The Climate Institute

Infrastructure Interdependencies and Business-Level Impacts

A new approach to climate risk management

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A new approach to climate risk assessment

Infrastructure interdependencies and business-level impacts: A new approach to climate risk assessment

Report from a workshop on climate change and infrastructure interdependencies on 13 December 2012.

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Assessing Climate Impacts on Interdependent Infrastructure

A new approach

This report examines some of the physical impacts of climate change on the infrastructure sector and the resulting cascade of consequences for the broader economy. The report summarises findings from a workshop conducted in December 2012 by The Climate Institute, Manidis Roberts (a part of the RPS Group) and KPMG, which piloted a process for analysing the climate-related risks associated with interdependent infrastructure systems of a major city. The workshop was informed by a range of sources: a desktop review of academic, business and government documents; analysis from experts in the fields of risk, resilience, sustainability and infrastructure planning; analysis of historical events; interdependency mapping and quantitative modelling.

This workshop report follows The Climate Institute's recently published report *Coming Ready or Not: Managing climate risks to Australian infrastructure* (2012). *Coming Ready or Not* synthesised research on the physical impacts and flow-on consequences of climate change and analysed preparations for climate change impacts in Australia amongst owners and operators of major infrastructure assets. This work made several recommendations in relation to the importance of managing infrastructure interdependencies, noting:

Despite some examples of collaboration, preparation for climate change tends to focus on organisation-level risk management. The implications of climate impacts on interdependent systems and communities remain underexplored. Adaptation is an ongoing process. Generally, the most effective strategies are those that can accommodate a range of likely climate change scenarios, recognise systemic interdependencies, and take account of the broader community context.[1]

Australia's climate is highly variable and predisposed to extreme weather events. These can be shocking and sudden, like the 2009 heatwaves in Melbourne and Adelaide and the "Black Saturday" bushfires in Victoria, or they can be long and drawn out, like the drought experienced by south-eastern Australia through much of the previous decade. Climate change is predicted to increase many of Australia's weather extremes. For example, CSIRO estimates that the number of days over 35 degrees Celsius and the frequency of heatwaves experienced by major southern Australian cities will double by 2030 and triple by 2070.[2]

Climate change increases the probability of many climate impacts that present significant risks to organisations. These risks including direct damage, indirect operational and logistical interruptions within the supply chain or customer base, or natural resource constraints. The costs of these impacts can have ripple effects through the wider economy. Organisations that plan for the impacts of climate change are able to mitigate against increased operation and maintenance costs, and potential reduced capacity to supply. Understanding potential impacts on a business enables an informed assessment of the costs and benefits of adaptation strategies.

The workshop aimed to pilot a package of analysis that examined a comprehensive range of costs resulting from climate impacts on interdependent infrastructure, and to make such analysis relevant to key public and private sector infrastructure and service providers. For this workshop, the chosen scenario was an extreme heat event in Melbourne, consistent with climate projections for 2030. Analysis comprised two main sections:

Qualitative analysis of the direct and indirect impacts of the heatwave experienced in Melbourne in summer 2009. Research on the consequences of the heatwave was supplemented with data gathered from participants representing the energy, transport, and services sectors. The analysis examined interconnectivity and interdependency, vulnerability of critical infrastructure and the cascading effects throughout the economy from disruption to services or altered asset performance. The consequences were then considered against potential impacts of an extreme heat event in 2030.

Quantitative analysis of the costs to a hypothetical business resulting from three scenarios of a projected heat event in Melbourne in 2030. This approach produced indicative costs of disruption and reduction in performance of key assets and services at a company level. Under three scenarios of labour supply disruption, the estimated costs (due to increased labour costs and/or lost production) ranged from 0.2-1.1 per cent of revenue (equivalent in the case of the modelled business to $1-5 million).

Key Findings

Businesses and organisations are largely unprepared for a heatwave event of magnitude. The consequences for operations, infrastructure capacity, coping ranges and system interactions would be severe.

Mapping the interdependencies and impacts of the heatwave shows both the range and paths of its cascading consequences. It also shows that while costs arising from such an event may be extremely high, they are diverse, and spread across multiple parties. This may obscure the extent to which failure to manage such an event damages the economy. Responsibility for planning and actions to reduce vulnerabilities lies with multiple parties, and failure by any one party to take such actions may have severe adverse impacts on others. It is essential that climate risk management take place at the systems level rather than just the organization or even sector level.

Modelling showed that the degree of cost impacts was highly dependent on the specific characteristics of the individual business. While much of the costs were imposed by external factors (eg. infrastructure failures affecting inputs), in many cases firms may be able to moderate such costs by taking steps to reduce their exposure (eg. back-up power sources; flexible labour arrangements). This requires understanding the firm's climate risk exposure at both systems and organization levels, in order to assess the cost and benefits of adaptation options.

Recommendations

Data about the state of infrastructure assets needs to be shared within and across sectors for effective planning. The following recommendations for managing infrastructure interdependencies for future climatic events apply to both public and private sector infrastructure owners and operators, and should be read in conjunction with the Action Plans for business and government in The Climate Institute's report *Coming Ready or Not: Managing climate risks to Australia's infrastructure*.

+ Develop common methods and tools for interdependency analysis to inform strategies to improve infrastructure resilience.
+ Establish city-wide taskforces with private and public sector participation to share and better coordinate information and climate risk management strategies for each of the major capital cities across Australia.
+ Disclose material climate risks, both indirect and indirect, to major infrastructure systems.
+ Disclose and update plans for management of these risks.

