

Garnaut Climate Change Review

Impact of climate change on Australia's telecommunications infrastructure

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1 Introduction

On 30 April 2007 Professor Ross Garnaut was commissioned by Australia's State and Territory Governments to undertake an independent study titled the Garnaut Climate Change Review (GCCR).

This review examines the impacts of climate change on the Australian economy and recommends medium to long-term policies to achieve sustainable prosperity and address key climate change issues.

The Terms of Reference provided by the States and Territories require the GCCR to report on:

- 1) The likely effect of human induced climate change on Australia's economy, environment and water resources in the absence of effective national and international efforts to substantially cut greenhouse gas emissions;
- 2) The possible ameliorating effects of international policy reform on climate change and the costs and benefits of various international and Australian policy interventions on Australian economic activity.

To achieve this, the GCCR Secretariat, established to facilitate the review, proposes to undertake an assessment of the impacts of climate change on a range of infrastructure types. Maunsell Australia Pty Ltd (Maunsell) was engaged by the Secretariat to identify and assess the impacts of climate change on telecommunications infrastructure in Australia.

The purpose of this report is to qualitatively describe the impacts of climate change on Australian telecommunication infrastructure and to provide further technical information relating to assumptions made while developing the matrix of impacts.

2 The Australian telecommunications sector

Telecommunication is the assisted transmission of signals over a distance for the purpose of communication. Telecommunications make a significant contribution to the Australian economy—the Australian Telecommunications Services sector posted revenue of \$35 billion in 2005–06 (DIISR 2008). This report examines the following key components of the Australian telecommunications sector:

- telecommunication services:
 - broadband services
 - mobile voice and data services
 - fixed voice services
- broadcast services.

2.1 Telecommunication services

Basic network architecture overview

Traditionally, telecommunications networks are classified as either fixed or mobile, depending on the degree of mobility afforded to subscribers. Fixed networks generally consist of multiple local access networks (LANs), linked together by a transmission backhaul network. LANs are also referred to as the 'local loop' and represent the 'last mile' of a fixed network. The LAN includes the connection between each subscriber and a local network node via a transmission media such as copper wire, optical fibre, mobile, wireless or satellite technology. This is commonly known as an exchange or switching point.

The backbone (or trunk) network incorporates the connections between exchanges in different cities and states and has a greater diversity of ownership, and utilises similar transmission media to the local access network. The public network is interconnected to a number of private networks that are usually dedicated or unswitched connections over private lines used by customers requiring a higher bandwidth than traditional copper wires are able to provide.

Telstra Corporation (seventeen per cent of which is controlled by the Federal government) owns most of Australia's telecommunications infrastructure, with the remainder privately owned. This infrastructure tends to be at its most concentrated in urban areas, especially that providing fixed line, mobile and data services. Today, most businesses, communities and public services rely on telecommunications services of some kind, and prolonged interruption to these will therefore have serious repercussions for the economy and lead to a variety of social disruptions.

Broadband services

Australian consumers have access to a range of broadband access technologies, including digital subscriber line (DSL), hybrid fibre coaxial, wireless, satellite and optical fibre services. Seventy eight per cent of Australian broadband subscribers use DSL services, which rely on an existing copper wiring to the customer's premises (ACMA 2007).

According to the Australian Bureau of Statistics (2007) internet activity survey conducted in March 2007, there were approximately 6,429,000 active internet subscribers in Australia, comprised of 5,668,000 household subscribers and 761,000 business and government subscribers. Broadband subscribers constituted 67 per cent (4,331,000) of all internet subscribers in Australia.

Mobile voice and data services

Global System for Mobile communications (GSM) provides coverage to 96% of the Australian population (ACMA 2007). There are three GSM networks in Australia which are owned and operated by Telstra, Optus and Vodafone. Although GSM networks were primarily designed for voice carriage, they have been modified to transmit data, using technologies such as GPRS (general packet radio service).

Consumers are beginning to move from GSM to 3G technology, which has the advantage of providing higher bandwidth data services. This is achieved through greater spectral efficiency (i.e. the amount of information that can be transmitted over a given bandwidth).

The number of mobile services in operation in Australia grew by seven per cent in 2005–06 to 19.7 million (ACMA 2006).

Fixed voice services

The universal service obligation (USO) requires Telstra to ensure standard telephone services are reasonably accessible to all people in Australia, wherever they reside or carry on business. This obligation is generally fulfilled via a fixed-line standard telephone service, but is sometimes met by a mobile, satellite or wireless local loop service. However, voice over internet protocol (VoIP) is an expanding market, and two publicly listed companies on the Australian Stock Exchange (ASX) reported a total of 84,000 subscribers between them (ACMA 2007).

2.2 Broadcast services

Commercial television and radio services are heavily relied upon for the delivery of entertainment and news services in Australia. There are 28 distinct commercial television license areas across Australia, and two national broadcasting services which are funded by the Federal government. Digital television services are currently available in all capital cities and in most major regional centres. Research by ACMA and Eureka Strategic Research (2006) indicated that 29.6 per cent of Australian households had digital free-to-air television.

