

26 March 2025

Australian Energy Market Commission
Level 15
60 Castlereagh Street
Sydney NSW 2000

Submission on including distribution network resilience in the National Electricity Rules

I welcome this opportunity to provide Infrastructure Victoria's submission on including distribution network resilience in the National Electricity Rules (NER).

Infrastructure Victoria is an independent advisory body established by the *Infrastructure Victoria Act 2015*, and has the functions of:

- preparing a 30-year infrastructure strategy for Victoria
- advising the Victorian Government on specific infrastructure matters
- publishing research on infrastructure-related issues.

In this submission we respond to 2 priority areas of the proposed draft rule seeking to establish a formal framework for distribution resilience in the NER.

In April 2024, Infrastructure Victoria published a report on adapting Victoria's infrastructure to climate change, *Weathering the Storm*. We have also recently released *Victoria's draft 30-year infrastructure strategy 2025-2055*. These reports and supporting technical reports are published on our website at www.infrastructurevictoria.com.au. Copies of these reports are attached for consideration.

Priority area: Formal Network Resilience Guidelines that the AER must develop, publish and maintain in accordance with a set of requirements

The draft rule considers formal resilience guidelines. Our climate change adaptation research report, *Weathering the storm* can help to better assess and prepare infrastructure for the impacts of climate change. It shows how to identify the risks from extreme weather, decide how and where to invest in adapting infrastructure, and assess different solutions to better protect infrastructure assets.

We geospatially mapped regions in Victoria that are more exposed to climate hazards, such as the impacts of high wind events on electricity distribution networks. We then conducted an economic analysis to compare the benefits of different adaptation solutions such as aerial bundled cables, undergrounding distribution cables, tree replacement and grid-forming inverters.

Our work provides a repeatable methodology and toolkit which can be used to help build the case for investment in adapting infrastructure to more frequent and severe weather, keep communities safer, minimise disruptions and reduce disaster recovery costs.

Priority area: New distribution annual planning and reporting requirements for resilience

Most infrastructure was not built for more frequent and severe weather, and we can't do everything, everywhere all at once. *Weathering the storm* contains 7 recommendations that can help assess and prepare infrastructure to climate-related risks. These are to:

- Boost priority and oversight for infrastructure adaptation.
- Coordinate and standardise climate projections.
- Use asset management systems to improve resilience.
- Integrate climate risk into government risk management.
- Align climate and financial risks to infrastructure.

- Update business case and investment guidance.
- Build confidence that good adaptation measures will receive funding.

Climate risks to infrastructure can be better managed by strengthening policy structures and requirements. This includes embedding climate risk management into the usual business of government, using more standardised climate projections data and conducting local area analysis to identify the best fitting adaptive options. We also recommend the costs of climate change be fully accounted for and factored into operational costs and business cases.

Victoria's draft infrastructure strategy 2025-2055

In our draft 30-year strategy 2025-2055, we recognise that governments need to plan, build and maintain infrastructure to be resilient to climate change and other risks. We provide draft recommendations to improve Victoria's resilience to climate change and to reduce disruptions such as widespread prolonged power outages in Victoria. These recommendations include:

- **Recommendation 27: Better prepare infrastructure for climate change**
Fund high-priority, cost-effective infrastructure adaptation actions when climate adaptation action plans are updated in 2026. Produce an energy sector adaptation plan.

Infrastructure Victoria is committed to sharing its knowledge of the risks and impacts severe weather events to help improve the resilience of infrastructure.

Thank you again for the opportunity to respond to the draft rule and determination. If you would like to discuss any of the information in Infrastructure Victoria's submission, please contact me or Llewellyn Reynders, Director of Research and Policy at llewellyn.reynders@infrastructurevictoria.com.au.

Yours sincerely,



Dr Jonathan Spear
Chief Executive Officer

Encl.



INFRASTRUCTURE
VICTORIA

April 2024

Weathering the storm

Adapting Victoria's infrastructure to climate change

About us

Infrastructure Victoria is an independent advisory body with 3 functions:

- preparing a 30-year infrastructure strategy for Victoria, which we review and update every 3 to 5 years
- advising the government on specific infrastructure matters
- publishing research on infrastructure-related issues.

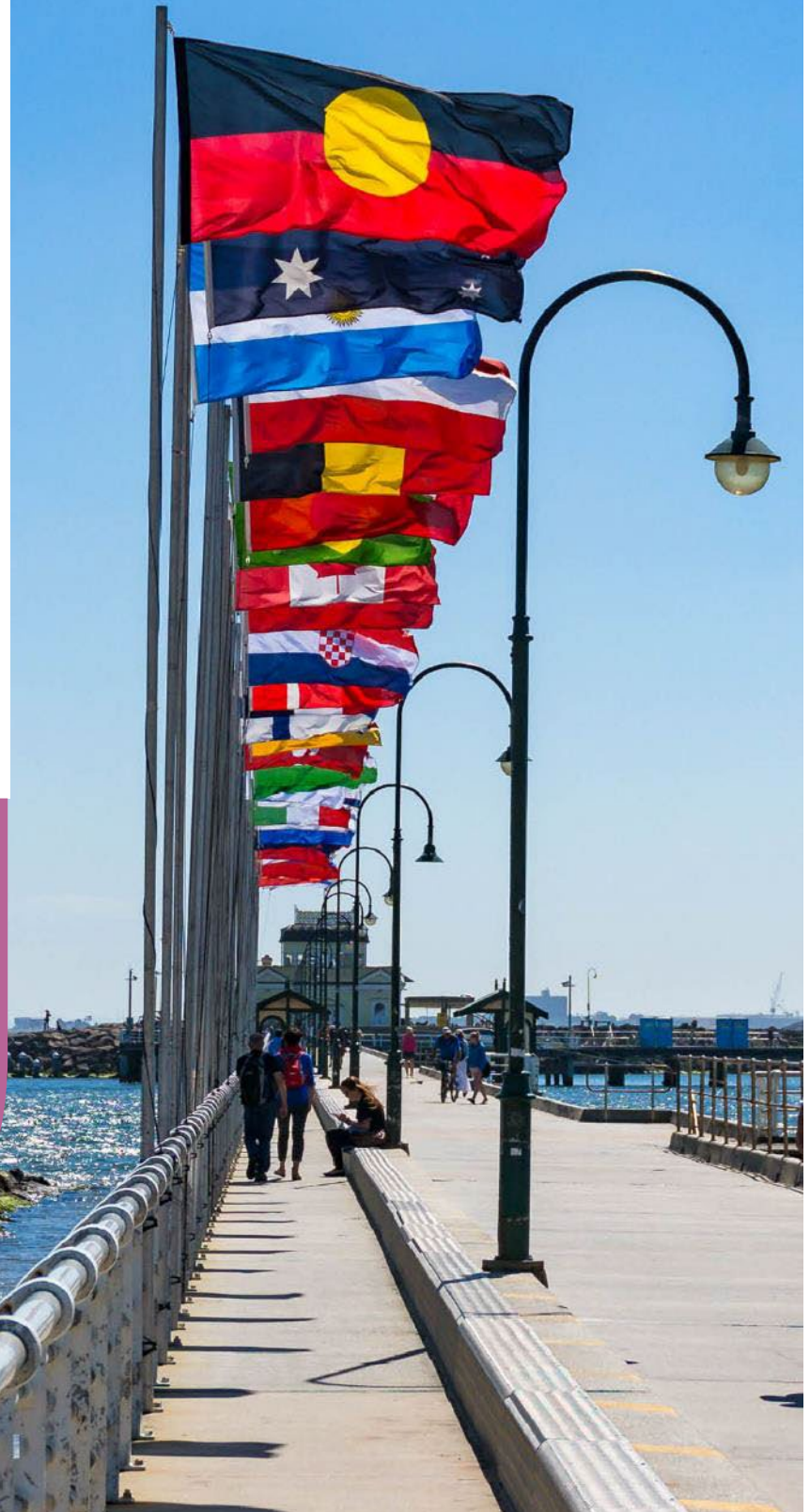
Infrastructure Victoria also helps government departments and agencies develop sectoral infrastructure plans.

Infrastructure Victoria aims to take a long-term, evidence-based view of infrastructure planning, and we inform community discussion about infrastructure provision.

Infrastructure Victoria does not directly oversee or fund infrastructure projects.

Acknowledgement

Infrastructure Victoria acknowledges the Traditional Owners of Country in Victoria and pays respect to their Elders past and present, as well as Elders of other First Peoples' communities. We recognise that Victoria's infrastructure is built on land that has been managed by Aboriginal people for millennia.





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Summary

Adapting Victoria's infrastructure to climate change can keep communities safe and functioning, while also saving governments and businesses money.

The world's climate is changing. This means Victoria will have more severe weather and intense rainfall events, more hot days and bushfires, and higher sea levels. Most of Victoria's infrastructure, such as roads, electricity networks and buildings, was not built to perform in this new climate.

Victoria's infrastructure strategy 2021–2051 recommended the Victorian Government conduct a strategic review of the climate change consequences for infrastructure. In 2022, the Victorian Government published 7 system-based adaptation action plans to help Victoria adapt to climate change.

This report extends that work. It makes recommendations that will allow the Victorian Government to select wise and prudent investments that reduce the risks climate change poses to infrastructure. These investments can help keep people, communities and businesses functioning, and reduce the cost and harm of damaged or destroyed infrastructure.

Governments have traditionally waited until infrastructure fails, and then spent large amounts of money trying to fix it, instead of investing upfront.¹ The Productivity Commission estimates that just 3% of Australian Government spending on disasters is invested in proactive efforts to limit the impact of future events.²

Climate events can affect many infrastructure sectors at once, which adds to their cost and harm. Between 2007–2016, recovering from extreme weather events cost Victoria an average of \$2.7 billion a year.³ Climate damage might cost Victoria nearly \$1 trillion by 2100 if it does not act to reduce emissions and adapt its infrastructure.⁴ The benefits of investing in resilient infrastructure can outweigh the costs of repairing and rebuilding it after extreme weather events.⁵

Victorians are already paying the costs of a changing climate. If governments do nothing, Victoria's infrastructure will fail more often, causing harm and cost to people and businesses. Underinvesting in infrastructure resilience leads to higher economic, social and environmental costs over time.⁶

Governments have many options to make infrastructure more resilient to climate change now. Some options cost very little. Governments can build infrastructure in safer, less hazardous locations. They can build infrastructure using materials or designs that minimise the impacts of climate risks. They can change the way they manage infrastructure. For example, they can change the type and frequency of their maintenance activities or retrofit infrastructure to reduce the risk of damage. And they can reduce the severity of climate risks, such as managing vegetation to mitigate flood risks or the chance of trees falling on power lines. This causes less damage, and communities and businesses experience less harm, fewer costs, and can return to normal faster after a serious event.

What does infrastructure adaptation mean?

Adaptation in infrastructure can involve building, maintaining or renewing physical infrastructure to better prevent, prepare, respond and recover from actual or expected impacts of climate change.

Examples assessed in this report include:

- better flood preparation through water sensitive urban design
- improving the ability of roads to withstand flooding with techniques such as foamed bitumen stabilisation
- using insulated cables to reduce the impacts of high winds for electricity distribution networks.

The Victorian Government already has some policies and guidance about climate change adaptation. But many departments still do not always consider climate risks and take action to adapt their infrastructure. Infrastructure managers told us they do not yet have the obligation, tools or confidence to propose adaptation actions. This report sets out ways they can embed adaptation in their normal activities.

The government can support its asset managers to consider climate change risks during the infrastructure life cycle as part of normal business. This helps them prioritise, coordinate and sequence adaptation activities to produce more value over time as climate change generates more frequent and intense impacts.

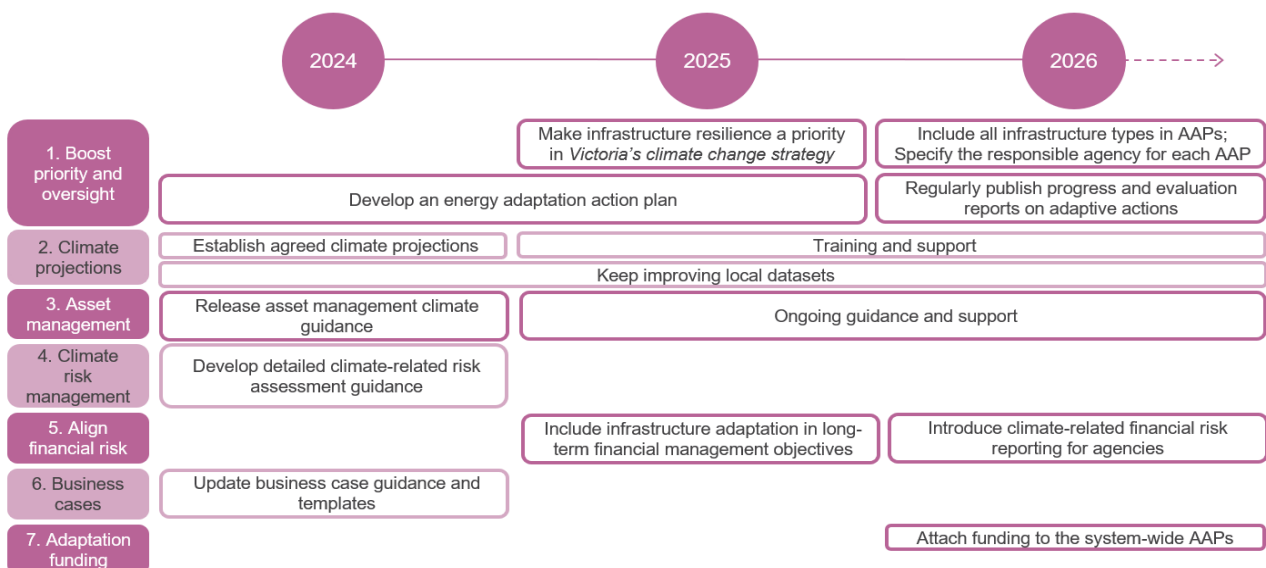
The government might have to invest in adapting high-risk infrastructure to climate change. Infrastructure owners might need to modify or enhance it to withstand more frequent and severe weather events and return to service quickly. This is not a one-size-fits-all proposition. Infrastructure’s vulnerability to climate change will be different depending on its type and location. So will the best adaptation options.

Infrastructure managers can select the best adaptation measures by completing site-specific analysis for high-risk locations and infrastructure and determining the most cost-effective response. Infrastructure agencies can audit their infrastructure, prioritise assets at high risk, and identify and prioritise measures to mitigate these risks. During this research, we conducted 3 cost-benefit analyses of specific adaptation measures and demonstrated that some options generate a positive return on investment. Some adaptation proposals can also have unintended consequences. Site-specific analysis can identify these problems.

The Victorian Government can change its systems and requirements for its infrastructure agencies, so they adapt their assets to climate change, and thereby help better protect Victorian communities and businesses, and keep costs down. They can develop contemporary policy settings that give clear direction, and supply asset managers with easy-to-use climate data. They can give infrastructure agencies a suite of tools for professional adaptation analysis that embed adaptation in normal practices, including in asset management, risk management, and financial analysis and disclosure. And they can provide guidance on conducting quality business cases to secure appropriate funding for prudent adaptation initiatives.

Our 7 recommendations provide a pathway to better assess and prepare Victoria’s infrastructure for the impacts of a warming climate.

Figure 1: Timeline for recommended Victorian Government action on adaptation



Note: AAPs = Adaptation action plans

Recommendations

1. Boost priority and oversight for infrastructure adaptation

- Make public infrastructure resilience a priority in *Victoria's climate change strategy*.
- Develop an adaptation action plan for Victoria's energy system.
- Include all infrastructure types in future adaptation action plans.
- Specify the responsible agency for each adaptation action.
- Regularly publish a progress and evaluation report on adaptation actions.

2. Coordinate and standardise climate projections

- Establish an agreed set of climate projections for use in government infrastructure planning and management, especially projections of extreme weather events.
- Keep improving local level data that infrastructure managers can use for site-specific analysis.
- Deliver training and ongoing support for infrastructure managers to apply the data to climate risk assessments.

3. Use asset management systems to improve resilience

- Release climate change guidance on assessing climate vulnerability and risk, designing for resilience, and adopting preventative maintenance.
- Support agencies to develop the processes, tools and expertise to embed climate considerations in asset management practice.

4. Integrate climate risk into government risk management

- Develop detailed guidance to accompany the Victorian Government *Risk management framework* on how to assess climate-related risks to infrastructure and integrate them into decision-making.

5. Align climate and financial risks to infrastructure

- Include climate adaptation in the government's long-term financial management objectives for infrastructure.
- Require departments and agencies with infrastructure holdings to prepare climate-related financial risk disclosures.

6. Update business case and investment guidance

- Update existing business case guidelines, technical guidelines and templates to include the risks and impacts of climate change.

7. Build confidence that good adaptation measures will receive funding

- Attach funding to the 2026 updates of the system-wide adaptation action plans, to encourage government agencies to evaluate and prioritise assets for adaptation and incorporate adaptation into business cases.

By the numbers



Victoria's climate is already 1.2°C warmer than when records began in 1910. Global average temperatures are expected to increase by 1.5°C by 2030.



Extreme weather events in Victoria between 2007–2016 averaged \$2.7 billion in damage a year. Costs associated with Victoria's 2009 Black Saturday bushfires were estimated at more than \$4 billion.



Without action, climate-related damage in Victoria could cumulatively cost at least \$115 billion by 2030, and more than \$986 billion by 2100.



Climate impacts are estimated to cost greater Melbourne local governments \$90–\$120 million annually. These costs are projected to increase to \$210–\$300 million annually by 2050 and \$400–\$540 million annually by 2100.



The Australian Government spends 97% of its natural disaster funding after an extreme weather event, while 3% goes towards proactive efforts to limit the impact of future events.



Canada's national adaptation strategy sets the expectation that 80% of public organisations will factor climate change adaptation into decision-making processes.



Early investment in adaptation action can reduce the costs of future damage. A study of 28 adaptation projects in over 16 countries found a wide range of positive returns on investment. The projects produce benefits that outweighed their cost by between 1.3 to 60 times. The median project saved \$6 saved for every \$1 spent.

Sources Intergovernmental Panel on Climate Change, '[Summary for policymakers](#)', in H Lee and J Romero (eds) *Climate change 2023: synthesis report*, Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change, 2023, accessed 7 August 2023; Department of Environment, Land, Water and Planning, '[Victoria's climate science report 2019](#)', State of Victoria, 2019, accessed 9 June 2023; Deloitte Access Economics, '[Building resilience to natural disasters in our states and territories](#)', Australian Business Roundtable for Disaster Resilience & Safer Communities, 2017, accessed 10 August 2023; Victorian Bushfires Royal Commission, '[Victorian bushfires royal commission final report – summary](#)', State of Victoria, 2010, accessed 9 June 2023; T Kompas, M Keegan and E Witte, '[Australia's clean energy future: costs and benefits](#)', Melbourne Sustainable Society Institute, University of Melbourne, 2019, accessed 9 June 2023; NCEconomics, '[Adaptive community assets](#)', Eastern Alliance for Greenhouse Action, 2023, accessed 27 September 2023; Productivity Commission, '[Natural disaster funding arrangements](#)', vol. 1, Commonwealth of Australia, 2014, accessed 21 August 2023; Environment and Climate Change Canada, '[Canada's national adaptation strategy: building resilient communities and a strong economy](#)', Government of Canada, 2023, accessed 14 September 2023; CM Shreve and I Kelman, 'Does mitigation save? Reviewing cost-benefit analysis of disaster risk reduction', *International Journal of Disaster Risk Reduction*, 2014, vol 10a:213-235, doi:10.1016/j.ijdr.2014.08.004; L Martinez-Diaz, 'Investing in resilience today to prepare for tomorrow's climate change', *Bulletin of the Atomic Scientists*, 2018, vol 74(2):67, doi:10.1080/00963402.2018.1436805.

Climate change threatens infrastructure

Infrastructure Victoria did this research to assess the benefits of adapting infrastructure to the changing climate. It examines Victoria's climate policy framework to determine how departments and agencies are assessing resilience and adapting their infrastructure. It follows our recommendation in *Victoria's infrastructure strategy 2021–2051* for the Victorian Government to strategically review the climate consequences for public infrastructure after delivering the adaptation action plans under the *Climate Change Act 2017*.⁷ The government published the plans in 2022.

In 2006, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), Maunsell Australia and Phillips Fox undertook an assessment of climate risks to Victorian infrastructure.⁸ They found that climate change amplifies the risks to Victoria's water, energy, telecommunications, transport and built environment infrastructure. Since then, we have much more information about climate change and its effects on infrastructure.

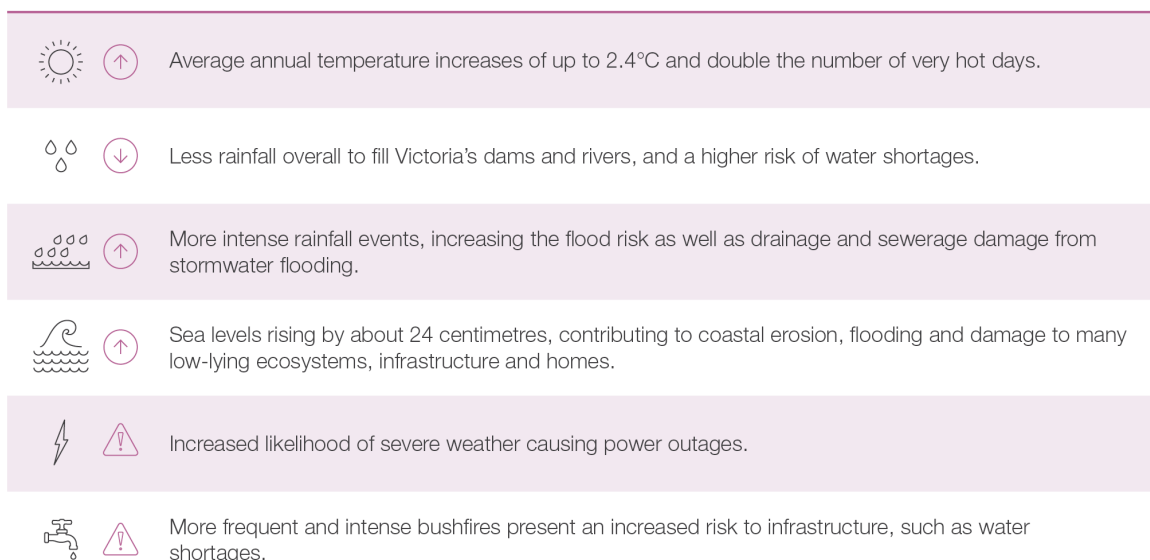
In this research, we used this new information to examine how climate change might affect Victoria's infrastructure. We took a longer-term and statewide view to consider new measures the Victorian Government can take to improve the climate resilience of infrastructure it owns or manages, including how to assess climate risks, determine the return on investment of adaptation measures and fund these measures consistently over time.

Climate change already presents unavoidable risks

Victoria's climate is 1.2°C warmer than when records began in 1910.⁹ This has produced a drier climate with more frequent and intense weather events, such as heatwaves, floods, and more dangerous fire seasons.¹⁰ The Intergovernmental Panel on Climate Change (IPCC) finds that current global efforts are not enough to prevent climate change.¹¹ They predict that climate change is set to increase global average temperatures by 1.5°C by 2030.¹² The extent of the temperature rise depends on ongoing global action to reduce greenhouse gas emissions. The IPCC says governments must make deep, rapid and sustained cuts to greenhouse gas emissions to keep global warming below 1.5°C to limit further damage to health, wellbeing and ecosystems.¹³ The risks to these systems increase as global average temperatures rise.

Climate change presents a real and accelerating danger to Victoria's infrastructure. For instance, more frequent bushfires can destroy critical buildings and facilities, electricity and telecommunication cables, mobile phone towers, and block roads and rail lines. Floods can damage buildings and equipment and wash away roads and bridges. Storms, winds and hail can knock down trees onto power lines and roads, tear off roofs and smash windows. Sea level rise threatens coastal infrastructure, which can be washed away during storm surges, flooded, or undermined by coastal erosion. These events will become more frequent and severe as climate change intensifies.

Figure 2: Predicted climate change impacts on Victoria by 2050s under a high emission scenario



Source: Department of Environment, Land, Water and Planning, [Victoria's climate change strategy](#), State of Victoria, 2021, accessed 7 August 2023; Infrastructure Victoria, [Victoria's infrastructure strategy 2021–2051](#), Infrastructure Victoria, 2021, accessed 8 August 2023; Department of Energy, Environment and Climate Change, ['Power outages'](#), DEECA website, 2023, accessed 8 August 2023.

Climate change will not affect every place evenly.¹⁴ Climate projections vary in different regions of the state. For example, by the 2050s Bendigo, Ballarat and Shepparton might have over 60% more high fire danger days. Melbourne may have around 40% more.¹⁵ But more frequent extreme weather events will have consequences for people all over Victoria. For example, more frequent and higher floods will damage roads which will disrupt movement around Victoria, compromising access to jobs, goods and services. More frequent and intense bushfires can damage electricity transmission and telecommunications, resulting in extended blackouts and loss of internet and mobile phone reception. Damage to critical buildings, like hospitals, can mean people cannot get emergency medical care. All these impacts will endanger lives and disrupt Victoria's economy.¹⁶

The Victorian Government is acting to reduce greenhouse gas emissions, which will help reduce the global total. But some climate change effects are now unavoidable and cannot be entirely prevented.¹⁷ For example, flooding events in Melbourne and regional Victoria are becoming more frequent, which accelerates the deterioration of roads. This means the Victorian Government will need to repair and rebuild roads more often.

The IPCC calls on governments to act rapidly this decade to adapt at a scale that can prevent the worst consequences for people and nature.¹⁸ The Victorian Government can reduce these unavoidable risks through climate adaptation in local projects and by re-designing its infrastructure systems.¹⁹

Storm causes power outages and blocks roads

In June 2021, heavy rain, lightning, and severe winds hit eastern and central Victoria, especially Gippsland and the Yarra Ranges. The storm caused major damage to the electricity distribution network, leaving thousands of homes without power.