And for Government:

+ Implement a national initiative to better identify current and emerging climate risk impacts for interdependent infrastructure networks and engage stakeholders in cross-sectoral collaborative solutions.
+ Expand the approach for "critical" infrastructure taken by the Federal Critical Infrastructure Program for Modelling and Analysis (CIPMA) to all other key infrastructure assets and industry sectors.
+ Require private-sector proponents or owners of infrastructure—especially those seeking Commonwealth approval or funding—to disclose how their assets and interdependencies will manage climate risks under likely and plausible climate scenarios such as 2 and 4 degrees of warming.

Setting the Scene

Melbourne temperatures and community vulnerability

The heatwave of 2009

Between 27 January and 8 February 2009, southern Australia experienced one of the nation's most severe heat waves. Temperatures in Melbourne reached a record high of 46.1 degrees and remained above 40 degrees for four consecutive days. The National Climate Change Adaptation Research Facility noted:

Compared to the 100-150 years of historical observations, the 2009 heatwave in southern Australia was exceptional—producing severe, extensive and prolonged heat exposure. It was a major and unexpected heatwave in both Australian and international contexts, with extreme heat stress in the first phase and a bushfire disaster in the second phase of the heatwave. Climate change over the next 30-60 years will make such events more likely, and test the resilience of the expanding metropolitan areas, unless forewarning and other adaptation strategies are successful.[3]

Government agencies, businesses and the community were largely underprepared for an extreme event of this magnitude. During the heatwave, electricity demand, primarily driven by air conditioning, broke Victorian load records by approximately 7 per cent. Supply was compromised by a shutdown of the Basslink connection between Tasmania and Victoria (which provides Victoria with 6 per cent of its electricity) and an inability of the generators to supply additional power. This occurred during a period of high demand across the national grid. Reduced transmission efficiency and faults in up to 50 local voltage transformers led to outages of major transmission lines, load shedding and power blackouts; for example, on 30 January more than 500,000 Melbourne residents were without power.

Potential heatwaves in 2030

The workshop used climate hazard modelling inputs for Melbourne under an extreme temperature event in 2030. This climate scenario was chosen due to the frequency and severity of extreme heat under predicted climate change, and because of the threat extreme heat poses to human health and community wellbeing. Heat events have killed more people than any other natural hazard in Australia over the past 200 years.[4]

While there is no standard definition of a heat wave, the Bureau of Meteorology (BOM) defines one as a period of abnormally hot weather lasting several days. Using SimClim modelling and 2009 as a baseline, Melbourne's summer days over 35 degrees are projected to grow by 28 per cent by 2030, from 24 days per summer in 2009 to 30 days per summer in 2030.

