduction objectives, but goes beyond to consider social equity concerns and the risk of exacerbating path-dependency in the sector. We add that further research is needed to support the underpinning investment models and regulatory tests.

1 Introduction

National scale 'centralised electricity' systems around the world face unprecedented challenges. Changing climate, increasing infrastructure costs, shifting settlement patterns and socio-economic and demographic changes and technological developments are presenting interconnected challenges for these systems, and posing complex dilemmas for policy makers and industry.

Climate change related extreme weather can cause storm related outages (Willbanks 2007), and reduce system efficiency and increase demand on hot days due to the wide use of mechanical air-conditioners, most particularly in warmer climates (Mideksa and Kallbekken 2010; Miller et al. 2008; Thatcher 2007). Continued urbanisation and economic growth are increasingly associated with energy intensive lifestyles (Madlener and Sunak 2011; Dhakal 2009; Martinez-Zarzoso and Maruotti 2011; Kim and Barles 2012). Globally, these lifestyles are being fed by more affordable mass produced high electrical demand appliances, such as air-conditioners and flat-screen televisions, forcing governments and utilities to build more infrastructure to keep up with demand. Electric vehicles are poised to add further demand pressure.

According to Shell's recent scenarios report, growing global energy demand over the coming decades will open up a massive gap with supply, around 400 Exajoules[1] by 2050 (Shell 2011), with significant implications for electricity supply as the developing world progressively brings light and power to more people through centralised electricity configurations. Termed the "zone of extra-ordinary opportunity or misery", this supply-demand gap is symbolic of a new "era of volatile transitions" (Shell 2011, p. 10). Climate change policy is compounding the complexity of this challenge as governments consider how to meet demand and do so by rapidly shifting to more efficient and renewable means.

While directly impacting on security of supply and increasing consumption, the above factors are also driving up electricity demand peaks, a phenomenon that underlines a complex tension between electricity supply-chain players and end-users. Demand peaks are short periods of elevated electricity use with different seasonal and daily patterns depending on climate zone. For example, early evening peaks are characteristic in summer afternoons of warm regions. Recent evidence from North America and Australia identifies rapid diffusion and high penetration rates of residential air-conditioners as the main source of the problem (eg, Garnaut 2011; Newsham and Bowker 2010). This tension between the electricity supply-chain and end-users relates to the way these different groups adapt to the changing environment.

The role of adaptation to climate change is of increasing importance to policy makers, planners and practitioners from different sectors. It is being recognised at national and international levels and it is analysed in academic and technical literature. Adaptation to climate change and variability is an alternative and complementary response to 'mitigation' – a policy response aiming to reduce greenhouse gas (GHG) emissions (Smit et al. 2000). The meaning of mitigation is to abate, moderate or alleviate GHG levels, while the meaning of adaptation is to alter, adjust or modify activities in the socio-economic environment related to greenhouse gas emissions and climate change. Adaptation is a set of responses to actual or expected climatic stimuli and their impacts (Smit et al. 2000). The adaptation refers both to the process of adapting and the condition or situation to be adapted. The importance of adaptation is growing as mitigation to date has had a limited success to constrain or reduce greenhouse gas emission levels.

There are a number of adaptive options for addressing the peak demand problem including, building new electricity generation and network infrastructure, remotely controlling air-conditioners and other electricity 'hungry' devices during peak periods, introducing new time-of-use electricity tariffs, educating consumers to shift demand and improving household energy efficiency. From the standpoint of effective adaptation, it is important to understand how such options are enacted by different groups of actors responding to

[1] 1 EJ = 10^{18} joules

different stimuli and with different adaptation needs and capacities. For example, end-users are more concerned about amenity from electricity (e.g., thermal comfort) than the problem of peak demand. For this group, adopting refrigerant air-conditioners may be a valid adaptation response to climate change related increases in temperature, but a maladaptive response from an electricity network perspective as it increases peak demand and decreases network asset utilisation. Network operators are obligated to reinforce the grid in response, placing upward pressure on electricity prices, which adversely impacts vulnerable low-income groups. On the other hand, electricity retailers and generators benefit from increased electricity sales associated with high demand appliances like air-conditioners, but this can be at odds with climate mitigation policy, especially where the generation mix is skewed toward fossil fuel sources.

This interplay between actors illustrates a key adaptation risk – actions carried out by different groups of actors with different needs and objectives can lead to maladaptation (Barnett and O'Neill 2010; Burton 1997), or a situation which increases vulnerability to climate change. Barnett and O'Neill defined 5 types of maladaptation based on observed adaptation responses to drought and water security concerns in the greater Melbourne region (Victoria, Australia). Responses included the construction of large-scale desalination plant and pipeline from a regional irrigation system, which they argue will contribute to:

1) Increased greenhouse gas emissions from increased energy use associated desalination,
2) Disproportionate burden on the most vulnerable associated with higher water rates to pay for the infrastructure,
3) High opportunity costs due to adverse local environmental impacts of desalination (salinity on marine ecosystems) and piping water from catchments (reduced environmental flows) ,
4) Reduced incentive for individual users to adapt their consumption to water scarcity, and
5) Path dependency through long-term capital commitments that are difficult to change in the future.

These maladaptation types could be used to describe potential risks associated with centralised electricity systems planning to respond to climate change impacts by reinforcing the grid. While not detailing the reasons why maladaptation occurs, Barnett and O'Neill (2010) cite the time lag between climate change and institutional change as a key factor. This paper adds to the literature by analysing the historical socio-technical factors that bring about maladaptive responses in vast infrastructural systems.

Specifically, the aim of this paper is to examine the risks associated with adapting centralised electricity systems in response to interconnected drivers that are pushing up peak demand. We contextualise this problem within the region of South East Queensland (SEQ), Australia, applying a broader definition of adaptation that goes beyond responses to climate change, but includes socio-economic, geographic, demographic and technological factors. We employ socio-technical transitions theory to understand the multi-level, multi-factor and multi-actor dynamics of change. This perspective is used as an analytical lens to describe the evolution of the electricity system in SEQ and Australia, the major drivers of adaptation in the region, and to analyse the interplay of different actors and social groups and contrast their adaptation responses. We then offer a framework for adapting centralised electricity systems, and conclude with a discussion of implications and recommendations for policy makers and further research.

2 Theoretical framework

The socio-technical transitions literature has gained prominence over the past couple of decades, particularly in addressing complex sustainability issues (Elzen and Wieczorek 2005; Kemp et al. 1998; Smith et al. 2010). Stemming from the sociology of technology and evolutionary economics, this literature domain deals with human agency and technological development, and the multi-layered interactions that have led to historically significant technological shifts within societal functions, such as mobility, sanitation, and energy supply. This approach has yielded valuable insights into the processes and patterns of change of large infrastructural systems (Markard and Truffer 2006; Geels 2005b). Following this tradition, central electricity grids are conceptualised as evolving 'socio-technical systems' (STSs); products of a 'seamless web' of interacting social, cultural, physical and institutional elements (Hughes 1987). These elements are illustrated in Figure 1.

The multi-level perspective (MLP, Geels 2002; Rip and Kemp 1998) is an important theory within this domain, proposing that STS change is an emergent phenomenon of three interacting heuristic levels of the system: socio-technical *regimes* (meso level), *landscapes* (macro level) and *niche innovations* (micro level). Socio-technical regimes are defined as the dominant and stable configurations of physical, social and institutional elements which constitute a socio-technical system (e.g., centralised electricity supply). These regimes are characterised by lock-in dynamics, as the elements within them are 'aligned and coordinated' based on legacy infrastructure/technology, policies, user practices, industry rules and regulations and organisational routines that develop over long periods of time. Niche innovations refer to small scale networks of actors, which are distinct from regimes in that they are relatively loosely coordinated relationships, based on trial-and-error experimentation with novel technologies and configurations (Kemp et al. 1998). The landscape level consists of slowly changing exogenous factors such as climate change, population growth, resource availability or cultural values; influential factors that impact on the interplay between regime and niche levels, but are beyond the control of individual actors.

According to the MLP, incumbent regimes undergo shifts or transitions when landscape pressures (e.g., climate change) weaken the alignment between regime elements, thus opening *windows of opportunity* for new configurations or niche innovations to change previously set institutions, technologies, and user practices etc. During these periods of opportunity, regimes can change from one socio-technical configuration to another. However, the course of regime change is often a slow and contested process, as actors become uncoordinated with differing priorities, goals and visions, which open multiple emergent futures for the socio-technical system (Brown 2000; Smith et al. 2005). The governance challenge presented by technological change and transition has been highlighted in recent years, with calls for a deeper appreciation for the political nature of shifting societal scale functions like stationary energy supply (Smith et al. 2005; Shove and Walker 2010; Frantzeskaki et al. 2012). This issue was evident in the history of electricity systems across Australia, and poses critical questions about how these systems can adapt effectively and equitably into the future.