Around 297,000 customers had no electricity at the same time.²⁰ Over 25,000 homes were still without power 5 days later, and suppliers advised 3,000 households that they would be without electricity for up to a month.²¹

Cascading events hampered efforts to reconnect homes to electricity after the storms. For example, fallen trees blocked roads, meaning workers had to wait for road to be cleared before they could reach the damaged power lines.²²

Later events compounded the storm's effects. Stormwater contaminated the water supply, leaving residents without safe drinking water.²³ The storm also degraded the region's electricity and telecommunications infrastructure. For example, residents of Kalorama, where the storm destroyed 44 houses, suffered 41% more power outages and 31% more internet outages in the year the followed.²⁴

Prolonged power outages badly disrupt and distress communities:²⁵

- 'At my house no power meant no light, lost food storage, no water, no septic (and untreated sewage leakage!!), no internet, mobile phone was also out, so no communication.'
- 'Our driveway... was blocked by approximately 30 trees. It took us 3 days to be able to cut our way out, so we had no means of communication and no way of getting fuel for our generator.'

After the storm, the Victorian Government commissioned an independent review into the resilience of the electricity distribution network. The review recommended that the Department of Energy, Environment and Climate Action conduct local geospatial analyses in the short term to identify risks and recommended that distribution businesses conduct cost-benefit analyses on investments to improve network resilience.²⁶

These short-term recommendations form the basis of the Victorian Government and distribution businesses 5-year *Network Resilience Plan* to roll out network resilience investments across the Victorian electricity network.²⁷



Infrastructure damage has costs and consequences

Victoria's infrastructure was not built for frequent and severe climate events.²⁸ This includes some of Victoria's critical infrastructure such as the road network, electricity distribution network and hospital facilities. Some infrastructure was built in locations now more exposed to bushfire, flooding, landslides and storm surges. At the time, engineers presumed events like high winds, extreme heat, or heavy hail were very rare. A different climate means that those assumptions might not be valid anymore.²⁹ Climate change will increase the risk of damage to infrastructure and affect its performance.

Damage from extreme weather events already causes large economic costs. These costs will get progressively higher as the climate changes. Extreme weather events in Victoria cost \$2.7 billion a year, on average, over the 10 years to 2016.³⁰ Victoria's 2009 Black Saturday bushfires cost more than \$4 billion.³¹ The 2022 floods cost the Victorian Government \$1.8 billion in immediate relief funding and another \$677 million for flood recovery.³² Other costs can include loss of life, worse health and wellbeing, less safety, and the loss of species and biodiversity.³³

Communities can have strong expectations that governments should be adequately preparing for climate events. They want governments to ensure that people can stay safe and healthy during and after these events, and that services and economic activity can quickly resume. For example, the Legislative Council Committee inquiry into the 2022 flood event in Victoria was inundated with over 800 submissions. Many people expressed deeply personal stories of loss, trauma and anger. They felt governments had failed to adequately prepare, protect and revitalise their communities.

If humans keep producing more greenhouse gas emissions and Victoria does not adapt to the effects of climate change, climate-related damage in Victoria could cumulatively cost at least \$115 billion by 2030, and more than \$986 billion by 2100.³⁴ These figures likely understate the total cost because they only include lower productivity, worse health impacts and losses from land and infrastructure. They do not include many other costs of floods, bushfires, pollution and biodiversity loss.³⁵

More extreme weather caused by climate change damages and disrupts infrastructure, costs money to repair, and has extensive consequences for the people and businesses relying on it. For example, extreme wind events can damage electricity distribution infrastructure and result in many thousands of customers experiencing power outages at the same time. Victorians experienced this in June 2021. Heavy rainfall and strong winds damaged power lines, and about 330,000 homes lost electricity, especially in the Dandenong Ranges. About 68,000 customers had no power for more than 72 hours.

People need infrastructure so they can stay safe, well and productive.³⁶ Infrastructure provides many services. It delivers energy, water and telecommunications to homes and businesses, and gives people transport access to work and other valuable destinations. Facilities provide access to essential services like education, healthcare, and other commercial, community and public services. Vulnerable people especially rely on these infrastructure services to stay healthy and safe.

Much Victorian government-owned or regulated infrastructure is already vulnerable to climate change events.³⁷ To keep communities functioning and businesses open, Victoria's infrastructure must be able to keep functioning in a warmer, drier climate and during more extreme weather.

Early investment in adaptation action can reduce the costs of future damage. One academic study of 28 adaptation projects in over 16 countries found a wide range of positive returns on investment. The projects produce benefits that outweighed their cost by between 1.3 to 60 times. The median project saved \$6 for every \$1 spent.³⁸

The case study on the next page shows Queensland road adaptation delivered a similar return. More resilient infrastructure can reduce climate-related damage, and consequently reduce recovery costs.³⁹ This includes the costs of disruption to the economy and reductions in labour productivity.⁴⁰ Investing now to adapt infrastructure will allow governments to minimise the costs of recovering from extreme events and reduce the harm to people and the environment. It will enable communities, services and supply chains to resume normal functioning faster.

Making Queensland roads more resilient delivers savings

Between 2010 and 2013, major cyclones and heavy rain hit Queensland, which caused \$6.5 billion dollars of damage to its roads. Over 8,000 kilometres of Queensland Government roads needed to be fully or partially rebuilt after flooding.

The government established the Transport Network Reconstruction Program to deliver long-term disaster repairs to the state-controlled road network resulting from floods and cyclones.

The program commissioned a study to measure the damage caused by extreme weather events to Queensland roads over their useful life. This helped identify the funding needed for more flood resilient roads.

The study used a life cycle costing model to demonstrate that investing in more resilient roads delivers benefits. This work documented the life cycle costs to roads, including the damage itself, its immediate recovery time and cost, its eventual reconstruction and the cost of repairs, community and industry delays, and associated costs.

The researchers selected 7 case studies in 4 representative Queensland regions. These included urban and rural locations that allowed the researchers to compare 3 investment scenarios: the base case of what actually happened, a full resilience scenario and a preventative maintenance approach to road rehabilitation.

The study found that moving to a preventative maintenance strategy for selected roads meant an extra dollar of spending would deliver \$6.90 in road user cost savings and produce cumulative life cycle savings of nearly \$600 million.⁴¹

Image below: Volunteers help clean up flooded streets in Brisbane in 2011. Source: Shutterstock.



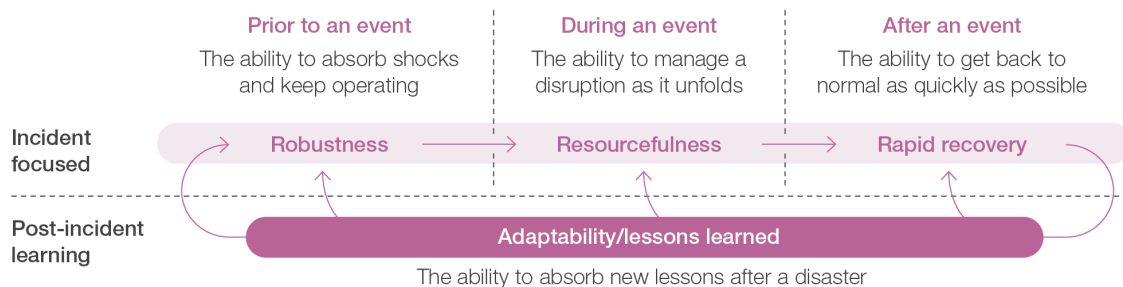
Adapting infrastructure for the future climate

Governments cannot completely eliminate the risk of damage to infrastructure from future climate change events, or the consequences for communities. But they can reduce the risks. Adaptation can make infrastructure more resilient before, during and after extreme weather events, as Figure 3 illustrates.

Infrastructure lasts for a long time, but its designers have typically assumed it will operate in similar climatic conditions as in the past. A different climate that has more frequent and intense extreme weather events means that infrastructure may not function, because it was not built for these conditions.⁴² Other factors also affect whether infrastructure can keep performing. This includes its age, condition, design and construction materials, and how essential it is for physical, functional or social requirements.⁴³ It also means that infrastructure owners must plan, design, build, and operate new infrastructure in ways that account for the future climate change that might occur during its life.⁴⁴

Adaptation comes in many forms. Adaptation measures do not always have to be expensive. In this report, we document different adaptation options to help inform decision-making. Options can include building infrastructure to better prevent and prepare the infrastructure before an event, such as undergrounding of distribution networks to reduce power failures from high winds. They can include actions that reduce the exposure and severity of the event on the infrastructure, such as catchment upgrades to reduce flooding exposure. They can include response measures undertaken during an event, such as traffic management and emergency repairs. Or they can include activities that mean infrastructure can recover and be repaired more quickly after an event, such as bushfire risk management plans which reduce downtime after landslides.

Figure 3: Resilience categories



Source: The National Infrastructure Advisory Council, *A framework for establishing critical infrastructure resilience goals*, 2010, in PIARC, *Uniform and Holistic Approaches to Resilience: Climate Change and Other Hazards*, 2023.

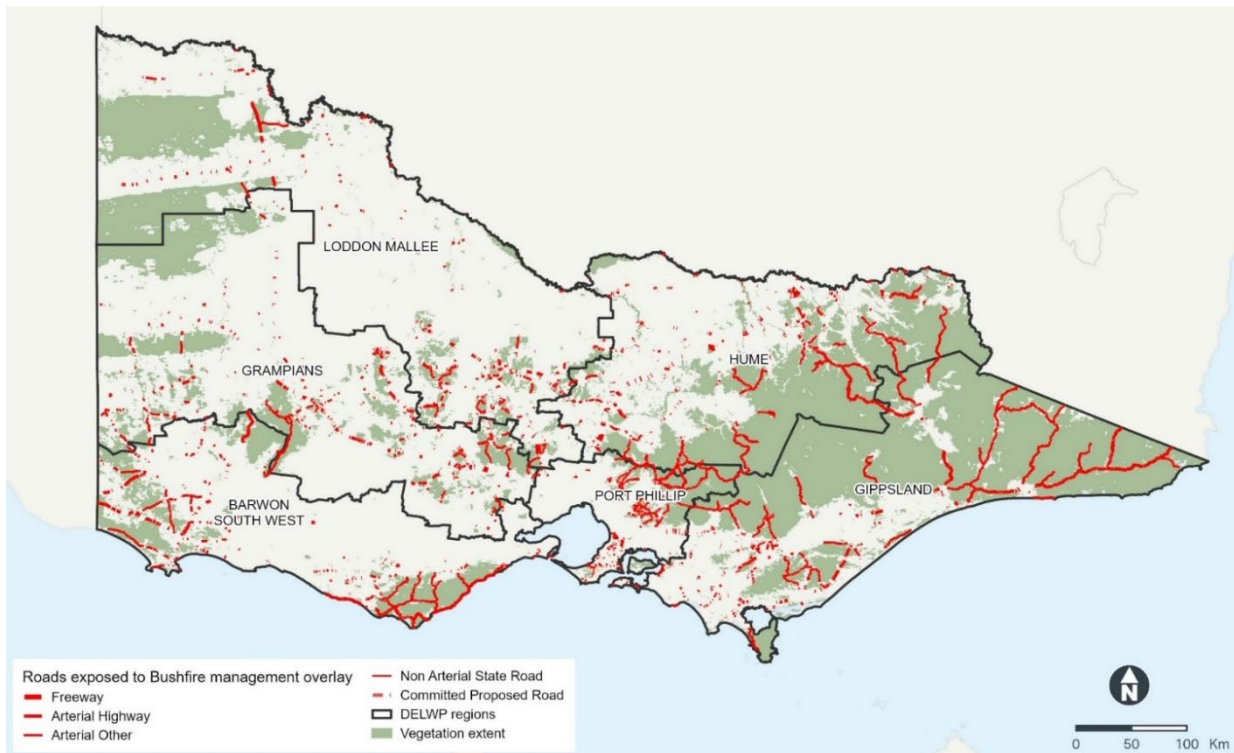
Adaptation increases the robustness, resourcefulness and rapid recovery of infrastructure assets and systems. But making infrastructure more resilient to effects of climate change is not an end in itself.⁴⁵ Resilient infrastructure contributes to more resilient communities and economies.⁴⁶ It supports communities to withstand, respond to and recover from events linked to climate change, such as a heatwave or extreme flooding.⁴⁷ It can give communities early warning information so they can better prepare, provide emergency shelter during extreme weather, enable transport and communications during times of emergency, and support emergency services' response.

Resilient infrastructure allows essential services to keep operating, such as food, water, energy, transport, telecommunications and health care services.⁴⁸ It provides venues and access to support services that help communities recover.⁴⁹

Adaptation is not one-size-fits-all

Victoria's climate risks to infrastructure will vary between different asset types and different locations, and different climate change events will occur at different frequencies and intensities. Exposure to extreme weather events varies in different parts of Victoria. Climate projections suggest they will not intensify evenly in different regions. For example, the increase in bushfire risk will rise most rapidly in heavily forested areas. Figure 4 shows the variation in Victoria of road exposure to bushfires. Infrastructure managers can learn from past events, and use scenario planning to examine different possible futures, to assess infrastructure's local vulnerability and risks.⁵⁰

Figure 4: Roads exposed to bushfire risks (bushfire management overlay)



Source: AECOM, *Climate change consequences study*, 2023.

Note that these figures illustrate assets that intersect or are near hazard zones and may therefore be exposed to climate hazards. Further analysis is required at the subregional or site level to determine if assets are actually at risk or are sensitive to these hazards.

Victorian Government agencies routinely manage risks to their service delivery, reputation, finances and people's safety. Climate change introduces new risks for agencies to manage and makes some existing risks more severe. Infrastructure managers can identify assets and locations that might be particularly vulnerable and assess their climate risks. Conducting these climate risk assessments allows infrastructure managers to make informed decisions about adaptation investments that get the best returns.

Infrastructure managers can then select the best priority adaptation measures by undertaking site-specific analysis of the impacts of climate change for vulnerable and high-risk locations. The effects of climate change are different for every location because of their individual socioeconomic, physical, geographic and functional characteristics. For example, site-specific analysis can identify the local impacts on vulnerable people, cultural heritage, biodiversity and ecological health, alongside the likelihood and severity of impacts on infrastructure safety, embodied carbon, and considering the resilience for multiple climate hazards.

Testing individual adaptation measures is also highly site-specific. What may work in one location may not be effective or suitable in another. In this research, we examined 3 asset types in detail:

electricity transmission and distribution infrastructure, public hospital buildings and roads. We identified that extreme weather events have negatively affected each of them and will continue to do so.

The best adaptation measures might be specific to that location. For example, increasing roadside vegetation for stormwater management can reduce flood risk. Vegetation can slow down and absorb rainwater, which reduces flooding and erosion risks. But vegetation can also mask signs of slope instability. In another location, increasing vegetation can be maladaptive. Vegetation can act as a fuel for bushfires, potentially increasing the severity and spread of the fire. This is why infrastructure managers must carefully assess local conditions to decide whether specific adaptation measures are suitable.

Assessing climate risk for Victorian regional hospitals identifies several themes

In February 2022, the Department of Health released the *Health and human services climate change adaptation action plan 2022–26*. One of the plan's objectives is to make infrastructure more resilient to climate hazards, such as severe weather events.⁵¹ In March 2023, the department commenced a project to assess climate hazard risks to 6 regional hospitals across Victoria. The project analysed their exposure to flooding, extreme heat, grassfire and bushfire. It was delivered in a partnership between the Department of Health and hospitals with funding from Emergency Management Victoria. It included 3 phases:

- Desktop analysis of historic weather patterns for each of the regions surrounding the hospitals. This was mapped to projected trends in increased temperatures and extreme weather to provide site-specific climatic projections.
- Engagement with key stakeholders in water, planning, and emergency services to source data, better identify local risks and existing actions to mitigate and respond to these risks.
- Visits to each hospital to assess infrastructure, meet with hospital staff and workshop the challenges and opportunities the hospital faces in adapting to projected future climate hazards.⁵²

While climate risk is specific to the type of asset and its location, several themes emerged across the health services in the study:

- While hospital locations vary, it was generally found that the centralised location of hospitals in towns largely protected assets from the direct impacts of severe weather events.
- Hospital services are at greater risk than infrastructure during climate-related events than hospital buildings. For example, access to and from the hospital by staff and patients and the reliance on external sources for critical services such as utilities and supplies present challenges for the effective delivery of health services during severe weather events.
- Aged care facilities were shown to be more exposed to severe weather events given aged care patients are broadly more susceptible to climate extremes and the inherent risks associated with evacuation.⁵³

The study proposed adaptation options to increase the resilience of infrastructure and services. Options included relocation of critical assets (such as electrical switchboards) to increase their protection from severe weather and upgrading buildings components to better manage extreme heat (for example, double-glazed windows).

Service delivery options included reviewing emergency management protocols to address site-specific risks, installing backup communications (such as satellite phones, UHF radios) and strengthening supply chains through stress-testing arrangements and backup options.⁵⁴

The study will assist with embedding climate resilience into the health system in line with the *Health and human services climate change adaptation action plan 2022–26*.

Climate change impacts can be interdependent

Extreme weather events that affect one sector can have flow-on effects to others. These are also known as ‘cascading impacts’. For example, blackouts caused by storms in June and October 2021 also disrupted water, sewerage and communication services. The storms also knocked over trees, which closed roads and delayed repairs to electricity distribution lines.⁵⁵ This means that even if infrastructure is not directly exposed to a climate risk, it can be indirectly vulnerable from another type of infrastructure failing. For instance, road disruption can cut access to critical locations, such as hospitals, residential areas, or industrial zones. This can also sever access by emergency services or stop businesses operating.

‘Compounding impacts’ occur when extreme events happen at the same time or in short succession to produce combined impacts that are worse than the individual effects of each event.⁵⁶ For example, storms and flooding rapidly followed the 2019–20 East Gippsland drought and bushfires, compounding the effects on those communities.⁵⁷

By identifying interdependencies, infrastructure managers can more comprehensively assess their risks beyond direct damages, and improve resilience in other sectors.⁵⁸

Local area analysis can avoid maladaptation

Climate risk assessments are useful for determining which assets to prioritise, but asset managers will need to analyse local conditions to identify how climate change will affect specific infrastructure assets.⁵⁹ This allows them to decide which adaptation measures are effective in terms of planning, performance and cost.

Many different variables determine whether an adaptation measure will be beneficial. Otherwise, infrastructure operators cannot tell what the measure will do when they implement it. The appropriateness of adaptation measures depends on the situation in which they are applied. There are no universally ‘good’ options. Infrastructure managers must closely analyse the region, area and infrastructure to determine its appropriateness.⁶⁰

If infrastructure managers do not undertake localised analysis, they risk investing in measures that might not be effective for decades or might be ineffective or maladaptive. Maladaptation refers to negative consequences following the implementation of an adaptation measure.⁶¹ This occurs when an adaptation measure, meant to protect the community from climate change, inadvertently increases the vulnerability of a system, sector or social group.⁶² Researchers have found that maladaptation is often caused by information gaps, where an adaptation measure has been introduced without fully assessing all the risks and impacts.⁶³ The next case study shows an example of maladaptation in Fiji floodwall construction. Localised and site-specific assessments can capture detailed data to help decision makers avoid proceeding with maladaptive measures.

This is especially relevant when an adaptation measure might affect other sectors. Infrastructure does not operate in isolation, and ideally adaptation measures should not be maladaptive for infrastructure and services in the same location. Our research found that extreme weather events can have compounding and cascading impacts on electricity and road infrastructure and for hospital buildings. For example, powerlines knocked over by extreme wind can block a road, which could then stop staff and patients accessing a local hospital.⁶⁴

Fiji floodwall construction shows impact of maladaptation and need for local knowledge

In 2015, government contractors constructed floodwalls on the Fijian island of Vanua Levu. Rising sea levels were increasingly flooding the low-lying villages of Karoko and Korotasere. But the contractors built them without engaging local people or conducting local assessments.

The contractors built floodwalls that were not long enough to protect the villages from flooding. Flood waters could travel around the floodwall. Worse, the floodwalls made the flooding worse because the villages did not have good drainage systems. The floodwalls prevented water flowing out to the sea, trapping floodwater and heavy rainfall in the villages.⁶⁵

An academic study of the Karoko and Korotasere floodwalls found that the project could have prevented this maladaptation if it had placed the long-term concerns of the locals at its centre. Instead, the project was undertaken as a short-sighted response to recent flooding events.⁶⁶

Building from similar experiences globally, the Intergovernmental Panel on Climate Change identified 4 key factors for successful adaptation:

- ensuring vulnerable communities are included in adaptation planning
- creating an inclusive consultation process that encourages participation
- ensuring that the effects of adaptation are distributed fairly and do not make existing inequalities worse
- creating strong, flexible institutions, which integrate policies into risk management and account for long-term goals.⁶⁷

These factors can help to evaluate the shared benefits and trade-offs between different adaptation responses and reduce the likelihood of maladaptation.

Image below: Savusavu marina and Nawi islet, Vanua Levu island, Fiji. Source: Shutterstock.



Victoria has committed to climate adaptation

Victoria's *Climate Change Act 2017* sets out the processes for the government to manage climate risks and transition to net zero emissions. It requires the Victorian Government to develop a climate change strategy every 5 years. This strategy sets out how Victoria will meet emissions reduction targets and adapt to the impacts of climate change.⁶⁸

The government released *Victoria's climate change strategy* in 2021. It sets out priorities for adaptation: addressing current climate change impacts, reducing barriers to adaptation, and laying the foundations for future adaptation action.⁶⁹ These adaptation priorities set the direction for Victoria's 7 system-based adaptation action plans. The plans guide Victorian Government adaptation efforts in each sector. The sectors are the built environment, education and training, health and human services, natural environment, primary production, transport, and water cycle systems.⁷⁰

The Victorian Government has also published 6 regional adaptation strategies to guide local action.⁷¹ These regional strategies use local knowledge to set out place-based climate change adaptation actions. To date, the government has allocated \$1.5 million to deliver projects identified by them.⁷²

The *Climate Change Act 2017* requires the government to update the adaptation action plans in 2026. That is an opportunity for the government to commit to more tangible and extensive action to adapt infrastructure to climate change.

But Victoria spends little on adapting infrastructure

Victorian Government agencies and infrastructure owners are at different stages in adapting to a changing climate. Some agencies and infrastructure managers still assume that the future climate will be the same as the past climate. For example, they make decisions using historical climate data. This includes decisions about maintenance, asset management, upgrades and possible new projects.

The government's existing approaches prioritise funding for repair and recovery after the event has already occurred.⁷³ This is true of most governments.⁷⁴ For example, in 2014 the Productivity Commission found that the Australian Government spent 97% of its natural disaster funding after an extreme weather event, but only spent 3% on proactive efforts to limit the impact of future events.⁷⁵

The commission said that state governments also underinvested in risk mitigation, and that natural disaster costs were a growing unfunded liability.⁷⁶ The National Emergency Management Agency is also conducting an independent inquiry into Commonwealth disaster funding, including funding arrangements for risk reduction and preparedness, which is scheduled for release in April 2024.⁷⁷

Recent Victorian budgets contained little new funding for infrastructure adaptation to better prepare for events. The Victorian Government says it has provided over \$2 billion over several budgets towards climate action.⁷⁸ The vast majority of identified spending is for reducing greenhouse gas emissions.

The Victorian Government allocated \$166 million in the 2023–24 budget to climate resilience, largely for revegetation projects, waterways management or drought resilience projects for agriculture.⁷⁹ We could not separately identify Victorian Government spending on infrastructure adaptation projects.

This funding might feasibly be included as part of other infrastructure spending or maintenance activities, but not separately accounted for.

Our research method

This research uses a mixed methods approach. Our methodology report explains the components of our approach in more detail. The methodology report is published on [our website](#), alongside other technical reports we commissioned for the research.

We consulted with stakeholders throughout the project including Victorian Government departments and agencies, asset managers, academics, regulators and think tanks. For instance, we engaged around 90 participants in our initial risk assessment workshops from a variety of sectors. We also engaged with selected government departments to assess our thinking and recommendations.

We learned from other governments and jurisdictions

We started by reviewing literature about the difficulties governments and policymakers confront to adapt infrastructure to climate change. We also examined reports about successful adaptation.

We assessed climate change adaptation policies and initiatives in other Australian and international jurisdictions. We show some of these lessons using case studies in this report.

We also reviewed the application of Victoria's climate change policy framework to infrastructure adaptation. We considered progress in delivering Victoria's adaptation action plans and regional adaptation strategies, ways to improve future updates to these plans and barriers to taking adaptation action.

We assessed climate change risks for infrastructure

In the early phases of our work, we considered different types of physical infrastructure including energy, telecommunications, transport and water infrastructure, and buildings and facilities. We conducted a first pass risk assessment of climate change impacts in the infrastructure sectors of transport, utilities, and the built environment. We considered the socio-economic, environmental and cross-sectoral impacts of climate change. We then conducted detailed analysis of climate risks in 3 more specific infrastructure sectors – road networks, electricity networks, and public hospital buildings. This helped us identify adaptation actions which could build on those already planned or underway.

We examined the effects of extreme weather events on these 3 sectors in a *[Climate change consequences study](#)*.⁸⁰ The study included geospatial analysis to identify regions where these types of infrastructure may be exposed to flood and bushfire risk. We used planning scheme instruments such as bushfire management and flood overlays, and urban flood zones to find existing areas of potential fire and flood risk.⁸¹ This analysis was statewide and high level, aiming to identify regions where assets are exposed to climate hazards because of their location, rather than identifying specific assets.

We also identified physical and policy-based adaptation actions relevant to road networks, electricity networks, and public hospital buildings. For these sectors, we identified assets and risks to assess in more detail using a multi-criteria analysis to prioritise risks that:

- had fewer effective controls in place
- had more flow on impacts, including direct and indirect impacts on other sectors

- had limited redundancy, back-up solutions or where recovery would take a long time
- can inform the next [30-year infrastructure strategy](#) and/or the government's adaptation action plans.

We analysed site-specific adaptation costs and benefits

We generated new quantitative and qualitative evidence and analysed possible public policy responses.

We conducted economic analysis of 2 infrastructure sectors, electricity distribution and road networks, to test the potential return on investment for different adaptation measures. This approach demonstrated how economic evaluation can guide adaptation action, by factoring the benefits of risk reduction into investment decision-making.