Figure 1. *Frequency of summer days over 35 degrees in Melbourne*

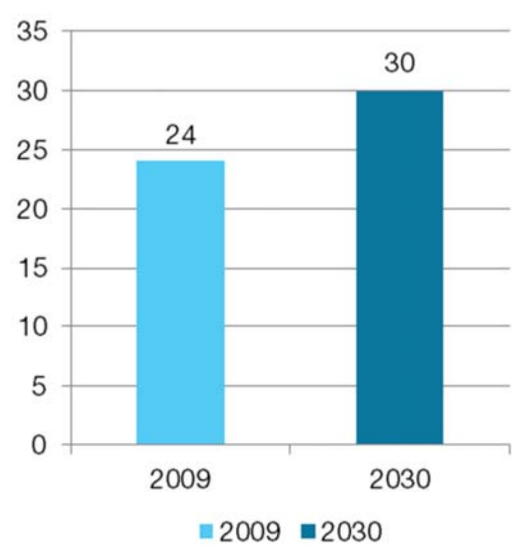


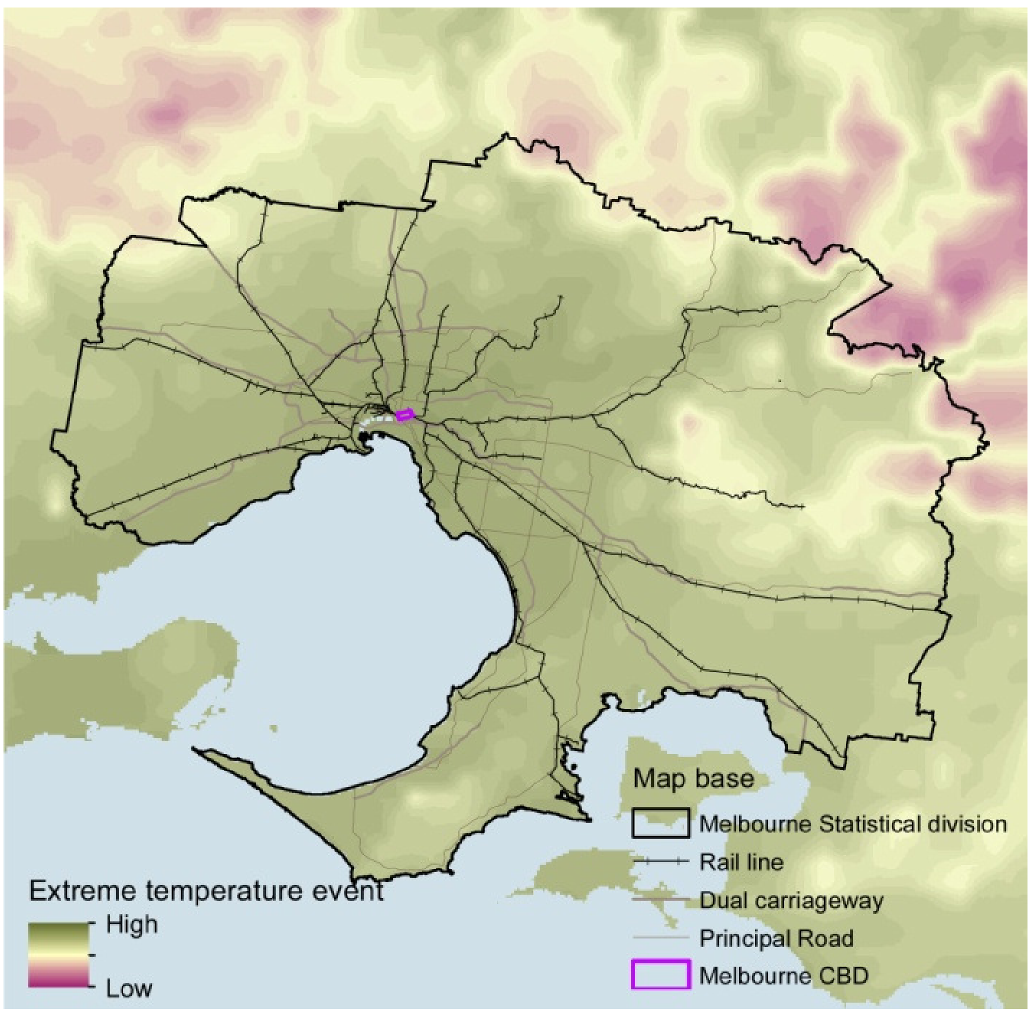
Table 1. Projections of extreme temperature events of more than 3 days for Melbourne

Temperature range	Events per year (3 consecutive days)	
	2009 baseline	2100 projection (A1B)
Number of single days >34.5 to <37°C	2	7
Number of single days >37 to <40°C	1	2
Number of single days >40°C	1	1

Using the SimClim regional climate modelling capability we mapped temperature exposure for 2030. We also modelled community vulnerability using the Griffith University VAMPIRE approach; this concept of vulnerability draws on the work of CSIRO and the Sydney Coastal Councils Group. We used 2006 Australian Bureau of Statistics data.

Figure 2 is a spatial representation of the temperature change from the 1990 average baseline to 2030. This figure demonstrates that Victoria will experience an increase in extreme temperatures, although Melbourne will experience a smaller change relative to the rest of the state. This does not take account of the urban heat island effect.

Figure 2. *Temperature rise across Melbourne to 2030*



These images have been developed to help communicate the changes in climate and are subject to the full conditions of the Manidis Roberts climate change disclaimer document. These maps are not to be reproduced or distributed separate from the report in which they are enclosed.

Figure 3 represents the community vulnerability in the greater Melbourne region. Figure 4 represents population density. Taking Figures 3 and 4 together, it is possible to identify areas of particular vulnerability within the community. Vulnerability is characterised by both high sensitivity to external events such as heatwaves, and low capacity to adapt to such events. Groups widely recognised to be more vulnerable include people above 65 years and living alone, people who are fully dependent (four years and under), or those who are non-English speaking, do not own their homes, live in densely populated areas and/or have low household incomes. During a heatwave these groups typically have less access to air conditioning, due to high energy running costs; have greater difficulty understanding emergency response and health warnings; and potentially suffer greater health effects due to their age. These groups require greater assistance during emergencies and ongoing social services support; however service providers may also be adversely affected by extreme events. Figure 3 also demonstrates that Melbourne's highly vulnerable communities are concentrated along the major transport nodes that are also found to be vulnerable during an extreme heat event.

