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Assessing resilient urban systems to support long term adaptation to climate change

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Climate Adaptation for Decision-Makers

Climate Adaptation for Decision-Makers is published by the Victorian Centre for Climate Change Adaptation Research (VCCCAR). The series identifies policy issues emerging from VCCCAR research to inform decision-makers with responsibility for climate adaptation policies at local and state levels of government. Information on publications in this series and the research on which they are based can be found on the VCCCAR website at **www.vcccar.org.au**.

Assessing resilient urban systems examines some key findings arising from research on the resilience and adaptive capacity of energy and water infrastructure systems in two Melbourne housing developments – one in the city's outer north and the other in a rapidly gentrifying inner suburb.


Credit: Ifte Ahmed

Policy implications

Challenges posed by the impacts of climate change and extreme weather suggest that new approaches are required to increase the resilience of energy and water systems and build the adaptive capacity of householders and communities. There is a clear need to better understand how individuals, communities, organisational, economic and political arrangements interact with these new and emerging technical systems.

Opportunities exist for climate resilient design in new urban developments

Significant investments are being made in new energy and water infrastructure to service extensive urban fringe developments across Australia. This infrastructure is designed to be in place for many decades. Significant opportunities exist to design for climate resilience in new urban developments.

Community-scale systems can provide cost and resource use-efficiency advantages over conventional systems

Development- and community-led system designs are meeting individual and community energy and water needs in new and diverse ways. Unlike conventional energy and water infrastructure systems that have changed little over the past 50 to 100 years, these community-scale systems have been designed with contemporary environmental challenges in mind, including the need for adaptive capacity to climate change. They provide valuable and instructive examples of innovative approaches that involve learning-by-doing and adaptive management.

Innovative systems can be more resilient and build adaptive capacity

These new approaches are potentially important in building the adaptive capacity of householders and communities. Early research has observed different levels and types of user participation in the design and management of innovative water and energy systems compared to those in conventional settings. These have implications for those living with and reliant on innovative systems.

The success of these systems depends on regulatory support and policy alignment

Further research will help develop a more systematic understanding of these community scale systems, their contribution to adaptive capacity, and the regulatory support required to maximise and extend their benefits. This research will assist policy makers to better understand where infrastructure regulation and investment can support or undermine the resilience of energy and water systems to climate change and extreme events.

Background

This research considers the ways in which stakeholders interact with community-scale energy and water infrastructure systems, and the implications for improving infrastructure resilience to climate change. The preliminary findings presented in this brief are based on a literature review, two (on-going) case study investigations and an online survey, conducted in early 2010, targeted at climate change and alternative technology interest groups in Victoria.

Climate change poses significant risks to Victorian communities through expected impacts on energy and water infrastructure (CSIRO 2007). Recent droughts, bushfires and floods have demonstrated how energy and water systems are vulnerable to existing climatic conditions – and may become increasingly so in the future (Table 1). Potential impacts on Victoria's energy and water systems as a result of these changes include:

- Increased frequency of blackouts and brownouts
- Increased risk of contamination of water catchments and damage to energy distribution lines from fires, floods and storms
- Rising operational costs
- Increasingly unreliable services
- Individual system collapse

From: CSIRO (2005, 2006, 2007); VicGovt (2008, 2010)

More specific risks posed by climate change to water and energy infrastructures include the degradation and failure of drainage infrastructure, offshore infrastructure storm damage and substation flooding (CSIRO, 2007) (refer to Table 2 for more examples). Furthermore, the interdependency of water and energy infrastructure means that disruption and damage in one system will inevitably affect other connected infrastructures, causing "derivative losses" (GriffUni, 2010).