Figure 5: Building the economic case for adaptation action in 4 stages



We selected 3 climate risks to assess: flooding and bushfire for roads, and extreme winds for electricity distribution. We then examined adaptation measures relevant to these sectors and risks.

Infrastructure adaptation can take many different forms, and for ease of analysis we divided the identified options into 4 categories:

- higher-cost investment options, such as large-scale projects requiring the construction of infrastructure or higher-cost materials
- lower-cost investment options, including nature-based solutions
- maintenance, including increasing periodic maintenance and incorporating preventative maintenance
- hazard management solutions, such as communication and early warning systems, removal of hazards and temporary structures.⁸²

To conduct an economic analysis, we created a base case 'do nothing' scenario under current climate conditions. We then projected future climate conditions for 2070 against which we compared the costs and benefits of our adaptation measures.

We examined the cost of implementing and maintaining each adaptation measure, including replacement costs where appropriate. Our analysis also included the embodied carbon emission cost of each adaptation measure.

Our research confirmed adaptation measures can produce a compelling case for investment when direct, indirect and intangible costs and benefits are considered together. It also shows that site-specific analysis is essential for assessing potential adaptation measures, because not all measures generate a return on investment because of their specific location, features or local climate conditions.

The next 3 examples show a summary of each cost-benefit analysis.

Adapting the road network for flooding – hypothetical suburban scenario

Our research explored the economic costs and benefits of investing in climate adaptation for a site-specific road network. We did this work in partnership with Arup.⁸³ Our analysis indicated that damage to roads due to extreme weather events was a high climate risk for the transport network.

We examined how floods might affect a major suburban Melbourne arterial road, and how the costs and benefits of adaptation measures performed against a 'do nothing' base case. Our scenario was based on real world data. It featured a 7-kilometre, 2 lane road, in a flood zone. Eleven thousand vehicles used the road each day.⁸⁴

We created a long list of adaptation measures relevant to the scenario. We then conducted a multicriteria analysis to create a shortlist of adaptation measures. We also considered community impacts during construction and maintenance, recovery time, cost of construction, road service level impact, embodied carbon emission impact, level of net impact on the environment and maladaptation risks.

We assessed the embodied carbon associated with the production and transportation of materials for the adaptation measures. We selected 8 measures to examine:

- using foamed bitumen stabilisation, a road pavement treatment which improves its strength
- upgrading the road grade and improving drainage now to absorb one-in-20-year flood events
- staged upgrading of the road grade and improving drainage now to absorb one-in-20-year flood events, and upgrade in future to absorb one-in-100-year flooding
- building a new raised road viaduct over a floodplain or waterway
- using water sensitive urban design to harness natural infrastructure and systems to capture, treat and manage stormwater runoff from roads
- increasing preventative maintenance to preserve pavement condition and extend the road's life
- programming road rehabilitation involving more frequent extensive repairs and maintenance to improve the overall condition of the road
- using intelligent transport system solutions and rerouting to prevent further damage to roads after flooding.⁸⁵

Our results showed that good adaptation does not have to be expensive

Our analysis showed positive benefits related to low-cost measures such as maintenance activities.

Five adaptation measures produced a positive return on investment in all conditions: foamed bitumen stabilisation, water sensitive urban design, preventative maintenance,

programmed rehabilitation, and optimising the road grade now to absorb one-in-20-year flood events.⁸⁶

Preventative maintenance and foamed bitumen stabilisation produced the highest returns on investment under both current and future conditions. Preventative maintenance produced \$5.10 for every \$1 spent in current climate conditions, increasing to \$8.29 under future conditions. This was shown to extend the lifespan of infrastructure assets, helping to avoid costly repairs and premature replacements.

Foamed bitumen stabilisation showed \$2.98 for every \$1 spent in current conditions and \$4.83 under future conditions.⁸⁷

The viaduct option had a unique outcome. It was resilient to flooding but, for our hypothetical suburban road, it did not show benefits that outweighed the installation costs under current and future climate conditions. It was the only adaptation measure that did not produce positive results under any scenario.⁸⁸ However, it may still be an option to consider if a road is deemed critical, such as access for emergency services.

Table 1: Benefit-cost ratio (BCR) for flooding adaptation measures under current (2022) and future (2070, high emission scenario) climate conditions based on a 7% discount rate

Adaptation measure	BCR current conditions (7% discount rate)	BCR future conditions (7% discount rate)
Preventative maintenance	5.10	8.29
Foamed bitumen stabilisation	2.98	4.83
Water sensitive urban design	2.90	4.66
Programmed maintenance	2.51	4.06
Upgrade road and drainage to one-in-20-year flood events	1.26	2.03
Staged road and drainage upgrading to one-in-20-year and one-in-100-year flood events	1.04	1.71
Hazard management solution	0.77	1.26
New raised road viaduct	0.09	0.14

Source: Arup, *Adapting Victoria's infrastructure to climate change: economic analysis of adaptation for roads*, Infrastructure Victoria, 2023.

Planning the implementation of adaptation may produce better results

Our research explored individual adaptation measures compared to a base case scenario. But some adaptation measures that do not produce a high return on investment by themselves may work better when coordinated with other measures or implemented using a staged approach. This is known as adaptation pathway planning.

A pathway approach also allows decision makers to consider new information and adjust their decisions over time to enhance infrastructure and community resilience. This can help with the use of resources and optimises the benefits from specific adaptation measures.

We examined one high-cost adaptation measure with a pathway approach: optimising the road grade and improving drainage now to absorb one-in-20-year flood events, and upgrade in future to absorb one-in-100-year flooding.

This produced a positive return on investment under future climate conditions. Other individual adaptation measures that produced lower results, such as hazard management, may work better when coordinated with other measures.⁸⁹

By considering some adaptation measures together and their sequencing in the future we can help to make infrastructure more resilient as new information becomes available.

Full details of this cost-benefit analysis are in the technical report, *Adapting Victoria's infrastructure to climate change: economic analysis of adaptation for roads*, available on [our website](#).

Adapting the road network for bushfires and bushfire-induced landslides – hypothetical rural scenario

We examined the economic costs and benefits of investing in climate adaptation for a site-specific road network. We did this work in partnership with Arup.⁹⁰ Our analysis indicated that service interruption of roads caused by bushfires and subsequent rainfall-induced landslides was a highly rated climate risk for the transport network.

We examined how bushfires might affect a regional road in Victoria, and how the costs and benefits of adaptation measures compared to a 'do nothing' base case. Our area was based on site-specific real world data, consisting of a 50-kilometre undivided road carriageway in a bushfire zone. The road connects 3 small towns with a total population of 600 people and provides essential access for residents, freight, tourists and emergency services. Aside from unsealed roads, the surrounding area has few alternative roads.⁹¹

We examined the extra risk of post-bushfire induced landslides. Bushfires rarely cause direct damage to roads, but they can destabilise the surrounding landscape by causing erosion and creating debris. Bushfire-induced landslides can cause more disruption to the road than a bushfire itself.⁹²

We created a long list of relevant adaptation measures. We then conducted a multicriteria analysis to create a shortlist of adaptation measures. We considered community impacts during construction and maintenance, recovery time, cost of construction, level of net impact on the environment and maladaptation risks. We also assessed the embodied carbon associated with the production and transportation of materials for the adaptation measures. This method produced a shortlist of 8 measures to examine:

- remediate 2 high-risk slopes with flexible barriers to protect the road from landslides, debris or rockfalls
- remediate 11 high and moderate-risk slopes with flexible barriers
- fire-resistant plants that do not burn easily from continuous flame or from the first wave of a bushfire
- fire break (vegetation clearance zone from the road) to reduce the rate of spread and intensity of fire
- increased programmed drainage clearing and vegetation management such as clearing or controlled burns
- immediate post-fire responsive drainage clearing for embankments and cuttings along slopes following a bushfire
- post-fire erosion protection and slope stabilisation using seeding, matting and drainage clearance
- risk management plan including intelligent transport system signage alerts, disaster response planning procedures for inspections, maintenance and rehabilitation.⁹³

Table 2: Benefit-cost ratio for bushfire and landslide adaptation measures under current (2022) and future (2070, high emission scenario) climate conditions based on a 7% discount rate

Adaptation measure	BCR current conditions (7% discount rate)	BCR future conditions (7% discount rate)
Programmed drainage clearing and vegetation management	5.88	11.52
Post-fire erosion protection and slope stabilisation	0.73	1.37
Risk management plan	0.71	1.07
Post-fire responsive drainage clearing	0.57	1.07
Fire-resistant plants	0.42	0.82
Remediate 2 high-risk slopes with flexible barriers	0.19	0.58
Remediate 11 high and moderate-risk slopes with flexible barriers	0.19	0.28
Fire break (vegetation clearance zone from the road)	0.17	0.32

Source: Arup, *Adapting Victoria's infrastructure to climate change: economic analysis of adaptation for roads*, Infrastructure Victoria, 2023.

Programmed drainage produced over 5 times the return on investment

Our analysis clearly demonstrated that, in this scenario, increasing programmed drainage and vegetation management would produce a large return on investment. At a 7% discount rate, increasing programmed drainage under current climate conditions would return \$5.88 for every \$1 spent. For future climate conditions, this increases to \$11.52 in benefits for every \$1 spent.⁹⁴ Increased programmed drainage would increase flood resilience, reducing the effects of post-bushfire landslides without more expensive interventions.

Higher cost does not equal the best return on investment

Lower-cost investments such as maintenance measures and hazard management showed the largest positive return on investment. Their lower upfront initial expenditure makes these measures a 'no regrets' adaptation measure.

Immediate post-bushfire erosion and drainage clearing produced positive returns on investment under future climate scenarios.⁹⁵ The results also showed that some adaptation measures can be combined, enhanced and sequenced when implemented in a certain order. For example, improving soil erosion control and vegetation restoration before undertaking infrastructure upgrades can help stabilise slopes and minimise erosion impacts. These results suggest that these types of adaptation measures may be worth investigating for application for roads in Victoria soon.

Our results suggest that the most cost-effective solution to this scenario is through increased maintenance and hazard management options. Neither of the high cost slope

remediation measures produced a positive return on investment under a 7% discount rate, although remediating the 2 high-risk slopes had a neutral result under future climate conditions at a 4% discount rate.⁹⁶

The low-cost fire-resistant planting measure did produce a positive return on investment for future climate projections but only at a 4% discount rate.⁹⁷ Fire breaks received a lower result in this analysis due to the high costs associated with their establishment and maintenance in this particular exemplar for roads. Fire breaks can be an effective measure, with cost differences across regions based on environmental constraints and terrain, scale of treatment and purpose of protection.⁹⁸

Our result emphasises the importance of place-based approaches to prioritising investments in infrastructure resilience. The full details of this cost-benefit analysis can be found in the technical report on our website, [Adapting Victoria's infrastructure to climate change: economic analysis of adaptation for roads.](#)

Adapting electricity distribution lines for extreme wind events – hypothetical urban scenario

We examined the economic costs and benefits of investing in climate adaptation for electricity distribution infrastructure with ACIL Allen (pictured).⁹⁹

Electricity distribution networks transport electricity from the high voltage transmission network to homes, businesses and industrial premises. They include poles and wires, substations, transformers and switching equipment.¹⁰⁰

Our analysis indicated that damage to, or degradation of, assets due to extreme weather events were a high rated climate risk for electricity transmission and distribution infrastructure.

We examined how extreme winds may affect a typical metropolitan Melbourne area, and how the costs and benefits of adaptation measures compare to a 'do nothing' base case. Our area was based on real world site-specific data, rather than an actual location, consisting of a service area of 2,000 customers.¹⁰¹

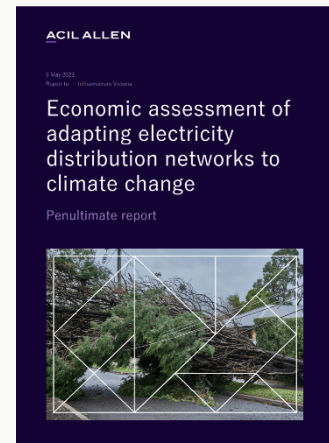
We created a long list of adaptation measures but found only a handful had moderate to high effectiveness for this scenario. After considering community acceptance, financial costs and maladaptation risks, we selected 4 measures to examine:

- undergrounding distribution cables, existing overhead distribution infrastructure is replaced with the same underground infrastructure
- insulated cables, existing overhead conductors are replaced with overhead insulated cables
- replacement of large trees that have potential to damage overhead distribution infrastructure with lower growth trees
- grid-forming inverters, electricity customers that install solar and battery systems to also install inverters that can operate on their own or as an island system in the event of a grid outage.¹⁰²

Our findings from the cost-benefit analysis were mixed

We found that all 4 adaptation measures reduced electricity outages and helped to adapt distribution networks to the effects of extreme wind but only one adaptation measure, insulated cables, delivered a positive return on investment.¹⁰³

We also assessed the present value of embodied emissions associated with manufacturing and construction emissions required for specific adaptation measures. For example, emissions from manufacturing new capital items, such as cables, and construction



emissions, such as from installing new insulated cables or trenching for underground cables.

Embodied carbon costs were found to be less than 2% of the total capital cost for the base case, undergrounding and insulated cable. For tree replacement, the embodied carbon of this measure was higher, at about 4% of the total capital cost of the measure.

Further research can strengthen the evidence base for future investment

Our analysis pointed to several research gaps and complexities that influenced our findings. These included the amenity benefits of undergrounding electricity distribution power lines.

We analysed the costs and benefits of undergrounding power lines. Undergrounding is expensive and we found that it is not a cost-effective way to adapt electricity distribution networks to the likely future effects of extreme wind in this example.

However, undergrounding can deliver major amenity benefits, including a better streetscape and more tree cover. Studies in other parts of Australia suggest that undergrounding can deliver a positive return on investment when amenity benefits are included in the analysis, but we did not consider that these estimates could be extended to Victoria.¹⁰⁴

The effects of climate change on future generations

The decision-making process can capture future benefits and avoid maladaptation by identifying where adaptation options fit in a pathways approach to climate resilience. But benefits that occur a long time into the future can be difficult to capture in a cost-benefit analysis.

Analysts use discount rates to compare benefits that occur at different points in time, and the choice of discount rate affects the value placed on future benefits.

Our study used the Victorian Government's recommended approach in selecting discount rates, but other methods are available that might be more appropriate for analysis over very long periods. More research and guidance can help address these uncertainties for future analysis.

The full details of this cost-benefit analysis can be found in the technical report, *Economic assessment of adapting electricity distribution networks to climate change*, available on our [website](#).

Image below: Melbourne's distribution network is vulnerable to damage or degradation due to extreme weather events. Source: Shutterstock .



Victoria can better manage climate risks to infrastructure

Boost priority and oversight for infrastructure adaptation

If governments do not act to adapt to new climatic conditions, Victoria's infrastructure will fail more often. Infrastructure failure causes real harm to people and businesses. It is also expensive for governments to repair, especially urgently, in affected communities with potential worker and materials shortages.

The Victorian Government cannot reduce the risk of climate-related disruptions to infrastructure to zero.¹⁰⁵ But successful adaptation can reduce, manage or avoid many adverse effects of climate change.¹⁰⁶ Governments with strong policy frameworks can make better, more informed and cost-effective decisions to adapt infrastructure. The government can better manage or reduce risks by considering climate risk when planning for new infrastructure, maintaining or retrofitting existing assets.

Victoria already has the policy architecture for climate change adaptation. Victoria's *Climate Change Act 2017* requires the government to produce a climate change strategy, including 7 sector-based adaptation action plans and 6 regional adaptation action plans. These plans set out adaptation actions, which can include specific changes to make infrastructure more resilient.

Despite Victoria having a policy framework to guide adaptation action, asset managers told us they do not feel empowered to assess climate risk or suggest adaptation measures. The Victorian Government can strengthen its policy structures and requirements to direct infrastructure managers to assess climate risk, act upon it, and demonstrate how their assets are more resilient.

Recommendation 1: Boost priority and oversight for infrastructure adaptation

- Make public infrastructure resilience an adaptation priority in *Victoria's climate change strategy*.
- Develop an adaptation action plan for Victoria's energy system.
- Include all infrastructure types in future adaptation action plans.
- Specify the responsible agency for each adaptation action.
- Regularly publish a progress and evaluation report on adaptation actions.

Make public infrastructure resilience an adaptation priority in Victoria's climate change strategy

Victoria's *Climate Change Act 2017* has 5 policy objectives. One of them is to build the resilience of Victoria's infrastructure, built environment and communities through adaptation and disaster preparedness.¹⁰⁷ But *Victoria's climate change strategy* does not reproduce this specific legislative objective. It details 16 adaptation priorities to guide Victoria's 7 adaptation action plans, but none prioritise making public infrastructure more resilient.

The Victorian Government should specify a new priority to make infrastructure more resilient in the next version of *Victoria's climate change strategy*. The next version is due by 31 October, 2025. Updated adaptation action plans, due in 2026, should have actions to achieve this new priority.

Develop an adaptation action plan for Victoria's energy system

The government has no specific adaptation plan for Victoria's energy sector. The built environment adaptation action plan includes some elements of the energy sector, but it does not mention other elements. It has few actions that apply to improving the resilience of energy infrastructure.

Most other adaptation action plans identify energy as critical to services due to interdependencies across many other sectors such as health, transport, and education. Victoria's storms in June and October 2021 illustrate the disruption that occurs when energy systems fail. Almost 300,000 Victorians were without power following the June storms, and over 525,000 lost power in October's extreme winds.¹⁰⁸

Energy assets are largely privately owned and operated. But the Victorian Government helps shape energy policy by regulating energy consumer rights and safety. It issues planning approvals for energy infrastructure. The government is also now preparing to be an energy market participant via the State Electricity Commission.¹⁰⁹ The Victorian Government can use its different regulatory, funding, and producer roles to improve energy infrastructure resilience.

The *Climate Change Act 2017* requires the Victorian Government to produce new adaptation action plans by 2026. The 2026 update should also include a new adaptation action plan for Victoria's energy system. This can build on the work of the *Electricity distribution network resilience review*, completed in 2022. The energy system adaptation plan should aim to clarify the respective roles of private businesses, governments, regulators and local communities in strengthening resilience.¹¹⁰ This recommendation is in line with section 34 of the *Climate Change Act 2017* which allows other adaptation action plans to be developed, provided they are prescribed in regulations.¹¹¹

Include all infrastructure types in future adaptation action plans

Victoria's 7 adaptation action plans guide government action to manage climate change risks and opportunities across the built environment, education and training, health and human services, natural environment, primary production, transport, and water cycle systems.¹¹² Collectively, they contain around 125 actions to build capability, improve tools and information to support decision-making, strengthen frameworks and coordinate activities.

The plans cover most infrastructure, but not all. For example, the plans do not mention justice and community safety infrastructure, and do not mention some telecommunication infrastructure, such as telecommunications towers, poles and wires, and VicTrack's telecommunications network.¹¹³ These omissions mean there are no clear actions to adapt some infrastructure types to climate change.

The Victorian Government should include all infrastructure it owns, manages or regulates in its adaptation action plans.

Specify the responsible agency for each adaptation action

Each adaptation plan has a lead department, but the plans do not identify which department, unit or agency is responsible for individual actions. Some plans cover multiple portfolios and agencies. This can make it difficult to tell which area of government is accountable for delivering each action, particularly as departmental responsibilities change over time. For example, the Department of Transport and Planning leads the *Built environment climate change adaptation action plan*, but the Department of Energy, Environment and Climate Action is responsible for energy policy, which this plan contains. The government should assign all adaptation actions to the department or agency

responsible for delivery. This will strengthen the line of sight between ministers, agencies and their adaptation responsibilities, and allow them to monitor progress. These arrangements should also be clarified following any machinery of government changes.

The government could further clarify agency responsibilities in responding to climate risks to infrastructure by issuing ministerial guidelines under the *Climate Change Act*.¹¹⁴ These can show agencies how to incorporate the Act's policy objective to build Victoria's infrastructure and community resilience and the guiding principle of risk management in policy and decision-making.¹¹⁵

Regularly publish a progress and evaluation report on adaptation actions

The Victorian Government can help infrastructure managers make better decisions in the face of the uncertainties of climate change by more effectively monitoring and evaluating the actions they take to adapt. These processes can also generate the evidence that allows practitioners to learn from past efforts and adjust future programs to perform better.¹¹⁶

One purpose of the *Climate Change Act* is to improve clarity and accountability through information collection and reporting.¹¹⁷ The Victorian Government publishes a report every year on progress towards reducing Victoria's greenhouse gas emissions. But it does not track progress on climate change adaptation efforts.¹¹⁸

The Act requires the government to report on the implementation and effectiveness of previous adaptation action plans in each update.¹¹⁹ This commits government to a 5-yearly reporting cycle. Each adaptation action plan flags that a monitoring and evaluation framework will be developed to guide implementation. The government is yet to publish a framework for any of the system plans and there is no publicly available monitoring on adaptation actions and outcomes. We could not identify progress on implementing infrastructure adaptation actions from publicly available information. As climate change is fast-moving and dynamic, waiting 5 years in between cycles to assess progress is too slow, and we will miss opportunities to learn and adapt.

Best practice adaptation requires reporting and assessment mechanisms to determine whether adaptation is progressing and is effective in building resilience.¹²⁰ The Victorian Government should develop a monitoring and evaluation framework to guide ongoing improvement of adaptation plans, and report results mid-way and at the end of each 5-yearly adaptation cycle. The framework should cover:

- Monitoring individual adaptation actions in each system plan. System-focused monitoring and evaluation should be undertaken by the lead department for each adaptation system, overseen by a clearly designated part of government such as the Department of Energy, Environment and Climate Action or a central agency.
- Whole-of-system, statewide adaptation progress to build knowledge of Victoria's resilience to climate change over time, including infrastructure. This should consider collective progress on adaptation plans and the overall effectiveness of Victoria's adaptation framework. Whole-of-system reporting can be undertaken by the Department of Energy, Environment and Climate Action or a central government agency. Alternatively, an independent agency can monitor government progress in building resilience.¹²¹

Monitoring implementation of Victoria's adaptation action plans and evaluating their collective effectiveness can demonstrate successes and find areas for improvement. Reporting at the action, system and statewide level can build evidence of what works and guide future investment decisions. It can identify and address gaps and areas for improvement, particularly in addressing shared or cross-system climate risks where departmental accountability is less clear.¹²²

Incremental progress towards climate resilience

The United Kingdom has a well-established policy framework to reduce domestic emissions and promote adaptation action.

Their *Climate Change Act 2008* commits the UK to reduce its greenhouse gas emissions by 100% of 1990 levels (net zero emissions) by 2050. The legally binding emissions reduction target was the first of its kind.¹²³

The Act also set up an independent Climate Change Committee to advise government on emissions targets and report on progress in reducing emissions and preparing for climate change. It requires the UK Government to produce a Climate Change Risk Assessment and a National Adaptation Programme every 5 years.

The risk assessment shows the hazards and opportunities the UK faces from climate change and provides evidence that informs the development of adaptation actions. The third assessment was published in 2022.¹²⁴

The adaptation program is the government's response. The latest report sets out the actions that government and others will take to adapt to the impacts of climate change from 2023 to 2028.¹²⁵

The UK's 5-yearly cycle to review and update its adaptation program provides transparency on the actions taken to build resilience. The progress reports assess each sector's efforts.¹²⁶ Every 2 years the progress towards achieving effective adaptation is reported to Parliament.¹²⁷ This approach helps keep attention on climate change policy and means that sectors can make changes and improvements over time as new evidence becomes available.

Despite the strong policy framework, adaptation is still challenging to implement. The most recent progress report on adaptation found that the scale of action is not enough to prepare the UK for the climate risks it faces. It recommended a step change to fully embed adaptation in government policies and decision-making.¹²⁸

Image below: Mechanical diggers on a construction site in Cornwall, UK, repair coast defences and sea walls with rocks from a quarry after rising sea levels caused erosion and damage. Source: Shutterstock.



Coordinate and standardise climate projections

Climate change means that historical data is no longer a reliable indicator of future weather patterns and events.¹²⁹ Climate projections can help infrastructure managers determine how their assets are likely to perform in a future climate and how current infrastructure might be adapted.

Some infrastructure sectors, such as in water infrastructure planning, have begun to incorporate climate projections into decision-making about infrastructure management and new investment. But people in many other sectors do not feel equipped to do this. They report that they do not have the requisite skills to interpret the data, or that the data is not available in a form that they can easily apply to their infrastructure assessment tools.

Climate projections generally follow global standards set by the IPCC.¹³⁰ But they are complex to use. Future climate projections produce a variety of outcomes, often expressed as range of possibilities, because they are constantly evolving with new information.¹³¹ Understanding how to interpret them with confidence is difficult because they rely on highly technical datasets, containing multiple models and emissions scenarios. It is not obvious to infrastructure managers which data to use and for what purpose. Climate scientists recommend using multiple scenarios to account for the uncertainty surrounding Victoria's future climate (for example, high and low future emissions scenarios).¹³² Stakeholders told us that they struggle to interpret and apply climate data when assessing risks, developing policies and making investment decisions.¹³³

The Victorian Government has developed reports and climate projections data to provide insights into how Victoria's climate is changing. For example, *Victoria's climate science report 2019* provides a statewide summary of available evidence.¹³⁴ The Victorian Government and CSIRO have also developed *Victoria's future climate tool*, an interactive website that contains local area climate projections (to a spatial resolution of 5 kilometres) to make it easier for policy makers to visualise how the latest projections show climate change affecting Victoria.¹³⁵ Full datasets are available from the *Climate change in Australia* website.¹³⁶

These tools are valuable, but public servants need more support to use climate data properly in infrastructure planning. Climate projections model how different aspects of the climate are likely to change in the future, but they do not predict how extreme weather events will affect particular locations.¹³⁷ For example, average rainfall projections might indicate changes in flood risk. But actual flooding will depend on how intense storms are, detailed local geography and topography, and how much water can be absorbed by drains, land and waterways in different areas. Translating climate projections into sensible estimates of the frequency of hazards requires specialist knowledge that asset managers and policymakers typically do not have.

Victoria's future climate tool includes multiple climate models. Users are advised to use as many models as possible to explore the range of possible futures, or to carefully select the model that best suits the task at hand.¹³⁸ This involves a level of judgement, potentially leading to different models being applied to similar analyses or inappropriate data. Different infrastructure business cases may rely on different climate models and assumptions, making it difficult to compare costs and benefits for different proposals.