Figure 3. *Community vulnerability*

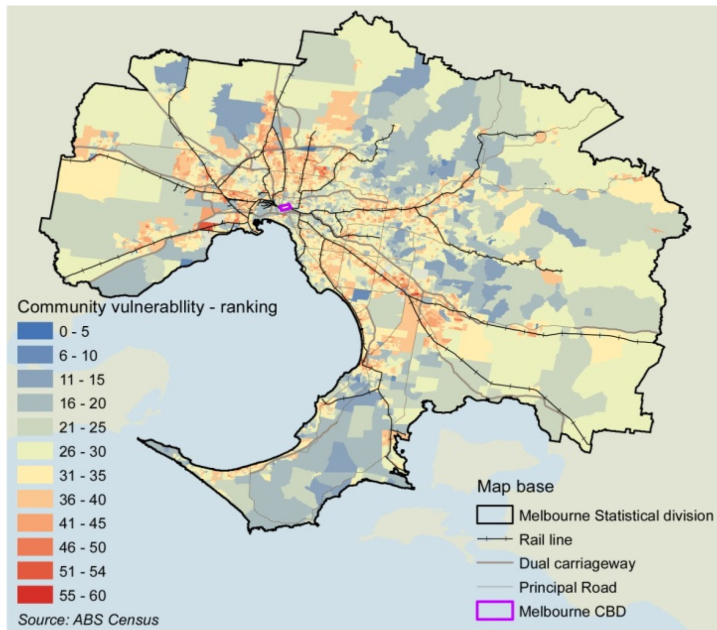
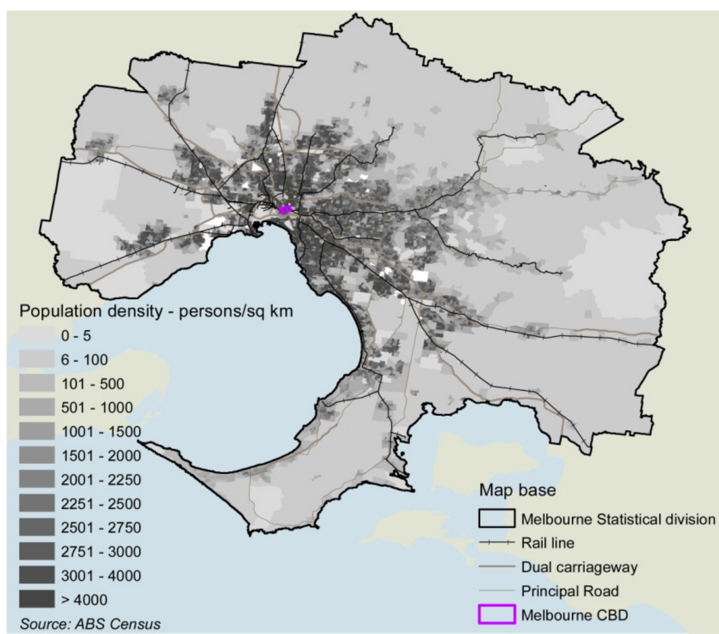


Figure 4. *Population density*



Infrastructure Interdependencies

Mapping impacts and consequences

A high level risk-mapping exercise identified impacts from the 2009 extreme heat event in order of their flow-on effect. We ranked impacts as first order impacts, which lead to second order impacts, which lead in turn to third and so on. The mapping started with first order impacts such as: heat effects on materials and structures, increased evaporation, heat effects on people and increased ozone pollution. These infrastructure impacts, along with trigger points and thresholds, have been analysed based upon the historical records (see Table 2 and Figures 6 and 7).

For each type of infrastructure a flow of impacts was mapped and qualitatively assessed. This identified nodes of interdependency and areas of vulnerability.

This mapping showed that the cycle of interaction between transport and energy network infrastructure led to the most significant consequences of the 2009 heatwave. On 28 and 29 January 2009, peaked demand, reduced performance of energy transmission lines and distribution equipment failure combined to cause rolling electricity blackouts throughout western and central Melbourne, in turn cutting the power supply to overhead power lines and signals for the train system. This resulted in the cancellation of a quarter of city-bound train services, rising to over a third by the third day. Table 2 outlines the heat impacts on infrastructure sectors, their interdependencies and consequences.

Figure 6 maps the flow of impacts. Figure 7 includes only the major impacts and critical interactions. Lines between risks indicate related impacts. Thicker lines indicate greater severity of impact. This analysis was used to inform the economic assessment.

The increase in frequency and severity of heatwaves produced by climate change means that these impacts are likely to intensify, unless we take steps to prepare for them. The 2009 Melbourne heatwave was estimated to cost the economy $800 million.[5] Ensuring future heatwaves do not inflict major economic damage requires climate risk management to be undertaken system-wide.

Figure 5. *Example of flow-on impacts in an extreme heat event*

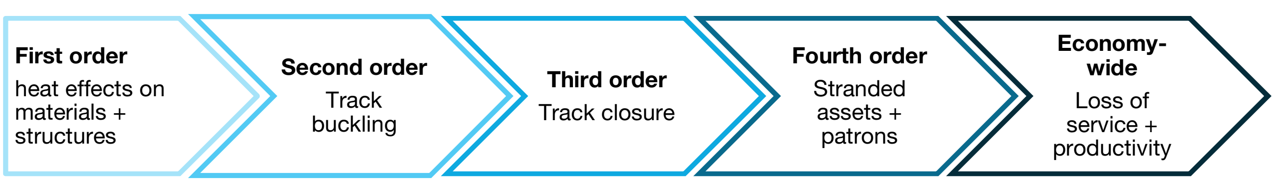


Figure 6. *Infrastructure impacts across Melbourne as a result of an extreme heat event*