3 Climate change information

Seven climate change scenarios were used to assess each of the four key infrastructure areas. The climate scenarios are as follows:

3.1 'Business as usual' scenarios

- **Unmitigated Scenario 1 (U1).** Hot, dry business as usual scenario, using A1FI emission path, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100.
- **Unmitigated Scenario 2 (U2).** Best estimate (median) business as usual scenario using A1FI emissions path, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100.
- **Unmitigated Scenario 3 (U3).** Warm, wet business as usual scenario under A1FI emissions path, 90th percentile rainfall and relative humidity surface for Australia (wet extreme), 50th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100.

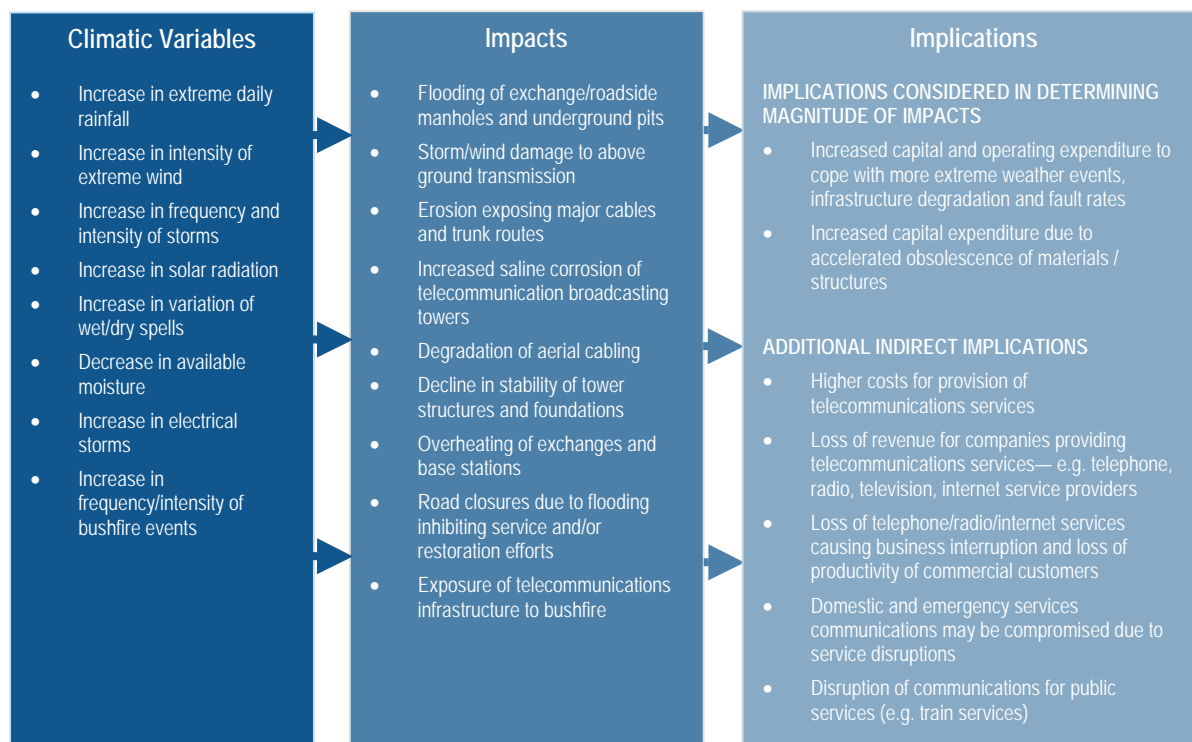
3.2 Strong mitigation scenarios

- **Mitigation Scenario 1 (M1).** Dry mitigation scenario where stabilisation of 550ppm CO₂ equivalent (CO₂ stabilised at 500ppm) is reached by 2100, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.
- **Mitigation Scenario 2 (M2).** Best estimate (median) mitigation scenario where stabilisation of 550ppm CO₂ equivalent (CO₂ stabilised at 500ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.
- **Mitigation Scenario 3 (M3).** Wet mitigation scenario where stabilisation of 550ppm CO₂ equivalent (CO₂ stabilised at 500ppm) is reached by 2100, 90th percentile rainfall and relative humidity surface for Australia (wet extreme), 50th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.
- **Mitigation Scenario 4 (M4).** Best estimate (median) strong mitigation scenario where stabilisation of 450ppm CO₂ equivalent (CO₂ stabilised at 420ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~1.5°C in 2100.

4 Summary of climate change impacts

Figure 1 outlines the impact storyline identified for telecommunications infrastructure. This storyline was assessed against climate conditions considered in the seven climate scenarios U1, U2, U3, M1, M2, M3 and M4 to develop the matrix of impacts for each state and territory.