Ireland's meteorological service has developed a national set of standardised future climate projections to aid decision-making in multiple sectors, such as transport, energy and water. This is detailed in the case study: Ireland's Translate project helps people 'speak the same climate language' (p.36).

Recommendation 2: Coordinate and standardise climate projections

- Establish an agreed set of climate projections for use in government infrastructure planning and management, especially projections of extreme weather events.
- Keep improving local level data that infrastructure managers can use for site-specific analysis.
- Deliver training and ongoing support for infrastructure managers to apply the data to climate risk assessments.

Establish an agreed set of climate projections for use in government infrastructure planning and management, especially projections of extreme weather events

To make climate projections easier to apply, the Victorian Government should determine which climate models to use for different variables as standard to inform infrastructure decision-making across government. This should include work to translate these into standard parameter estimates for climate hazards and impacts. The government can regularly update the projections to incorporate new evidence from climate science as it becomes available.

For example, the government should produce standard projections of increases in the frequency and intensity of bushfires, storm events, flooding, and coastal inundation. These should include a central estimate of the parameters, which can be supplemented by a range of scenarios to indicate uncertainty. This is like the approach taken with official state projections in *Victoria in future* for populations and households.¹³⁹ It can remove the judgement currently required and improve consistency in assessing climate risks.

Keep improving local level data that infrastructure managers can use for site-specific analysis

The Victorian Government should keep improving local area climate projections. This will enable agencies to conduct site-specific risk assessments on the assets they manage and give government a clearer picture of priority locations and assets for infrastructure adaptation. The government should develop the data in collaboration with the National Partnership for Climate Change Projections so it is consistent with the *Climate projections roadmap for Australia*.¹⁴⁰

Deliver training and ongoing support for infrastructure managers to apply data

The government should accompany this with training and ongoing support for the relevant government staff to incorporate climate risks into asset management processes and investment decision-making. Sharing examples of risk assessments and business cases can assist them to learn and apply them consistently.

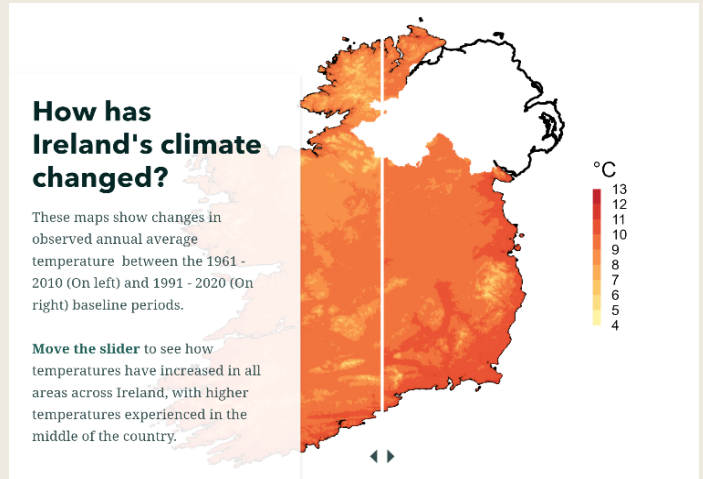
The next update to *Victoria's climate science report* is due by October 2024.¹⁴¹ This will be a timely opportunity to focus on the tools and support for Victorian Government agencies to incorporate climate data in asset management and investment decision-making (see also [recommendation 4: integrate climate risk into government risk management](#) and [recommendation 6: update business case and investment guidance](#)). The government can also review resourcing and governance for climate modelling, to determine whether there is merit in a dedicated body to develop and guide the use of climate change data in government decision-making.

Ireland's Translate project helps people 'speak the same climate language'

Communicating complex scientific information in a way that can be understood and actioned by policy and decision-makers is an issue shared around the world, particularly for climate change.¹⁴² To meet this challenge, the Translate project has developed standardised climate projections for Ireland alongside climate services that meet the information requirements of decision-makers.¹⁴³

Translate delivers a dataset to support Ireland's climate adaptation and mitigation efforts. Climate services communicate the data and information into products, such as risk assessments and uncertainty estimates, that are tailored to meet the needs of different stakeholders and sectors. For example, road managers are using Translate data to 'stress test' the rural road drainage system using future surcharge and flooding conditions. This will facilitate adaptation of vulnerable or exposed roads.

The project's aim is to deliver climate projections, information and services that are easily accessible to all users.¹⁴⁴ Translate released its first climate projections in June 2023. A follow-on project will build upon these results to develop more climate products and services for Ireland.¹⁴⁵



Ireland's Meteorological Service has developed a tool to communicate the impacts of climate change on the island's weather. Source: Met Éireann,

Image below: Silverstrand beach in Galway, Ireland. Source: Shutterstock.



Use asset management systems to improve resilience

Adaptation measures do not have to be expensive or involve large rebuilding or retrofitting of infrastructure in projects. We explored many different adaptation options focusing on physical adaptation measures to infrastructure, including improving maintenance, nature-based solutions and asset management standards. Managing existing assets so they still are fit for purpose for changing climatic conditions is cheaper than building new infrastructure. But much of Victoria's existing infrastructure might need to be maintained, managed differently, or retrofitted, to increase its climate resilience and keep critical services and communities functioning.¹⁴⁶

Climate risks to new infrastructure can be managed from the planning and design stages, well before building begins.¹⁴⁷ Managing climate risks means rethinking how and where infrastructure is built in the future to be more resilient to the effects of climate change.¹⁴⁸ For example, the Insurance Institute for Business and Home Safety is working with James Cook University in Australia to improve resilience of buildings from wind and rain events.¹⁴⁹

Victoria cannot build its way out of the problems posed by a changing climate. Building new assets will generate more greenhouse gas emissions, including from the materials and processes used in constructing it.¹⁵⁰ This means better using the infrastructure that already exists and planning for alternatives for networks, for example alternative evacuation routes. When rebuilding is unavoidable, *Victoria's infrastructure strategy 2021–2051* recommends rebuilding priority public infrastructure to more resilient standards or in less vulnerable locations.¹⁵¹

Increasing the resilience of infrastructure using better asset management practices minimises repairs.¹⁵² It reduces disruptions to people and communities. It also helps prevent shocks to businesses and freight supply chains, which helps Victoria maintain its productivity. But international studies have found that governments often overlook management of their existing assets.¹⁵³ A 2019 audit found that many Victorian Government agencies should improve their asset management practices.¹⁵⁴

The *Asset management accountability framework* is the government's policy framework for asset management.¹⁵⁵ The framework requires departments and agencies to assess their asset management maturity levels. Their 2020–21 self-reported assessments indicate that some areas of government can develop better knowledge of the performance of their full asset portfolio.¹⁵⁶

Good portfolio asset management involves organisations knowing the infrastructure they hold, the purpose it serves, the risks it faces, a strategy to manage each asset, and regularly reviewing the plan so it stays relevant.¹⁵⁷ Organisations can integrate climate adaptation into asset management practices using site-specific data and qualitative information as part of existing functions and processes to make infrastructure more resilient to a changing climate.¹⁵⁸

Recommendation 3: Use asset management systems to improve resilience

- Release climate change guidance on assessing climate vulnerability and risk, designing for resilience, and adopting preventative maintenance.
- Support agencies to develop the processes, tools and expertise to embed climate considerations in asset management practice.

Release climate change guidance on assessing climate vulnerability and risk, designing for resilience, and adopting preventative maintenance

Asset management maturity levels vary in different Victorian Government departments and agencies for different infrastructure types. Less mature practices focus on operational asset maintenance, where asset managers are still developing data and knowledge about the condition and performance of their assets. A more integrated approach builds infrastructure resilience to risk exposure such as climate change.¹⁵⁹ Asset managers told us they find it challenging to detect the vulnerability of their assets to climate change and to choose an appropriate adaptation response.¹⁶⁰

A step change can better incorporate resilience planning into Victorian Government asset management practices. Achieving this requires:

- using vulnerability and risk assessments to identify locations and infrastructure vulnerable to climate risks
- designing infrastructure facilities to be more robust to future climate impacts
- programming maintenance cycles and preventative maintenance so existing infrastructure can better withstand these impacts
- adjusting operations to prepare for and respond to extreme events.

Asset managers must have systems with sufficient maturity and the right information to conduct this type of analysis. Without such systems and information, it proves difficult to make the decision-making case for adaptation and overcome the hurdles and challenges that exist to incorporate resilience into asset management practices. Some private companies, such as insurance companies, might have better developed systems and data to conduct this analysis. Governments might be able to learn from these practices or access this data.

The Victorian Government does not clearly allocate responsibility for taking action to adapt infrastructure.¹⁶¹ The *Asset management accountability framework* requires agencies to manage their assets effectively and efficiently.¹⁶² The Department of Treasury and Finance is preparing to provide additional guidance on how climate risks to infrastructure can be assessed or managed, but this is yet to be published.¹⁶³ All infrastructure owners and operators must rapidly increase their asset management maturity to comprehensively consider climate change in their practice. This change is becoming more urgent because climate change effects are already occurring and will accelerate.¹⁶⁴

The government should release its planned accountability framework climate change guidance to build knowledge and capability to manage climate risks. The guidance should clarify responsibilities and demonstrate approaches to manage climate risks, including advice on standardised climate models and datasets (see also recommendations 2 and 4) The guidance should support asset managers to consider climate change and resilience at each stage of the asset management life cycle, which includes during asset planning, acquisition, operation and disposal (see recommendation 6: update business case and investment guidance).

Support agencies to develop the processes, tools and expertise to embed climate considerations in asset management practice

When the government releases new climate change guidance, it should also consider methods that assist asset managers to follow it. The Victorian Auditor-General found that the government can give more support and clarity to agencies to interpret and apply accountability framework requirements, and that agencies should keep investing in developing staff skills and their asset management systems to improve their performance.¹⁶⁵ Agencies will face similar challenges to incorporate climate considerations into asset management.

The government should deliver targeted training and support on adopting the new guidance. For example, it should develop further processes, tools and standards, and facilitate knowledge sharing and good practice between agencies, so staff can better understand the methods that can improve their asset management.¹⁶⁶

Collaboration and preventative approach better supports school asset management

Victoria's school buildings asset base includes over 1,500 schools, 27,000 buildings, land and other assets valued at over \$20 billion.¹⁶⁷ The Department of Education identified a \$420 million maintenance backlog in 2012. A 2017 audit attributed the backlog to government underfunding, a lack of attention to maintenance by schools and differences in school leaders' asset management capability.¹⁶⁸

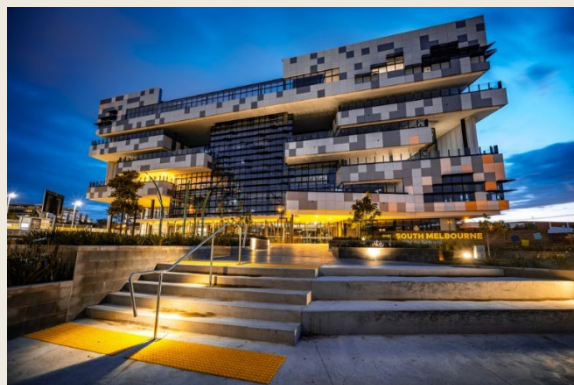
Victorian Government schools adopted a devolved governance model in the 1990s which put individual schools at the centre of decision-making, including for asset management. But the devolved model did not support the skills and systems development to keep pace with changes in asset management practice.¹⁶⁹ The department has since shifted towards more central support for schools, offering oversight and more resources to develop shared systems and processes.¹⁷⁰

The department established the Victorian Schools Building Authority in 2016 to oversee school design, construction and upgrades. It refreshed its asset strategy in 2018 and launched a new shared responsibility model. Individual schools remain responsible for asset condition, but the building authority offers school principals more support to grow their asset management capability. This includes a centralised IT system, consistent processes in the education system, and targeted training.

The new approach recognises that schools can be well-managed locally as principals and school communities understand their unique needs. The centralised IT system allows the department to monitor of the physical condition of its assets and it can use that information to advise on maintenance tasks, allocate central funding for high-priority maintenance, and inform capital funding allocations.

The Asset Management Reform program aims to move from reactive and backlog-driven maintenance to a more preventative approach. The department considers the program integral in reaching full compliance with the *Asset management accountability framework* and is rolling it out to schools progressively over the 5 years to 2023.¹⁷¹ The reforms are not specific to climate adaptation, but they offer lessons for other government agencies with devolved service models seeking to strengthen asset management practices and capabilities.

The department has identified climate adaptation for future improvement.¹⁷² The Asset Management Reform program places it in a much stronger position to act. The department can consistently assess portfolio data and assets. It has the tools and processes to embed climate resilience in school buildings.



The Asset Management Reform program helps Victorian schools better manage their buildings and other assets. Source: Shutterstock.

Integrate climate risks into government risk management

Not every piece of Victoria's infrastructure must be adapted, and of that which does, it cannot all happen at once. The Victorian Government can prioritise the infrastructure exposed to the highest priority risks. It can sequence adaptation actions by prioritising assets or combinations of actions by their potential exposure to the effects of climate change, their location and their value to the communities they support. This report helps identify some high-level infrastructure risks, barriers to adapting to them, and methods to select economically feasible infrastructure adaptation measures.

Evaluating what infrastructure is most vulnerable to climate change, and which is most critical, allows decision makers to prioritise actions. The challenge is for each department and agency to conduct their own climate risk assessments for their infrastructure. This should include detailed local assessments of assets to document their potential exposure and sensitivity to climate change effects. They can then identify measures and prioritise adaptation actions.

Risk assessments can use up-to-date climate projections to estimate how climate change might affect infrastructure and consider the likelihood and consequence of events. Incorporating climate projections into risk assessments allows infrastructure managers to assess the potential impacts of climate change, any emerging risks, and which risks the asset is exposed to. Decision makers can also use critical asset lists, alongside climate risk assessments, to prioritise what to focus on in a detailed evaluation of adaptation measures.

We documented numerous climate risks to government-owned and regulated infrastructure in our research, including electricity supply failure due to storms, extreme rainfall damage or disruption to roads and flood damage to hospitals.¹⁷³ Some local governments in Victoria have begun similar work by analysing climate damage and risks to their assets. The Eastern Alliance for Greenhouse Action has calculated that climate hazards cost greater Melbourne local governments \$90 to \$120 million annually. The same research projects that, without adapting infrastructure to climate change, this will increase to \$210 to \$300 million annually by 2050 and \$400 to \$540 million annually by 2100.¹⁷⁴ Local governments can use these estimates as a baseline assessment for their cost-benefit analyses of adaptation measures.

Climate change has relevance for several state-significant risks for Victoria, including the risk of harm to the economy, community, environment and government due to the physical effects of a changing climate.¹⁷⁵ The *Climate Change Act 2017* requires departments and agencies to consider climate risk when developing policies or making decisions.¹⁷⁶ Risk management is a guiding principle of the Act, but the government has not offered detailed advice on what this means for specifically managing climate risks to government assets.

The Victorian Government *Risk management framework* sets out the steps government agencies must take to manage risks effectively.¹⁷⁷ Agencies can tailor their approach to suit their organisational context, provided it is consistent with Australian Standard *AS ISO 31000:2018 Risk management – guidelines*.¹⁷⁸ The framework does not give examples of specific risks, including climate risks. It points instead to the Victorian Managed Insurance Authority for practical guidance.¹⁷⁹ Despite the severity of risks created by climate change, the *Risk management framework* does not necessarily prompt agencies to reflect them or show how to specifically address climate risks.

Some asset managers told us they do not know how to assess climate risks and develop appropriate responses. This compromises their ability to proactively plan for climate change and misses opportunities to identify cost-effective adaptation measures they can implement.¹⁸⁰ Because they have scarce funding, time and resources, asset owners and managers may focus only on immediate operational issues. This might not change unless agencies elevate their obligations to manage climate risks and have ready access to appropriate resources, information and tools.

Nangak Tamboree project increases university resilience to drought and flooding

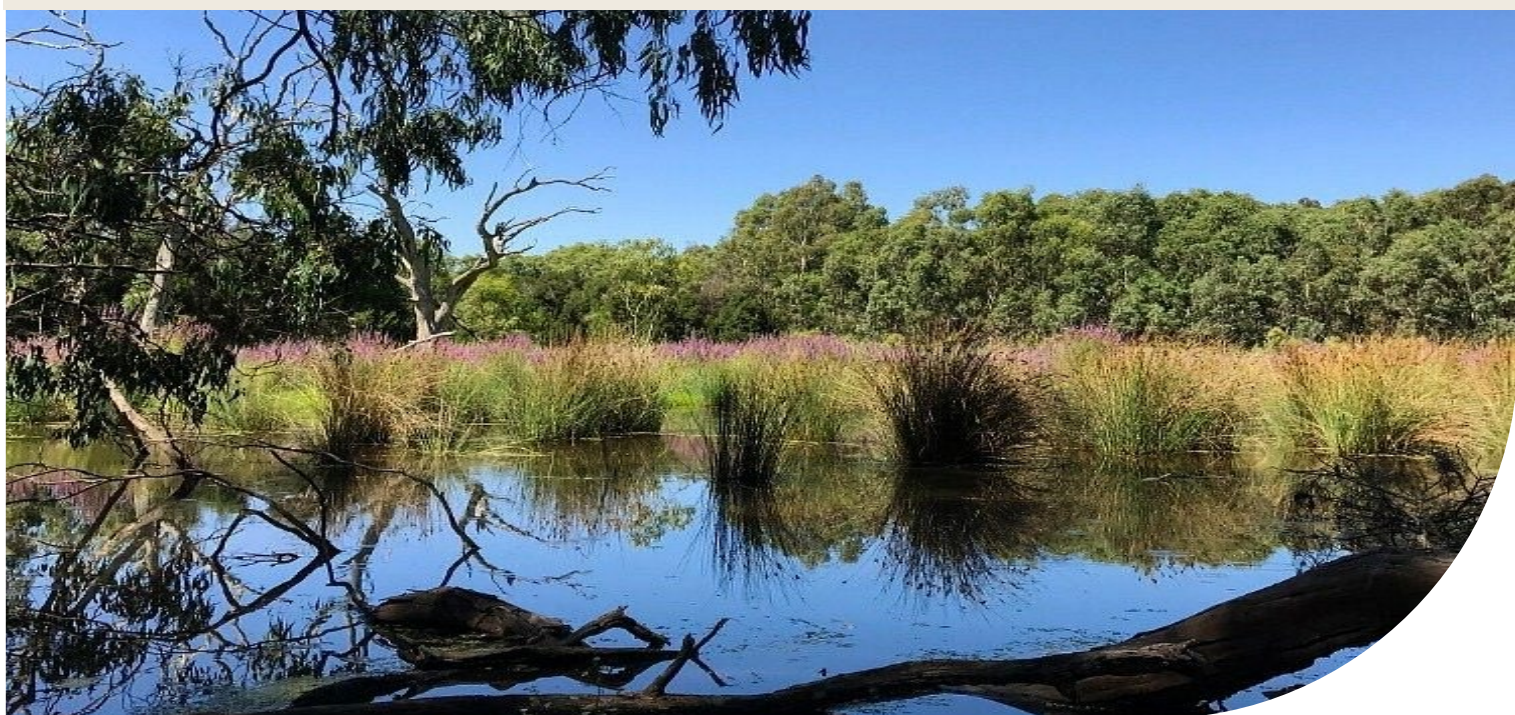
In 2018, La Trobe University conducted new flood modelling of their university campuses. The modelling showed that climate change increases the risk of severe weather events impacting the Bundoora campus. The university's analysis showed that the best way to reduce climate-related risks to students and staff was to restore the waterway which runs through the campus.

La Trobe engaged with stakeholders to develop a 10-year plan for the renewal of the waterway to absorb flooding rains and protect the university.¹⁸¹ The university also acknowledged the significance the waterway holds for the Traditional Owners, the Wurundjeri people.

The waterway was named Nangak Tamboree (a Woiwurrung phrase meaning respecting, sharing, and looking after the waterways) in a collaborative process with Traditional Owners.¹⁸² The university collaborated with Traditional Owners Melbourne Water, Darebin Creek Management Committee, and the Wurindjeru Woi-wurrung Cultural Heritage Aboriginal Corporation, First Nations Elders and community groups to lead the rehabilitation process through multiple projects, incorporated into the *Nangak Tamboree vision*.¹⁸³

The Wurundjeri Woi-wurrung Cultural Heritage Corporation reintroduced local land management practices such as cultural burning. The burns cleared invasive species from the waterway and revitalised native plant life. Following burns in 2021, the critically endangered Matted Flax-lily began growing in Nangak Tamboree. The plant can be found in grassy woodland, but it was previously unrecorded in the area. Its emergence shows the wetlands are returning to health and are more resilient to drought and flooding.¹⁸⁴

Image below: The Nangak Tamboree waterway has increased the university's resilience to drought and flooding, led by First Nations knowledge. Source: La Trobe University.



Recommendation 4: Integrate climate risks into government risk management

- Develop detailed guidance to accompany the Victorian Government *Risk management framework* on how to assess climate-related risks to infrastructure and integrate them into decision-making.

The government should develop information to guide departments and agencies through the steps involved in undertaking climate risk assessments for infrastructure and incorporating these into investment decision-making. These can align risk assessment processes with international standards specific to climate change, such as *ISO 14090:2019 Adaptation to climate change – principles, requirements and guidelines* and *ISO 14091:2021 Adaptation to climate change – guidelines on vulnerability, impacts and risk assessment*.¹⁸⁵ These climate standards can help departments and agencies to prioritise, develop and implement adaptation measures that respond to the climate challenges they face.¹⁸⁶

The new guidance can extend the Victorian Managed Insurance Authority's Climate Change Risk Management service, which includes introductory resources to help practitioners address climate risks.¹⁸⁷ The guidance should integrate with existing government policies and frameworks so that climate risk management becomes embedded in the usual business of government. This is like the approach taken in the New South Wales Government's Climate risk ready NSW guide.¹⁸⁸

We recommend that the guidance expands its scope to include approaches relevant to infrastructure, including aspects required for an economic assessment of climate adaptation (see also [recommendation 6: update business case and investment guidance](#)).¹⁸⁹ This can include information on:

- prioritising where to undertake site-specific climate risk analysis
- establishing a sensible base case to compare changes under different climate scenarios
- identifying potential infrastructure adaptation measures and shortlist priority interventions
- methods to assess the potential risk reduction from adaptation measures.

Alongside the proposed guidance, the government should consider changing the Victorian Government *Risk management framework* to incorporate clear examples of the type of risks agencies face. The framework describes minimum risk management requirements for agencies, but it does not reference climate change or any other state significant risk. Other jurisdictions take a different approach. For example, the New South Wales Government's *Risk management framework* lists climate and cyber security risks as examples of emerging risks that agencies should assess, and points to practical information on how to manage them.¹⁹⁰

This will complement [recommendation 3: use asset management systems to improve resilience](#) and [recommendation 6: update business case and investment guidance](#) by integrating considerations of climate change and adaptation into existing government policies and practices.

New South Wales climate risk process offers 4 practical steps to manage climate risks

The New South Wales *Internal audit and risk management policy for the general government sector* is a mandatory policy similar to the Victorian Government *Risk management framework*.

It extends beyond basic requirements to give examples of best practice.¹⁹¹ The policy adopts Australian Standard AS ISO 31000, the same as Victoria, and flags climate-related risks as emerging risks that agencies should address.

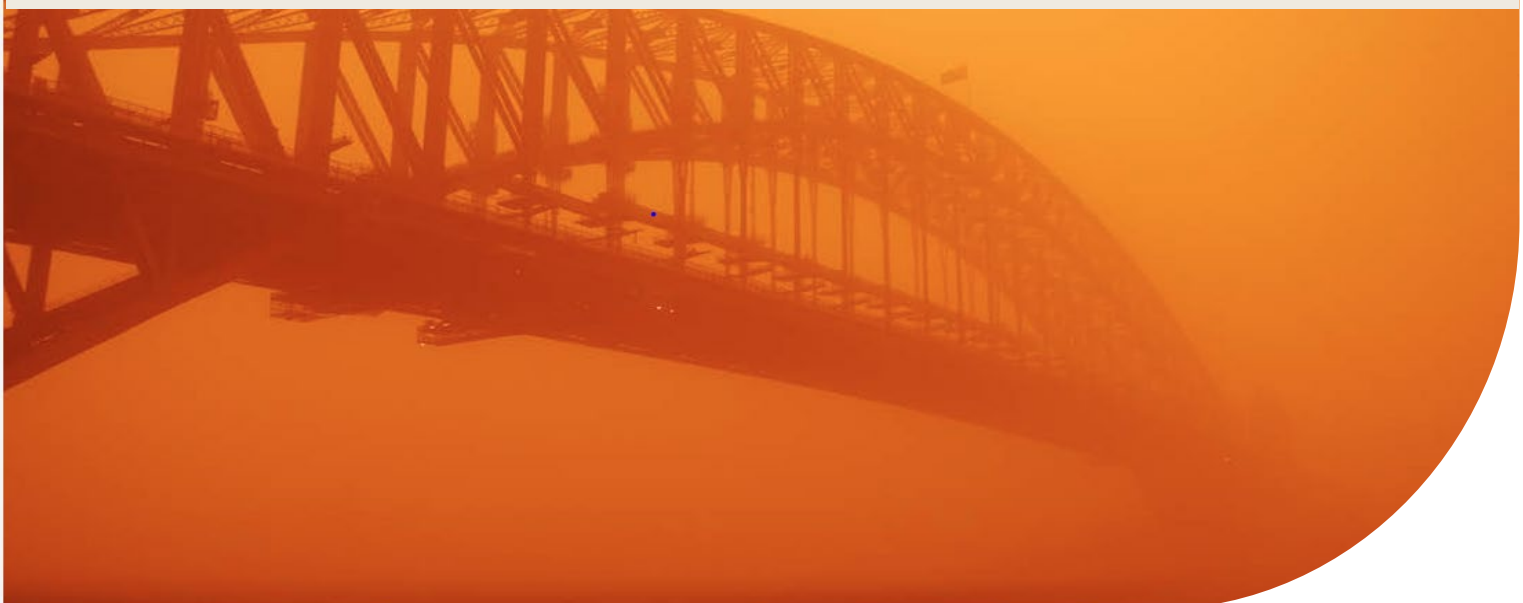
The *Climate risk ready NSW guide* details how agencies should do this.¹⁹² It draws on the international standard on adaptation to climate change (ISO 14091:2021) alongside AS ISO 31000 to use a 4-step process to achieve a consistent approach to climate risk assessment and management.