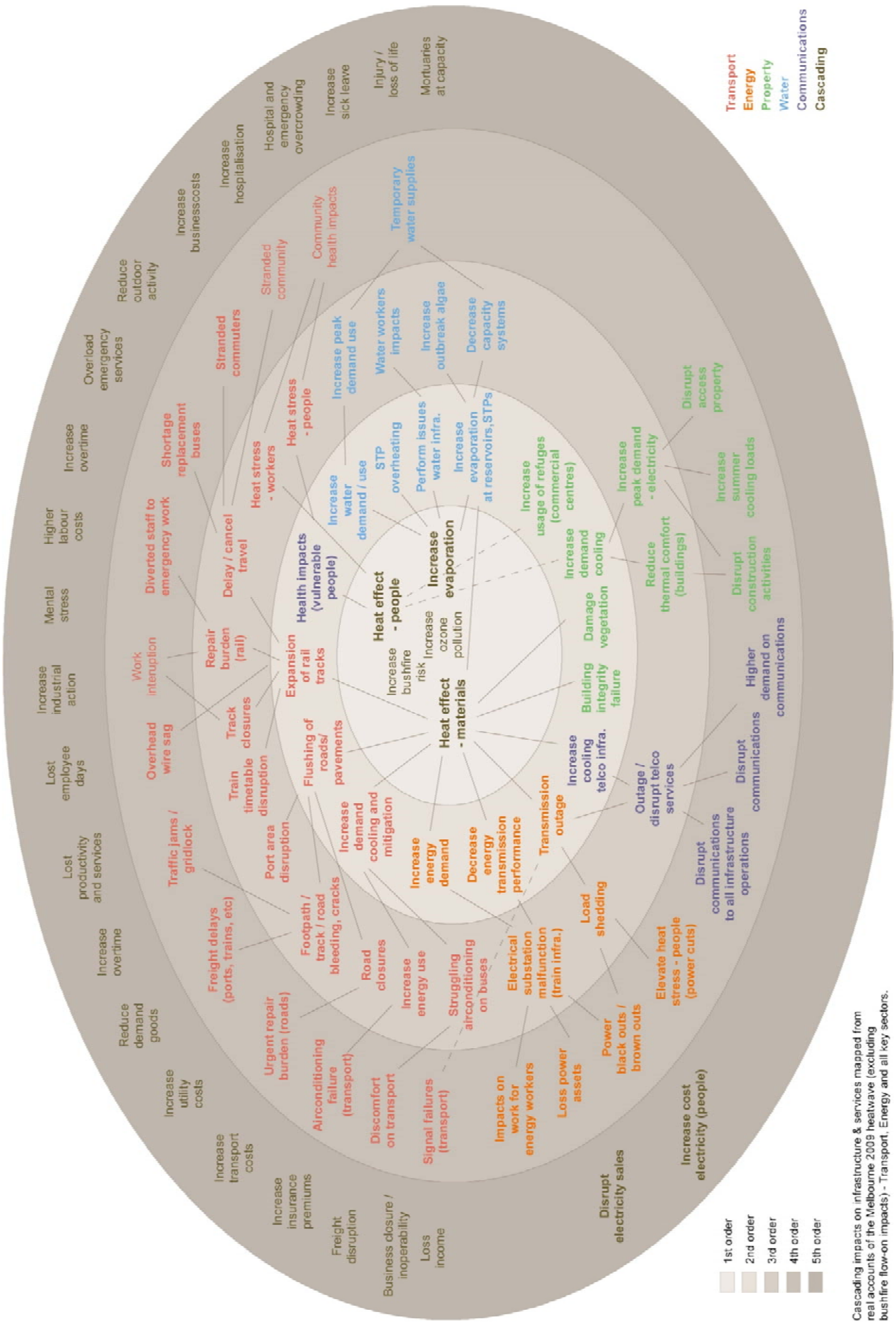


Figure 7. *Major impacts and critical interactions*

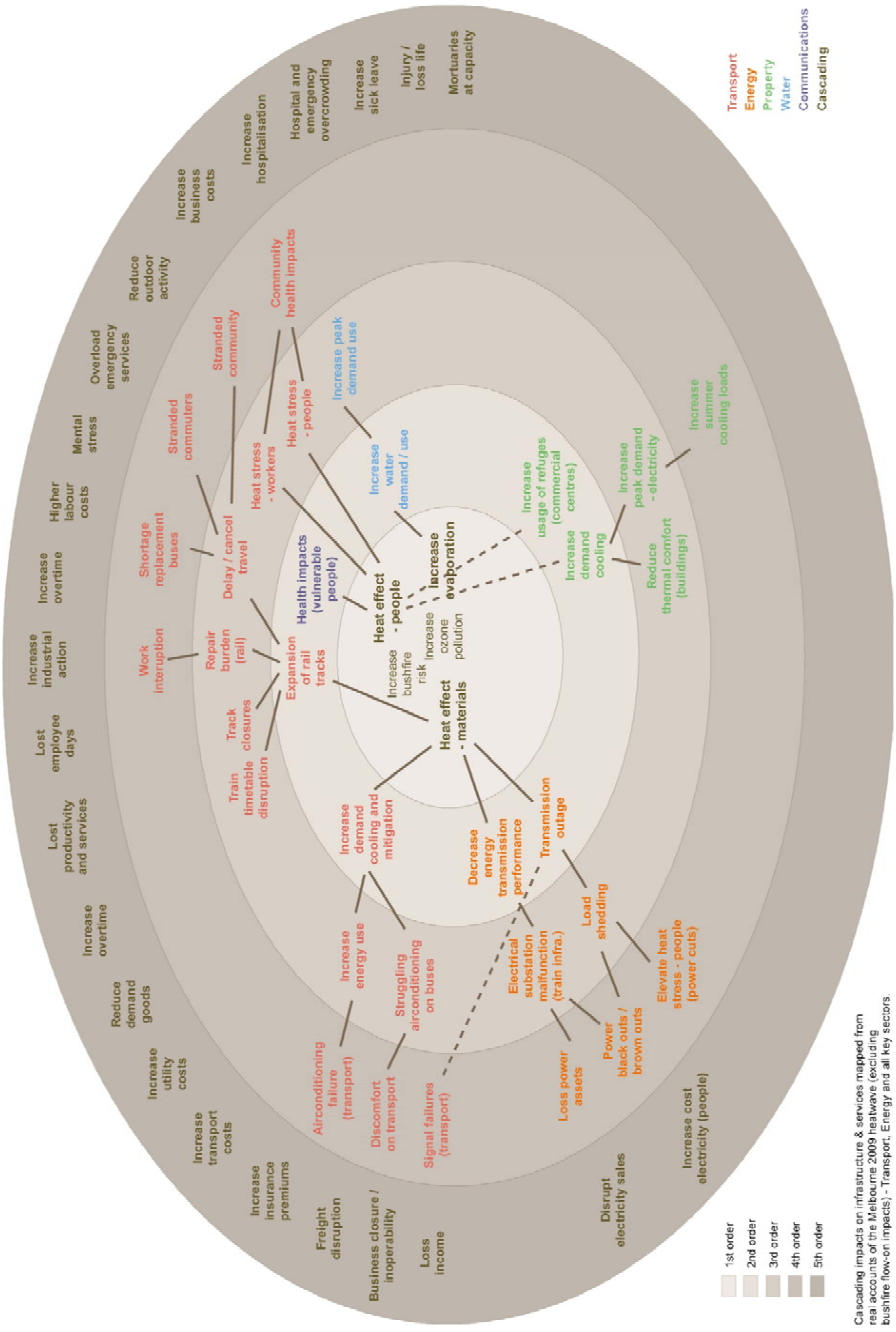


Table 2. Infrastructure impacts of 2009 heatwave in Melbourne

Sector	Sub-sector	Impact level	Description	Reported trigger points and thresholds
Energy	Electricity	Highly impacted	+ Rapid spikes in temperature created record demand for electricity. This resulted from a combination of population growth and significantly increased deployment of air conditioners. + Supply was compromised by a shutdown of the Basslink connection between Tasmania and Victoria. + Reduced transmission efficiency and faults in up to 50 local voltage transformers led to outages of major transmission lines, load shedding and power blackouts. On 30 January more than 500,000 Melbourne residents lost power.	+ Power generation and distribution operating at full capacity, and unable to supply additional power. + Narrow climatic operating bands for plant and infrastructure for atmospheric cooling. + Heat lowers transmission performance. + Reduction in insulator capacity and breakdown at higher temperatures. + Faults in instrumentation transformers. + Positive feedback loops as increased demand (eg for air conditioning) combines with reduced performance to further increase demand.
Energy	Gas	Minimally impacted	+ High level of resilience to the impact of heat.	+ No reported sensitivities.
Energy	Generators	Minimally impacted	+ Impaired cooling for thermal power stations + Higher coal combustibility reduced coal production on high-risk days. + Risk of bushfire to certain assets in bushfire-prone areas (eg. Latrobe Valley).	+ Limits on water available for cooling.
Transport	Train	Highly impacted	+ 29 instances of buckling slowed and disrupted service. + An explosion at the South Morang transmission station cut power to city loop trains, cancelling services and stranding many inner-city commuters. + Air conditioning failures contributed to service cancellations + During the three days of the initial heatwave peak, train services operated at 76% of normal capacity, falling to 64% on the third day. More than one-third of train services (750 out of 2,400) were cancelled.	+ Buckling of rail tracks, particularly elevated tracks. + Signaling equipment also vulnerable to extreme heat. + Overhead wire can sag.
Transport	Trams	Moderately impacted	+ Several trams broke down in the heatwave, but too few to cause significant disruption. On the hottest day some trams' engines were taken off the network to prevent overheating. + Recently installed air conditioning withstood heat	+ Tram engines are sensitive to heat. + Air conditioning potentially vulnerable.