Societal changes will exacerbate the challenges posed by climate change to energy and water infrastructure by increasing the demand for secure services at a time when resource supplies may be less predictable and more susceptible to supply disruptions. At current rates of population growth, Victorian energy and water services will need to cope with an estimated extra 4 million residents by 2050 (ABS, 2010). This population is also aging, adopting increasingly resource intensive lifestyles, exacerbating existing urban sprawl as well as becoming more densely settled. These changes are likely to see further growth in per-capita energy demand, greater overall demand on limited water resources and a need for new and upgraded infrastructure (ABS, 2010; Australian Government, 2006, 2008; Sandu and Petchey, 2009). Given the emergence of new pressures, a fresh look at the adequacy of existing energy and water systems and an assessment of alternatives is needed.

Conventional energy and water systems provide services through 'pipes and wires' that link remote resources to users across Victoria. These systems are generally large scale with users disconnected by vast distances and large organisational structures from the management decision-makers, system hardware and raw materials on which they rely. This 'disconnect' may exacerbate community vulnerability by reducing the ability of end-users and system managers to influence and learn from each other.

In contrast, community scale energy and water systems may strengthen relationships and proximity between users, system managers and technical infrastructure. This has the potential to foster new understanding and behaviour change that may improve system resilience. For example, studies show that people living near and connected to distributed energy sources often reduce their energy use and change their timing of their most intensive energy use to coinside with 'off-peak' periods. In doing so, they can reduce user costs and alleviate pressure on the wider energy grid. Strong

Table 1: Victorian climate change risks in 2030 and 2070 (Victorian Government 2008)

Our climate in 2030 (compared to 1990)	Our climate in 2070 (compared to 1990)	How will we experience these changes?
Average annual temperatures up to 1.2ºC higher More days each year when temperatures exceed 35ºC Up to a 9% decrease in average annual rainfall Global sea level rise of up to 15 centimetres	Average annual temperatures up to 3.8ºC higher Nearly twice as many days each year when temperatures exceed 35ºC Up to a 25% decrease in average annual rainfall Global sea level rise of up to 47 centimetres	Longer, hotter summers Hotter, drier conditions will result in significant reductions in run-off for major water catchments More intense droughts as a result of warmer temperatures and higher evaporation rates Fewer rainy days, but increasing rainfall intensity when it does rain Fewer 'wet' years (or years with above average rainfall) Reduced extent and duration of snow cover in Victoria's alpine areas More high fire danger days each year Higher 100-year storm tide heights

stakeholder relationships may also foster exchange of information about infrastructure performance, potential risks and problem-avoiding behaviours. Both factors may increase the capacity of communities to cope with changes in supply conditions and faults caused by climate change. However, little is known about how people interact with local supply systems and how these interactions might influence system resilience.

Defining resilience and adaptation

'Resilience' and 'adaptation' are two important concepts for understanding how energy and water infrastructure can be designed to function despite climate change. They are closely related. Resilience is the capacity of a system to adjust to, and absorb change, in order to maintain essential structures and functions despite disturbances (Walker et al. 2004).

The greater disturbance a system can sustain and still maintain core functions – the greater its resilience. Adaptation is a measure of a systems' ability to learn, and deliberately change in order to adjust its resilience (resilience can be deliberately increased or decreased). According to Folke (2006), systems are considered more or less resilient depending on their capacity to:

i. Absorb disturbance;
ii. Self-organise; and
iii. Incorporate learning and adaptation in order to maintain core functions.

In this project, the term 'system' is used in reference to all connected elements and processes involved in the creation, distribution and consumption of an energy or water service. This may include environmental, technical and organisational functions, and the behaviour of end-users.

Table 2: High and extreme risks facing Victoria's water and energy infrastructure (CSIRO 2007)

Water	Energy
Water shortage	Increase in demand pressure blackouts
Storm water drainage and flooding damage	Substation flooding
Bushfire damage on catchment and storage	Storm damage to above ground transmission
Degradation and failure of water supply piping	Reduction in hydroelectricity generation
Degradation and failure of sewer piping	Reduction of coal electricity generation
Sewer spills to rivers and bays	Offshore infrastructure storm damage
Degradation and failure of drainage infrastructure	Significant damage to transmission infrastructure and service from increased frequency and intensity of extreme storm events
Decrease in annual rainfall in catchments	Damage to transmission lines and structure from increased wind and lightning
	Significant increases in the cost of supply and infrastructure maintenance
	Damage and shut-down of off-shore supplies due to increases in storm surge, wind, flooding and wave events, especially when combined with sea level rise
	Shorting-out due to bushfire and smoke

Adaptive challenges and opportunities #1: retro-fitting water and energy systems into older housing stock. **Credit:** Fairfax Photos

What can influence the resilience of energy and water systems?