Figure 1 Impact storyline for telecommunications infrastructure



The impacts on telecommunications infrastructure are anticipated to increase over time varying in severity from state to state. Table 1 provides a summary of the impacts for each climate scenario across the three time scales assessed; 2030, 2070 and 2100. The most significant impacts are anticipated to occur under the U1 and U3 climate scenarios in the 2071–2100 timeframe.

The high and extreme impacts in U3 are principally due to an increase in extreme rainfall events and catchment flooding. The high impact for U1 (in Western Australia only) between 2071 and 2100 is due to a sharp reduction in rainfall causing drying of the ground and subsequent damage to foundations, cables and conduits. Under the U3 scenario Northern Territory is expected to the most significant impacts (High up to 2070 and Extreme up to 2100) due to increased extreme weather events and associated rainfall events.

Table 1 Summary of magnitude of impacts on telecommunications infrastructure for seven climate scenarios

	2008–2030	2031–2070	2071–2100
U1	Neutral to Low	Low to Moderate	Low to High
U2	Neutral to Low	Low to Moderate	Neutral to Moderate
U3	Neutral to Low	Low to High	Low to Extreme
M1	Neutral to Low	Neutral to Moderate	Neutral to Moderate
M2	Neutral to Low	Neutral to Moderate	Neutral to Low
M3	Neutral to Low	Neutral to Moderate	Low to Moderate
M4	Neutral to Low	Neutral to Low	Neutral to Low

5 Climate change impact storyline

Figure 1 outlines the impact storyline identified for telecommunication infrastructure. This storyline was assessed against climate conditions considered in the seven climate scenarios U1, U2, U3, M1, M2, M3 and M4 to develop the matrix of impacts for each state and territory. The impacts are a combination of telecommunication capital expenditure and operational expenditure impacts over the given time period.

Table 2 outlines the magnitude of impacts on telecommunications infrastructure the seven climate scenarios for each state. Table 3 outlines the scale used to assess the magnitude of impacts.

Table 2 Magnitude of impacts on telecommunications infrastructure for seven climate scenarios

Timeframe 2008 - 2030							
Climate Scenario	U1	U2	U3	M1	M2	M3	M4
VIC	N	N	N	N	N	N	N
NSW	N	N	N	N	N	N	N
WA	L	L	N	L	L	N	L
NT	N	N	L	N	N	L	N
SA	N	N	N	N	N	N	N
QLD	N	N	L	N	N	L	N
ACT	N	N	N	N	N	N	N
Tas	N	N	L	N	N	L	N

Timeframe 2031 - 2070							
Climate Scenario	U1	U2	U3	M1	M2	M3	M4
VIC	L	L	L	L	N	N	N
NSW	L	L	L	L	N	L	N
WA	M	M	L	M	M	N	L
NT	L	N	H	N	N	M	N
SA	L	L	L	L	L	N	N
QLD	L	L	M	L	L	L	N
ACT	L	L	L	L	N	L	N
Tas	L	N	M	N	N	L	N

Timeframe 2071 - 2100							
Climate Scenario	U1	U2	U3	M1	M2	M3	M4
VIC	M	L	L	L	N	L	N
NSW	M	L	M	L	N	L	N
WA	H	M	L	M	L	L	L
NT	M	N	E	N	N	M	N
SA	M	M	L	L	N	L	N
QLD	M	L	H	L	L	M	N
ACT	M	L	M	L	N	L	N
Tas	L	N	H	N	N	M	N

Table 3 Scale of impacts

	Magnitude of net impact	Description of impact
N	Neutral	No change in, capital expenditure, operational expenditure.
L	Low	Minor increase in capital expenditure and operational costs but no significant change to cost structure of industry. For example, minor increase in operational costs associated with repairing/restoring telecommunication network.
M	Moderate	Moderate increase in capital and operational expenditure with a minor change to cost structure of industry. For example, moderate increase in capital and operational expenditure for telecommunication infrastructure due to increased design standards, maintenance regimes and damage from extreme events.
H	High	Major increase in capital and operational expenditure with a significant change to cost structure of industry. For example, major increase in capital expenditure for replacement or repositioning of infrastructure.
E	Extreme	Extreme increase and major change to cost structure of industry with an extreme increase in operational and maintenance expenditure, potentially unsustainable. For example, extreme increase in capital expenditure from significant investment in new or replacement of existing telecommunications infrastructure.

5.1 Business as usual scenarios

The business as usual climate change scenarios provided by the CSIRO on behalf of the Garnaut Climate Change Review Secretariat and considered in the telecommunications storyline are discussed in turn below.

U1: *Hot, dry reference scenario—A1FI emissions path, 3°C climate sensitivity, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches 4.5°C in 2100.*

This ‘hot and dry’ scenario adopts a ‘business-as-usual’ approach to greenhouse gas emissions and therefore assumes the highest level of temperature increase, along with the greatest decline in rainfall and relative humidity. With this level of emissions mainland Australia experiences a 1 degree temperature increase by 2030 and generally exceeds 5 degrees by 2100. Varying in different regions, rainfall mostly decreases across the country, particularly in the southern areas.