Transport	Buses	Minimally impacted	+ Buses affected by the heatwave due to air-conditioning failure. + Buses served as a backup service for cancelled train services.	+ Bus air conditioners struggle at temperatures above 35°C. Above 40°C they tend to blow warm air, creating discomfort for bus drivers and passengers. + Limited supply of replacement buses.

Sector	Sub-sector	Impact level	Description	Reported trigger points and thresholds
Transport *(continued)*	Roads	**Minimally impacted**	+ Patches of stickiness - bleeding and flushing (excess surface asphalt) impacts at a number of places, with 15 incidents on major highways. + Some (older) equipment, such as controllers, CCTV cameras and traffic signals malfunctioned	+ Sprayed seal road surfaces (bitumen and stone aggregate) sensitive to hot weather + Sensitivity of electrical traffic equipment to heat.
	Other	**Minimally impacted**	+ Some City of Melbourne footpaths became too hot for pedestrian use. The City Council cooled footpaths by sprinkling them with water.	+ Paths can become too hot to use.
	Other - Ports/Airports etc	**Minimally impacted**	+ Facilities inconvenienced by power loss. + Pavement bleeding across facilities – 5% of 36 hectares of port terminal affected. + Outdoor port workers required extra breaks/stoppages. This led to lost productivity at Port Melbourne (72 hours loss in crane activity). + Melbourne Airport needed additional cooling of 2°C to maintain comfort in the terminals – this led to a 10-15% increase in electricity consumption over January 2009. The airport also needed increased water for cooling. The airport has stand-alone generators so experienced no electricity failures.	+ For ports when temperature exceeds 35°C then outdoor workers require breaks or above that to stop work. + Pavement bleeding at certain temperatures + Need for additional cooling drives greater demand for electricity and water.
Human & Health services		**Highly impacted**	+ Sharp rise in heat-related illness and deaths among the most vulnerable groups. 374 excess deaths and more than 3000 reports of heat-related illnesses, predominantly among the elderly. + Emergency services suffered from inadequate planning and cross-agency coordination.	+ Not analysed for this report.
Water		**Minimally impacted**	+ Sharp increase in water use - domestic consumption rose from 220ML to 1500ML at temperatures over 40°C. + Negligible increase in evaporation from reservoirs + Increase in blue-green algae growth at open lagoons in one treatment plant. + Reduced sewage treatment capacity for 4-5 days that lead to lead to a slight reduction in volume recycled water available to customers + Back-up generators were used for critical water operations.	+ No reported trigger points.
Communications		**Minimally impacted**	+ Adequate cooling provided at exchanges. + Back-up power is available at all exchanges. + Telecommunication traffic can be redirected in response to transmission line failure or damage.	+ No specific sensitivities reported.