Design choices can influence how well energy and water system hardware will maintain function under climate change conditions. Decisions on the types of smart technologies used; the location, size and number of components; their stress-limits, mechanisms, operation and use - all influence the nature and degree of disturbance a system is likely to be exposed to and absorb. Here are some examples:

- A projected increase in the severity of droughts and rainfall variability due to climate change is likely to affect water catchments positioned inland more than those on the coast;
- An increase in the frequency and intensity of bushfires will increase the risk of forested water catchments becoming contaminated;
- In areas susceptible to fires, cyclones and floods, long-distance infrastructure may exacerbate risks to energy or water distribution – particularly where distribution occurs above ground; and
- Where the frequency of climate related shocks to infrastructure may increase, systems designed with a high degree of interdependence can exacerbate the extent and duration of impacts when those faults occur. For example - water shortages can affect power generation, and heatwave triggered blackouts can affect the backup water systems.

Infrastructure management and design also influences the capacity for system stakeholders to learn, adapt and self-organise in response to climate change threats. For example, the physical and institutional distance between system managers and end-users can affect the level of trust and quality of feedback on decisions. This may influence the ability of one stakeholder to motivate behaviour change in another or affect the speed of problem detection and response. Service systems that involve smart-technologies or some form of responsibility covenant may also encourage (or require) improved stakeholder learning and engagement. In contrast, systems that lack transparency and connection between stakeholders may also lack the self-awareness to coordinate adaptive response to climate change.

Social factors can also affect the level of self-organisation, learning and adaptation that communities can undertake. These may directly and indirectly affect how badly climate change disruptions affect energy and water services. For example, wealth, demographic characteristics, the degree of social equity and cohesion, and practice 'norms' can affect people's capacity to:

- Access and use alternative sources and/or services of energy and water;
- Access and use appropriate assistance and information;
- Predict and prepare for system failures;
- Manage and control system operation and the resources they depend on;
- Develop or access backup measures;
- Manage, adjust or re-design the way technical supply systems operate;
- Access and use social networks to meet needs in alternative ways; and/or
- Draw on their past experience, practical skills and readiness to reduce vulnerability.

Designing energy and water infrastructure without understanding and incorporating wider system characteristics may limit infrastructure and community resilience. A focus on improving the robustness of technical hardware to climate change impacts may inadvertently restrict the capacity of end-users to adapt. Or it may create barriers to further learning – stifling needed innovation. Energy and water systems that foster interaction between end-users, managers, resources and technical hardware are likely to have greater capacity for self-organisation, learning and adaptation. What is unknown is whether certain responses to climate change can also reduce the resilience of energy and water systems over the long term. Such responses are considered 'maladaptive'.

Sydney Road, Brunswick: Melbourne's inner suburbs have many attractions but pose adaptive challenges. **Credit:** Fairfax Photos

Maladaptation

Maladaptation is defined by Barnett and O'Neill (2010) as "action taken ostensibly to avoid or reduce vulnerability to climate change that impacts adversely on, or increases the vulnerability of other systems, sectors or social groups". One example is household water conservation measures reducing the volume of water entering the sewerage network triggering a failure in the wastewater system (Howe et al. 2005). The increased use of air-conditioners on very hot days spiking energy demand and triggering blackouts or reducing people's heat tolerance is other example (Wilkenfeld 2004).

The research planned in this project aims to explore whether existing community scale energy and water systems are resilient and what this means for householders' and communities' adaptive capacity. Understanding how different system designs interact with broader social and organisational arrangements will assist policy makers and planners better anticipate the long-term efficacy of their energy and water programmes and related policy decisions.