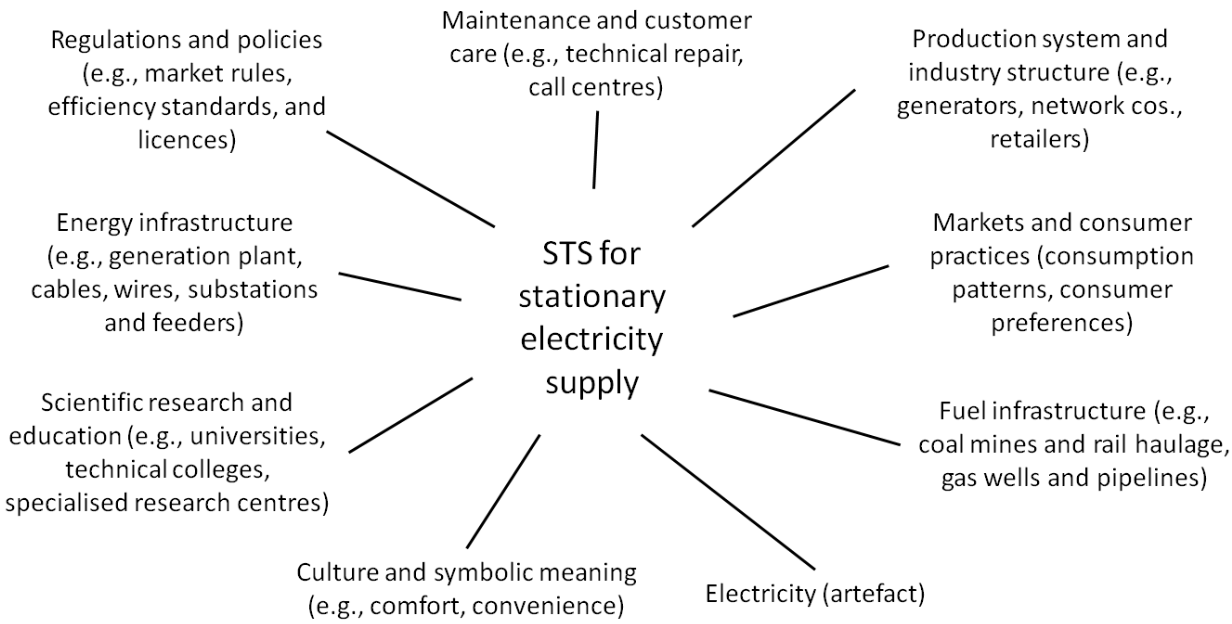

Figure 1. The elements that constitute the socio-technical system (STS) for stationary electricity Adapted from (Geels 2005a)

3 South East Queensland's electricity system within an evolving centralised paradigm

As a process theory, the multi-level perspective (MLP) is concerned with patterns and processes of change over long periods of time. In this section we are concerned with how adaptation of the centralised electricity system is regionally situated within the industry's historical context, and how these play out across scales – national and state as well as regional. SEQ's peak demand problem, available adaptation options, and the system's history therefore constitute the context of our later application of the MLP approach on the past decade of adaptation.

SEQ is a relatively small sub-tropical region within the Queensland state government jurisdiction, mainly located between 26˚ S and 28˚ S latitude. It spans an area of 22,890 square kilometres, and is highly urbanised, with most of its 3 million inhabitants located in the major centres of Brisbane (Queensland's capital), Gold Coast, Sunshine Coast, Ipswich and Toowoomba (ABS 2011). The development of a centralised electricity system in the region emerged from the interplay of major social, economic, political and technological changes that occurred in Australia (and throughout the OECD) during the twentieth century.

The electricity industry in Australia emerged in the late 19th century, with many small utilities based in colonial town centres, and evolved and developed into a national-scale and nationally regulated sector over a period of more than 100 years (Booth 2003). The colonial centres became capital cities within six states and two territories (referred to in this paper as states for simplicity) after federation in 1901. Early electricity utilities were niche innovations in the context of a broader regime for stationery energy, typically dominated by wood fuel for heating and cooking, and kerosene, gas and candles for lighting. Electricity suppliers were vertically integrated companies owned privately or by local government municipalities, typically supplying electricity to nearby customers, street lighting and tramways (Sharma 2003). One of SEQ's first utilities was the Brisbane Tramway Company, which supplied electricity to Brisbane's inner city commercial and industrial customers and the railways; later the company was the first to supply electricity to suburban customers in SEQ, following the adoption of more efficient alternating current generators (Simmers 2004).

From a market perspective, the early decades of the 20th century were a highly contested period for Brisbane's burgeoning electricity industry, characterised by competition for customers and between private and public (local government) interests (Simmers 2004). The industry was loosely regulated by the state government, which held powers to grant permission for electricity companies to build network infrastructure to new customers. Electricity was expensive, but the demand for electric lighting was substantial due to perceived superiority over traditional lighting, in terms of convenience, safety and reduced heat. This demand prompted investment in progressively larger coal fired generator sets (Simmers 2004), enabling local socio-technical electricity systems to become the dominant regime for lighting. Demand continued to grow with the diffusion of electrical appliances and industrial machinery, while technical improvements and economies of scale in the supply of electricity reduced retail prices. State governments soon recognised the political appeal of supplying electricity and began enacting legislation to own electricity supply assets during this early market phase (Sharma 2003).

State ownership was all but complete by the late 1940s (Sharma 2003). Each state jurisdiction operated vertically-integrated monopolies with centralised planning and operation (Moran 2008; Sharma and Bartels 1997). State governments pursued economies of scale with centralisation and also sought to address air quality concerns by moving generators far from users. Therefore, utility planners assumed a hub-and-spoke model, which linked a few large generators to all customers, irrespective of load size and distance from a generator, and network infrastructure costs (Weinberg et al. 1993). Queensland's network in particular became more dispersed than any other state as demand grew with rising living standards (Wadley 1981).

In the 1950s, Australia (along with much of the world) entered a prolonged economic boom lasting until the early 1970s. This growth was brought about by a combination of landscape factors stemming from widespread acceptance of Keynesian economic policy, immigration policy and population growth, shifting employment from agriculture to manufacturing and services, and urban policy that promoted home ownership and low density suburban development of outer metropolitan areas (Berry 1999; Spearritt 1994). During this time city-regions began competing for investment and accommodated the needs of both labour markets and capital through highway enabled suburban sprawl and detached housing (Berry 1999; Harvey 1989; McCarty 1970). Urban expansionist policy in the second half of the century became particularly evident along SEQ's coastal strip, as the region became the fastest growing in Australia, and small towns in the Gold Coast and Sunshine Coast merged with Brisbane through an apparent sea of housing estates (Spearritt 2009).

The size of housing also grew substantially across Australia, particularly during the 80s and 90s, with average floor area for new dwellings reaching 200 square meters by the year 2000, up from about 155 in the mid 80s (ABS 2001). Growth in the electricity network necessarily accompanied urban growth, and increases in supply capacity accelerated to accommodate the proliferation and diffusion of electrical appliances and corresponding consumer appetite for greater "comfort, convenience and cleanliness" (Shove 2003; Schipper 1987). Seasonal and daily electricity demand peaks emerged as heating and cooling appliances became more common, while pronounced daily peaks can be traced to a combination of spatial segregation of residential areas (dormitory suburbs) from other uses (e.g., commercial and industrial) (Schnore 1957) and increasing participation of women in the workforce (Evans and Kelley 2008), shifting most household electricity consumption outside of normal working hours.

Towards the latter part of the century, the global economic policy landscape shifted to less government involvement and more open, competitive and deregulated markets. Concerns about the efficiency and international competitiveness of Australia's electricity industry were evident during the 80s, and political momentum for a national approach to governing the sector was well established by the early 90s (Moran 2008; Sharma 2003). Up until then, each state governed their own electricity system according to their own economic objectives (jobs, use of state resources), and ensured independence from other states (Sharma 2003). This situation all but ended in 1998 with the establishment of the National Energy Market (NEM) – a wholesale spot market facilitated by a single grid linking all Eastern Australian states, including Queensland. The formation of the NEM was accompanied by progressive disaggregation of the electricity supply-chain and privatisation of both electricity generation and retail businesses.

3.1 The National Energy Market and SEQ's supply chain

The NEM includes all Eastern states in Australia: Queensland, New South Wales, Victoria, Tasmania, South Australia and the Australian Capital Territory. This forms one of the longest interconnected electricity systems in the world, with a distance between end points of more than 5,000 km (AEMO 2010). Today the NEM is operated by the Australian Energy Market Operator (AEMO), which has planning and operations functions for both electricity and gas markets. One key role for AEMO is to signal investment in generation assets through annual electricity forecasting. Another national institution, the Australian Energy Regulator (AER), oversees investment in network infrastructure.

Each state is a region in the NEM, connected to other regions via high voltage transmission lines. All generator companies with generating units above 30 MW capacities must sell their output to the market. Generators make offers to supply electricity and AEMO dispatches them every five minutes based on cost effective optimisation. Retail companies buy electricity from the wholesale electricity market at wholesale prices and sell it to residential, commercial and industrial customers at retail prices (see Figure 2). Retail prices are regulated by the states, based on calculated costs of electricity through the supply chain. Market spot prices for each region can vary from -$1,000/MWh to $12,500/MWh. As government-owned monopolies, transmission and distribution network service provider revenues are regulated by the AER, which determines revenue caps based on anticipated costs for forward five-year periods. This determination includes asset costs, and the AER allows a guaranteed rate of return on assets to cover debt related to capital expenditure plus a margin for profit.

SEQ is a large net importer of electricity from Central Queensland and South West Queensland. In the 2009/10 financial year SEQ's total electricity consumption was 20.9 TWh, from which 18.3 TWh (87.6 %) were imported (AEMO, 2012). The imported electricity to SEQ is produced by power stations fuelled predominantly by black coal. SEQ has only two large power plants – Swanbank B & E, located in Swanbank. Swanbank B has four generating units 125 MW each powered by black coal. Swanbank E was commissioned in 2001 and it has a single 385 MW combine cycle gas turbine. A small hydro generator at Wivenhoe dam has a generating capacity of 5 MW. Powerlink Queensland is the transmission company that services most of Queensland (including SEQ), while Energex provides distribution network services to all customers in SEQ. Various private retail energy companies manage customer billing and selling electricity typically at a single flat (peak) tariff, while some customers have off-peak tariff arrangements for certain appliances such as hot water systems.