Company-Level Analysis

How might businesses be affected?

Using inputs from an extreme temperature event in 2030, we modelled a number of potential impacts on a hypothetical Melbourne business, called 'GoodCo'.

GoodCo Company Profile

- **GoodCo is a large manufacturer and wholesaler of a wide range of consumer goods.**
- **Head office is within the CBD and 50 per cent of products are manufactured within the greater Melbourne metro region.**
- **The company employs 2,000 FTEs around the Melbourne metro region. 500 are in head office, with the remainder in production and distribution.**
- **Inputs and outputs are delivered via a variety of transport networks.**
- **Head office relies on power and communications networks to operate.**
- **Manufacturing requires significant inputs of power and water to operate.**

Following is a summary of the estimated impacts from a 2030 heatwave on five interlinked aspects of GoodCo's operations: cost structure, transport, labour, key infrastructure and demand for goods.

Cost structure

There is little evidence to date of cost structure impacts due to rising power costs, as firms typically keep such information confidential. However possible impacts include:

- Increases in short-term business costs as a result of increased use of power and water.
- Changes to short-term pricing structure of suppliers due to disruption in supply chain.
- Increases in labour costs.

Other costs could include employees having to work overtime, to make up for lost production, infrastructure deficiencies or system failures as a result of the heat event. For instance during a two-day heat event in the United States in August 2012, maintenance crews were reported to have charged up to $380,000 ($US 400,000) in overtime (6,865 hours) repairing overloaded air-conditioning units.[6]

Transport associated losses

During an extreme heat event, reduced transport capacity can result in a loss of employee output. For example, employees may be unable to get to work, or attend work for fewer hours, as a result of train delays (signal issues due to electricity outage or track buckling issues), traffic light black outs (due to electricity outage issues) or bus breakdowns. Increased breakdowns in private cars are also typically experienced. In addition, reduced transport capacity can cause output losses through the supply chain, as goods transportation may be affected. For example, cargo vessel delays resulting from a slowdown in loading/unloading processes can have impacts throughout the supply chain.

Reduced labour output

In an extreme heat event employees may be required to care for vulnerable family members or experience heat-related illnesses themselves. (See pages 6-7 for discussion of vulnerability within the community.) Melbourne's heat-related deaths among those aged over 65 are projected to rise from the current 289 deaths per annum to 582-604 by 2020 and 980-1318.[7]

In addition, heat stressed workers may be less productive. The Maritime Union agreement states that if the temperature exceeds 35 degrees outdoor workers can take a 15-minute break per hour.

Above 38 degrees, outdoor workers are entitled to stop working until the temperature cools (though workers operating air-conditioned machinery such as cranes can continue working). As a result, research highlighted that there was a loss of 72 crane hours in January 2009.[8]

Loss of infrastructure

The electricity sector is most vulnerable to extreme heat; and any infrastructure systems reliant on electricity may be exposed to power failure. For example, direct impacts on telecommunications from a heat event appear to be relatively minor, but power failures may limit the availability of internet communications and, as noted above, transport systems. Communications failures in turn limit the availability to work remotely, and result in loss of output. The more reliant a firm is on energy and communication networks, the greater the potential operational losses. Back-up generators may, of course, alleviate impacts.

Demand for goods

Data suggest that an extreme heat event may boost retail trade. Heat events typically lead to greater numbers of people staying at home, but can also increase the number of people going to shopping centres to keep cool. Some shopping centres are designated community refugees. Official retail trade data for Melbourne in January 2009 show a counter-cyclical increase in retail sales in Melbourne in the month not seen elsewhere in Australia where temperatures were closer to normal.[9] Some of the increase in sales will be permanent—for example, sales of fans— but some will be temporary, as activity is brought forward. The impact for the firm will therefore be chiefly around timing of deliveries and inventory management.

In the longer term, delays in the supply of orders can lead to contractual penalties. Online sales may also be affected if energy and/or communications networks go down.

Table 3. *Event scenarios*

+ **The greater Melbourne area is affected by extreme heat over five days.**
+ **Some employees cannot work due to loss of transportation and/or illness and subsequently work overtime to make up for lost production.**
+ **Some employees cannot make up for lost production and planned production falls.**

Scenarios	Employment profile
	Of the 2000 FTE employees in Melbourne,
+ Scenario 1: assumes that 20% of employees cannot get to work on a given day of extreme heat.	+ 500 are able to telework so there is no loss of production.
+ Scenario 2: assumes 50% of employees cannot get to work on a given day of extreme heat.	+ 500 are able to work overtime to compensate for lost output, increasing GoodCo's labour costs.
+ Scenario 3: assumes 100% of employees cannot get to work on a given day of extreme heat.	+ 1000 employees can neither telework nor work overtime. GoodCo suffers from a fall in revenue due to reduced production.