The guide has actions and objectives for agencies at each step of the process. It makes recommendations on data and information sources to use in climate risk assessments and offers tools to help agencies put the process into practice. It links into other New South Wales Government policies and guidance so that climate risk management becomes embedded in agency operations.

Training is available to help agencies assess, treat and monitor climate risks and embed these practices into existing risk management systems.¹⁹³ Victorian Government agencies would benefit from something similar.



Outline of the Climate risk ready NSW process aligned to AS ISO 31000. Source: *Climate risk ready NSW guide*. Photo below: Sydney Harbour Bridge during a red dust storm. Photo: John Byrne



Reduce financial risks and target funding

Align climate and financial risks to infrastructure

The Victorian Government spends billions of dollars responding to emergencies, and helping communities recover afterwards. The Melbourne Sustainable Society Institute estimates that climate damage in Victoria will cost nearly \$1 trillion by 2100 without action to reduce emissions and adapt infrastructure.¹⁹⁴

Climate change creates financial risks for government, including the cost of repairing damage to government assets. Our research identified over 40 high-level climate-related risks to Victoria's infrastructure.¹⁹⁵ If these risks are realised, communities will expect the government to spend more to restore critical infrastructure and services. Insurance premiums might also cost more as climate events intensify.¹⁹⁶ The Organisation for Economic Co-operation and Development recommends that governments invest more to prevent risk. This can reduce the financial losses from climate events.¹⁹⁷

The Victorian Government does not document the financial risks of climate change in its financial reporting or financial management objectives. The *Financial Management Act 1994* and supporting legislative instruments set out public financial administration processes and allocate financial management responsibilities for government agencies. The Act directs government agencies to manage the state's financial risks, including risks to infrastructure, but it does not refer to climate change.¹⁹⁸

The Act requires the government to document its long-term financial objectives based on sound financial management principles. These include considering the financial effects of government policies on future generations.¹⁹⁹ The government's most recent financial objectives include building new infrastructure and fostering a resilient economy. They do not mention infrastructure or community resilience to the effects of climate change. This means that climate adaptation objectives do not explicitly influence the government's financial policy, priorities or practice.²⁰⁰

The government has several major policy frameworks relevant to infrastructure adaptation, made under the Act, including:

- the Victorian Government *Risk management framework*
- the *Asset management accountability framework*
- the *Resource management framework*.

These frameworks do not reference climate change or specify integration of climate considerations.²⁰¹ The government will not have direct knowledge of its financial exposure to climate-related risks if it does not compel agencies to assess the financial risks of climate change on the assets they manage.

Recommendation 5: Align climate and financial risks to infrastructure

- Include climate adaptation in the government's long-term financial management objectives for infrastructure.
- Require agencies with infrastructure holdings to prepare climate-related financial risk disclosures.

The government should manage the financial risks of climate change by including infrastructure adaptation and climate resilience in its long-term financial management objectives. This will help make the financial costs of climate change explicit.

The government should know more about its climate-related risks to infrastructure so it can assess the financial implications. The government can do this by requiring departments and agencies with infrastructure holdings to prepare climate risk disclosures each year to provide more financial rigour for the Victorian Government climate-related risk disclosure statement.²⁰² This reporting offers a regular process to regularly review climate-related financial risks to infrastructure.

Internationally, many companies must already make climate-related risk disclosures, including some with an Australian presence. Government might adapt some practices and lessons from these companies in their own disclosure processes. Agencies might need more resources to implement these new reporting requirements.

Recommendation 3: use asset management systems to improve resilience, recommendation 4: integrate climate risk into government risk management and recommendation 6: update business case and investment guidance, also reinforce this recommendation.

Climate-related financial risk disclosures

In 2015, the International Financial Stability Board created the Task Force on Climate-Related Financial Disclosures to improve reporting of climate-related financial information.

The task force developed consistent disclosure guidance for companies and banks, so that investors can better assess their climate-related risks and opportunities.²⁰³

The Australian Government has committed to introducing standardised reporting requirements for large businesses and public sector entities to make climate-related disclosures on governance, strategy, risk management, targets and metrics.²⁰⁴

Other countries have introduced mandatory climate-related disclosures or are developing new requirements, including the United Kingdom, New Zealand and Singapore.²⁰⁵

Climate-related financial risk disclosures were developed for private businesses, but they can be applied to the public sector.

The Victorian Government prepared a climate-related risk disclosure statement in 2022.²⁰⁶ Other jurisdictions are considering similar measures. For example, the New South Wales Government completed a pilot for 3 public sector organisations to produce climate disclosure statements in 2022.²⁰⁷

The government can potentially extend this mechanism to clarify how its departments and agencies are managing climate-related financial risks and opportunities, including risks to infrastructure.

Governments also use other mechanisms for this. For example, the Australian and New South Wales governments assess long-term budget risks, including climate change risks, by producing intergenerational reports.²⁰⁸

These reports project 40 years into the future to estimate how global and local trends might affect the economy and budget. The Victorian Government does not do this.

Update business case and investment guidance

More resilient infrastructure can reduce future costs of climate change.²⁰⁹ Our research confirms that climate change poses increasingly severe risks to infrastructure. It also shows that infrastructure managers could find adaptation measures that can reduce the long-term economic, social and environmental costs of extreme weather events.²¹⁰ But current government practices do not seek, identify or select these measures.²¹¹ In part, this is because they do not routinely assess the costs of climate change, use them for making investment decisions, or disclose them in business cases for budget funding.

The financial costs of climate change go beyond the direct cost of infrastructure damage. This research also examined the indirect impacts of climate change. These include disruptions to services and supply chains, loss of productivity and lower incomes in disaster affected areas.²¹² For example, we analysed a bushfire affected road in a regional area. We found the disruption to freight and passenger vehicles was the single largest indirect cost and exceeded the cost of damage to the road itself.²¹³

Adaptation measures can also have costs other than their financial costs. For example, we measured the cost of embodied carbon emissions of each adaptation measure we tested.²¹⁴ Infrastructure produces embodied emissions by using materials that generate greenhouse gas emissions in their production and transportation, and by releasing greenhouse gases during construction. Adaptation assessments should measure embodied emissions because infrastructure projects can generate many greenhouse gas emissions. For example, we measured greenhouse gas emissions for different adaptation measures for roads prone to flooding. Building a road viaduct provides strong resilience to flooding. But we found that building a viaduct would produce 5 times more carbon emissions than the next most carbon intensive option, because it used a large volume of materials and required heavy construction.²¹⁵

Infrastructure operators should fully account for the costs of climate change and factor them into their operational costs and any business cases for adaptation action. This includes calculating the embodied emissions inherent in some adaptation measures and calculating their differential costs against the base case.

But because the government does not require infrastructure managers to include these costs, and does not give clear direction on their measurement, they make fewer investments in adaptation planning, preparation and resilience.²¹⁶ Stakeholders told us that they are unsure how to use risk assessments to identify investment proposals. They said they struggle to quantify the costs and benefits of adaptation action. They are also unsure how to assess potential adaptation measures and build a case for investment.²¹⁷

Measuring climate costs and incorporating climate science into business cases can be difficult. The effects of climate change are difficult to quantify, and the impacts are not immediate.²¹⁸ The benefits of adaptation can be hard to calculate because they are not solely financial savings. For example, adaptation measures can have positive impacts on the environment and can improve community resilience to climate change.²¹⁹

These factors make it difficult for infrastructure managers to proactively plan for and invest in adaptation measures when they face competing priorities for resources and funding. Assessors must consider and quantify as many costs and benefits as possible to produce a rigorous investment analysis for decision makers. Decision makers also have to consider other strategic objectives, including achieving net zero emissions, among other social, environmental and economic outcomes.²²⁰

Our work demonstrates how infrastructure operators can capture both quantifiable and unquantifiable factors, and where further research can support decision makers.

Implementing climate change adaptation in decision-making and guidelines

Many European road authorities find that climate change has large effects on their assets, operations and services.

They have developed frameworks to assess the impacts of climate change, but some find fully embedding these frameworks challenging. This is because staff do not know how to use these frameworks in their ordinary work to build the case for adaptation. They also have challenges in identifying appropriate data, capacity and resources.

The Conference of European Directors of Roads has initiated the ICARUS project. It identifies current barriers and gaps in the application of resilience assessments and makes suggestions on ways to overcome them.²²¹

The project uses the key performance indicators of road authorities and some of their other policies. It shows how adaptation measures can work within an organisation's existing policies and processes to build the case for adaptation.

It aims to produce:

- a baseline for climate change resilience assessments, resilience evaluation and the use of cost-benefit assessments for climate change adaptation
- a report on the use of impact chains of direct and indirect impacts
- guidelines on defining and using optimum service levels for evaluating resilience and adaptation options
- guidelines that show and explain adaptation measures that can be applied to the specific processes road authorities use
- a demonstration report showing how evaluations of adaptation measures include their wider benefits
- a report showing the factors associated with successfully delivering nature-based solutions
- resource training for different target audiences to ensure implementation of output.²²²

This work seeks to better implement resilience into existing asset and maintenance guidelines and decision-making processes. Victorian Government agencies would benefit from similar measures embedding resilience into business cases and decision-making processes.

Recommendation 6: Update existing business case guidance

- Update existing business case guidelines, technical guidelines and templates to include the risks and impacts of climate change.

Infrastructure managers told us that difficulty securing funding prevents them from investing in infrastructure adaptation.²²³ They said fiscal constraints are further hampering climate change adaptation efforts, as Victoria is still recovering from the financial cost of the COVID-19 pandemic, supply chains are recovering from disruptions, and inflation is high.²²⁴

The Victorian Government's *Investment lifecycle and high value high risk guidelines* help agencies to develop investment proposals, inform government investment decisions and monitor project delivery.²²⁵ The *Investment management standard* also supports this.²²⁶ These guidelines direct agencies to consider climate adaptation and resilience when developing infrastructure investments, but do not give practical advice on how to assess climate vulnerability or consider climate risk when developing investment proposals.

A technical supplement guides the economic evaluation of investment decisions for infrastructure, but it does not cover physical risks from climate change.²²⁷ The *Sustainable investment guidelines* give advice on incorporating sustainability into project planning and delivery, but they are not detailed enough to guide asset managers in justifying adaptation options for investment decision-making.²²⁸ If project proponents do not have clear guidance on how to incorporate climate considerations, they will not be included in infrastructure decisions.

Victorian Government agencies can benefit from practical guidelines and worked examples of incorporating climate change into cost-benefit analyses and business cases. The government should clarify in the *Investment lifecycle and high value high risk guidelines* and the *Long form business case template* how agencies can incorporate climate change into investment decision-making. For example:²²⁹

- Revise questions in the checklist for business case developers and assessors that discourage proactive action on climate adaptation (for example, in the investment case section: 'Does the problem need to be addressed now and by this government?').
- Add climate risk and vulnerability assessment to the list of tasks agencies should undertake when considering a new investment (section 2.1 'How long-term planning relates to this stage').
- Incorporate climate change scenarios in the investment base case (section 2.5.1 'Defining the base case – the first response option').
- Require agencies to undertake a climate risk assessment when building the business case for all high value infrastructure investments and point to our recommended climate risk assessment guidance (see [recommendation 4: integrate climate risk into government risk management](#)). This can be added to section 2.6 Step 4: 'Project options assessment of the *Investment lifecycle and high value high risk guidelines – business case*'.
- Update the *Long form business case template* to require agencies to record the options they considered to embed resilience, their recommended approach, and the financial implications of each.²³⁰

The government should update the *Economic evaluation for business cases: technical guidelines* to include consideration of climate risks.²³¹ These should direct agencies to incorporate climate risk assessments into infrastructure cost-benefit analysis and give examples of how this can be approached, linking with other relevant guidance. Updates will offer the government an opportunity to review its current preferred discount rates to determine whether the current approach

appropriately accounts for the long-term effects of climate change and adaptation action (see Discount rates and climate change below for further details).

The updated business case guidance will work with our recommendations to use asset management systems to improve resilience ([recommendation 3](#)) and integrate climate risks into government processes ([recommendation 4](#)) to guide agencies in how to consider climate change risks throughout the infrastructure lifecycle.

Discount rates and climate change

Discount rates convert future costs and benefits to current values

Analysts use cost-benefit analysis to assess the relative merits of different policies and proposals, including infrastructure investments.²³² Discount rates allow them to compare costs and benefits produced at different points in time.²³³

The Victorian Government recommends using a discount rate of 7% when an analysts can easily translate proposed benefits into monetary terms, such as for housing and roads. They recommend a rate of 4% when benefits are more difficult to quantify, such as in public health and education.²³⁴

Higher discount rates devalue future costs and benefits

The discount rate affects the value of costs and benefits produced at different points in time. For example, they will affect the assessed value of avoiding future costs in a climate adaptation project.²³⁵

Projects usually have large upfront costs but produce accumulated benefits in the future. When a project produces benefits in the distant future, a higher discount rate places less value on those future benefits. This means that analysts will calculate a lower ratio of benefits to costs for that project. Higher discount rates favour benefits for present generations over future generations. This means that adaptation projects might not compare favourably against projects that deliver more immediate benefits.

The government can review its discount rate guidance

Policy and investment decisions acting on climate change will have large impacts many generations from now.²³⁶ Decisions that do not appropriately factor in the long-term costs and benefits of climate change will have far-reaching consequences if they contribute to poor future resilience.

Other jurisdictions are starting to do things differently. For example, New South Wales lowered its standard discount rate from 7% to 5% in 2023.²³⁷ The United Kingdom uses discount rates that decline over time to evaluate long-term projects, starting at 3.5% for years 0 to 30, falling to 3% for years 31 to 75 and 2.5% for years 76 to 125.²³⁸ Analysts can also conduct sensitivity tests to different discount rates to show their effects.

Build confidence that good adaptation measures will receive funding

The Victorian Government has not attached dedicated resources or funding to its adaptation action plans. They instead entwine adaptation funding with broader climate action funding, including for reducing greenhouse gas emissions and recovering from emergencies. This means funding for adaptation and resilience measures can easily be overlooked in the budget allocation process. For example, the 2023–24 Victorian Budget included over \$2 billion for climate action, nearly all of which was directed to emergency management and recovery, skills development, transport emissions reduction and \$1 billion towards new renewable energy projects.²³⁹

Infrastructure adaptation measures can sometimes need upfront investment. In some cases, the government might need to fund new infrastructure to better protect communities from more frequent and intense weather events. It might need to adapt current infrastructure systems, including energy and transport, to function in more variable future weather conditions or return to service quickly after extreme events. The government might also need to retrofit some public buildings to stay safe and comfortable during more intense heatwaves and other extreme weather.²⁴⁰ Government agencies can fund some infrastructure adaptation measures from existing maintenance budgets. Other measures will need extra funding to implement change or for major capital works.²⁴¹

Infrastructure managers report that they are not confident that the government will fund even the best adaptation projects. The government has limited resources over and above existing budgets for new adaptation projects. But conducting risk analysis, vulnerability assessments, and cost-benefit analysis takes time and resources. Infrastructure managers are hesitant to do this work if they believe that adaptation projects will not be funded afterwards.

Carefully chosen infrastructure adaptation projects can deliver benefits that outweigh the costs of repairing and rebuilding infrastructure following catastrophic events.²⁴² Our cost-benefit analysis shows examples of specific adaptation measures that demonstrate a positive benefit over time.²⁴³ For example, we identified 16 priority adaptation measures to adapt roads against the impacts of floods and bushfires. Most of them outperformed the base case (the scenario of ‘taking no action’) and produced a positive return on investment. For example, foamed bitumen stabilisation and water sensitive urban design have the highest return on investment under both current climate conditions in 2022 and future climate conditions in 2070 under a high emissions scenario, even when using different discount rates.

The availability of government funding will affect the extent of adaptation action.²⁴⁴ But governments still prioritise funding for emergency response and repair over proactive investments in resilience, despite the potential benefits. The Productivity Commission estimates that the Australian Government spends just 3% of its natural disaster funding on preventative measures.²⁴⁵ If governments keep underinvesting in resilience, they will produce higher economic, social and environmental costs over time.²⁴⁶ A temporary increase in government spending can help break the cycle of low upfront investment and high repair and recovery costs.²⁴⁷

The United Kingdom’s Climate Change Committee identified unreliable and inconsistent funding as a major barrier to improving infrastructure’s resilience.²⁴⁸ Stakeholders confirmed this during our research.²⁴⁹ Agencies are unlikely to allocate resources towards infrastructure adaptation if it is not a funding priority for government.

Recommendation 7: Build confidence that good adaptation measures will receive funding

- Attach funding to the 2026 updates of the system-wide adaptation action plans, to encourage government agencies to evaluate and prioritise assets for adaptation and incorporate adaptation into business cases.

The Victorian Government can signal to agencies that the release of the 2026 adaptation action plans will include funding for adaptation actions with strong business cases. The Victorian Government should establish a Climate Adaptation Fund for the 2026 update. This will allow agencies to bid for funding for adaptation projects that they cannot fund from existing budgets and give confidence that priority projects will be considered. This can encourage government departments and agencies to incorporate adaptation in their business cases. To do this, they would first conduct appropriate risk and vulnerability assessments and have rigorously selected high-performing adaptation measures.

Agencies should audit the infrastructure in their portfolio, prioritise assets at high risk of being affected by climate change and identify adaptation measures to mitigate these risks. The next adaptation action plans should include concrete adaptation measures for assets facing near-term climate risks that can also demonstrate a return on investment. Community and stakeholder consultation on the draft plans can help further prioritise potential adaptation actions and inform likely funding requirements.

The Victorian Government has previously established climate adaptation funds. For example, it allocated dedicated funding for adaptation in the Supporting Our Regions to Adapt program, which funded Victoria's regional adaptation strategies and initial implementation of priority projects.²⁵⁰ Other jurisdictions have established targeted funds for infrastructure adaptation, such as the New Zealand Transport Agency's NZ\$419 million Transport Resilience Fund. This invests in preventative resilience projects on state highways and local roads to better protect the transport network.²⁵¹ The Canadian Government also supports adaptation with dedicated financial resources. Since 2018, it has invested CA\$3.86 billion in more than 80 projects, as the next case study shows.

Similarly, the Greener Government Buildings program allows government agencies to secure funding outside routine maintenance requirements. It funds energy efficiency initiatives for existing government buildings.²⁵² It is self-funded through operating cost savings from lower energy use. The proposed Climate Adaptation Fund will not be self-funded, but more resilient infrastructure can deliver substantial savings over time including lower repair and recovery costs from extreme weather events and improved social and economic outcomes.

Canada links infrastructure financing to climate risk

Climate change is already costing Canadians billions of dollars each year. Over the last 5 decades, the costs of climate-related disasters have risen from tens of millions to billions of dollars each year.²⁵³

The Canadian Government launched its national climate adaptation strategy in 2023, to reduce risks from extreme weather events and limit the impacts of global warming.²⁵⁴

The government recognises it should scale up adaptation and build resilience into infrastructure. This is reflected in its adaptation strategy, which specifies that climate resilience will be factored into all new Canadian government funding for infrastructure from 2024.

The strategy sets the expectation that 80% of public organisations will factor climate change adaptation into decision-making processes by 2030, supported by robust guidance covering climate risks for infrastructure systems.²⁵⁵ This is a significant step to integrating climate considerations into infrastructure planning and decision-making throughout Canada.²⁵⁶

The Canadian Government is supporting adaptation with dedicated financial resources. Since 2018, it has invested CA\$3.86 billion in more than 80 projects, most to address flood and wildfire risks. It has also established a CA\$200 million Natural Infrastructure Fund, Canada's first fund dedicated to nature-based solutions.²⁵⁷ Both funds help manage the risks and impacts of climate change while generating other benefits such as enhancing natural habitats or increasing green space for communities.²⁵⁸ Adaptation measures can therefore have benefits in addition to reducing climate risk.

Image below: The Parliament of Canada, located on Parliament Hill, Ottawa, Ontario, Canada. Source: Shutterstock.



Sequencing adaptation responses can help manage uncertainty

Adapting the right infrastructure, in the right order, can achieve better results. It is possible to create flexibility in planning for future climate change events by staging the implementation of adaptation measures as more information becomes available. This is known as an adaptive pathway approach and can help determine how likely different future climate change scenarios are, or decide what the consequences are from decisions made today.²⁵⁹ This approach allows consideration of multiple possible futures to test the likely effect of different adaptation options.²⁶⁰ It provides the flexibility to adapt to changing circumstances and future uncertainties.

Adaptation pathways also recognise that different adaptation measures can have complementary effects and build on each other over time. Options can be sequenced as a long-term plan.²⁶¹ This can be adjusted and updated as new information becomes available or as climate conditions evolve.²⁶² By adopting this approach, decision-makers can make best use of limited resources and achieve a higher level of overall resilience over time.²⁶³

Our cost-benefit analysis of road network adaptation explored sequencing to respond to increasing climate hazards over time. In this example, a staged approach allows the resilience of the road to be reassessed after the first adaptation measure has been implemented and defers the cost of large road upgrades until the benefit of further action in the future is justified as more information emerges.²⁶⁴

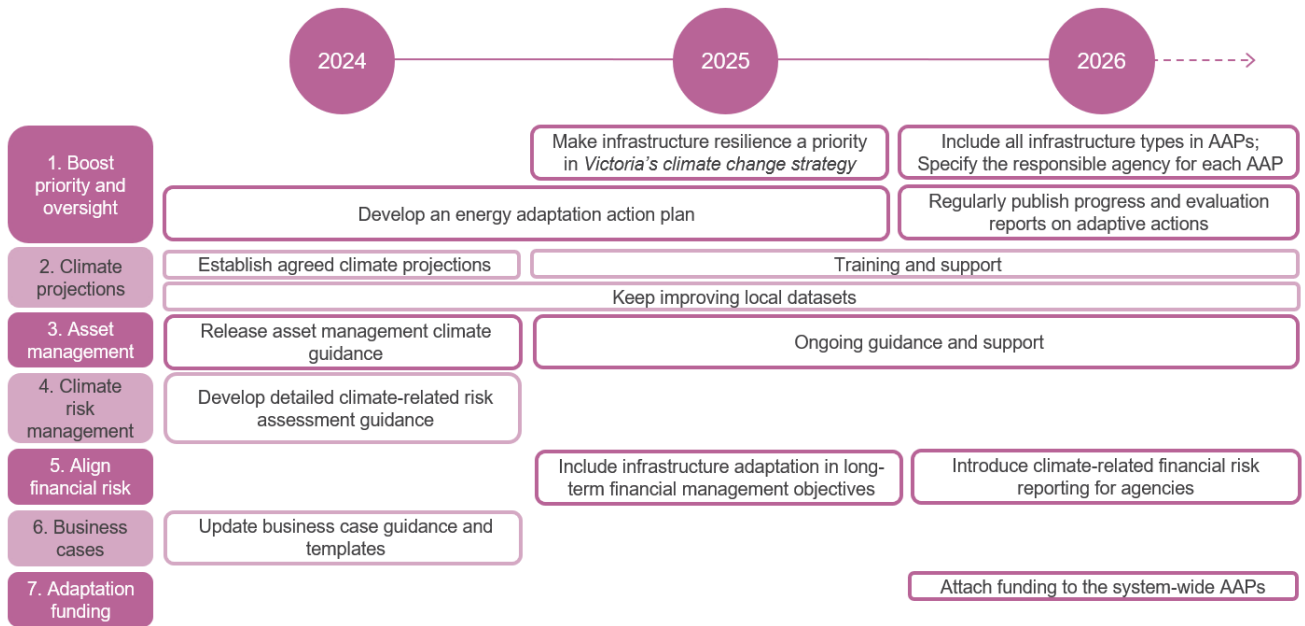
The combined impact of multiple adaptation measures can be more effective. It encourages a coordinated approach to adaptation, where measures are planned and sequenced to create a more resilient and adaptive system. Sequencing and potentially bundling adaptation measures can be a cost-effective way to improve baseline resilience.²⁶⁵

Implementation of adaptation measures can be coordinated and sequenced for greater effect to create better resilience outcomes. For example, not all adaptation measures need to be put in place at once. They can be added over an extended timeframe with staged investment, as more information becomes available. This can also help with budgeting for measures that must be implemented now for high-risk vulnerable areas, and those measures that can be added later.

Further details on how to approach infrastructure planning under uncertainty are available in our methodology report. Sequencing the implementation of adaptation measures improves their effectiveness by maximising their impact, reducing the impacts of climate change and maximising a return on investment.

Figure 6 (below) sets out a proposed timeline for the Victorian Government to implement our recommendations.

Figure 6: Timeline for Victorian Government action (note: AAPs = adaptation action plans)



Glossary

Term	Definition
adaptation	Adaptation is adjustment within natural or human systems in response to actual or projected stimuli or their effects, which aims to moderate harm or exploit beneficial opportunities.
adaptation action plans	Victoria has 7 system-based adaptation action plans. The plans guide Victorian Government adaptation efforts in each sector. The 7 sectors are the built environment, education and training, health and human services, natural environment, primary production, transport, and water cycle systems.
adaptation measure	A specific action implemented to reduce the impacts of climate change.
adaptive capacity	The ability for infrastructure or a system to successfully adjust to, take advantage of or respond to the consequences from climate change impacts.
adaptive pathway approach	Sequences of interlinked and flexible adaptive actions and decision points, which can be implemented progressively over time depending on future dynamics and changes to climate change risks.
benefit-cost ratio	An indicator used to estimate the overall value-for-money of a project or proposal. A BCR greater (or less) than one means the net present value of all benefits exceed (or is smaller than) the net present value of costs.
business case	A business case is a document that establishes an investment need, defines its benefits, explores interventions, estimates costs and confirms a preferred solution is deliverable.
carbon	A naturally occurring gas, also a by-product of burning fossil fuels from fossil carbon deposits, such as oil, gas, and coal, of burning biomass, of land use changes, and of industrial processes (e.g. cement production). It is the principal anthropogenic greenhouse gas that affects the Earth's radiative balance.
critical asset	Critical assets (physical, data/information, intellectual, process, technology) are those that are essential for supporting the social and business needs of both the local and national economy.
cascading impacts	Occur when an extreme hazard generates a sequence of secondary events in natural and human systems that result in physical, natural, social or economic disruption, whereby the resulting impact is significantly larger than the initial impact.
compounding impacts	The combination of multiple drivers and/or hazards that contributes to societal and/or environmental risk.