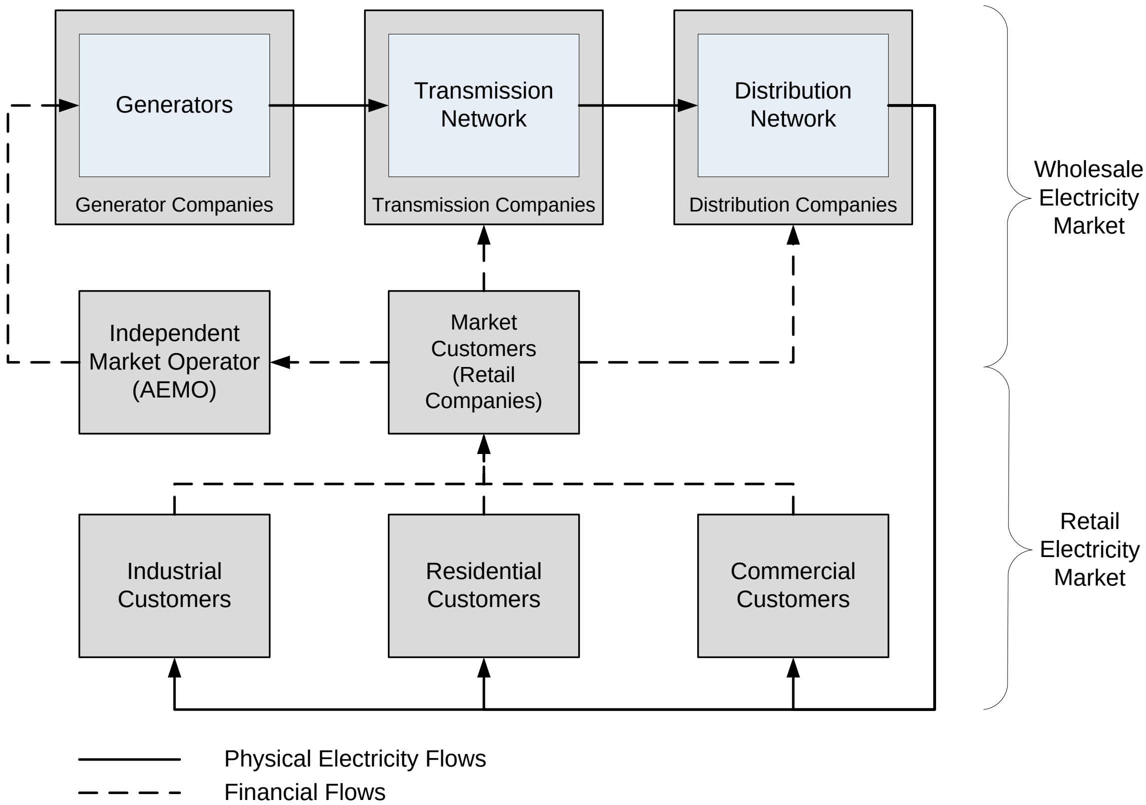

Figure 2. Wholesale and retail electricity market structure.

3.2 The peak demand challenge and adaptation options

As a fast growing region in Australia, SEQ has a well documented peak demand problem (Queensland Government 2008). According to Energex (www.energex.com.au), 13% of the region's capacity is only used for a few hours, a few times a year. One recent study on peak demand in the region was undertaken as part of the SEQ Climate Adaptation Research Initiative (Wang et al. 2012). In summary, this study gathered and analysed demand data for a period of 10 years (2002-2011) based on half-hour time series data obtained from Energex. Peak annual demand growth was estimated at 4.1%, about double the rate of overall annual demand growth (2.2%) (see Figure 3). Rising use of air-conditioners coinciding with other residential loads (in the early evening) has been identified as a major driver of peak demand growth. Based on historical and simulated projections, Wang et al (2012) suggested that annual peak electricity demand will continue to grow independently from average demand.

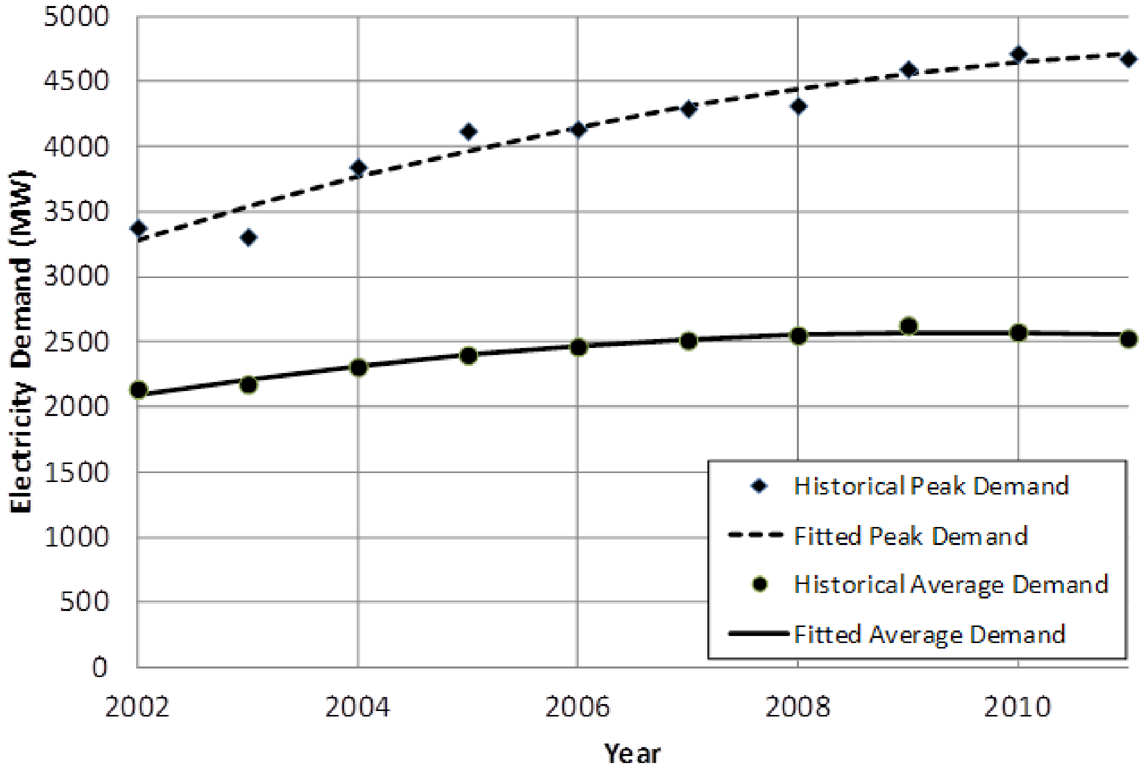

Figure 3. Annual peak and average electricity demands in the region of SEQ, Australia.

The U-shape of the electricity demand to temperature relationship is well known in the literature (Wang et al. 2012) as the air temperature is the most important climate variable driving electricity demand. Figure 4 illustrates the relationship between peak electricity demand and air temperature in SEQ. It is not a symmetrical U-shape and for temperatures less than 15°C the peak electricity demand seems to be constrained and does not grow. For changes to higher temperature (from approximately 20° C to 35° C) the peak electricity demand grows nearly 30% more.

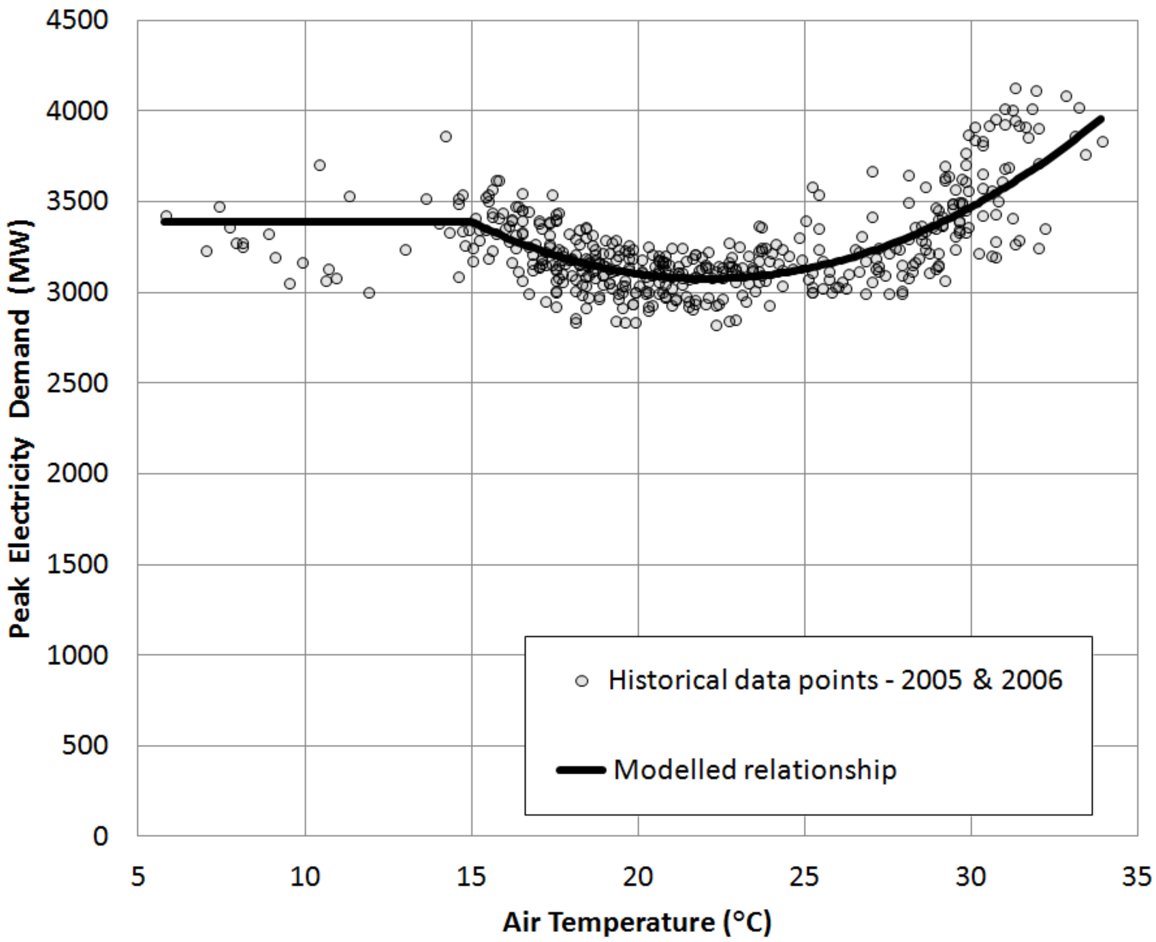

Figure 4. Relationship between peak electricity demand and air temperature in the SEQ region.

(Historical points represent maximum daily electricity demand values in MW for weekdays in 2005 & 2006, excluding weekend days, public holidays and the summer holiday period from 16th of December to 15th of January.)

As mentioned earlier, various demand-side adaptation strategies have been identified in the international literature. Newsham and Bowker (2010) reviewed several pilot projects for direct load control in North America and concluded that a reduction between 0.3 kW and 1.2 kW per air-conditioning (AC) unit could be achieved. A number of North American studies have also examined the impact of dynamic tariff structures on peak electricity reductions (Newsham and Bowker 2010; Faruqui and Sergici 2010). Based on reviews of previous studies, Newsham and Bowker (2010) found that critical peak pricing – a price signal applied on a small number of peak event days advertised by the utility company a day in advance – is the most effective strategy from this class, achieving 30% load reduction compared to 5% for time-of-use tariffs. A less direct approach to shaping customer usage patterns is through education and feedback (Vine 2012), though no research has evaluated the impact on peak demand. Building energy efficiency has received widespread attention as a cost-effective strategy for energy (and emission) reduction (Miller et al. 2012) that can also reduce demand peaks (Steinfeld et al. 2011). This option incorporates passive solar design, cross ventilation, shading and building orientation, and also appropriate building materials, facades and colours. Steinfeld et al. (2011) analysed peak load characteristics of Sydney office buildings and found that peak loads for office buildings with best-practice energy performance were 26 % lower than for buildings with average energy performance, while the total annual energy consumption was 57 % lower.