The A1FI emissions scenario, upon which U1 is based, describes a ‘future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income’ (IPCC SPM 2007). A1FI has a fossil fuel-intensive technological emphasis. It is with this guide that these ‘business-as-usual’ developments are based. This scenario is expected to result in neutral to low economic impacts by 2030, low to moderate impacts by 2070 and low to high impacts by 2100.

The climatic characteristics associated with U1 do not have such a significant impact as those experienced under U3. Although U1 results in hotter days with lower humidity, this does not impact telecommunications infrastructure as severely as an increase in extreme rainfall events. The most significant consequence of an increased number of hot days will be an additional requirement for air conditioning in telephone exchanges and base stations to avoid equipment overheating. This will result in greater energy demand and be manifested in the form of higher capital and operating expenditure.

Western Australia experiences the most pronounced reduction in rainfall under U1 (in excess of 70% by 2100), and all states except Tasmania are subject to reductions of more than 30% by 2100. The effects of reduced rainfall are compounded by temperature increases of approximately 5°C in all states except Tasmania which is limited to a 4°C temperature increase.

During extended dry periods, degradation of the structural integrity of tower structures and foundations may be amplified by increased ground movement or reductions in ground water. This may affect the chemical structure of foundations, causing more rapid fatigue of structures from extreme weather events (CSIRO 2007). This would compromise the stability of tower structures and foundations, affecting mobile voice and broadcasting which rely on telecommunications towers. Conduits and cables would also be vulnerable to damage from drying of the soil and ground movement. An increase in solar radiation may contribute to more rapid obsolescence of aerial cables, such as broadband over power line (BPL).

Service interruptions due to asset damages caused during extreme weather events are more likely under an U1 scenario. The damage from extreme events will increase maintenance costs and depreciation rates. This rise in asset renewal rates will also affect capital expenditure budgets and renewal cycles. While wind load thresholds of climate-exposed telecommunications assets are generally high, flying debris is the most damaging factor during high winds. Between 2071 and 2100 infrastructure in Queensland, Northern Territory and Northern Western Australia will be particularly at risk as exposed infrastructure (such as telecommunications towers or BPL) may be pushed beyond its design limits. However, it is expected that telecommunications infrastructure will have evolved considerably by the latter half of the century, with more of a focus on wireless technologies and less reliance on the existing copper wire network. As such, economic impacts are not significantly affected by wind related events.

The more rapid obsolescence of telecommunications assets and increased maintenance costs associated with U1 may be passed on to consumers in the form of higher costs for services reliant on telecommunications technology (e.g. telephone, radio, television and internet services). These demand-side impacts have not been considered in the matrix of impacts but provide an important context for economic modelling.

In addition to wind damage, service interruptions inflicted by other climatic events such as lightning strikes or bushfires are also of increasing concern in a U1 scenario. Lightning strikes have potential to cause significant disturbance to telecommunications infrastructure (see Case Study 1), particularly mobile voice and broadcast services. Bushfire also presents risks for exposed infrastructure in more rural areas, and a recent study forecasts unprecedented extreme fire danger conditions in future years, particularly under a U1-like scenario (Bushfire CRC 2007). Not only is the intensity and frequency of bushfires projected to increase in areas which already experience significant bushfire damage (N.B. south east Australia), but those areas exposed to fire danger could potentially expand.

For U1, sea level rise is expected to be approximately 17cm by 2030, 50cm by 2070 (CSIRO 2007, Hennessy et al, 2006) and 70cm by 2100 (Weller 2005). Towards the end of the century, coastal telecommunications assets could be affected by inundation and likely to require relocation in line with settlement retreat or increased coastal protection investment. Flooding of exchange and roadside manholes and underground pits would cause major disruptions to the provisions of broadband, mobile and fixed voice services, and lead to moderate economic impacts for all state and territory capital cities (except for the ACT) which are situated in proximity to the coast.

Increases in sea level and extreme rainfall events are expected to significantly affect storm surge height causing the projected inundation area of current 1 in 100 year events to potentially double, in low lying areas (McInnes et al 2003). This could have major ramifications for fixed voice, mobile and data services, which often relies on analogue or digital transmission via subterranean cables. Furthermore, this infrastructure tends to be most concentrated in urbanised areas, many of which lie in close proximity to the coast. This inundation of coastal zones not previously at risk is likely to cause increased damage to telecommunications infrastructure.

U2: Best estimate (median) business as usual scenario using A1FI emissions path, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~4.5°C in 2100.

This scenario is most closely related to U1 due to the modelled reduction in rainfall. However, the drying and humidity is less extreme than U1 as is the temperature increase. The temperature increase and evaporation is the same as U3.

Compared to the projected impacts under the U1 scenario, the impacts projected under the U2 storyline are similar up to 2030. During the remainder of the century the spread of the impacts is anticipated to be similar to U1 although the magnitude or severity is anticipated to be less than U1. This scenario is expected to result in neutral to low economic impacts by 2030 and low to moderate for 2070 and 2100.