Term	Definition
catastrophic event/s	Natural or man-made incident that causes extreme levels of damage, harm or disruption to the community.
climate change	A change in the state of the climate that persists for an extended period, typically decades or longer. Human-induced climate change is the result of a growing concentration of carbon and other greenhouse gases in the atmosphere
climate hazard	A phenomenon or human activity that may cause loss of life, injury or other health impacts, property damage, social and economic disruption or environmental degradation.
climate projections	<p>A simulated response of the climate system (including variables such as temperature, precipitation, wind, solar radiation, sea level) to a scenario of future emissions or concentrations of greenhouse gases and changes in land use, generally derived using climate models.</p> <p>Climate projections depend on an emission scenario, in turn based on assumptions concerning factors such as future socioeconomic and technological developments that may or may not be realised.</p>
climate model	Simulation of current and future climate change projections using modelling techniques.
cost-benefit analysis	A structured method that quantifies in monetary terms as many of the costs and benefits of a proposal as far as possible, including items for which the market does not provide a satisfactory measure of economic value.
disaster	Situation where widespread human, material, economic or environmental losses have occurred which exceeded the ability of the affected organisation, community or society to respond and recover using its own resources.
discount rate	A percentage rate used to convert future costs and benefits into present values to allow costs and benefits occurring at different points of time to be compared.
direct costs	Quantifiable losses incurred as a result of an event that have a direct market value, including damage and downtime of the asset from climate related hazards.
embodied emissions	The type of greenhouse gas emissions associated with materials used in construction, maintenance and disposal of infrastructure. This includes the emissions from the extraction, manufacturing, transportation, installation, maintenance, renovation and disposal of the materials used in these processes.
exposure	The presence of people, livelihoods, species or ecosystems, environmental services and resources, infrastructure, or economic, social, or cultural assets in places that could be adversely affected by a hazard.
extreme weather event	An event that is rare at a particular place and time of year. The characteristics of what is called extreme weather may vary from place to place.
geospatial analysis	Visualisation and mapping of the exposure of vulnerable assets and operations in areas based on proximity to climate hazards.

Term	Definition
greenhouse gas emissions	The production of gaseous constituents of the atmosphere, both natural and human-made, that absorb and emit radiation at specific wavelengths on the spectrum of terrestrial radiation emitted by the Earth's surface, the atmosphere itself, and clouds. This property causes the greenhouse effect.
hazard	The potential occurrence of a natural or human-induced physical event or trend or physical impact that may cause loss of life, injury, or other health impacts, as well as damage and loss to property, infrastructure, livelihoods, service provision, ecosystems, and environmental resources.
indirect costs	Quantified flow-on consequences from downtime, including economic costs of disruption to freight and the community.
infrastructure life cycle	The process from the beginning of design through to the end of the asset's life, including planning, development, construction, use, and decommissioning.
intangible	Direct and indirect damage that cannot be easily quantified in monetary terms, such as impacts on biodiversity, nature and health.
maladaptation	Actions that may lead to increased risk of adverse climate-related outcomes, including generating more greenhouse gas emissions, increased or shifted vulnerability to climate change, more inequitable outcomes, or diminished welfare, now or in the future. Most often, maladaptation is an unintended consequence.
mitigation	Actions taken to reduce greenhouse gas emissions or increase the amounts of greenhouse gases removed from the atmosphere.
net zero emissions	A state where the amount of greenhouse gas emissions produced by human activities equals the emissions removed from the atmosphere.
overlays	An overlay is a planning instrument/tool that applies to land with special features such as flood or bushfire risk.
preventative measures	The use of predictive analysis to forecast asset failure and reduce the risk of failure by scheduling maintenance ahead of time based on historical data.
programmed drainage clearing	Clearing of surface and sub-surface drainage to reduce the extent and frequency of climate impacts.
recovery	The coordinated efforts and processes used to bring about the immediate, medium-term, and long-term holistic regeneration and enhancement of a community following an emergency.
resilience	The ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events. This involves the capacity of a system to continue providing services, when exposed to hazards or if a disruptive event occurs, in a timely and efficient manner, including by preserving and restoring its essential basic structures and functions.

Term	Definition
retrofit	Addition of new technologies or features to old assets.
return on investment	A measure of the efficiency of an investment, expressed as a percentage or ratio by subtracting the cost of the investment from the gain from the investment and then dividing this amount by the cost of the investment.
risk	Effect of uncertainty on objectives or system operation. Risk is often characterised by reference to the likelihood of potential events, consequences, or a combination of these and how they can affect the achievement of objectives or system operation. Risk is often expressed in terms of a combination of the consequences of an event or a change in circumstances, and the associated likelihood of occurrence.
risk assessment	Process of comparing the results of risk analysis against risk criteria to determine whether the level of risk is acceptable or tolerable. Process to comprehend the nature of risk and to determine the level of risk. Risk analysis provides the basis for risk evaluation and decisions about risk treatment.
robust	The strength or ability of elements, systems and other units of analysis to withstand a given level of stress or demand without suffering degradation or loss of function.
sensitivity	The degree to which a system is adversely or beneficially affected by hazard-related stimuli.
site-specific analysis	Analysis of local conditions and resource planning specific to an asset and its location.
vulnerability	The degree to which a system is susceptible to, or unable to cope with, adverse effects of hazards, including climate change, variability and extremes.

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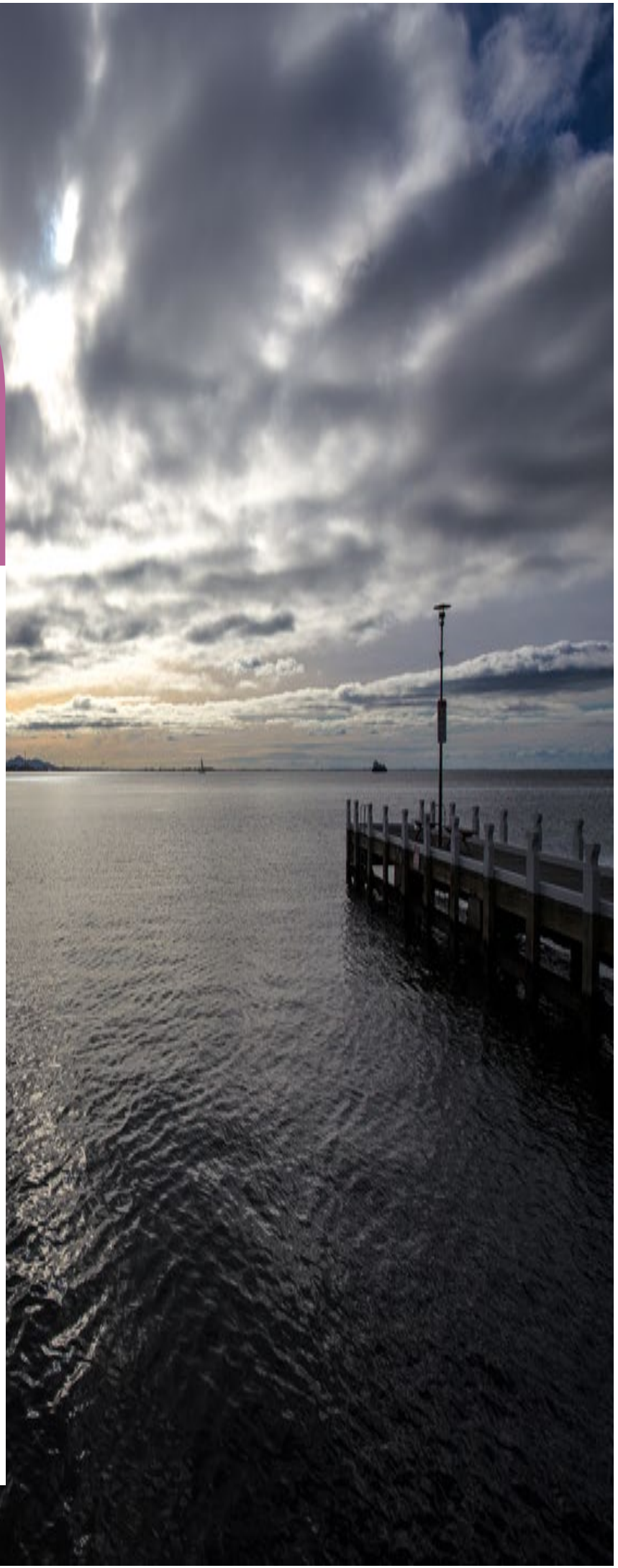
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26 June 2023

Report to Infrastructure Victoria

Economic assessment of adapting electricity distribution networks to climate change

Final report



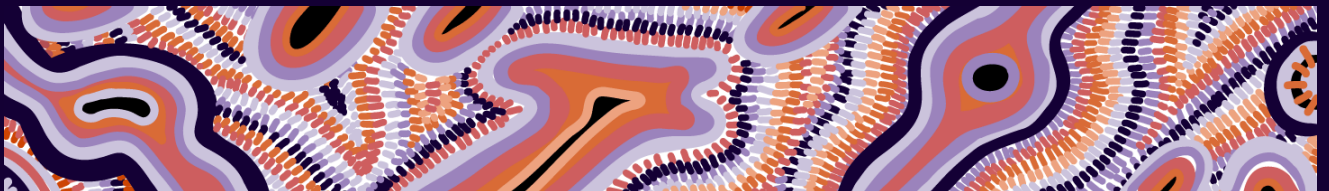
About ACIL Allen

ACIL Allen is a leading independent economics, policy and strategy advisory firm, dedicated to helping clients solve complex issues.

Our purpose is to help clients make informed decisions about complex economic and public policy issues.

Our vision is to be Australia's most trusted economics, policy and strategy advisory firm. We are committed and passionate about providing rigorous independent advice that contributes to a better world.

ACIL Allen acknowledges Aboriginal and Torres Strait Islander peoples as the Traditional Custodians of the land and its waters. We pay our respects to Elders, past and present, and to the youth, for the future. We extend this to all Aboriginal and Torres Strait Islander peoples reading this report.



Goomup, by Jarni McGuire

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Abbreviations

ABS	Australian Bureau of Statistics
AER	Australian Energy Regulator
BCR	Benefit-cost ratio
CBA	Cost-benefit analysis
HV	High voltage
km	kilometre
kV	kiloVolt
kVA	kiloVolt-Amp
kW	kiloWatt
kWh	kiloWatt-hour
LV	Low voltage
mm	millimetre
MVA	MegaVolt-Amp
MWh	MegaWatt-hour
NPV	Net present value
RBA	Reserve Bank of Australia
RCP	Representative Concentration Pathway
SAPS	Stand-alone power system
VCR	Value of Customer Reliability

Executive summary

Climate change is increasing the impact of weather on infrastructure, and this impact will continue to grow over time. Climate change amplifies a range of hazards including extreme heat, bushfires, floods and storms. For example, the 2019-20 Black Summer bushfires caused widespread damage to critical infrastructure, with wide-ranging impacts on communities and essential services. Thirty-eight towns lost communication, mostly caused by power outages, and impassable roads cut access to 17 of these towns.ⁱ

Infrastructure Victoria is assessing the risks and opportunities of adapting the state's infrastructure to climate change, and seeking to identify priority adaptation measures to improve the climate resilience of infrastructure. This report supports this wider project by examining the economic case for appropriate investment to mitigate the effects of climate change on electricity distribution networks. It sits alongside a study examining the economic case for adaptation of road infrastructure.

Electricity distribution networks transport electricity from the high voltage transmission network to end customers, and typically do so using overhead infrastructure. This creates a risk of disruptions to supply ('outages') due to weather-related damage. Extreme wind events can result in many thousands of customers experiencing outages at the same time, which stretches the resources available to restore power and can result in some customers experiencing very long periods without power. As the severity and frequency of extreme wind events is likely to increase over time due to climate change, the risk of these outages is also likely to increase.

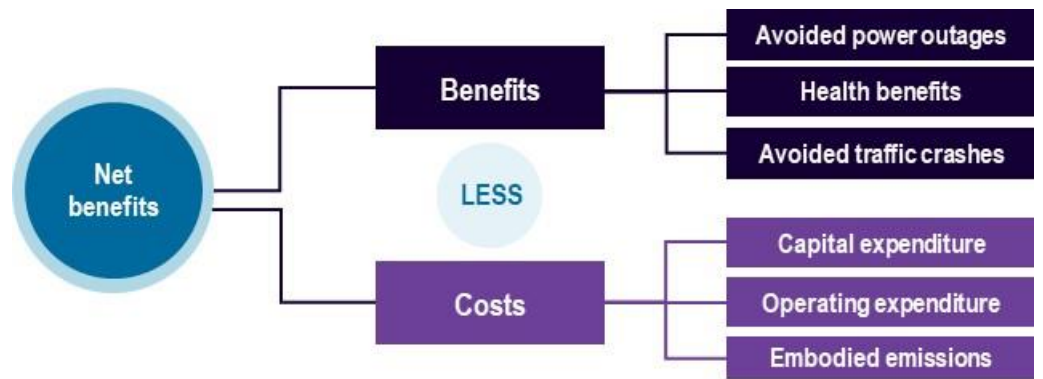
Increasing electricity distribution resilience and adapting this infrastructure to expected climate impacts is an increasing focus of governments and the electricity industry. For example, the Victorian Government commissioned an *Electricity Distribution Networks Resilience Review* to improve the resilience of these networks following a major storm and widespread power outages in June 2021.ⁱⁱ Similarly Energy Networks Australia has developed guidance to help its electricity distribution network members manage the growing effects of climate change.ⁱⁱⁱ

Reflecting the importance of electricity distribution adaptation, Infrastructure Victoria engaged ACIL Allen to assess the economic costs and benefits of potential adaptation measures to address climate-related risks associated with extreme wind in the electricity distribution network.

Study approach and scenarios

We considered a range of potential adaptation measures to adapt electricity distribution networks to increasing impacts from extreme wind and short-listed four prospective measures for detailed analysis. We used a cost-benefit analysis framework to compare the costs and benefits of these short-listed adaptation measures (Figure ES 1).

Figure ES 1 Cost-benefit analysis framework for this study



Note: Health benefits stem from changes in tree canopy. Where adaptation measures allow an increase in tree canopy they will deliver health benefits to local residents by reducing local temperatures on hot days.

Source: ACIL Allen analysis

We compared the four short-listed adaptation actions to a base case to estimate the costs and benefits of these actions relative to a ‘do-nothing’ approach:

- The **base case**: existing overhead distribution infrastructure is replaced like-for-like incrementally as individual components reach end-of-life.
- **Undergrounding**: existing overhead distribution infrastructure is replaced with equivalent underground infrastructure at the start of the modelling period.
- **Tree replacement**: large trees that have the potential to damage overhead distribution infrastructure are removed and replaced with mature trees of a lower-growing species.
- **Grid-forming inverters**: electricity customers that install solar and battery systems are required to install ‘grid-forming’ inverters that are capable of operating as a stand-alone or ‘islanded’ system in the event of a grid outage, reducing the cost of these outages.
- **Insulated cable**: existing overhead conductors are replaced with overhead insulated cables at the start of the modelling period.

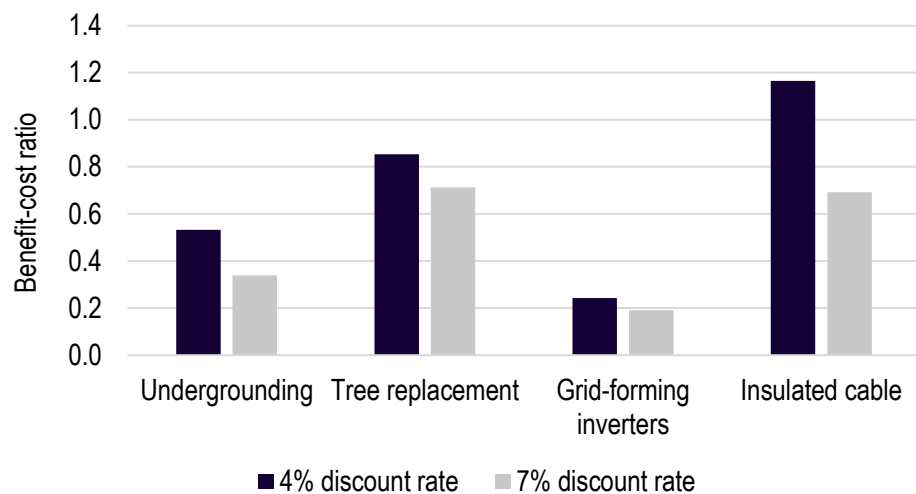
We modelled the costs and benefits of these adaptation actions on an ‘exemplar’ or case study consisting of a single hypothetical urban supply area serving about 1,900 customers. Reflecting the focus of this analysis on the effects of extreme wind on the distribution network, we assume that this supply area has higher than typical exposure to wind and vegetation related outages and higher than typical reliance on overhead distribution infrastructure. We further assume that climate change will drive an increase in both the severity and frequency of extreme winds events in all scenarios, with a particularly large impact on outages in the base case as no adaptation actions are in place.

Although the exemplar only represents about 1,900 hypothetical customers, our analysis indicates that over 300,000 urban customers across Victoria (about 10% of all customers) have similar exposure to outages and similar reliance on overhead distribution network infrastructure to our exemplar. These customers are located both across metropolitan Melbourne and in a range of regional towns. This means that the findings of this cost-benefit analysis are likely to be applicable across a large range of supply areas.

Results

Our analysis finds that all of the adaptation measures modelled are effective in reducing electricity outages to varying degrees and so help to adapt the distribution networks to climate-driven effects of extreme wind, but we find that only one adaptation measure – insulated cable – delivers a net societal benefit using a 4% discount rate, and no measure does so at a 7% discount rate (Figure ES 2). While the benefit-cost ratios generally do not exceed one (the level at which an investment delivers a net societal benefit), this finding reflects the specific assumptions of this study and will not necessarily be the case when considering wider factors that were not formally quantified as part of our cost-benefit analysis. In particular, formally quantifying the amenity benefits of undergrounding could significantly change the benefit-cost ratio of this measure and push its benefit-cost ratio well above one (see Figure ES 3 and the associated discussion on the next page).

Figure ES 2 Benefit-cost ratios, by scenario and discount rate



Source: ACIL Allen analysis

While the cost-benefit analysis could be interpreted as indicating that installation of insulated cable is justified at a discount rate of 4%, we consider that this result should be interpreted with caution:

- The result is sensitive to assumptions, with our sensitivity analysis showing that increasing capital cost assumptions or reducing the assumed cost of power outages results in the costs of this measure exceeding the benefits.
- Our analysis of distributional outcomes highlights difficult questions about who should pay for insulated cable investments, because the general base of electricity consumers would incur significant costs, while local residents and local electricity consumers enjoy the vast majority of the benefits.

Our sensitivity analysis indicated that the results for other adaptation measures were generally less sensitive to assumptions, with the benefit-cost ratio of undergrounding and grid-forming inverters remaining well below one under all modelled sensitivities. Tree replacement delivered a net societal benefit under some assumptions, particularly higher outage costs from extreme wind, but did not under most sensitivities analysed.

Discussion and conclusions

Examine the reliability benefits of insulated cable

Our analysis suggests that there may be merit in further investigation of the costs and benefits of using insulated cable to better adapt electricity distribution networks to the effects of climate change and reduce power outages. However, this finding is subject to some uncertainty.

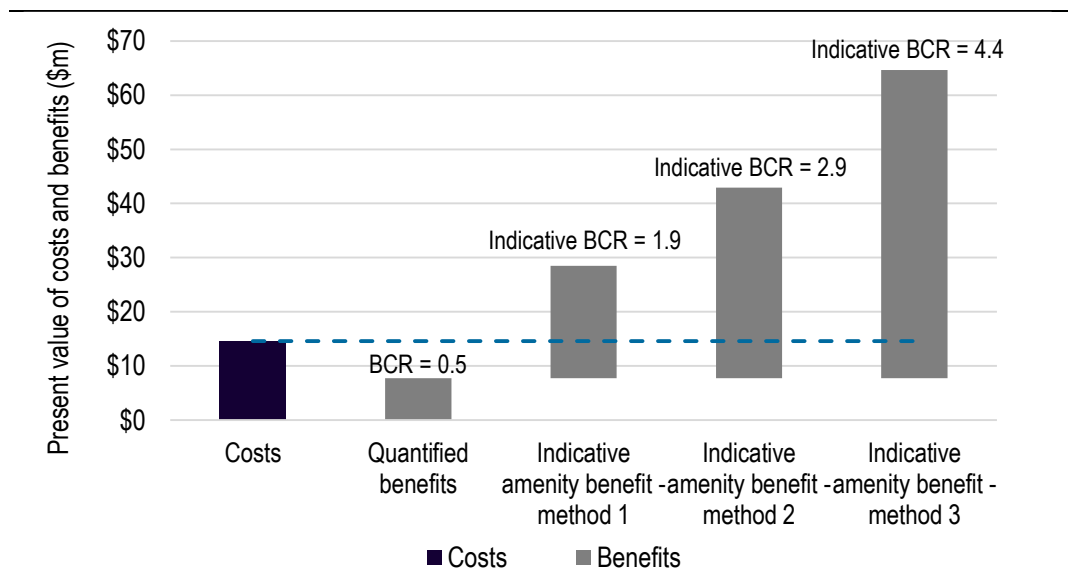
An important area of uncertainty is the effectiveness of insulated cable in reducing outages, but this uncertainty may be able to be reduced at relatively low cost. Some networks routinely use insulated cable for replacement of low voltage circuits, and this could provide conditions for a ‘natural experiment’ to demonstrate its reliability benefits. Comparing the reliability of network sections that have insulated cable with the rest of the network could give greater confidence on the effectiveness of insulated cable in preventing outages, which would be valuable for informing future decisions on the use of this adaptation measure.

Examine the amenity benefits of undergrounding

Our analysis finds that undergrounding is very effective in reducing outages, but that it is not a cost-effective way to reduce power outages from the effects of extreme wind for the hypothetical urban supply area modelled, even when the health benefits it can deliver through increased tree cover and reduced traffic crash costs are taken into account.

However, undergrounding may also deliver significant amenity benefits, such as improved streetscape aesthetics, reduced physical obstacles and the visual amenity of increased tree cover. We have only provided indicative quantifications of these benefits in this study, because the relevant literature is from over ten years ago and examined locations outside of Victoria. However, if benefits of a comparable size translate from earlier Western Australian and Canberran studies to Victoria, then undergrounding could offer significant net benefits, with benefit-cost ratios well in excess of one (Figure ES 3). In that case, the combined benefits of undergrounding may well justify investment, and this investment would help distribution networks adapt to climate change.

Figure ES 3 Present value of costs and benefits of undergrounding using a 4% discount rate, including indicative estimates of amenity benefits



Source: ACIL Allen analysis

Undergrounding is a complex exercise that delivers benefits to multiple groups in societies – including home-owners, businesses, visitors, local governments, electricity distribution companies

and state governments – and so implementation requires cooperation across a number of these parties. This complexity, and the experience of undergrounding programs in Western Australia and South Australia, suggests that the Victorian Government would need to play a significant role to facilitate future undergrounding projects in the state.

Potential Victorian Government actions to support future undergrounding of electricity infrastructure include:

- building contemporary knowledge on the benefits of undergrounding in the Victorian context, as reliable estimates of amenity benefits are needed to support the business case for widespread undergrounding, and active Victorian Government support to build this business case will help to both unlock these amenity benefits and better adapt distribution networks to expected impacts from climate change
- working with parties that benefit from undergrounding, such as local governments (acting on behalf of home-owners and businesses) and electricity distribution network businesses
- establishing standardised processes to simplify undergrounding for both electricity network businesses and local governments.

Preparing Victorian distribution networks for the future

Our analysis assumes that the existing overhead network infrastructure is of mixed age and is replaced periodically over its expected life of 50 years. However, if network re-investment is required more urgently than we have assumed, the base case investment cost increases in present value terms and the case for investing in undergrounding or insulated cable is strengthened.

One potential driver of network re-investment is rapid growth in electricity demand that outstrips the capacity of existing network assets. While peak electricity demand growth has been muted in recent years, there is a high likelihood of significant increases in demand throughout Victoria's electricity distribution networks over coming decades from two main sources: electric vehicles and the electrification of household heating.

While the scale and speed of this demand growth is highly uncertain and hotly debated, the potential need for investment to accommodate electric vehicles and heating electrification creates an opportunity to also better adapt these networks to the effects of climate change by insulating or undergrounding power lines when reinvestment is required. Additionally, insulating or undergrounding power lines helps Victoria prepare for a hotter future under climate change, as they allow increased levels of urban vegetation that reduces the effect of extreme heat on local residents.

Lessons for other studies

ACIL Allen used a typical cost-benefit analysis framework for this analysis, and this broad framework can be applied to a range of infrastructure assessments, including the cost-effectiveness of climate change adaptation measures. For example, Infrastructure Victoria has concurrently commissioned a similar assessment of adaptation measures for road infrastructure.

We had to address a range of significant complexities and uncertainties to undertake this study, and this is likely to be common to many cost-benefit analyses of climate adaptation for infrastructure. Some particularly difficult methodological issues we have encountered in this study are summarised below.

- Climate change impacts are particularly uncertain and sensitive to assumptions on global emissions concentration pathways. This is particularly true of extreme wind due to its localised impacts, but other studies will still likely need to reflect this uncertainty through scenario and sensitivity analysis.