4 Adaptation in the new millennium

Thus far, we have shown how population and economic growth, rising affluence (and double income households) and urbanisation patterns combined with technological advances and changing social values and practices to drive up electricity consumption in SEQ, particularly consumption during peak times. The adaptation response to these drivers has been largely directed toward augmenting and reinforcing the network, with serious consequences for electricity prices. In recent years, evidence has grown regarding the adaptation value of demand-side management options, underscoring an increasing awareness for the need to change investment rules and practices in the electricity sector.

The new millennium marked a threshold for Australia' electricity system, with the roll out of various climate change policy measures supporting demand-side management and renewable energy. These policies arose in the context of new changes at the landscape level, which placed pressure on the centralised electricity regime, allowing windows of opportunity for niche innovations based on decentralised (small-scale) electricity technologies and supply configurations, and causing previously coordinated and aligned groups on the supply- and demand-side to pursue divergent adaptation strategies. In this section we present a narrative of these adaptation dynamics, illustrating the indications of maladaptation and the prospect of two emerging and contested futures for the centralised grid in the SEQ region and Australia.

4.1 The socio-technical dynamics of adaptation

The latter part of the 20th century and early years of the 21st century saw historic drought, floods, heat waves and fire events across Australia, which arguably impacted on the political mood toward environmental issues (Gascoigne 2008). Global shifts in political mood regarding anthropogenic climate change also impacted on Australian politics. These landscape changes resulted in new energy policies to promote renewable energy, energy efficiency and demand management. Diffusion of refrigerant air-conditioners also reached the take-off phase at this time, causing steep growth in peak demand and network investment.

The dramatic penetration of residential air-conditioners was arguably an adaptation response to historically high summer temperatures in Australia (see Hadley Centre 2011), but also a response to increasingly affordable air-conditioners and the relatively poor thermal performance of Australian housing (Horne and Hayles 2008). Penetration of air-conditioners surged from 35% in 2000 to an estimated 70% today (EES 2006), placing significant strain on residential distribution systems in particular. Growth in average floor area of new dwellings continued to rise, growing approximately 10% since 2000, or from 200 to around 220 square meters (ABS 2010). Distributors responded by making significant investments in additional network infrastructure (AEMC 2010; Garnaut 2011). For example, about AUD$45 billion is scheduled for network investment for the current planning period (July 2010-June 2015), about one third of which is for peak demand growth alone (Dunstan et al. 2011). Still, the majority of network investment is being allocated to replacing aging assets.

In SEQ, Energex received approval from the energy regulator (AER) to invest AUD$6.4 billion for the current period, a 58% increase from the previous five-year period. Previous increases in network spending resulted in dramatic electricity price rises, in the order of 30% in the 2007-2010 period; a result that is expected to be replicated in the following three years as locked-in network investments for the current determination period flow through to retail pricing determinations (AEMC 2010). Queensland's economic regulator recently approved electricity price rises, which will effectively raise electricity bills for the average residential customer in 2013-14 by more than 20% compared to the preceding year (QCA 2013).

To counter increasing electricity costs, some end-users took advantage of recent solar photovoltaic (PV) technology developments and favourable climate change policies. Specifically, more affordable mass produced solar PV systems from China and government incentives for solar PV enabled typically middle-high income households (Bruce et al. 2009) to hedge against electricity price rises. A federal solar PV rebate was established in 2000 to encourage small end-users (typically households, small businesses and community groups) to invest in grid-connected renewable energy. The federal and state governments introduced rebates for solar hot water and heat pump systems as well. This was followed by a raft of further incentives, including a federal renewable energy target underpinned by a renewable energy certificates (RECs) market, and notably, state based feed-in tariffs (FiTs) for small grid-connected solar PV systems typically less than 5kW capacity. Queensland's net FiT was among the highest in the country at 44 cents/kWh, or about double the retail electricity price in SEQ, which allowed some solar PV owners to generate an income from the excess electricity they produced. Before the introduction and eventual take-off of residential solar rebates, solar PV was a niche innovation for off-grid systems in rural and remote areas.

Government policy incentives drove meteoric growth in the solar PV market, with over 500,000 systems installed across Australia, or over 1031MW in capacity by 2011 (up from 0.4MW in 2000 and 111.9MW in 2009) (CEC 2011). This reduced the cost of solar PV to grid parity for residential systems in 2012 (APVA 2011). In recent years, electricity regime actors became concerned about the impact of high solar PV penetration on grid stability and social equity, and the influence of generous FiTs on electricity prices (eg, Nelson et al. 2012). As a result, most state governments removed or vastly reduced their FiTs in the last couple of years. In July 2012, Queensland's FiT was reduced to eight cents/kWhr as part of a suite of policy changes to address factors driving up electricity prices.

Climate change politics also shifted investment practices in the large scale generation sector, as financiers factored in carbon pricing and a carbon constrained future. Climate change policy and pricing or taxing carbon dioxide emissions was debated during the 2007 federal election. This and other environmental issues arguably resulted in the ousting of the incumbent conservative government, and election of Kevin Rudd's pro-carbon pricing Labour government (Gascoigne 2008). Prime Minister Rudd signed the Kyoto Protocol soon after election, signalling the government's intent to set emission reduction targets for Australia. Consequently, more investment flowed to more expensive but lower-emission gas generators for peaking and base-load power, particularly in Queensland, where significant coal seam gas resources were identified (Simshauser et al. 2011a). Towards the end of 2011, the Australian Government passed laws to price carbon, commencing in July 2012 with a carbon tax set at $23/tonne.

In terms of demand management and energy efficiency, both federal and state governments were active in delivering programs to reduce emissions, to address peak demand and reduce the burden of mounting electricity prices. The Australian government implemented minimum energy performance standards for major appliances. In 2008, an insulation rebate was rolled out as part of the government's stimulus package during the global financial crisis. However, this program was discontinued amid concerns regarding the program's implementation. Other federal programs included smart grid trials and financing mechanisms and agencies to fund renewable energy and energy efficiency. In SEQ, Energex initiated remote demand management trials with 1800 customers, and the Queensland government established an energy audit program for households and businesses, which provided education and advice on how to reduce electricity costs.

Early signs of policy success emerged in 2010, with the NEM registering a modest fall in consumption of 212 MWh (0.1%), followed by a further fall of 1,836 GWh (1.0%) in 2011, and an estimated sharp fall of 4,660 GWh (2.4%) in 2012 (AEMO 2012). These falls were brought about by a combination of economic factors (declining manufacturing activity due to high Australian dollar, and lower than expected domestic economic growth) and notably, significant penetration of small scale solar PV and demand-side curtailment (AEMO 2012). Despite three consecutive falls, the AEMO forecasted growth, albeit modest, over the coming decade, signalling further investment in generation and network capacity.

5 Signs of maladaptation

Historical analysis of the emergence of electricity centralisation in Australia shows that electricity demand and peak demand are products of complex interactions at the landscape, regime and niche levels. On the landscape level, government policy trends related to population and economic growth and urban expansionism shaped a supply-oriented electricity sector. Large generators and vast transmission and distribution systems developed with the aim of achieving economies of scale in a market-growth context. End-users responded to economic growth/consumer-capitalist policies by enacting practices that have become increasingly energy intensive; a process enabled by an increasingly abundant supply of cheap mass-produced electrical goods and growing household income.

Amidst this historical background, recent adaptation patterns across Australia's electricity system reveals a tension between supply-chain actors and end-users (see Figure 5). Supply-chain actors are employing an adaptation strategy within the dominant centralisation *paradigm* (Dosi 1982), whereby innovation (e.g., direct demand management, smart grids/redundancy etc.) is path dependent, or aimed at preserving the profitability and viability of legacy assets and organisational competencies, and at meeting regulated standards for safety, reliability and security of supply. Most end-users or consumers, used to meeting needs and wants with increasingly affordable electrical gadgets, are choosing to actively manage thermal comfort with high demand refrigerant air-conditioners, and increasing numbers of end-users are responding to electricity price consequences through energy independence in the form of small-scale solar PV systems. Clean energy and energy efficiency policy measures illustrate how global and national momentum for climate change mitigation is placing pressure on the regime to fundamentally change.

Unfortunately, this dynamic is leading to early signs of maladaptation. That is, vulnerable groups such as low income households are beginning to experience fuel poverty as system-wide costs escalate (Simshauser et al. 2011b), and path dependency appears likely as additional investments in smart grid technology are made to solve problems related to peak demand and high penetration of solar PV systems. In the future, social inequity risks becoming more pronounced as cost/performance ratios for small scale generations systems improve, further eroding market share from the NEM. This situation would trigger further retail price rises to pay for existing assets. For instance, the cost of solar electricity systems are expected to decline further (APVA 2011), and the emerging market for electric vehicles is projected to reduce the cost of battery storage (Narula et al. 2011; Hensley et al. 2012). Such developments could improve the cost/performance ratios of off-grid systems, possibly to a point where these systems are more cost effective than grid electricity for more end-users, particularly those at the grid's fringe (SKM 2011).

The main implication is that the electricity sector is set to emerge along two different technological trajectories – a *super grid* and an *off-grid revolution*. The super grid involves continual improvement and reinforcement of the centralised system, albeit with demand management and smart grid technology to help manage peak demand issues and grid connected micro-generators. Alternatively, the off-grid revolution involves end-users, typically affluent, un-plugging from the central grid in response to improving economies of scale for small-scale off-grid systems. It is worth noting that we do not think these patterns of response are not mutually exclusive, but represent socio-technical configurations that are emerging in parallel, resulting in infrastructure hybridisation, as different actors interact and respond to multi-factor interplay. The point here is that electricity supply appears to be evolving along divergent paradigms, with adverse consequences for centralised grid costs and social equity.