Under the U2 scenario mainland Australia experiences a gradual increase in temperature. Between 2030 and 2070 all capital cities exceed a 2°C increase in temperature. Rainfall decreases in most of the country, with the exception being Greater Hobart and Darwin. The greatest reductions in rainfall are anticipated to be in Perth and Adelaide.

Significant increases in dry periods and consequent degradation of tower structures and foundations amplified by increased ground movement are likely to be restricted to Western Australia and South Australia. As in U1, this will affect the chemical structure of foundations, causing more rapid fatigue of structures from extreme weather events (CSIRO 2007). This would compromise the stability of tower structures and foundations, affecting mobile voice and broadcasting which rely on telecommunications towers. Conduits and cables would also be vulnerable to damage from drying of the soil and ground movement. There is some risk under this scenario of solar radiation contributing to more rapid obsolescence of aerial cables, such as broadband over power line (BPL).

The more rapid obsolescence of telecommunications assets associated with U2 may be passed on to consumers in the form of higher costs for services reliant on telecommunications technology (e.g. telephone, radio, television and internet services) but will be less severe than U1. These demand-side impacts have not been considered in the matrix of impacts but provide an important context for economic modelling.

Similar to U1, service interruptions as a result of extreme events such as storms, floods or bushfires are also more likely in U2. While wind load thresholds of climate-exposed telecommunications assets are generally high, flying debris is the most damaging factor during high winds. The damage from extreme events will increase maintenance costs and depreciation rates. This rise in asset renewal rates will also affect capital expenditure budgets and renewal cycles. The impact of extreme events is anticipated to be the greatest in Western Australia, Northern Territory and Queensland, particularly in the latter half of the century. However, it is expected that telecommunications infrastructure will have evolved considerably by the latter half of the century, with more of a focus on wireless technologies and less reliance on the existing copper wire network. As such, economic impacts are not significantly affected by wind related events.

Sea level rise is expected to be gradual up to 2100. Coastal telecommunications assets could be affected by inundation and likely to require relocation in line with settlement retreat or require increased coastal protection investment.

U3: Warm, wet reference scenario—A1FI emissions path, 3°C climate sensitivity, 90th percentile rainfall and relative humidity surface for Australia (wet extreme), 50th percentile temperature surface. Mean global warming reaches 4.5°C in 2100.

This scenario adopts a 'business as usual' approach to greenhouse gas emissions and assumes the most likely level of temperature increase, along with the greatest increase in rainfall and relative humidity.

This scenario results in the most significant impacts on telecommunications infrastructure out of the seven scenarios discussed in this paper, predominantly due to increased levels of rainfall and

catchment flooding. However, all states do not experience these impacts. Rainfall is projected to increase at the greatest rate in the Northern Territory, Tasmania and New South Wales, with rainfall in Darwin modelled to increase by over 30% towards the end of the century. Conversely, Victoria, South Australia and Western Australia are likely to experience little or no increase in annual rainfall. This scenario is expected to result in neutral to low economic impacts by 2030, low to high impacts by 2070 and low to extreme impacts by 2100.

This increased rainfall in some states will cause flooding of exchange and roadside manholes and underground pits. The rate of soil erosion is also likely to intensify, exposing major cables and trunk routes. These climatic events will damage telecommunications infrastructure, causing interruptions to broadband, fixed voice, mobile voice and data services. A number of adverse affects are likely to occur as a result of these impacts, including: a potentially significant increase in repair and replacement costs of telecommunications infrastructure; relocation of telecommunications infrastructure; and disruption of telecommunications services. Owners of infrastructure will have to cope with higher operating and capital expenditure (e.g. increased bunding requirements, purchase of additional pumping equipment etc) in order to maintain acceptable levels of service reliability.

Under the U3 scenario it is anticipated that extreme storm events will become more frequent and severe. Exposed infrastructure such as telecommunication towers or BPL is generally designed to withstand substantial wind loads, but remain vulnerable to damage from flying debris in extreme weather events. The potentially increased wind speeds and storm intensity of U3 will increase storm related damages and service interruptions, perhaps more significantly than U1, in the northern and eastern regions of Australia. As Melbourne, Adelaide and Perth are unlikely to have an increase in rainfall; these areas are likely to be more aligned to conditions and implications of the U1 scenario, although to a lesser extent.

The storm related damage and flooding associated with U3 has the potential to disable telecommunications services for significant periods of time. This leads to a loss of revenue for companies reliant on telecommunications technology (e.g. telephone, radio, television, internet services), and consequently reduced productivity for most businesses. A range of public services including transport and emergency services would be severely disrupted should their ability to communicate become impaired. This would inconvenience large numbers of people, and perhaps more worryingly, hamper any emergency service responses during periods of telecommunications breakdown. These demand-side impacts have not been considered in the matrix of impacts but provide an important context for economic modelling.