- Adaptation measures both mitigate the impacts of climate change and contribute to it through embodied emissions. We found embodied emissions were not large enough to be a material barrier to use of the adaptation measures we assessed, but this finding may not translate to other infrastructure assessments and so case-specific analysis is essential.
- The benefits of adaptation actions can be sensitive to the scale at which they are applied. For example, the benefit of more reliable electricity supply to transport infrastructure and other essential services will be modest if the measure is only applied narrowly but could increase significantly if it is adopted widely. This finding is likely to translate to other types of network infrastructure, such as transport and telecommunications.
- Climate adaptation measures could reduce the impact of the identified hazard (in our case, extreme wind), but cause maladaptations that exacerbate other risks to the infrastructure. We assessed that the maladaptation risk was not material for our adaptation measures, but this finding may not translate to other infrastructure assessments and so case-specific analysis is essential.
- Some cost or benefit elements are particularly uncertain and hard to estimate. In our case, important examples included amenity benefits, the number of trees that can materially impact electricity distribution infrastructure and the cost premium on grid-forming inverters. Other infrastructure assessments are likely to require similarly difficult cost or benefit estimates.

In many cases the methodologies and sources used in our study reflect costs and benefits that are specific to electricity distribution infrastructure and the effects of extreme wind, while in other cases a broad range of studies will be able to use similar approaches and assumptions. For example:

- our chosen discount rates and carbon price assumptions would be common to a broad range of cost-benefit analyses
- our analysis of health benefits from increased tree canopy would extend beyond electricity distribution infrastructure to include broader 'green infrastructure' such as parklands
- our analysis of power outages, network capital and operating expenditure, and embodied emissions are all specific to electricity distribution infrastructure, but this infrastructure is relatively standardised across Australia so our assumptions could be extended to studies in a large range of comparable locations – that is, a well-treed Australian urban area with primarily overhead electricity distribution infrastructure.

Study overview

1

Infrastructure Victoria is the state's independent infrastructure advisory body. It has three main functions:

- preparing a 30-year infrastructure strategy for Victoria, and reviewing and updating the 30-year strategy every 3 to 5 years^v
- advising the Victorian Government on specific infrastructure matters
- publishing research on infrastructure-related issues.

As part of its research program, Infrastructure Victoria is assessing the risks and opportunities of adapting the state's infrastructure to climate change. The project considers existing climate change adaptation actions in Victoria, identifies priority adaptation measures to improve the resilience of infrastructure in response to climate-related risks and evaluates the return on investment for adaptation actions.

The project phases include:

1. a high-level risk assessment of climate impacts across key infrastructure sectors including a literature review and workshops with government stakeholders
2. detailed analysis of shortlisted climate risks across Victoria and potential adaptation actions for selected asset categories (for example, roads and electricity)
3. an economic assessment of the return on investment for specific climate change adaptation measures including a quantitative and qualitative assessment of direct and indirect costs and benefits
4. a final research report.

This report is part of Phase 3, which aims to build the economic case for appropriate action and investment in climate resilient roads and electricity networks by asking the following question:

What is the economic return on investment for selected climate change adaptation measures in selected infrastructure sectors?

This report focuses on climate adaptation measures for electricity distribution infrastructure (Box 1.1) by demonstrating a cost-benefit analysis of adaptation measures relevant to a selected exemplar. The outcome of this analysis will aid in identifying appropriate investments and showcase the significance of adaptation in enhancing the resilience of electricity infrastructure. It also presents a methodology which may be used by other stakeholders to assess the return on investment in climate adaptation of infrastructure. It has been written alongside a separate assessment of potential climate adaptation measures for the road network, led by Arup.

Box 1.1 Electricity distribution networks

Electricity networks transport electricity from the point it is generated to end customers. They are typically classified into two parts:

- The **transmission** network, which connects large-scale power stations to major points of supply.
- The **distribution** network, which transports power from the transmission network to end customers.

Distribution networks, rather than transmission networks, are the focus of this study.

Victoria has five distribution networks (**Figure 1.1**).

Figure 1.1 Victoria's electricity distribution networks



Source: ACIL Allen adaptation of Victorian Government, *Find your energy distributor*, <https://www.energy.vic.gov.au/for-households/find-your-energy-distributor>.

1.1 Problem definition

Climate change is increasing the impact of weather on infrastructure, and this impact will continue to grow over time. Climate change amplifies a range of hazards including extreme heat, bushfires, floods and storms. For example, the 2019-20 Black Summer bushfires caused widespread damage to critical infrastructure, with wide-ranging impacts on communities and essential services. Thirty-eight towns lost communication, mostly caused by power outages, and impassable roads cut access to 17 of these towns.^v

As noted above, this report is part of a wider Infrastructure Victoria research project that identifies priority adaptation measures to improve the climate resilience of infrastructure. Although electricity distribution networks are significantly impacted by bushfire events (as occurred during the Black Summer bushfires) and floods, Infrastructure Victoria's work in Phase 2 of this broader research program identified the effects of extreme wind on electricity networks as a specific risk worthy of more detailed consideration. Accordingly, this study focuses on the effects of extreme wind events on electricity distribution networks.

Electricity distribution networks typically supply electricity consumers via overhead infrastructure, creating a risk of disruptions to supply ('outages') due to weather-related damage. As the severity and frequency of extreme wind events is likely to increase over time due to climate change, the risk of these outages is also likely to increase.

Extreme wind events can result in many thousands of customers experiencing outages at the same time, largely due to trees and other vegetation making contact with or falling across overhead power lines. When an extreme event affects a large number of customers at one time resources available to restore power supply are stretched, and consequently some customers can experience very long periods without power.

Recent examples of extreme wind events impacting Victorian electricity distribution networks include:

- 2 April 2008: a major windstorm hit the Melbourne metropolitan area causing power outages for about 660,000 customers
- 9-10 June 2021: heavy rainfall and strong winds affected much of the state, with particularly large effects in the Dandenong Ranges. About 330,000 customers experienced power outages, with 68,000 remaining without power for more than 72 hours
- 29-30 October 2021: strong winds hit the Melbourne metropolitan area, particularly the eastern suburbs, causing power outages for about 500,000 customers, with about 20,000 being without power for more than 72 hours.

As the likelihood and impact of geographically widespread and long duration outages increases with climate change, the economic and social costs of these outages are also likely to increase.

Increasing electricity distribution resilience and adapting this infrastructure to expected climate impacts is an increasing focus of governments and the electricity industry. For example, the Victorian Government commissioned an *Electricity Distribution Networks Resilience Review* to improve the resilience of these networks following a major storm and widespread power outages in June 2021.^{vi} Similarly Energy Networks Australia has developed guidance to help its electricity distribution network members manage the growing effects of climate change.^{vii} These efforts are particularly important for electricity distribution networks, as they are characterised by long-lived assets with a high level of exposure to extreme wind, and therefore to the effects of climate change.

1.2 Approach

As noted above, analysis undertaken for Infrastructure Victoria as part of Phase 2 of its infrastructure adaptation project identified extreme wind as a key risk factor for electricity networks. The strategic objective of this study is to understand the costs and benefits of early and proactive adaptation actions that can reduce the impact of extreme wind on the electricity distribution network, and therefore the economic and social cost of outages.

The study examines the costs and benefits of these actions on a de-identified hypothetical 'exemplar' or case study, consisting of a single hypothetical urban supply area serving about 1,900 customers. The exemplar is:

- de-identified, in that it refers to a non-specific geographical area
- hypothetical, as the measures analysed could be implemented in a range of locations
- an exemplar, meaning that the specific assumptions on costs and benefits applied in this study can be extended to a range of locations.

Reflecting the focus of this analysis on the effects of extreme wind on the electricity distribution networks, we assume that this supply area has:

- higher than typical exposure to wind and vegetation related outages
- higher than typical reliance on overhead distribution infrastructure.

Although the exemplar only represents about 1,900 hypothetical customers, our analysis indicates that almost 310,000 urban customers across Victoria (10% of all customers) have similar exposure to outages and similar reliance on overhead distribution network infrastructure. These customers are located across the entire Melbourne metropolitan area and in a range of regional towns, including Geelong, Ballarat, Bendigo, Morwell, Shepparton and Horsham.

This means that the findings of the economic assessment for the exemplar will have broad applicability to a large number of customers across Victoria. In other words, if our cost-benefit analysis identifies a strong case to do one or more adaptation actions for the exemplar, these actions could be considered in more detail across a large range of supply areas. Conversely, as the analysis looks at a general exemplar, analysis of similar actions in a more precisely defined location could include assumptions specific to that location, and this could lead to different results. For example, locations that serve major public facilities or critical infrastructure could likely identify higher benefits reflecting the wider impact of power outages for these facilities.

Section 2.2.2 gives more detail on the exemplar and how it was defined.

1.3 Report overview

The remainder of the report is set out as follows:

- Chapter 2 sets out the detailed methodology and assumptions used in the study.
- Chapter 3 summarises the key results of the study.
- Chapter 4 discusses some broader conclusions to inform further investigations by Infrastructure Victoria and the Victorian Government.

Detailed methodology and assumptions

2

This study uses a cost-benefit analysis (CBA) framework to assess the economic costs and benefits to the community of potential adaptation measures to address climate-related risks associated with extreme wind in the electricity distribution network, and to develop a replicable methodology for similar analyses of infrastructure adaptation actions.

Section 2.1 gives an overview of the CBA framework used in this study, while section 2.2.3 describes the adaptation measures, the exemplar and the scenarios examined. Sections 2.3 and 2.4 discuss the detailed methodology and assumptions used to estimate the major cost and benefit categories, respectively.

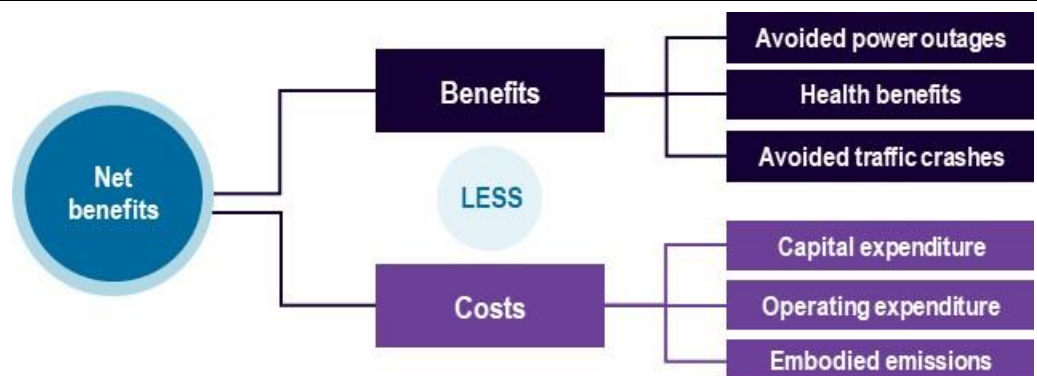
2.1 Cost-benefit analysis framework and key assumptions

CBA is a commonly used quantitative framework for logically analysing the social and economic costs and benefits of a particular policy, project or investment. The basis of a CBA is simple: for a given investment proposal, project or policy reform, a CBA compares the total projected costs of the investment or policy with the total projected benefits. This determines whether the benefits outweigh the costs, and by how much. A CBA typically assesses the economic costs and benefits associated with potential adaptation measures (an ‘adaptation scenario’) against those under a doing-nothing scenario or ‘base case’, and we have adopted this approach.

2.1.1 Cost-benefit analysis framework for this study

Figure 2.1 provides an overview of the CBA framework used in this study, including the major categories of benefits and costs.

Figure 2.1 Cost-benefit analysis framework for this study



Source: ACIL Allen analysis

We analysed three major benefit categories in this study (section 2.4):

1. **Avoided power outages:** the study considers a range of adaptation actions that can reduce power outages in the electricity distribution network, particularly in the case of extreme wind, and quantifies the economic benefits of these reductions.
2. **Health benefits from increased tree canopy:** several of the adaptation actions considered in this study reduce conflict between overhead electricity infrastructure and trees, and so support an increase in the local tree canopy. This increased canopy in turn reduces local temperatures on very hot days, and so can improve the health of local residents. Conversely, one adaptation action analysed reduces tree canopy and so causes a health dis-benefit to local residents.
3. **Reduced traffic crash impacts:** one adaptation action analysed in this study, undergrounding, removes the need for above-ground power poles, and therefore the risk that vehicles will collide with these poles (though these vehicles could collide with other objects instead).

Other benefit categories are discussed qualitatively in section 2.4, but we do not formally quantify them in our CBA framework as we either found the potential impacts to be immaterial to this study, or due to limited robust evidence in the relevant literature.

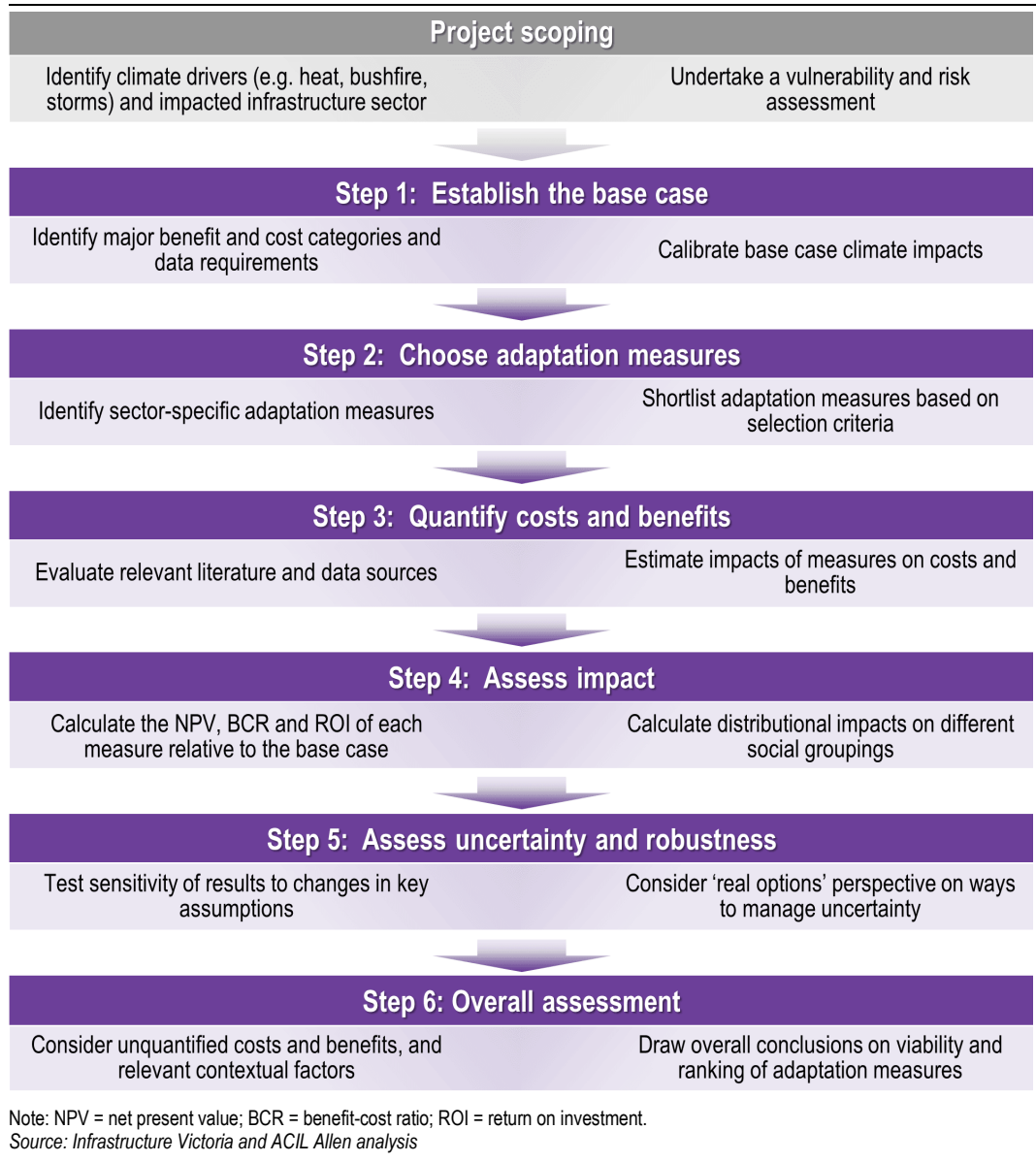
We analysed three major cost categories in this study (section 2.3):

1. **Capital expenditure:** the adaptation actions require upfront expenditure on new capital items, which represents an economic cost.
2. **Operating expenditure:** many of the adaptation actions require ongoing operational expenditure, which represents an economic cost. Some actions also reduce operating expenditure on the management of tree clearances around power lines ('vegetation management'), and this study takes these reductions into account.
3. **Embodied emissions:** many of the adaptation actions cause increased material requirements over what would otherwise be needed and so impose an economic cost on society in the form of embodied greenhouse gas emissions.

A CBA framework can be applied to a range of infrastructure assessments, including the cost-effectiveness of climate change adaptation measures. For example, as discussed in chapter 1, Infrastructure Victoria has concurrently commissioned a similar assessment of adaptation measures for road infrastructure.

Infrastructure adaptation assessments will have a number of common features and steps, stemming from the nature of the infrastructure being assessed and the specific climate risk or risks of interest. For this study we have built on assessments conducted by Infrastructure Victoria and AECOM to identify priority sectors and climate risks for analysis, and built on these prior assessments to deliver a sector- and risk-specific CBA. This combined process is described in Figure 2.2, and is likely to be illustrative of the general steps needed to prioritise and implement infrastructure adaptation assessments.

Figure 2.2 Step-wise approach to infrastructure adaptation assessments



The particular challenges of adapting a CBA framework to analyses of climate change impacts on infrastructure, and methodological lessons from this analysis, are discussed in section 4.6.

2.1.2 Treatment of climate change

The Intergovernmental Panel on Climate Change considers that it is 'unequivocal' that climate change is already occurring, and that is 'very likely' that, even under the most aggressive emissions reduction scenarios, an increase of 1°C to 1.8°C above late 19th century levels will occur by the end of the 21st century.^{viii}

A key driver of this study is that climate change will affect the severity and frequency of extreme wind events, and this will impact electricity distribution infrastructure. For this reason, it is essential to incorporate the climate change impacts in the base case. Specifically, the severity and frequency of extreme wind events were increased in the base case to reflect outcomes under the 2019 *Victorian Climate Projections*,^{ix} which in turn increases the expected cost of power outages from extreme wind in the base case (see the discussion on page 23 in section 2.4.1).

As the cost of power outages is higher in the base case than if climate change was not driving greater impacts from extreme wind, the economic benefit from adaptation measures that reduce these outages is correspondingly higher.

2.1.3 Discount rate

A key assumption in a CBA is the 'discount rate' used. The discount rate reflects that the economic behaviour of individuals, businesses and governments exhibits 'time preference', which means that they prefer to receive benefits earlier rather than later and prefer to incur costs later rather than earlier, all else being equal. This reflects, in part, the fact that the future is uncertain and so people put less weight on events the further into the future they are. To capture time preference, costs and benefits are weighted differently in a CBA depending on when they occur by discounting future costs and benefits using an annual discount rate.

The discount rate used has a very significant impact on the value placed on the benefits accumulated in the future over a long period of time as occurs, for example, in the case of investing in long-lived infrastructure with significant upfront costs but which delivers benefits over a long period of time.

There is extensive debate on the appropriate rate to discount costs and benefits in a CBA. A particular element of this debate that has arisen in the broader climate change context is whether discounting appropriately values the interests of future generations, for example from climate impacts that might be felt over centuries. For example, when the UK Government commissioned economist Nicholas Stern to review the economics of climate change in 2006, Stern adopted a low discount rate of 1.4% to appropriately value intergenerational damages.^x In part as a result of debate over Stern's approach to discounting very long climate impacts, a declining discount rate has emerged in the economic literature as an alternative approach to avoid excessively discounting very long-term costs and benefits, including climate impacts.^{xi}

We consider that declining discount rates are most appropriate for analysis over very long time periods with significant intergenerational impacts (broadly, measured in centuries). Here we are analysing measures that affect infrastructure with a long but finite lifespan, typically assessed as about 50 years, and the costs of these infrastructure choices will generally be borne by the same generations that experience the benefits. Accordingly, we have considered the Victorian Government's standard approach to discounting is appropriate for this study.

The Victorian Government's standard discount rates are:

- 4% for provision of goods and services in traditional core service delivery areas of government where the benefits are not easily translated to monetary terms
- 7% for provision of goods and services in traditional core service delivery areas of government where the benefits are more easily translated to monetary terms
- market rate for commercial investments with similar risks as the private sector.^{xii}

As electricity distribution infrastructure is regulated as a natural monopoly and is not subject to typical risks associated with private sector investments in competitive markets, we consider that the 4% and 7% discount rates are most appropriate for this analysis.

2.1.4 Key cost-benefit analysis metrics

The change in costs and benefits from the base case to those under each adaptation scenario are calculated, and used to estimate the following key CBA metrics:

- A benefit-cost ratio (BCR), which is the ratio of the present value of total benefits to the present value of the total costs. A BCR of greater than one indicates that the quantifiable benefits of the policy, project or investment exceed the quantifiable costs. All things being

equal, this suggests there is economic and social value in investing in the option. The reverse applies for a BCR below one.

- The net present value (NPV), which is the sum of the discounted annual net benefits (benefits less costs). A positive NPV indicates that the quantifiable benefits of the policy, project or investment exceed the quantifiable costs. All things being equal, this suggests there is economic and social value in investing in the option. The reverse applies for a negative NPV.
- A return on investment, which is the 'breakeven' discount rate at which the NPV of costs and benefits of a given adaptation measure are equal. All things being equal, a higher return on investment indicates a stronger case for investment in an adaptation measure.

2.1.5 Other over-arching assumptions

Reflecting the long-lived nature of electricity distribution infrastructure, we have analysed costs and benefits over the period to 2070 for this analysis. Given the time needed to deliver new equipment or change the way electricity distribution infrastructure is managed, we have assumed that upfront capital investments will start in 2025 and be completed by 2027.

All dollar values in the report are presented on an inflation-adjusted or 'real' basis and reflect price levels in 2023 (that is, they are presented in real 2023 dollars).

2.2 Study design

2.2.1 Study focus

As discussed in chapter 1, Infrastructure Victoria is delivering a research program that includes a high-level climate risk assessment across Victoria's regions for various government and regulated infrastructure sectors. This work short-listed a risk of damage to or degradation of electricity transmission and distribution assets due to extreme weather events, including both extreme wind and lightning.

We focused this study on the effect of extreme wind on the electricity distribution network because several factors indicate that the economic case for adaptation to address extreme wind will be stronger than for lightning:

- Extreme wind was the key driver of the largest outage events in recent Victorian history, including the April 2008 and October 2021 storms.
- The link between lightning and climate change is less clear than the link between extreme wind and climate change.
- Lightning effects are more severe in the north-eastern highlands of the state^{xiii}, where population is lower and so the economic and social costs of outages are lower.

This study focused on electricity distribution rather than electricity transmission (see Box 1.1) because issues in the electricity distribution network have a far greater impact on customers than issues in other parts of the supply chain. Distribution network issues typically account for about 95% of historic power outages when weighted by the outage duration and the number of customers affected.^{xiv}

2.2.2 The exemplar

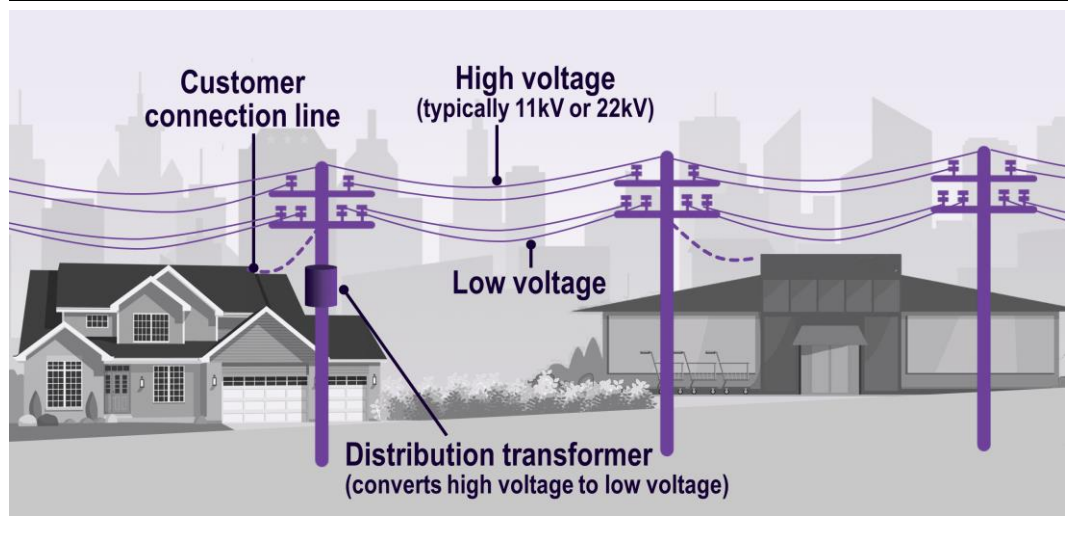
The decision to focus this study on extreme wind in turn led us to examine an urban 'exemplar' or case study. Extreme wind events in April 2008 and October 2021 had significant impacts in the Melbourne metropolitan region. Such urban wind storms affect a large number of customers and are have higher economic costs than extreme wind in more sparsely populated regional areas.

As discussed in section 1.2, our exemplar is a single hypothetical urban supply area with about 1,900 customers, characterised by:

- higher than typical exposure to wind and vegetation related outages
- higher than typical reliance on overhead distribution infrastructure.

This exemplar represents a single hypothetical feeder, which is a high voltage trunk supply line, and the associated infrastructure to deliver power to all connected customers, including transformers, low voltage power lines and connection points (see Figure 2.3 for a depiction of how overhead electricity distribution infrastructure typically looks in Victoria).

Figure 2.3 Typical overhead electricity distribution infrastructure in Victoria



The characteristics of this hypothetical exemplar feeder are based on the characteristics and performance of 54 real-world feeders termed the 'exemplar sample'.¹ This exemplar sample is drawn from feeders in more heavily vegetated suburbs of Melbourne but, as noted in section 1.2, reflects supply conditions in a range of urban areas across the state.

The 54 sample feeders were identified by analysing the performance data of a broad range of feeders over the period 1 January 2018 to 30 June 2022 and identifying those that:

- are defined as urban
- had a level of unplanned outages between the 75th and 95th percentiles of those feeders
- had a share of overhead feeder distance that was above the median of the feeders considered (i.e. it was at least as high as a 'typical' feeder).