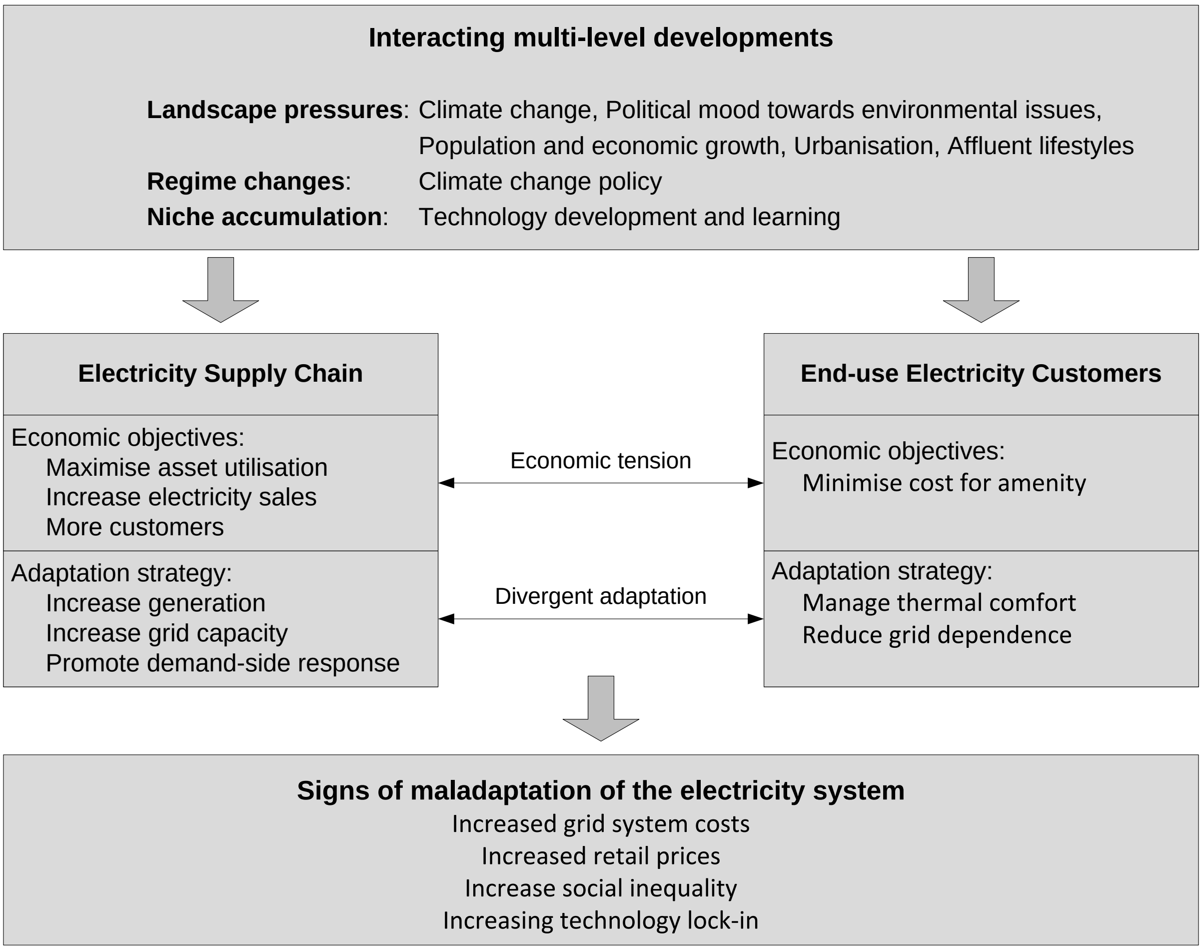

Figure 5. Signs of maladaptation emerging from different economic objectives and divergent adaptation strategies between electricity supply chain and end users

6 A framework for effective adaptation

Effectively adapting to peak electricity demand is a complex undertaking, requiring extensive research and analysis of many options that can be adopted on both electricity supply and demand side. Options are embedded within a heterogenous socio-technical system in which different actors and groups pursue their own agendas, resulting in unintended consequences in the long term. Effective adaptation or whole system response must therefore be considered in terms of multiple competing futures for the electricity system, giving rise to diverse socio-technical configurations as different networks of actors make sense of, and formulate responses to, changing landscape pressures. We offer a framework for effective adaptation that can be used to evaluate key adaptation options currently employed or being trialled in Australia.

Based on Smit et al.'s (2000) high level adaptation framework and drawing on Barnett and O'Neill's (2010) conceptualisation of maladaptation described earlier, we propose a criterion-based framework to evaluate the relative merit of adaptation options (see Figure 6). In relation to the first question (adaptation to what?), we add non-climate related stimuli including demographic, economic, urban spatial patterns and technological developments. Second, we use the following five criteria to evaluate how effective is adaptation:

1. Aligns with climate change mitigation
2. Addresses the needs of vulnerable groups
3. Low opportunity costs
4. Enhances incentive to adapt
5. Maintains system flexibility

It could be argued that these criteria for effective adaptation strategies are derived from several higher level guiding principles such as sustainable development and resilience of socio-technical systems (Franco and Sanstad 2008; Wang and Blackmore 2009).

6.1 Example of adaptation steps to mitigate peak electricity demand

Several adaptation actions are outlined here to demonstrate the variety of possible responses and heterogeneity of the corresponding actors. It is likely that a complex issue like fast growing electricity demand will require a set of responses and the electricity supply and demand systems may develop differently along different future trajectories, as it is unlikely to find just a single, very successful, response. Some examples of adaptation actions for adjusting peak electricity demand are remote control of air-conditioning systems during times of peak demand, possible new electricity tariffs to account for air - conditioning use and to discourage simultaneous use of many appliances and improving energy efficiency of residential houses (both for the appliances used and for the house thermal performance).

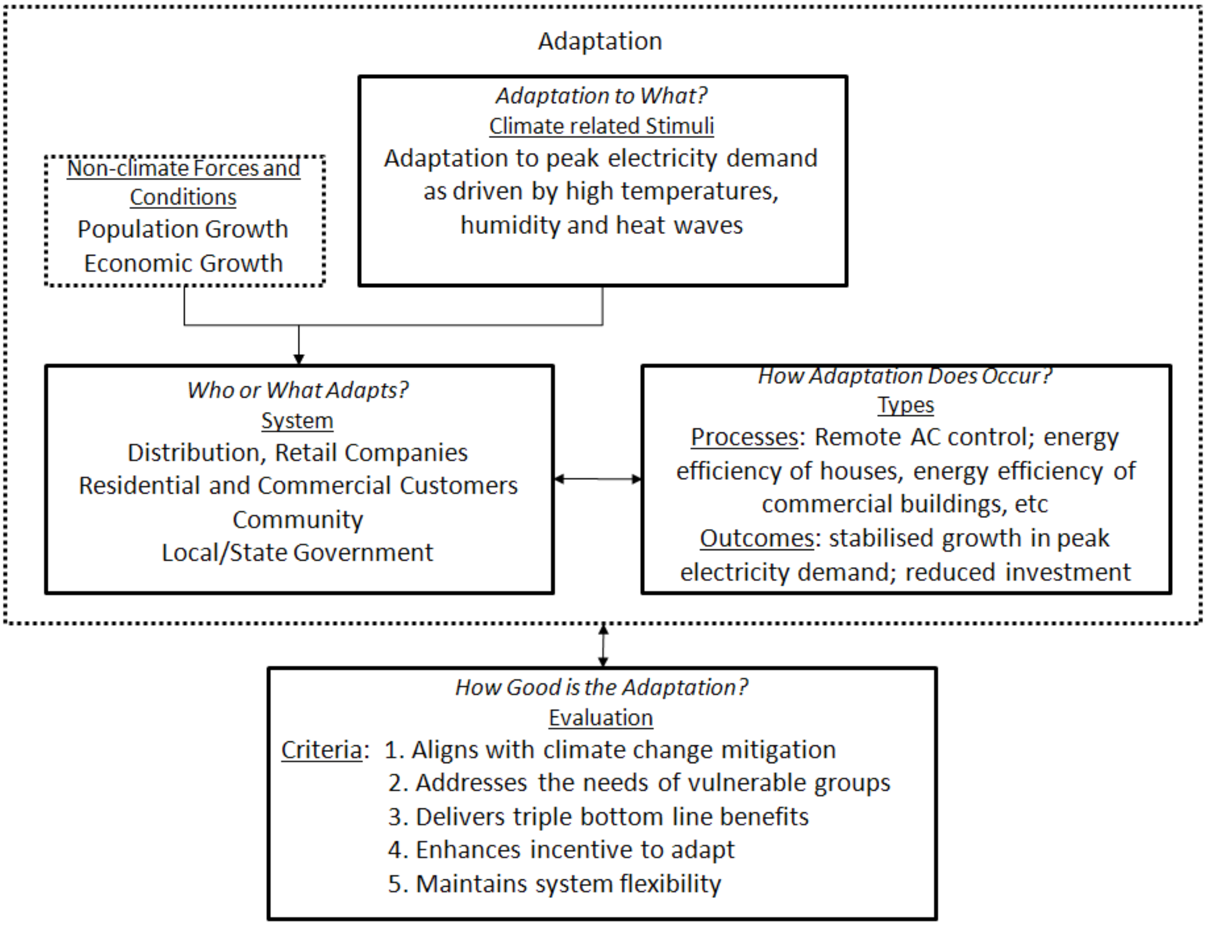

Figure 6. Framework for adaptation to peak electricity demand.
Adapted from (Smit et al. 2000)

6.1.1 REMOTE CONTROL OF AIR-CONDITIONERS AND POOL PUMPS

Remote control of air conditioners and other “electricity hungry” devices during peak electricity demand periods has been trialled by several companies, including Energex – the electricity distributor for SEQ. Energex has implemented a trial called “The cool change – energy smart suburbs” that has run for several summers, starting in the summer of 2007/2008. The trial involves several hundreds of electricity customers who agree to have a remotely controlled device installed at their home, which cycles off and on the air -conditioners, pool pumps and hot water systems usually between 4 pm and 8 pm on days with high electricity demand.

For example air conditioning units may be cycled off at the compressor for several minutes in every 30 minute block, while the fan continues to circulate air. Pool pumps are usually switched off for three to four hours at a time between 4 pm – 8 pm. Hot water systems (that are not already on off-peak night tariff) are controlled not to heat water during the period 4 pm – 8 pm (only on days with very high electricity demand).