Current approaches to risk reduction

Current efforts to address the risks to residential energy and water supplies associated with potential climate change impacts fall into four main categories:

1. Centralised 'supply-oriented' responses
2. Demand-oriented responses
3. Development-led community scale responses
4. Community-led community scale responses

1 Centralised 'supply-oriented' responses

This has been the primary approach taken by state governments to address climate change or climate-related resource scarcity in the energy and water sectors. Examples include the desalination plants commissioned in every mainland state, the Sugarloaf Pipeline in Victoria and the Wyaralong Dam in Queensland. Focused on increasing supply capacity, these responses seldom incorporate mitigative or adaptive strategies and are usually based on a single, large, centralised approach to problem solving. Broader social arrangements, such as how people are likely to interact with such systems, are rarely considered. These responses of this type can reduce problems of resource scarcity but have been criticised for potentially creating maladaptive behaviours, such as end-users becoming more complacent about their use of resources. 'Supply-led' responses may therefore reduce the ability of end-users to adapt to supply shortages if they occur – a potential reduction in system resilience. In short, centralised responses are designed for very stable and predictable conditions and de-prioritise the need for learning adaptation.

2 Demand-oriented responses

A complementary approach to supply-oriented solutions is demand management. This can involve the use of moral incentives (being seen to 'do the right thing'), economic instruments or laws to mandate performance standards that reduce individual resource consumption. This is a common and widespread strategy. Examples include water use restrictions and the mandating of half-flush toilets for new homes. By reducing per capita energy and water use, demand management could be seen as a successful adaptation measure. It can potentially alleviate supply shortfalls and increase system resilience by ensuring functions can be performed at lower rates of resource supply and inducing users to adopt more efficient resource use behaviours. However, demand oriented responses are not without problems. Campaigns to reduce water use can disproportionately affect the elderly and the poor; prove vulnerable to a breakdown in trust between users and suppliers; and require suppliers to advocate lower resource use (something that may contradict their business models). Furthermore, demand-oriented strategies do not significantly alter the technical design of supply systems and may not induce permanent changes in user behaviour. Any increases in system resilience as a result of supply-oriented strategies are marginal (and possibly temporary).

3 Development-led community scale responses

Development-led responses are the result of collaborative efforts between developers, utilities and state and local governments. They attempt to shape both supply and demand within urban developments through the use of energy saving features, 'low-flow' water fixtures, storm water harvesting and wastewater recovery systems. Examples include the industrial development at Kalkallo and the residential development at Aurora - both in outer Melbourne. These system arrangements may increase resilience of infrastructure systems to climate impacts by diversifying water supplies and reducing demand on primary sources. Compared to supply and demand management responses, development-led community scale systems may also allow for greater interaction between social, organisational and technical arrangements with potential for information exchange and mutual learning. However, these responses are a relatively recent innovation. Their long-term effectiveness in improving system resilience and the adaptive capacity of householders and communities is unknown.

4 Community-led community scale responses

Another form of innovation in the energy and water sector is the development of community scale systems that have an element of user involvement in their design and/or operation. These are more diverse and range in size. The most common form involves individual householders using localised technical systems to

reduce or eliminate their reliance on mains water and energy. Less common but increasing in number are multiple household systems that rely on community participation. These use commercial or collective organisations set up or run with the involvement of residents to co-ordinate delivery of energy and water services. Compared to development led responses, systems led by communities involve arrangements that are potentially less fixed by initial design decisions and are therefore able to evolve more freely. Local examples include WestWyck village in inner Melbourne and the Hepburn wind farm cooperative in Daylesford.

A small number of studies (ATA 2007; Biggs, Ryan & Wiseman 2010; Chappells & Shove 2004; Sofoulis et al. 2005) suggest that community scale responses represent a promising avenue for climate change adaptation. However, little is known about where they exist, how they can be scaled-up as a policy approach, the risks they pose and institutional arrangements that could support further development of this type.