Results

It was found that extreme heat could negatively affect GoodCo through:

+ increased labour costs resulting from more overtime being paid and
+ lost revenue as a result of a supply shock.

The net impact on GoodCo was estimated to be a decrease of 0.2-1.1 per cent of total revenue depending on the severity of the heat wave and the number of employees affected. This is a considerable impact arising from modelled losses (transport, labour, demand for goods etc.) and totalled roughly $1-5 million. The estimated impact is the result of disruptions to labour supply only (which leads to either increased costs or reduced production); significant additional costs from supply chain disruption could also be reasonably be expected.

Table 4. Estimated impact of extreme heat on GoodCo's financial performance

Workers unable to get to work	Overtime cost ($)	Wages bill (%)	Revenue lost ($m)	Total revenues (%)
Scenario 1 – 20%	147,000	0.1	1.05	0.2
Scenario 2 – 50%	368,000	0.3	2.61	0.5
Scenario 3 – 100%	735,000	0.6	5.22	1.1

Table 5. Impacts of extreme weather events (non-labour)[10,11] on GoodCo

Input costs	
Energy costs	+ Energy consumption may modify as GoodCo attempts to reduce the impact of higher energy costs. + GoodCo will experience increased usage requirements in the short term and potentially higher energy prices in the longer term resulting from increased capital expenditure from infrastructure augmentation.
Insurance costs	+ Due to a higher risk environment, insurance costs are expected to increase. + Heatwave adaptation-related innovations are not available in the Australian insurance market. GoodCo cannot insure against heatwaves at present.
Output profile	
Mode of delivery	+ GoodCo's ability to transport goods may be highly compromised in the event of a future heatwave. + The 2009 Melbourne heatwave had a worse impact on rail and road transport, and seaport infrastructure, than on water, telecommunications and airports. More than 25% of rail services were cancelled, major highways were unusable and electrical road signals ceased functioning.
Consumer demand	
How will consumer demand be affected by extreme heat?	+ Sales growth may be experienced as people attempt to avoid the heat by going to shopping centres. However, disruption to distribution networks and supply chains implies any short-term growth in retail sales will not be sustained over the course of a year.

Findings and Recommendations

What next?

An analysis of the 2009 Melbourne heat event combined with climate modelling for a 2030 event found that businesses and organisations are largely unprepared for a heatwave event of magnitude. The consequences for operations, infrastructure capacity, coping ranges and system interactions would be severe.

Mapping the interdependencies and impacts of the heatwave shows both the range and paths of its cascading consequences. It also shows that while costs arising from such an event may be extremely high, they are diverse, and spread across multiple parties. This may obscure the extent to which failure to manage such an event damages the economy. Responsibility for planning and actions to reduce vulnerabilities lie with multiple parties, and failure by any one party to take such actions may have severe adverse impacts on others. It is essential that climate risk management take place at the systems level rather than just the organisation or even sector level.

Modelling showed that the degree of cost impacts was highly dependent on the specific characteristics of the individual business and the nature of its reliance on such factors as labour inputs, transport needs and exposure to energy and telecommunications networks. While much of the costs were imposed by external factors, in many cases firms may be able to moderate such costs by taking steps to reduce their exposure (eg. back-up power sources; flexible labour arrangements). This requires understanding the firm's climate risk exposure at both systems and organization level, in order to assess the costs and benefits of adaptation options.

Infrastructure impacts

Melbourne's electricity supply and transport (especially trains) are the infrastructure sectors most vulnerable to extreme heat. Power supply was impacted by direct failure of equipment such as insulators, instrumentation and power lines, that lead to rolling brown-outs and black-outs. Plant and infrastructure with narrow climatic operating bands are particularly vulnerable. Within transport, the direct impact of heat on the trains is exacerbated by vulnerability to electrical power failure.

Community impacts

The distribution of impacts across the city, types of businesses and community impacts may be very uneven. The most vulnerable communities include the north and west of the metropolitan area of Melbourne – also the most densely populated areas. Increases in hospitalisation, illness and death increase pressure on the health sector

Economic impacts

The cascade of consequences results in many economy-wide impacts: increased labour costs and/or loss of labour, increased health costs, production losses, revenue losses, business closure and inoperability, freight disruption and overloaded emergency services. The modelled cost of disruptions to labour supply alone resulting from the heat event on the hypothetical business is estimated to be $1-5 million, or 0.2-1.1 per cent of total revenue.

These costs are significant. The predicted rise in the frequency and severity of extreme heat events could become unmanageable for many cities.

Recommendations

Data about the state of infrastructure assets needs to be shared within and across sectors for effective planning. The following recommendations for managing infrastructure interdependencies for future climatic events apply to both public and private sector infrastructure owners and operators, and should be read in conjunction with the Action Plans for business and government in The Climate Institute's report *Coming Ready or Not: Managing climate risks to Australia's infrastructure*.

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Endnotes

[1] The Climate Institute, *Coming Ready or Not: Managing climate risks to Australia's infrastructure* , The Climate Institute, 2012, http://www.climateinstitute.org.au/coming-ready-or-not.html/section/478.
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