As with U1, sea level rise is expected to be approximately 17cm by 2030, 50cm by 2070 (CSIRO 2007, Hennessy et al, 2006) and 70cm by 2100 (Weller 2005). The consequences for telecommunications infrastructure would be significant if coastal assets become affected by inundation, and similar to those listed for U1.

Increases in sea level and extreme rainfall events are expected to significantly affect storm surge height causing the projected inundation area of current 1 in 100 year events to potentially double, in low lying areas (McInnes et al 2003). This could have major ramifications for fixed voice, mobile and data services, which often relies on analogue or digital transmission via subterranean cables. Furthermore, this infrastructure tends to be most concentrated in urbanised areas, many of which lie in close proximity to the coast. This inundation of coastal zones not previously at risk is likely to cause increased damage to telecommunications infrastructure.

5.2 Strong mitigation scenarios

The four climate change scenarios with mitigation provided by CSIRO, on behalf of the Garnaut Climate Change Review Secretariat and considered in the telecommunications storyline are discussed in turn below.

M1: Dry mitigation scenario where stabilisation of 550ppm CO₂ equivalent (CO₂ stabilised at 500ppm) is reached by 2100, 10th percentile rainfall and relative humidity surface for Australia (dry extreme), 90th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.

This scenario adopts a policy intervention that leads to a greenhouse gas emissions trajectory that stabilises atmospheric greenhouse gas concentrations at a level that constrains the temperature increase to 2.0°C in 2100; as compared to 4.5°C in 2100 under the reference scenario U1.

Under this scenario, the changes in rainfall (decline), humidity (decline), temperature (increase) and evaporation (increase) are similar to U1 until around 2030. From the middle of the century the M1 temperature and rainfall changes begin to level out. The temperature and rainfall changes modelled in U1 significantly outpace the M1 scenario after this time period. The M1 temperature increases at 2100 are reached in the middle of the century under the U1 scenario. The temperature and rainfall changes for M1 are approximately 55% of the U1 changes at 2070 and 40% of U1 at 2100. This scenario is expected to result in neutral to low economic impacts by 2030, neutral to moderate impacts by 2070 and low to moderate impacts between 2071 and 2100.

The reduced rate and level of temperature increase relative to the U1 scenario has the impact of lessening the impact of increased extreme rainfall and flash flooding with less additional temperature driven storm energy in the climate system relative to U1. This would see similar impacts due to storms, bushfires and heatwaves during this period. However, there would be some difference in responses, as greater capital investment is likely in 2070 scenario U2 to minimise future operating expenditure. Western Australia experiences the greatest impacts as reductions in rainfall are greater here than in other regions.

A decrease in annual rainfall and increase in temperature and evaporation will lead to less ground movement and degradation in the foundations of telecommunication assets than under the reference scenario U1. Sea level rise is expected to be gradual up to 2100 in a similar trajectory as U1. The economic impacts are anticipated to soften in the latter half of the century as the rate of change in rainfall and temperature reduces and investment in asset protection and improved design standards better address the 'new' climate.

M2: Best estimate (median) mitigation scenario where stabilisation of 550ppm CO₂ equivalent (CO₂ stabilised at 500ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia, 50th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.

The modelled M2 climate changes are similar to the U2 climate changes. For the M2 scenario, the changes in rainfall (decline), humidity (decline), temperature (increase) and evaporation (increase) are anticipated to be greater than U2 at 2030. From the middle of the century the M2 temperature and rainfall changes begin to level out. However the temperature and rainfall changes modelled in U2 significantly outpace the M2 scenario after this time period. The M2 temperature increases at 2100 are reached in the middle of the century under the U2 scenario. The temperature and rainfall changes for M2 are approximately 55% of the U2 changes at 2070 and 40% of U2 at 2100. This scenario is expected to result in neutral to low economic impacts by 2030, neutral to moderate impacts by 2070 and neutral to low impacts between 2071 and 2100.

The impacts at 2030 are likely to be similar to that experienced under U2 with increased operating and maintenance costs for telecommunications operators. This is due to a combination of increased temperature and reduced rainfall causing more rapid deterioration of assets, worsened by more frequent and intense extreme events and bushfires. Western Australia experiences the greatest reduction in rainfall, followed by South Australia. These states suffer moderate and low impacts respectively between 2031 and 2070, but these impacts soften in the last quarter of the century. This is due to the changes in rainfall and temperature levelling off and investment in asset protection and improved design standards better addressing the 'new' climate conditions.

M3: Wet mitigation scenario where stabilisation of 550ppm CO₂ equivalent (CO₂ stabilised at 500ppm) is reached by 2100, 90th percentile rainfall and relative humidity surface for Australia (wet extreme), 50th percentile temperature surface. Mean global warming reaches ~2.0°C in 2100.

This scenario adopts a policy intervention that leads to a greenhouse gas emissions trajectory that stabilises atmospheric greenhouse gas concentrations at a level that constrains the temperature increase to 2.0°C in 2100; as compared to 4.5°C in 2100 under the reference scenario U3. The scenario assumes an increase in temperature, along with an increase in rainfall and relative humidity.