Energex claims that substantial reductions of peak electricity demand were achieved on hot summer days. Usually these periods with high electricity demand constitute less than 1% of the time in the year, however, they are responsible for up to 15% distribution network capacity utilisation of the eight billion dollar network. Success with this type of initiative may help to defer substantial network upgrades that are one of the main reasons for the latest electricity price rises.

Remote control of air -conditioners, pool pumps and other electricity intense devices is an example of a possible collective adaptation option that involves an electricity utility (in this case a distribution company) and many residential customers. In the future this type of control may be standardised and regulated or accepted in conjunction with a special electricity tariff.

6.1.2 TIME-OF-USE AND OTHER NEW ELECTRICITY TARIFFS

Introduction of time-of-use tariffs is a potential economic adaptation response to moderate air-conditioning use in periods of high electricity demand. Usually customers need to be connected via "smart" (interval) electricity meters to measure electricity use during time intervals, usually on a half-hourly basis. Higher electricity prices during peak summer periods (usually between 4:00 pm and 8:00 pm in SEQ) are expected to moderate and discourage air-conditioning use, however, this desired outcome may be more complicated in practice than expected. Other new potential electricity tariffs may be proposed that penalise simultaneous use of multiple electrical appliances aiming to keep the maximum household/customer demand below a threshold value.

On the other hand, air conditioning during the time of heatwaves or high temperatures can be vital for aged and vulnerable people. As the aged and the vulnerable are more likely to be people who may lack access to the cooling units, it is imperative for the community to build up social adaptive capacity and management to help aged and vulnerable people in times of heatwaves and electricity outages for example.

6.1.3 ENERGY EFFICIENCY OF RESIDENTIAL HOUSES

Housing energy efficiency means utilising the minimum amount of energy for heating, cooling, equipments and lighting that are required to maintain comfort conditions in a house. An important factor impacting on energy efficiency is the building envelope. This includes all of the building elements between the interior and the exterior of the building such as: walls, windows, doors, roof and foundations. All of these components must work together in order to keep the building warm in the winter and cool in the summer. Residential building can be rated for its energy consumption.

In 2003, ABCB (Australian Building Codes Board) introduced energy efficiency measures for residential building into the Building Code of Australia (BCA).

The energy consumption can vary depending on the design of the building fabric and its systems. The heating and cooling are the major energy consumption areas in household. To reduce this energy usage, a number of options/tips are introduced in existing and new residential buildings. One example for this is the building energy star rating. This is given as part of the Energy Efficiency Rating assessment of a building. This star rating provides an indication of how efficient the building is by providing a star rating from 0 to 10 (the higher the star rating, the better is the energy efficiency of a residential building).

A typical Australian house built in 1990 has a one-star energy rating, which consumes more than 203 MJ/m2 per year (DEWHA 2008). From 2010, the Queensland government introduced 6-star energy rating requirement for new houses and townhouses including major renovations (Queensland Government 2010). Comparing to typical residential building, the 6-star rating indicates that a building achieves a very high level of thermal energy performance. Also, this building is more comfortable to live in with much less energy usage for artificial heating and cooling energy.

To get 6-star energy rating for new house or townhouse, the most useful design options comprise air flow, shading and orientation. Queensland government (2011) provides high energy efficiency new house and townhouse design tips such as:

- Passive solar design: northern orientation of living rooms
- Ventilation: natural ventilation through windows and doorways
- Glazing: treated glazing
- Insulation: reducing heat entry by increased insulation in roof and walls
- Shading of thermal mass: wider eaves and awnings
- Building materials: light coloured roofs and walls
- Ceiling fans in living areas and bedrooms
- Well-designed outdoor living areas.

For the purposes of this report the above energy efficiency adaptation options are grouped in two categories: with low and high installation cost. There is no strict definition of these two categories – if the cost is in the order of hundreds of dollars, it is assumed "low cost"; if the cost is higher (thousands of dollars of more) it is assumed "high cost".

6.2 Evaluation of adaptation options

Adapting the region's electricity system will require extensive research and analysis of many options that can be adopted on both supply and demand side. However, as discussed in the previous sections, these options are embedded within a heterogeneous socio-technical system in which different actors and groups pursue their own agendas, resulting in unintended consequences in the long term. Effective adaptation must therefore be considered in terms of multiple competing futures for the electricity system, giving rise to diverse socio-technical configurations as different networks of actors make sense of, and formulate a response to, changing landscape pressures.

Table 1 aims to evaluate a subset of options described in the previous subsection using the set of criteria discussed earlier in this Section.

Table 1. Evaluation of possible adaptation options

	Adaptation option	Aligns with climate mitigation	Addresses the needs of vulnerable groups	Low opportunity costs	Enhances incentive to adapt	Maintains system flexibility
1	Investment in centralised electricity infrastructure (generation, transmission and distribution)	Maybe	No	No	No	Maybe
2	Time-of-use electricity tariffs	Yes	No	No	Yes	Yes
3	Remote control of air-conditioners and pool pumps	Yes	Yes	Maybe	Yes	Yes
4	Education of residential customers on how to reduce summer peak demand	Yes	Yes	Yes	Yes	Yes
5	Energy efficiency of residential houses	Yes	Yes	Yes	Yes	Yes

The table indicates that from the perspective of 'good adaptation', passive demand management and shaping of consumption should be prioritised over infrastructure investments and changing tariff structures. Unfortunately, electricity distributers tend to devalue non-network expenditure, as their primary economic driver is related to total asset value. That is, network companies earn most of their revenue based on a guaranteed rate of return on assets.

Australia's supply-chain invests in assets that produce, transmit and distribute electricity or gas. This infrastructure model is associated with business models that are based on consumption of these energy products, and return on investment in assets are realised through product-consumption tariff structures; the incentive for companies is to maintain consumption and throughput of energy products.

As indicated in this paper, growth appears to be a necessary condition for paying for and maintaining vast electricity assets. Population growth has gone hand in hand with increasing scale and life-span of assets, and as assets age and reach their end-of-life, significant investment is needed to replace them, which can be proportionally more than the investment in the original infrastructure – a phenomenon known as asset burden (O'Sullivan 2012). This phenomenon compounds the maladaptation dynamic. Costs will increase further due to climate change and variability, which are likely to shift infrastructure standards to boost the robustness of the electricity system during heat wave, fire and severe storm events.

This suggests that effective adaptation requires a shift in the underlying business model and investment strategy employed by the energy supply-chain. Further exploration of new business models could prove fruitful in addressing new objectives for the electricity system, such as clean and efficient production and use of energy resources. For example, a model based on delivery of *energy services*, or a fixed monthly fee according to agreed service standards, much like a mobile phone contract. Such an enterprise could span a variety of energy supply options from passive demand and active supply as indicated in Figure 7. Incorporating the full spectrum of available options would involve energy service providers traversing built environment domains that are normally fragmented across town planners, developers and builders. New levels of integration across the built environment may be required to meet the climate adaptation and mitigation challenge. New business models and integration can drive an energy conservation logic that reduces the need for costly infrastructure through improving building and urban amenity.

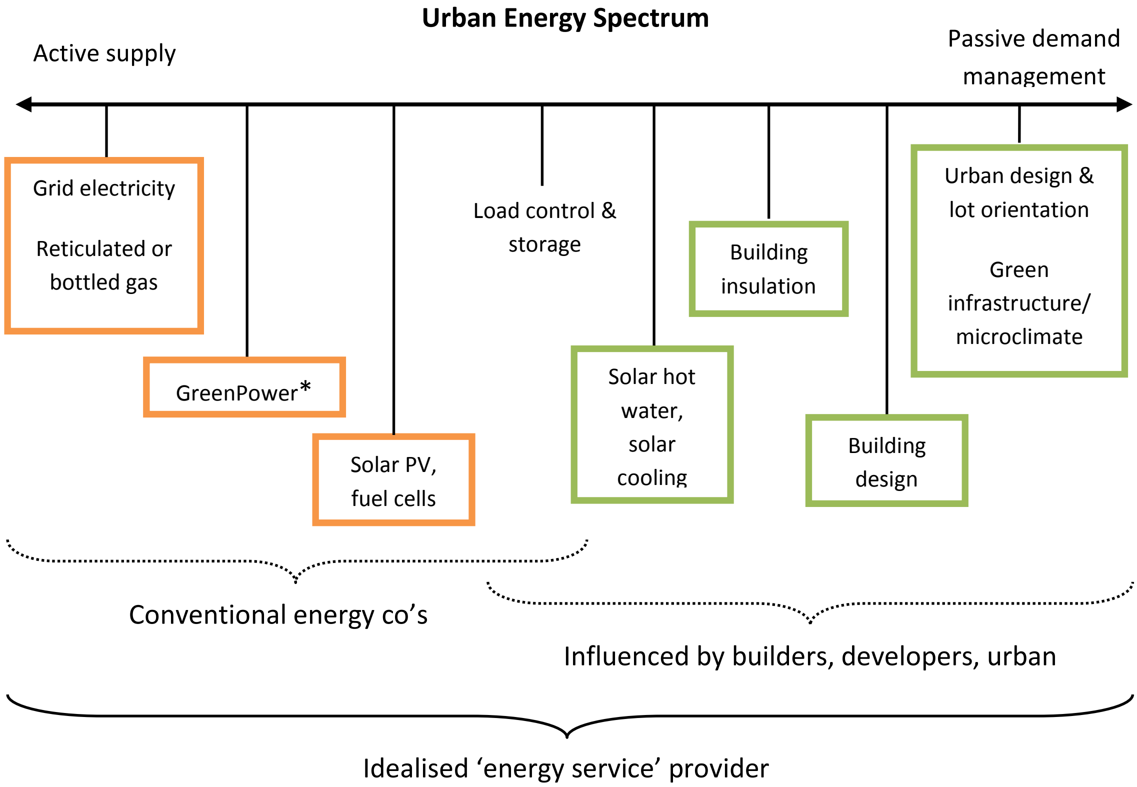

Figure 7: New energy service providers investing across common energy supply and passive demand options deployed in Australia

7 Future research directions

One major implication from this paper is that addressing the risk of maladaptation will require situating climate change policy in the context of historical momentum for economic growth and urban expansionism and related social transformation (i.e., rising affluent lifestyles). Recent economic reform agendas have focussed on notions of decoupling economic growth from consumption of resources, in this case shifting the energy market based on profit from throughput toward an energy services paradigm (Steinberger et al. 2009). Recent attempts to decouple utility incentives appear to be partial and inadequate (Kihm 2009), and some authors express concern about the prospect of rebound effects associated with technological and design improvements, particularly given the prevailing consumer-capitalist society (Herring and Roy 2007; Trainer 2011). While wholesale changes to economic policy are unlikely, the urban policy realm may hold some promise for addressing these concerns.