Community-scale systems survey

In mid-2010, the project team conducted an on-line survey to identify the range of community-scale energy and water systems in Victoria. The survey targeted individuals through alternative technology and environmental organisations and interest groups. Although results are unlikely to have captured all community-scale systems in existence, they indicate the growing diversity of ways in which energy and water services are being delivered, the links between these types of innovations and the role of government agencies in their development. Key findings are as follows.

A total of 31 community-scale existing or planned energy and water systems were identified. Systems included one or more of the following features:

On-site solar electricity
  14 systems

On-site wind generated electricity
  5 systems

On-site heat and power co-generation
  6 systems

On-site grey water
  10 systems

On-site black water
  5 systems

On-site desalinisation
  2 systems

Most of these systems were recent developments, with 19 identifying as recently operational or likely to be within one year. Only 7 had been operating for more than 5 years. Systems were diverse in scale with 14 designed to provide a direct service to less than 10 households and 10 designed to service more than 25,000 households. Government agencies and/or utilities assisted in the maintenance and operation of about two-thirds of the systems. A similar number of systems were owned, wholly or in part, by end-users.

Building community resilience and adaptation to climate change was an explicit aim in more than half of the cases identified. In all cases, respondents stated that systems had been designed with climate change in mind, though they did not specify how, or a timeframe for changes envisaged. In a self-assessment of vulnerability to extreme events, respondents indicated that between 16 and 26 systems would probably not be impacted by bushfire, flood, heatwave, blackout, drought, storm or water restrictions. In 21 cases, responses also indicated their belief that their systems were resilient and/or adaptive – defining these concepts in terms of economic, community or technological resilience and adaptive to community needs/demands. Where systems were in operation, most responses suggested that households or communities connected to them had changed their behaviours in response.

The survey also sought information regarding broader features of the systems. Figure 1 below shows the results for a selection of features considered key to a

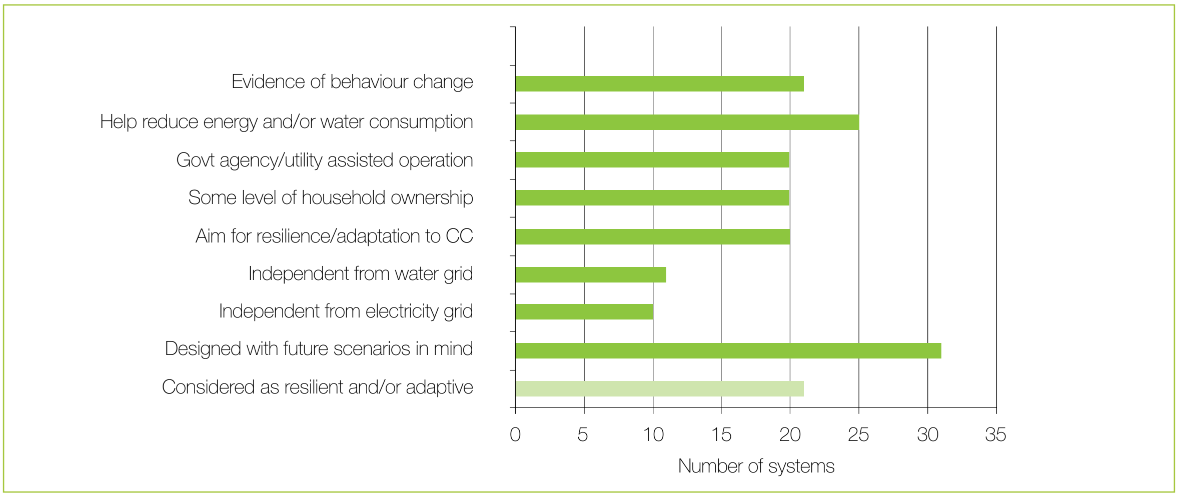

Figure 1: Survey responses to the adaptive capacity of alternative water and energy systems

preliminary assessment of adaptive capacity.