Under this scenario, the changes in rainfall (increase), humidity (increase), temperature (increase) and evaporation (increase) are anticipated to be greater than U3 at 2030. From the middle of the century the M3 temperature and rainfall changes begin to level out. However, the temperature and rainfall changes modelled in U3 significantly outpace the M3 scenario after this time period. The M3 temperature and rainfall increases at 2100 are reached in the middle of the century under the U3 scenario. The temperature and rainfall changes for M3 are approximately 55% of the U3 changes at 2070 and 40% of U3 at 2100. This scenario is expected to result in neutral to low economic impacts by 2030, neutral to moderate impacts by 2070 and neutral to moderate impacts between 2071 and 2100.

This scenario is likely to have the lead to the greatest impacts of the four mitigation scenarios. Neutral to low impacts are anticipated up to 2070 and low to moderate impacts are expected between 2071 and 2100.

The extreme rainfall events generating riverine flooding are likely to increase but to a lesser extent than U3, as the expected increase in temperature that drives extreme storm, wind and rainfall events is reduced. The more moderate temperature increase post 2050 is likely to reduce the likelihood of heatwaves and bushfires and the associated damages, service interruptions and mitigation costs.

South Australia, Victoria and Western Australia are expected to have lesser impacts than other regions in Australia as they experience a negligible increase in rainfall. Northern Territory, Queensland and Tasmania are anticipated to experience the greatest impacts between 2071 and 2100 as they are likely to experience the greatest increase in rainfall and extreme events.

Sea level rise is expected to be gradual up to 2100.

M4: Best estimate (median) strong mitigation scenario where stabilisation of 450ppm CO₂ equivalent (CO₂ stabilised at 420ppm) is reached by 2100, 50th percentile rainfall and relative humidity surface for Australia), 50th percentile temperature surface. Mean global warming reaches ~1.5°C in 2100.

This scenario is the 'best-case' of the group of scenarios assessed. The temperature and rainfall changes are modelled to stabilise around 2080 and begin to reverse toward 2100 therefore reducing the pressures generating increased storm related impacts. Of the scenarios that result in a decline in rainfall and relative humidity (scenarios U1, U2, M1, M2 and M4), this scenario would have the least impact on climate change induced storm, wind and bushfire impacts. This scenario is expected to result in neutral to low economic impacts by 2030, neutral to moderate impacts by 2070 and neutral to low impacts between 2071 and 2100.

Sea level rise is expected to be gradual up to 2100 with no step change in sea level expected.

This scenario would result in the lowest level of climate change impacts and hence would result in the lowest level of economic impact to telecommunications assets. Western Australia experiences higher levels of rainfall under this scenario hence the greater impact for this state. Impacts are likely to be similar across most states and territories over the century.

6 Opportunities for adaptation

Given the rapid rate of technological advances in the telecommunications sector, it is challenging to predict the impacts of climate change on future infrastructure, especially in the latter half of this century. Australia is currently experiencing a transition towards 'wireless' technologies (e.g. 3G mobile 'phones), which will reduce dependence on telecommunications infrastructure to some extent. However, this does not negate the need for infrastructure altogether, as there is still a requirement for equipment such as mobile or fixed wireless towers to operate this technology and integrated transmission with fixed line networks.

Large investments in telecommunications infrastructure have been made for a number of years (e.g. the copper wire network, and the more recent optic fibre and broadband rollouts), representing significant sunk costs. Any upgrades to these telecommunications networks, whether made in response to climate change or for other reasons, will need to occur gradually in order to replace current capital investment. However, future advances in technology may have the potential to greatly reduce reliance on current telecommunications infrastructure. Opportunities in these areas would need to be explored. Ongoing renewal and replacement programs could provide some potential for mitigating impact exposure by prudent consideration in renewal design and placement.

Federal and State governments play a pivotal role in incentivising telecommunications companies to invest in particular types of technology or infrastructure. For instance, the Australian government implemented HiBIS (Higher Bandwidth Incentive Scheme), a \$157.8 million scheme providing internet service providers with financial rewards to supply higher bandwidth services in regional, rural and remote areas at prices comparable to those available in metropolitan areas. These kinds of programs could be used to stimulate investment in technologies which minimise exposure of telecommunications assets to variations in climate.

7 Conclusion

A wide cross-section of businesses and public services are reliant on telecommunications services, meaning that any service interruptions are likely to have cascading economic impacts. Moreover, telecommunications systems are dependent on a number of inputs (notably a reliable power supply) and any restrictions to these due to climatic events will compromise service reliability. Vice versa, electricity generation and distribution rely on modern communication and data storage. Each of these issues is typically dealt with separately by individual institutions and analysed by specialists with different expertise. There are currently few incentives for infrastructure managers and planners to improve communication (let alone coordination) across institutional boundaries (Ruth and Kirshen 2002).

Given society's current reliance on telecommunications services, and the lengthy renewal cycles associated with much of the associated infrastructure, it may be prudent to consider potential impacts of climate change as new technologies and infrastructure are developed and rolled out. Opportunities for adjusting infrastructure design and location could also be considered at the time of renewal and replacement.