Much has been written about the potential role of eco-developments and cities in seeding new configurations for production and consumption systems (eg, Bulkeley et al. 2010; Romero-Lankao and Dodman 2011; Swilling 2011). Szatow et al. (2012) recently discussed the central role of property sector actors in driving cleaner and more efficient energy supply configurations. As outlined in this paper, urban development patterns in Australia have been a key contributor to energy demand, and peak demand issues emerge from suburban sprawl and segregated land uses. Addressing peak demand effectively involves moving away from segregating land uses toward mixed-uses, thus improving network utilisation. In terms of addressing consumption, some also point to the value of urban consolidation – a form of rationing – which involves reducing dwelling and lot size (Clune et al. 2012). Urban consolidation and densification appears to be a logical response and offers benefits in terms of using existing infrastructure more efficiently. However, the energy transition described in this paper is one of energy quality – from high quality (coal) to low (renewable) in terms of energy return. Some authors raise questions about urban densification in the context of an energy system based on low-gain renewable energy (Hagan 2012; Hui 2001; Tainter et al. 2003). Urban policy research is needed to examine the relationship between urban density and renewable energy, and to identify optimal urban planning models for a renewable energy future.

Undertaking this research will be enabled by institutional arrangements across land use and infrastructure regimes. For example, the Queensland Government has land use and infrastructure planning powers for certain state declared urban development areas, including new satellite cities in SEQ. This sort of institutional innovation offers substantial opportunities to explore new energy supply regimes that can effectively and equitably address climate change mitigation and adaptation policy objectives.

Another important implication, from an electricity market governance perspective, concerns the process for signalling investment in new generation and network infrastructure. Despite three consecutive years of market falls, AEMO persists with forecasting market growth, albeit modest in their 'low scenario'. This will continue to bring about new infrastructure with high risks of becoming stranded well before the end of their economic life. Current investment processes appear insensitive to market disruptions due to new technology and climate change and energy policy settings. That is, there is a 'signalled investment lag' whereby decisions of supply-side actors are slow to change in response to changes in demand side usage patterns.

Finally, new investment protocols may be required to more accurately and responsively reflect demand-side changes. Further research could explore modelling tools to underpin such investment protocols. Specifically, models of the impact of energy efficiency, demand management and distributed generation on consumption of different customer segments could signal alternative investments and/or regulatory instruments.

8 Conclusion

The aim of this paper was to examine the risks of adapting centralised electricity systems to climate change and other exogenous factors pushing up peak demand. We contextualised the problem of peak demand in SEQ, and used socio-technical transitions theory as an analytical lens to understand how centralisation evolved in the region and nationally, and how adaptation has proceeded in recent years. This analysis revealed two divergent adaptation strategies promulgated by the electricity supply chain and end users, both in response to technology and policy developments, resulting in early signs of maladaptation. Specifically, many end users are adopting high consumption lifestyles, and a growing number are pursuing energy independence with the help of federal and state government incentives. One critical element of consumption growth relates to the emergence of dormitory suburbs, shifting of most suburban electricity consumption to after normal works hours, and the massive penetration of high demand devices particularly mechanical air-conditioners. Together, these factors have contributed to a sharp rise in peak demand over the past 10 years. In response, network companies have been investing heavily in upgrading the grid to cater for this rise in peak demand, resulting in recent double digit growth in electricity prices; along with federal and state government incentives, this has brought about a high uptake of small solar PV systems (<5kWs) among typically affluent end users. This is problematic both on a technical and social level: Firstly, distribution systems were not designed for two-way flow of electricity, and augmentation is needed to support these new devices, placing an upward pressure on electricity prices; secondly, such systems are out of reach for low income and rental housing groups, who both suffer disproportionately from rising electricity prices and are also locked-out of energy independence.

In part, the high penetration of air-conditioners and solar PV systems is prompting policy makers and networks to embark on a 'super grid' strategy, whereby significant additional investment is made to upgrade distribution networks with smart grid technologies. Such a system is also expected to build resilience against extreme weather events related to climate change. The super grid approach would see incumbent electricity utilities and institutions preserving the dominance of the centralised grid paradigm, and engaging all energy users in new tariff structures (e.g., time of use) that enable value to be captured on super grid investments. The advent of a super grid may increase the cost of electricity further as the increased network infrastructure capital and maintenance costs are passed on to customers, again adversely impacting on low income groups.

Ultimately, this maladaptation dynamic is opening up divergent and competing future for electricity supply, which we term the 'off-grid revolution'; or a future that involves less dominance of the central grid as 'turn-key' off-grid systems develop and become more economic. During early market development, such systems will be more accessible to affluent groups, and result in more of the centralised system costs being transferred to low income households, or rental groups who are not able to take advantage of these technological developments.

New frameworks for identifying investment options for centralised electricity grids could manage the risk of increasing costs and social inequity. We offered a framework to help policy makers consider the multi-level and multi-actor nature of adaptation. Initial evaluation of this framework suggests there are opportunities to develop adaptation policy in the energy sector that focus on mechanisms to improve the energy efficiency of building and housing stock.

References

ABS (2001) Building Approvals, Australia, July 2001. Canberra, Australia

ABS (2010) Building Approvals, Australia, February 2010. Canberra, Australia

ABS (2011) Regional Population Growth, Australia, 2009-2010. Canberra, Australia

AEMC (2010) Future Possible Retail Electricity Price Movements: 1 July 2010 to 30 June 2013, Final Report. Sydney, NSW

AEMO (2012) National Electricity Forecasting Report For the National Electricity Market (NEM). Australian Energy Market Operator

APVA (2011) Modelling of PV and Electricity prices in the Australian Residential Sector, 2011. Australian PV Association

Barnett J, O'Neill S (2010) Maladaptation. Global Environmental Change 20 (2):211-213. doi:10.1016/j.gloenvcha.2009.11.004

Berry M (1999) Unravelling the "Australian Housing Solution": The Post-War Years. Housing, Theory and Society 16 (3):106-123. doi:10.1080/14036099950149974

Booth RR (2003) Warring Tribes: The Story of Power Development in Australia. 2nd Ed. Bardak Group, West Perth

Brown N, Rappert, B., and Webster, A (ed) (2000) Contested Futures: A Sociology of Prospective Techno-science. Ashgate Publishing Limited, Aldershot

Bruce A, Watt ME, Passey R (2009) Who buys PV systems? A survey of NSW residential PV rebate recipients. Paper presented at the Solar09, the 47th ANZSES Annual Conference, Townsville, Queensland, Australia

Bulkeley H, Broto CB, Hodson M, Marvin S (eds) (2010) Cities and Low Carbon Transitions. Routledge, London

Burton I (1997) Vulnerability and adaptive response in the context of climate and climate change. Climatic Change 36 (1-2):185-196. doi:10.1023/a:1005334926618

CEC (2011) Clean Energy Australia Report 2011. Clean Energy Council.

Clune S, Morrissey J, Moore T (2012) Size matters: House size and thermal efficiency as policy strategies to reduce net emissions of new developments. Energy Policy (0). doi:10.1016/j.enpol.2012.05.072

DEWHA (2008) Energy use in teh Australian residential sector 1986-2020. Commonwealth Government, Canberra

Dhakal S (2009) Urban energy use and carbon emissions from cities in China and policy implications. Energy Policy 37 (11):4208-4219

Dosi G (1982) Technological paradigms and technological trajectories: A suggested interpretation of the determinants and directions of technical change. Research Policy 11 (3):147-162. doi:10.1016/0048-7333(82)90016-6

Dunstan C, Boronyak L, Langham L, Ison N, Usher J, Cooper C, White S (2011) Think Small: The Australian Decentralised Energy Roadmap: Issue 1, December 2011. CSIRO Intelligent Grid Research Program. Institute for Sustainable Futures, University of Technology Sydney.

EES (2006) Status of Air Conditioners in Australia - Updated with 2005 data. Canberra, ACT

Elzen B, Wieczorek A (2005) Transitions towards sustainability through system innovation. Technological Forecasting and Social Change 72 (6):651-661. doi:10.1016/j.techfore.2005.04.002

Evans MDR, Kelley J (2008) Trends in women's labor force participation in Australia: 1984–2002. Social Science Research 37 (1):287-310. doi:10.1016/j.ssresearch.2007.01.009

Faruqui A, Sergici S (2010) Household response to dynamic pricing of electricity: a survey of 15 experiments. Journal of regulatory economics 38 (2):193-225. doi:10.1007/s11149-010-9127-y

Franco G, Sanstad AH (2008) Climate change and electricity demand in California. Climatic change 87 (1):139-151

Frantzeskaki N, Loorbach D, Meadowcroft J (2012) Governing societal transitions to sustainability. International Journal of Sustainable Development 15 (1-2):19-36