While these results are indicative only, they suggest a high level of self-awareness among system stakeholders and a strong understanding of the link between climate change and energy and water system design. This raises important questions about the availability and adequacy of information available to community level infrastructure developments about the risks of climate change. Communities represent a recent and potentially growing area of climate change innovation – one that is reportedly having an impact of people's behaviour. Further research into two case study projects will seek to better understand the impact and implication of these innovations for improving climate change adaptation in Victoria.

Conclusion

- Victorian communities are vulnerable to climate change through its impacts on energy and water infrastructure. These risks include an increased frequency of blackouts and brownouts, contamination of water supplies, damage to water and electricity distribution networks from fires or floods and rising operational costs.
- Proper and continued functioning of energy and water infrastructure in the face of climate change will depend on how well these systems can absorb disturbance, self-organise and incorporate learning and adaptation. Current infrastructure design could do more to encourage these attributes. In particular, decisions on design and management of system hardware must better reflect the likelihood of greater environmental volatility and acknowledge how interactions between systems and users shape infrastructure resilience and adaptability.
- Current large-scale 'supply-oriented' energy and water infrastructure systems are designed in a way that excludes end-users from interacting with or influencing factors such as quality of service, operation and management priorities or the location and choice of hardware. In effect they are 'passive' service recipients - unable to shape how infrastructure systems function or improve system adaptation through mutual learning and negotiated change. This arrangement has worked well during periods of stability but may limit adaptation to climate change.
- In community-scale energy and water infrastructure, novel system components may give users and managers greater response options when faced with climate change impacts. For example, community-scale systems may use novel resources and increase resource use efficiency. In addition, community scale systems can foster closer connections between users, infrastructure hardware, resource systems and operational decision-makers. Stakeholders may engage with each other directly (rather than across deep organisational structures) and live in physical proximity to the hardware on which they rely. Potentially, these arrangements may build system resilience by fostering learning and adaptation in system design and stakeholder behaviour.
- This project identified 31 community scale energy and water generation systems in use or planned across Victoria. These ranged in size from communities of less than 10 households to suburbs of more than 25,000 households and were primarily led by developers or communities. Each system involves a unique design configuration and unique ways in which end-users participate in operation, management and use. The diversity of systems suggests some are more likely to provide a basis for successful adaptation and learning that would increase resilience to climate change.
- This research examines user-infrastructure interactions to understand how different technical, management and user arrangements can increase the resilience of energy and water systems. In doing so, it seeks to identify areas in which infrastructure, planning and development policy can support the development of urban energy and water systems that are more resilient to climate change and thereby improve the Victorian community's adaptive capacity.

Resilient urban systems project

The resilient urban systems project aims to improve understanding of motivations to develop new systems of energy and water provision, opportunities and barriers to implementation and changes in practice resulting from these new systems. This brief is one of a number of project outputs that include journal articles, progress and final reports.

The project team comprises:

- Dr Ifte Ahmed, Paula Arcari, Professor Ralph Horne, Cecily Maller, Assoc. Professor Sujeeva Setunge, Dr Yolande Strengers, Julia Werner and Dr Kevin Zhang (RMIT University) and
- Che Biggs, Taegan Edwards, Professor Chris Ryan and Professor John Wiseman (University of Melbourne).

The Project Reference Group includes representatives from the Department of Planning and Community Development (DPCD), Department of Sustainability and Environment (DSE), Department of Human Services (DHS), the Alternative Technology Association (ATA), Yarra Valley Water and the Environmental Sustainability Accord (The Accord).

Visit the VCCCAR website for more information about the Urban Resilience Project: www.vcccar.org.au.

Adapative challenges and opportunities #2: providing adaptive energy systems to new communities. **Credit:** Fairfax Photos

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1. *Increase Government decision-making capacity about state-specific climate change impacts;*
2. *Encourage the inclusion of adaptation needs in Government strategic planning; and*
3. *Bring together expertise to work on the provision of multi-disciplinary advice to government, industry and the community.*

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