At the macroeconomic scale, a correlation between economic growth and the quality of telecommunications infrastructure has been proposed (Riaz 1997). Government incentives and communication of climate change risk to telecommunication infrastructure owners can play an important role in insulating the economy against future impacts due to result of climate change.

8 Key assumptions

- The regulations of the Australian wholesale electricity market were considered to likely remain largely consistent with the current framework and planning horizons in developing this storyline.
- A transition to digital television will occur in Australia.
- A transition to 3G mobile phones will occur in Australia.
- Technological advancements in the telecommunications sector are likely to converge towards 'wireless' technologies, which will reduce dependence on current infrastructure to some extent. However, this does not negate the need for infrastructure altogether, as there is still a requirement for equipment such as mobile or fixed wireless towers to operate this technology.
- As extreme events increase in frequency and severity it is anticipated stronger materials and techniques will eventually be utilised to increase infrastructure resilience. This will reduce vulnerability to future events presuming the increased standards can respond to the further increasing climatic pressures.
- Assets aboveground and near the coast will likely require increasing maintenance due to increased corrosion rates.
- Damage costs, due to increased extreme events, may reach a threshold that warrants increased expenditure to achieve higher resilience standards and reduce vulnerability and remediation costs. This would reduce vulnerability to subsequent events.
- Frequency of storms, wind intensity, lightning, rainfall, storm surges and increased temperature variations can all contribute to increased failure of telecommunications infrastructure.
- As extreme events increase in frequency and severity it is anticipated stronger materials and techniques will eventually be utilised to increase infrastructure resilience. This will reduce vulnerability to future events presuming the increased standards can respond to the further increasing climatic pressures.
- Renewal and replacement works will consider prone areas that are factored into design and placement.

9 Future research

As new technologies become available, there are opportunities to reduce exposure of new infrastructure to climate impacts. Prior to telecommunications networks being upgraded, there will be opportunities to assess the vulnerabilities of competing technologies to climate change risks, and ensure decisions regarding network upgrades are properly informed by this information. Further research on possible future innovations in the telecommunications sector and their associated vulnerabilities to climate change are necessary.

Flooding poses the greatest risk to telecommunications structure, especially in cities where copper and optical cables are commonly located in subterranean tunnels. Extreme rainfall events and sea level rise are both forecasted to occur under the U1 and U3 scenarios in the latter half of the century, and further research on the impacts of this on telecommunications (and other) infrastructure may be prudent in future years.

10 Case studies

Case study 1: Excerpt from Telstra's Carbon Disclosure Project 5 (CDP) report

CDP5 question

'What commercial risks does climate change present to your company including physical risks to your business operations from scenarios identified by the Intergovernmental Panel on climate Change or other expert bodies, such as sea level rise, extreme weather events and resource shortages?'

Telstra response

'Telstra has identified a number of potential physical risks to the company as a result of climate change. Changes to climate may affect Telstra as an owner of infrastructure throughout all areas of Australia in city and urban areas, rural and remote, desert, tropical and alpine. Infrastructure includes facilities such as exchanges and other network sites, offices and depots as well as an underground cable network, all of which is subject to damage or flooding during extreme weather events or to changes in climate. For example:

- increased temperature will see an increase in requirements for cooling in summer
- increased flood and storm frequency and severity may give rise to higher costs due to potential for damage to infrastructure requiring additional repair or replacement
- increased incidence of bushfires poses increased risk to Telstra infrastructure particularly that located in rural or remote locations
- increased severity and frequency of droughts may shift customers from rural areas making infrastructure less utilised, and may limit water availability to Telstra facilities. The extreme drying out of soils may lead to damage to conduits and cables.' (Telstra, 2007)

Case study 2: Impacts of lightning

An excerpt from *Natural Hazards in Australia. Identifying Risk Analysis Requirements* (Middleman 2007, p12) discusses the impacts of lightning on telecommunications infrastructure:

'Significant damage to electrical appliances and communications equipment from lightning strikes is also common. For example, the West Australian of 25 January 1999 states that lightning strikes during an electrical storm in January 1999 resulted in more than 10,000 Perth residents reporting phone damage, with some having to wait up to 10 days to be reconnected. The cost to a major telecommunications company was estimated to exceed \$1 million.'

Case study 3: Climate change risks for British Telecom

Sir Christopher Bland expresses his concerns about climate change during his time serving as Chairman of British Telecom (27 September 2005):

'We have an enormous UK investment in telecommunications infrastructure, which is increasingly at risk.

Gales last winter followed Scotland's wettest summer on record. For BT this meant we experienced numerous cable faults, overhead cables down and a whole car park full of vehicles ruined by floods.

BT scientists have done some computer modelling to predict expected fault rates from high rainfall levels. We are thinking carefully about where we place the new nodes for our 21st Century network. And we are working on more resilient, water tight cable joints.'

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