Garnaut R (2011) Garnaut Climate Change Review - Update paper eight: Transforming the electricity sector. Commonwealth of Australia, Canberra
Gascoigne T (2008) Climate change: "The" issue in the Australian national election 2007? Science Communication 29 (4):522-531. doi:10.1177/1075547008316306
Geels FW (2002) Technological transitions as evolutionary reconfiguration processes: A multi-level perspective and a case-study. Research Policy 31 (8-9):1257-1274. doi:10.1016/s0048-7333(02)00062-8
Geels FW (2005a) The dynamics of transitions in socio-technical systems: A multi-level analysis of the transition pathway from horse-drawn carriages to automobiles (1860-1930). Technology Analysis & Strategic Management 17 (4):445-445
Geels FW (2005b) Technological Transitions and System Innovations: A Co-Evolutionary and Socio-Technical Analysis. Edward Elgar Publishing Ltd, Cheltenham, UK
Hadley Centre (2011) Climate: Observations, projections and impacts - Australia. The Met Office Hadley Centre
Hagan S (2012) Metabolic suburbs, or the virtue of low densities. Architectural Research Quarterly 16 (1):9-13. doi:http://dx.doi.org/10.1017/S1359135512000243
Harvey D (1989) From managerialism to entrepreneurialism: The transformation in urban governance in late capitalism. Geografiska Annaler Series B-Human Geography 71 (1):3-17. doi:10.2307/490503
Hensley R, Newman J, Rogers M (2012) Battery technology charges ahead. McKinsey Quarterly July
Herring H, Roy R (2007) Technological innovation, energy efficient design and the rebound effect. Technovation 27 (4):194-203
Horne R, Hayles C (2008) Towards global benchmarking for sustainable homes: an international comparison of the energy performance of housing. Journal of Housing and the Built Environment 23 (2):119-130. doi:10.1007/s10901-008-9105-1
Hughes TP (1987) The evolution of large technological systems. In: Bijker WE, Hughes, T. P., Pinch, T. (ed) The Social Construction of Technological Systems: New Directions in teh Sociology and History of Technology. MIT Press, Cambridge, MA, pp 51-82
Hui SCM (2001) Low energy building design in high density urban cities. Renewable Energy 24 (3–4):627-640. doi:10.1016/s0960-1481(01)00049-0
Kemp R, Schot J, Hoogma R (1998) Regime shifts to sustainability through processes of niche formation: The approach of strategic niche management. Technology Analysis & Strategic Management 10 (2):175-175-195
Kihm S (2009) When Revenue Decoupling Will Work … And When It Won't. The Electricity Journal 22 (8):19-28. doi:10.1016/j.tej.2009.08.002
Kim E, Barles S (2012) The energy consumption of Paris and its supply areas from the eighteenth century to the present. Regional Environmental Change 12 (2):295-310. doi:10.1007/s10113-011-0275-0
Madlener R, Sunak Y (2011) Impacts of urbanization on urban structures and energy demand: What can we learn for urban energy planning and urbanization management? Sustainable Cities and Society 1 (1):45-53. doi:10.1016/j.scs.2010.08.006
Markard J, Truffer B (2006) Innovation processes in large technical systems: Market liberalization as a driver for radical change? Research Policy 35 (5):609-625. doi:10.1016/j.respol.2006.02.008
Martinez-Zarzoso I, Maruotti A (2011) The impact of urbanization on CO2 emissions: Evidence from developing countries. Ecological Economics 70 (7):1344-1353
McCarty JW (1970) Australian capital cities in the 19th century. Australian Economic History Review 10 (2):107
Mideksa TK, Kallbekken S (2010) The impact of climate change on the electricity market: A review. Energy Policy 38 (7):3579-3585. doi:10.1016/j.enpol.2010.02.035
Miller NL, Hayhoe K, Jin J, Auffhammer M (2008) Climate, Extreme Heat, and Electricity Demand in California. Journal of Applied Meteorology and Climatology 47 (6):1834-1844. doi:10.1175/2007jamc1480.1
Miller W, Buys L, Bell J (2012) Performance evaluation of eight contemporary passive solar homes in subtropical Australia. Building and Environment 56 (2):57-68
Moran A (2008) The emergence of Australia's electricity market. International Journal of Global Energy Issues 29 (1-2):88-108. doi:10.1504/ijgei.2008.016343

Narula CK, Martinez R, Onar O, Starke MR, Andrews G (2011) Economic Analysis of Deploying Used Batteries in Power Systems. Oak Ridge National Laboratory,
Nelson T, Simshauser P, Nelson J (2012) Queensland solar feed-in tariffs and the merit-order effect: Economic benefit, or regressive taxation and wealth transfers? AGL Applied Economic and Policy Research
Newsham GR, Bowker BG (2010) The effect of utility time-varying pricing and load control strategies on residential summer peak electricity use: A review. Energy Policy 38 (7):3289-3296. doi:10.1016/j.enpol.2010.01.027
O'Sullivan JN (2012) The burden of durable asset acquisition in growing populations. Economic Affairs 32 (1):31-37
QCA (2013) Draft Determination - Regulated Retail Electricity Prices 2013-14. Queensland Competition Authority, Brisbane
Queensland Government (2008) South East Queensland: State of the region. Technical report. Queensland Government, Brisbane
Queensland Government (2010) 6-star energy equivalence rating for houses and townhouses: Sustainable housing laws. Queensland Government, Brisbane
Queensland Government (2011) Design guide for 6-star energy equivalence housing: A guide to assist with achieving a 6-star house. Queensland Government, Brisbane
Rip A, Kemp R (1998) Technological Change. Human Choice and Climate Change: Volume 2: Resources and Technology (Battelle Press) 2:327-327
Romero-Lankao P, Dodman D (2011) Cities in transition: transforming urban centers from hotbeds of GHG emissions and vulnerability to seedbeds of sustainability and resilience: Introduction and Editorial overview. Current Opinion in Environmental Sustainability 3 (3):113-120. doi:10.1016/j.cosust.2011.02.002
Schipper L (1987) Residential electricity consumption in industrialized countries: changes since 1973. Energy (Oxford) 12 (12):1197
Schnore LF (1957) The growth of metropolitan suburbs. American Sociological Review 22 (2):165
Sharma D (2003) The Multidimensionality of Electricity Reform-An Australian Perspective. Energy Policy 31 (11):1093-1093
Sharma D, Bartels R (1997) Distributed electricity generation in competitive energy markets: A case study in Australia. Energy Journal 19 (SPEC. ISS.):17-39
Shell (2011) Signals and Signposts: Shell Energy Scenarios to 2050. Shell International BV,
Shove E (2003) Users, technologies and expectations of comfort, cleanliness and convenience. Innovation 16 (2):193-206
Shove E, Walker G (2010) Governing transitions in the sustainability of everyday life. Research Policy 39 (4):471-476. doi:10.1016/j.respol.2010.01.019
Simmers JM (2004) The coming of the light to suburban Brisbane. Australian Journal of Electrical and Electronics Engineering 1 (2):127-141
Simshauser P, Nelson T, Doan T (2011a) The Boomerang Paradox, Part I: How a Nation's Wealth Is Creating Fuel Poverty. The Electricity Journal 24 (1):72-91. doi:10.1016/j.tej.2010.12.001
Simshauser P, Nelson T, Doan T (2011b) The Boomerang Paradox, Part II: Policy Prescriptions for Reducing Fuel Poverty in Australia. The Electricity Journal 24 (2):63-75. doi:10.1016/j.tej.2011.01.017
SKM (2011) Preliminary assessment of stand alone power systems as an alternative to grid connections at the fringe of the grid. Alternative Technology Association, Melbourne, Australia
Smit B, Burton I, Klein RJT, Wandel J (2000) An Anatomy of Adaptation to Climate Change and Variability. Climatic Change 45 (1):223
Smith A, Stirling A, Berkhout F (2005) The governance of sustainable socio-technical transitions. Research Policy 34 (10):1491-1510. doi:10.1016/j.respol.2005.07.005
Smith A, Voß J-P, Grin J (2010) Innovation studies and sustainability transitions: The allure of the multi-level perspective and its challenges. Research Policy 39 (4):435-448
Spearritt P (1994) I shop, therefore I am. In: Johnson LC (ed) Suburban Dreaming: An Interdisciplinary Approach to Australian Cities. Deakin University Press, Geelong, pp 129-140
Spearritt P (2009) The 200 km city: Brisbane, the gold coast, and sunshine coast. Australian Economic History Review 49 (1):87-106

Steinberger JK, van Niel J, Bourg D (2009) Profiting from negawatts: Reducing absolute consumption and emissions through a performance-based energy economy. Energy Policy 37 (1):361-370

Steinfeld J, Bruce A, Watt M (2011) Peak load characteristics of Sydney office buildings and policy recommendations for peak load reduction. Energy Build 43 (9):2179-2187

Swilling M (2011) Reconceptualising urbanism, ecology and networked infrastructures. Soc Dyn-J Cent Afr Stud Univ Cape Town 37 (1):78-95

Szatow A, Quezada G, Lilley B (2012) New light on an old problem: Reflections on barriers and enablers of distributed energy. Energy Policy 43:1-5. doi:10.1016/j.enpol.2011.07.057

Tainter JA, Little A, Allen TF, Hoekstra TW (2003) Resource transitions and energy gain: contexts of organization. Conservation Ecology 7 (3):n/a-n/a

Thatcher MJ (2007) Modelling changes to electricity demand load duration curves as a consequence of predicted climate change for Australia. Energy 32 (9):1647-1659. doi:10.1016/j.energy.2006.12.005

Trainer T (2011) We Can't Have Our Cake and Eat it Too: Why the Energy and Climate Problems Cannot Be Solved in Consumer-Capitalist Society. Energy, Sustainability and the Environment: Technology, Incentives, Behaviour. Butterworth-Heinemann, Amsterdam

Vine E (2012) Adaptation of California's electricity sector to climate change. Climatic Change 111 (1):75-99. doi:10.1007/s10584-011-0242-2

Wadley D (1981) Cost, price, and revenue differentials in electricity supply: Queensland and Australia. Australian Geographical Studies 19 (1):25-46

Wang C-h, Grozev G, Seo S (2012) Decomposition and statistical analysis for regional electricity demand forecasting. Energy 41 (1):313-325. doi:10.1016/j.energy.2012.03.011

Wang CH, Blackmore JM (2009) Resilience concepts for water resource systems. Journal of Water Resources Planning and Management 135 (6):528-536

Weinberg C, Iannucci J, Reading M (1993) The distributed utility: Technology, customer, and public policy changes shaping the electrical utility of tomorrow. Energy Systems and Policy 15 (4):307-322

Willbanks TJ, Lankao, P. R., Bao, M., Berkhout, F., Cairncross, S., Ceron, J. P., Kapshe, M., Muir-Wood, R., and Zapata-Marti, R. (2007) Industry, settlement and society. Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, UK

CONTACT US

t 1300 363 400
+61 3 9545 2176
e enquiries@csiro.au
w www.csiro.au

YOUR CSIRO

Australia is founding its future on science and innovation. Its national science agency, CSIRO, is a powerhouse of ideas, technologies and skills for building prosperity, growth, health and sustainability. It serves governments, industries, business and communities across the nation.

FOR FURTHER INFORMATION

Ecosystem Sciences
George Quezada
t +61 7 3833 5553
e george.quezada@csiro.au
w www.csiro.au/people/George.Quezada

Ecosystem Sciences
George Grozev
t +61 3 9252 6035
e george.grozev@csiro.au
w www.csiro.au/George.Grozev