The characteristics of the exemplar and the exemplar sample are summarised in Table 2.1.

¹ The use of a broad exemplar sample reflects the fact that, while the historical performance of any single feeder is known, the future performance of that feeder is unknown, and so modelling future outcomes based on the historical performance of a single feeder (or a small sample) would be unreliable compared to modelling based on typical characteristics of a large sample.

Table 2.1 Exemplar and exemplar sample key statistics

	Exemplar	Exemplar sample		
		Min.	Median	Max.
Overhead high voltage (HV) circuit distance (km)	7.7	1.9	7.7	20.3
Overhead share of HV lines	86%	76%	86%	97%
Overhead share of low voltage (LV) circuit distance and connections	89%	Data not available at feeder level		
Overhead LV circuit distance (km)	13.4	Data not available at feeder level		
Overhead HV circuit sharing poles with LV (km)	6.2	Data not available at feeder level		
No. of customers	1,938	70	1,938	4,966
Overhead customer connections	1,732	Data not available at feeder level		
Unplanned outages as a share of energy supplied	0.022%	0.013%	0.022%	0.035%
Feeder maximum demand (MVA)	5.5	1.2	5.5	10.1

Note: Where data are not available at the level of individual feeders we have inferred assumptions from network-wide data. HV circuits are typically operated at 11,000 volts or 22,000 volts in Victoria; we have assumed 22,000 volts. The overhead LV distance and connections share were estimated based on the difference (3 percentage points) between the overhead shares for feeders and for LV circuits across the feeders considered. Unplanned outages as a share of energy supplied was estimated by proxy using maximum demand data for each feeder, as energy supplied per feeder is not publicly reported.

Source: ACIL Allen analysis of economic benchmarking data provided by electricity distribution businesses to the Australian Energy Regulator.

We analysed the average load per customer by connection type (residential, non-residential non-demand tariff, low voltage demand tariff and high voltage demand tariff), the network load profile (ratio of peak demand to average demand) and the peak demand of the exemplar from Table 2.1 to estimate the sectoral composition of demand for the exemplar (Table 2.2).

Table 2.2 Sectoral composition of exemplar electricity demand

	Residential	Commercial	Industrial	Total
Total customers	1,760	172	6	1,938
Share of customers	90.8%	8.9%	0.3%	100%
Total electricity consumption (MWh)	8,125	8,084	2,411	18,620
Share of electricity consumption	43.6%	43.4%	12.9%	100%
Annual average electricity consumption per customer (MWh/year)	4.6	47.0	376.7	

Source: ACIL Allen analysis of network economic benchmarking data and Table 2.1.

2.2.3 Potential adaptation actions

Infrastructure Victoria’s prior research identified 13 potential adaptation measures under four categories (see Box 2.1 for the definitions of these categories):

- **Higher-cost infrastructure:** underground assets, microgrids, pole replacement program, new lines on alternative routes, and fit spark plugs and surge arresters.
- **Lower-cost infrastructure:** increased or revised vegetation clearance and management, and reinforcing structures.
- **Maintenance:** self-healing networks.

- **Hazard management:** automated or remote asset inspection / monitoring devices, electrical isolation, stand-alone power systems (SAPS), energy back-up systems at community hubs / key sites and earth wires.

Box 2.1 Definition of adaptation types

Higher-cost infrastructure

Higher-cost infrastructure can include the use of physical structures to reduce the impacts of climate change. Investments are generally more capital intensive with examples including new construction, upgrades or significant reinforcement of infrastructure. This involves engineering solutions to the infrastructure under consideration or the surrounding system such as through protection measures.

Lower-cost infrastructure

Lower-cost adaptation measures can be simple and can also involve smaller investments that are modular, flexible and scalable. Lower-cost adaptation can include measures that interact with the natural environment, such as nature-based solutions. Nature-based solutions use characteristics of natural features and processes, or mimic it through human design and engineering, providing both risk reduction and ecological benefits.

Maintenance

Maintenance adaptation refers to altering maintenance regimes so that existing infrastructure remains resilient and functional in the face of changing climate conditions. Periodic and preventative maintenance regimes can be examined. Periodic maintenance adaptation refers to altering the set schedule for inspection and repair of assets to account for changing conditions. Preventative maintenance refers to the use of predictive analysis to proactively forecast asset failure and reduce the risk of failure by scheduling maintenance ahead of time based on historical data. Maintenance initiatives can also involve various technologies used for monitoring hazards and infrastructure condition.

Hazard management

Hazard management adaptation refers to improving operational plans for managing extreme weather events and natural disasters. Hazard management can be quite broad and cover areas such as preparation before an extreme event, response during an event and immediate recovery. This can include, and is not limited to, early warnings, user awareness and behaviour campaigns, communication of information during and after times of disruption or incidents, measures to ensure a level of service continuity, emergency repairs, removal of hazards, temporary set-up of structures, and immediate actions to reduce cascading impacts.

Source: Sovacool 2011, 'Hard and soft paths for climate change adaptation', *Climate Policy* (11), pp.1178-1179, <https://www.adaptation-undp.org/sites/default/files/downloads/sovacool-cp-hardsoft.pdf>; NZ Government National Resilience Programme Business Case, <https://www.nzta.govt.nz/roads-and-rail/highways-information-portal/technical-disciplines/resilience/national-resilience-programme-business-case/>; US Government 2019, *Nature-based solutions for coastal highway resilience: an implementation guide*, https://www.fhwa.dot.gov/environment/sustainability/resilience/ongoing_and_current_research/green_infrastructure/implementation_guide/; World Roads Association, *The World Roads Association 2019, Adaptation methodologies and strategies to increase the resilience of roads to climate change – case study approach*, <https://www.piarc.org/en/order-library/31335-en-Adaptation%20Methodologies%20and%20Strategies%20to%20Increase%20the%20Resilience%20of%20Roads%20to%20Climate%20Change%20%E2%80%93%20Case%20Study%20Approach>, p. 49, ROADAPT 2015, *Roads for today, adapted for tomorrow – Guidelines, prepared for the Conference of European Directors of Roads Transnational Road Research Program*, https://www.cedr.eu/download/other_public_files/research_programme/call_2012/climate_change/roadapt/ROADAPT_integrating_main_guidelines.pdf, p.22.

ACIL Allen identified a further three potential adaptation measures:

- Tree replacement (lower-cost infrastructure category): large trees that have the potential to impact on overhead distribution infrastructure are removed and replaced with mature trees of a lower-growing species that will remain below the height of this overhead infrastructure. We categorised this measure as lower-cost infrastructure as it involves working with natural hazards in a flexible way with low capital expenditure.
- Grid-forming inverters (hazard management): as electricity customers adopt combined solar and battery systems they are required to install 'grid-forming' inverters that are capable of operating as a stand-alone or 'islanded' system for that customer in the event of a grid outage,

reducing the cost of these outages. We categorised this measure as hazard management because it works to ensure continuity of service once a hazard has caused the power supply to be disrupted.

- Insulated cable (lower-cost infrastructure): existing overhead conductors are replaced with overhead insulated cables at the start of the modelling period, with other components replaced like-for-like as they reach the end of their life. We categorised this measure as lower-cost infrastructure as the investments involved are modular and incur relatively low capital expenditure.

Table 2.3 summarises our initial assessment of the suitability of each of the adaptation measures identified to mitigate the effects of extreme wind on urban electricity distribution network areas comparable to our exemplar.

Table 2.3 Initial assessment of suitability of adaptation measures

Adaptation measure	Effectiveness in mitigating the effect of extreme wind on urban electricity networks
Higher-cost infrastructure	
Underground assets	High. Effective adaptation measure, albeit at high cost.
Microgrids	Low. Extreme wind is likely to cause significant damage to the low-voltage network, which cannot be addressed through a micro-grid. It is not likely to be feasible to locate sufficient distributed solar generation to operate micro-grids in an urban area, which would necessitate an undesirable reliance on diesel generation. However, a microgrid may be more effective in a regional area with more room for local renewable electricity generation and longer feeder lengths that are subject to weather damage or other reliability risks.
New lines on alternative routes	Low. Power lines can be re-routed away from heavy vegetation, but this is only relevant for higher voltage lines because low voltage lines need to be located close to the loads they are supplying.
Lower-cost infrastructure	
Increased or revised vegetation clearance and management	Moderate. While increased vegetation clearance would reduce the risk of vegetation falling on powerlines, community expectations are for minimal vegetation clearance to maximise environmental and aesthetic benefits.
Reinforcing pole structures	Low. Would mitigate against power outages caused by wind events if any part of the pole structure is weak. Will only avoid outages caused by the failure of poles but not those caused by tree branches falling across power line conductors.
Pole replacement program	Low. Pole replacement will avoid power outages caused by the failure of poles but not those caused by tree branches falling across power line conductors.
Tree replacement	High. Tree replacement would remove large trees with significant risk of falling across or dropping branches on power line conductors, with this risk being particularly severe during major storm events. It would also greatly reduce the risk of incidental contact between branches and conductors.
Fit spark plugs and surge arresters	Not applicable as an adaptation measure as this equipment is already installed at scale in Victoria.
Insulated cable	Moderate. Insulated cable will avoid a range of power outages caused by vegetation and animal contact with power line conductors, but will not avoid outages caused by tree branches pulling down conductors.
Maintenance	
Self-healing networks	Not applicable, as all Victorian distribution networks are already implementing self-healing networks, such as enhanced fault location, isolation and service restoration technologies, to varying degrees.

Adaptation measure	Effectiveness in mitigating the effect of extreme wind on urban electricity networks
Energy back-up systems at community hubs / key sites	Low. Would mitigate a small portion of the impact of long-duration power outages, irrespective of cause, assuming the energy back up system is maintained. Unlikely to be utilised in the case of routine, shorter-duration power outages.
Hazard management	
Automated or remote asset inspection / monitoring devices	Not applicable, as all Victorian distribution networks are regularly implementing improvement initiatives such as enhanced remote monitoring using digital twin technology. Power outages can already be remotely detected using smart meters.
Electrical isolation	Not applicable as an adaptation measure as this equipment is already installed at scale in Victoria.
Earth wires	Not applicable as an adaptation measure as this approach is only effective in preventing power outages from lightning, not wind.
Stand-alone power systems (SAPS)	Low. Well-treed areas that are most susceptible to wind are generally not suitable for SAPS due to limited flat, clear land for solar installation, which would require significant diesel use (resulting in high costs, high emissions and unacceptable local noise and pollution impacts). SAPs are also more cost-effective in rural areas where the average length of power lines per connection is much higher than in urban areas
Grid-forming inverters	Moderate. When coupled with solar-battery systems, these inverters allow individual customers to operate on a stand-alone or 'islanded' basis, and so can avoid power outages of all kinds, including those from extreme wind. However, unlike SAPS, some level of outage is acceptable and so diesel back-up is not required. In general sufficient solar and battery capacity is needed to provide a meaningful volume of supply when islanded, which is more feasible for residential and small commercial loads than larger commercial and industrial loads.
<p>Note: The suggested allocation of adaptation measures reflects the category definitions provided in Box 2.1. The precise categorisation of measures is dependent on a range of assumptions about how it would be applied in a specific context.</p> <p>Source: ACIL Allen analysis</p>	

This initial review of effectiveness identified five measures that were clearly more effective than the others in an urban context (some measures, such as micro-grids, SAPS and installing new lines on alternative routes, are more effective in rural contexts):

- undergrounding
- tree replacement
- grid-forming inverters
- insulated cable
- increased or revised vegetation management.

We then further considered the merits of these measures against criteria including community acceptance, financial cost and the risk of maladaptation, that is, avoiding outages from extreme wind but creating significant exposures to other kinds of outages. Based on this assessment, enhanced vegetation management was not selected for further analysis due to concerns about community acceptance, specifically the feasibility of further strengthening electric line clearance regulations given community and local government opposition. Tree replacement is a comparable measure and would also face some community and local government opposition, but it offers a higher degree of effectiveness and a strong economic case could increase community acceptance.

Reflecting these considerations, we defined five scenarios to analyse the effects of four adaptation actions against our base case:

- The **base case**: existing overhead distribution infrastructure is replaced like-for-like incrementally as individual components reach end-of-life.

- **Scenario 1 (undergrounding):** existing overhead distribution infrastructure is replaced with equivalent underground infrastructure at the start of the modelling period.
- **Scenario 2 (tree replacement):** large trees that have the potential to impact on overhead distribution infrastructure are removed and replaced with mature trees of a lower-growing species that will remain below the height of this overhead infrastructure.
- **Scenario 3 (grid-forming inverters):** as electricity customers adopt combined solar and battery systems they are required to install 'grid-forming' inverters that are capable of operating as a stand-alone or 'islanded' system for that customer in the event of a grid outage, reducing the cost of these outages.
- **Scenario 4 (insulated cable):** existing overhead conductors are replaced with overhead insulated cables at the start of the modelling period, with other components replaced like-for-like as they reach the end of their life.

The need to adapt infrastructure to climate change impacts is central to this analysis, and so is also integrated into the design of the scenarios (see section 2.1.2).

2.3 Estimating costs

2.3.1 Capital expenditure

ACIL Allen engaged expert cost estimation services from WT Partnership to advise on the capital costs involved in each of the modelled scenarios. GHD provided qualitative engineering advice to ensure the robustness and overall feasibility of the modelled scenarios.

Base case

We estimated the cost of replacing existing overhead infrastructure as a single project. In practice, existing network infrastructure will be of varying ages and conditions and will be replaced periodically over its working life (assumed to be 50 years for this project), so we spread this cost as equal instalments of 1/50th of the total cost over each year of the projection. We estimate the cost to be \$10.0 million based on the following assumptions:

- exemplar defined as per Table 2.1
- 50 metre spacing between poles, which are assumed to be timber
- all works to zone substations, switchgear, customer switchboards and meters are excluded
- 13 megaVolt-amps of distribution transformation capacity (consistent with our analysis of the typical network-wide ratio of transformation capacity to feeder maximum demand), consisting of 300 kiloVolt-amp pole-mounted transformers
- 20 metre distance for customer connection lines
- a 20% increase in the cost of this work to reflect that it will occur as a series of small projects, rather than as a single larger project with economies of scale in planning and delivery.

Scenario 1: undergrounding

We estimated the cost of decommissioning existing overhead infrastructure and replacing it with equivalent underground infrastructure as \$20.3 million based on the following assumptions:

- exemplar defined as per Table 2.1
- 100mm of stabilised sand around all conduits, with 700 mm of cover above conduits
- excavated material is classified as virgin material suitable for landfill disposal
- 100 metre spacing between service pits for both high and low voltage circuits
- all works to zone substations, switchgear, customer switchboards and meters are excluded

- 13 megaVolt-amps of distribution transformation capacity (consistent with observed ratios of transformation capacity to feeder maximum demand), consisting of 500 kiloVolt-amp ground-mounted transformers
- 20 metre distance for customer connection lines
- basic landscaping to rectify works.

We assumed that this cost would be spread over three equal instalments from 2025 to 2027, reflecting the need to plan and stage the undergrounding project.

Scenario 2: tree replacement

We estimated the cost of removing an initial mature tree of up to 12 metres height and replacing with a mature low-growing tree at \$4,400 per tree. This costing includes an allowance of four hours of labour working at height to remove branches and ensure sufficient clearance around live wires prior to removal.

We used Google Maps to visually analyse the streetscape in five areas served by multiple feeders in the exemplar sample, covering a total of 35 kilometres of overhead circuit distance, and estimated that the exemplar sample has about 23 trees per kilometre that would need to be removed to avoid interaction with power lines. This estimate includes both trees that would grow into power lines without ongoing clearance, or those with a significant risk of dropping branches on, or falling across, power lines in the event of high winds. The exemplar has almost 15 kilometres of total overhead circuit distance (1.5 kilometres of standalone high voltage circuit, plus 6.2 kilometres of co-located high and low voltage circuits and 7.1 kilometres of standalone low voltage circuit), which implies almost 350 trees would need to be replaced under this scenario.

The total cost of replacing these trees for this scenario is almost \$1.6 million, which we assumed would be incurred over the period 2025 to 2027.

As the network continues to operate in its existing form under this scenario, the capital costs incurred in the base case were also incurred in this scenario.

Scenario 3: grid-forming inverters for solar-battery systems

We estimated the incremental cost of installing a grid-forming inverter in place of a standard 'grid-following' inverter for three inverter capacities: 5 kW, 7.5 kW and 15 kW as \$4,308, \$5,290 and \$12,799 respectively. We assumed that these cost premia would decrease by 4% per year in inflation-adjusted terms, reflecting technological improvements and more competition to supply this equipment.

We estimated the total stock of battery systems connected to the exemplar feeder by:

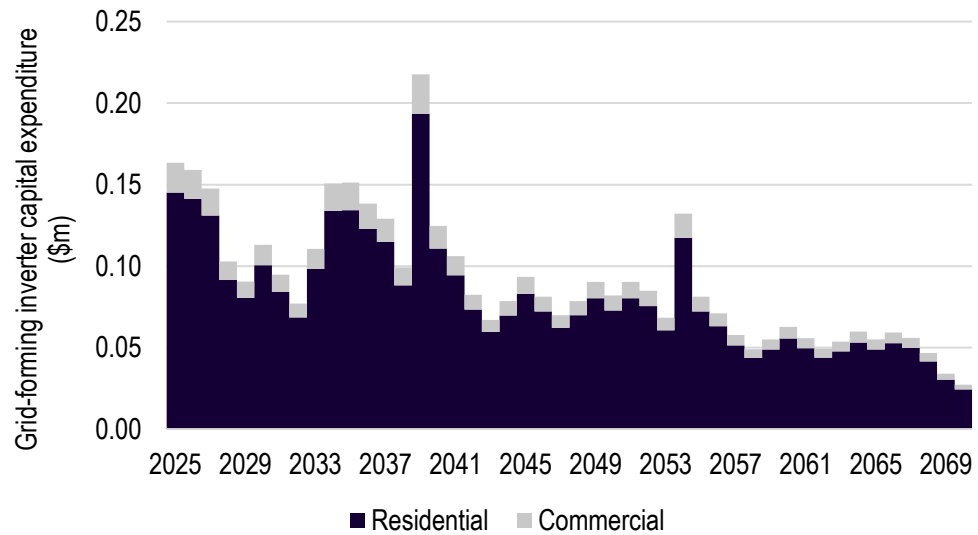
- assuming the Australian Energy Market Operator's projected uptake of small-scale battery capacity for the 2022 Integrated System Plan's Step Change scenario^{xv}
- calculating the implied penetration of batteries based on the ABS's projection of Victorian household numbers,^{xvi} which indicates that the share of customers with batteries is likely to increase from around 6% in 2025 to 27% by 2050
- assuming the uptake of 5 kW inverters by households, 7.5 kW inverters by small businesses and 15 kW inverters by large commercial customers, based on the proportion of customers in each of these segments in Table 2.2
- assuming that inverters would require replacement after 15 years.

These assumptions resulted in a varying profile of incremental capital expenditure on grid-forming batteries, with initial increases driven by a growing stock and a relatively high cost premium over grid-following inverters, with these costs declining in the long-term as the stock of batteries matures and the cost premium declines (Figure 2.4).

The total undiscounted, inflation-adjusted incremental cost of grid-forming inverters is estimated to be \$4.1 million based on these assumptions.

As the network continues to operate in its existing form under this scenario, the capital costs incurred in the base case were also incurred in this scenario.

Figure 2.4 Annual capital expenditure on grid-forming inverters, by customer segment



Source: ACIL Allen analysis

Scenario 4: insulated cable

We estimated the cost of replacing existing overhead uninsulated wires with equivalent insulated cables (at both high and low voltages) as \$3.8 million, using the same general assumptions as in the base case, as well as costs for:

- removal and disposal of existing cable
- replacement with new insulated cable
- modifications to pole top hangers and insulators to accommodate the new cables
- modifications to consumer connections to connect to the new cables.

Cable insulation can be applied in several ways, but we have costed an arrangement known as ‘aerial bundled cable’, where the three conducting wires are individually insulated and wound together as a bundle which can use a common fixing point. It is also possible to insulate wires but not bundle them, with multiple fixing points on a cross-arm as used for typical bare wire circuits.

We assumed that this cost would be spread over three equal instalments from 2025 to 2027, reflecting the need to plan and stage conductor replacement.

The costs of progressively replacing poles, transformers and customer connections are incurred as in the base case, reflecting that this infrastructure has not been replaced during the switch to insulated cable and will still need to be periodically replaced as it reaches the end of its life.

Summary of capital cost assumptions

We estimated costs in 2023 dollars and escalated these costs in nominal terms over the period 2023 to 2025. We then adjusted this nominal cost escalation using the RBA’s inflation assumptions to estimate the extent of inflation-adjusted cost escalation in real 2023 dollars (Table 2.4). Together

these assumptions imply real cost increases of about 3% by 2025. All costs beyond 2025 were assumed to hold constant in real terms, that is, to increase with the general rate of inflation.

Table 2.4 Cost escalation and inflation assumptions

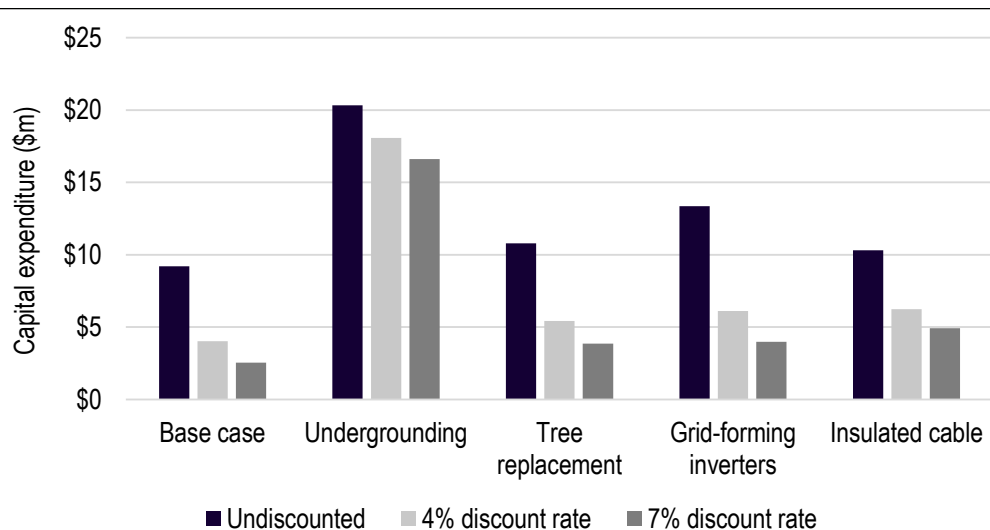
	2023	2024	2025
Nominal cost escalation	5.0%	4.4%	4.7%
Inflation	4.5%	3.25%	3%
Real cost index	1.005	1.016	1.033

Source: WT Partnership estimates; RBA 2023, Statement on monetary policy – May 2023, <https://www.rba.gov.au/publications/smp/2023/may/economic-outlook.html#:~:text=Economic%20growth%20is%20expected%20to,softness%20in%20recent%20activity%20data>.

Capital cost assumptions listed above assume that the network infrastructure installed operates to the end of its expected design life (typically 50 years for electricity distribution infrastructure). Where overhead distribution infrastructure remains in place and is subject to risk of early damage and replacement due to storms (in the base case and all scenarios except scenario 1), this is incorporated as an explicit repair cost and incorporated as maintenance expenditure (see section 2.3.2).

The base case has the lowest capital expenditure in undiscounted and discounted terms, undergrounding (scenario 1) has the highest capital cost, with the other adaptation measures in between these two scenarios (Figure 2.5). The proportional difference between the base case and the various adaptation scenarios is greater when discounting is applied, because adaptation measures typically involve upfront expenditures, whereas capital expenditure is incurred progressively in the base case – and upfront expenditure has a higher present value when discounting is applied.

Figure 2.5 Present value of capital expenditure, by scenario and discount rate



Note: base case network expenditure is incurred in the tree replacement and grid-forming inverters adaptation scenarios, alongside scenario-specific expenditure on the relevant adaptation measures. Base case network expenditure on poles, transformers and customer connections are incurred in the insulated cable scenario, alongside scenario-specific expenditure on new conductors.

Source: ACIL Allen analysis

2.3.2 Operating and maintenance expenditure

Annual operating and maintenance expenditure for distribution network assets was assumed to be 1% of the capital cost of equivalent new infrastructure, which is a common industry metric for operating and maintenance cost estimates. We assumed that these costs were inclusive of storm repair and vegetation management costs, which we then netted out and estimated directly. Storm repair and vegetation management costs must be estimated directly for each scenario as they are significantly affected by the adaptation measures – for example, undergrounding essentially eliminates storm repair and vegetation management costs. The remaining network operating expenditure was calculated as 0.6% of the capital cost of the relevant infrastructure. These costs were identical in the base case, scenario 2 (tree replacement) and scenario 3 (grid-forming inverters), and higher in scenarios 1 (undergrounding) and 4 (insulated cable), reflecting the higher capital cost of these solutions.

Storm repair costs

We made a specific allowance for repair costs following an extreme wind event to reflect the fact that undergrounding will essentially remove these costs, and tree replacement and insulated cable will reduce these costs due to reduced risk of major tree damage. We calibrated these costs based on the AusNet distribution network's estimate of about \$10 million in emergency repair costs following the October 2021 storms,^{xvii} which affected over 200,000 of its almost 800,000 customers, of whom almost 13,000 were without supply for three days. When this impact is scaled to the level of our exemplar we estimated that about 22 customers would experience a major disruption of three or more days, and scaling repair expenditure in line with this indicates about \$17,000 in total costs per storm event. This expenditure was probability-weighted to reflect that major storms do not occur every year (see section 2.4.1 on page 23).

Vegetation management costs

Vegetation management costs were a further category of operating expenditure estimated for each scenario. In the base case, vegetation management costs of about \$0.03 million per year were estimated based on the assumption of about 350 major trees requiring regular management, incurring a cost of \$380 per tree, with trees undergoing maintenance about once every four years. The cost and frequency estimates were derived from network vegetation management cost data^{xviii} and applied to tree management undertaken by both networks and local governments.

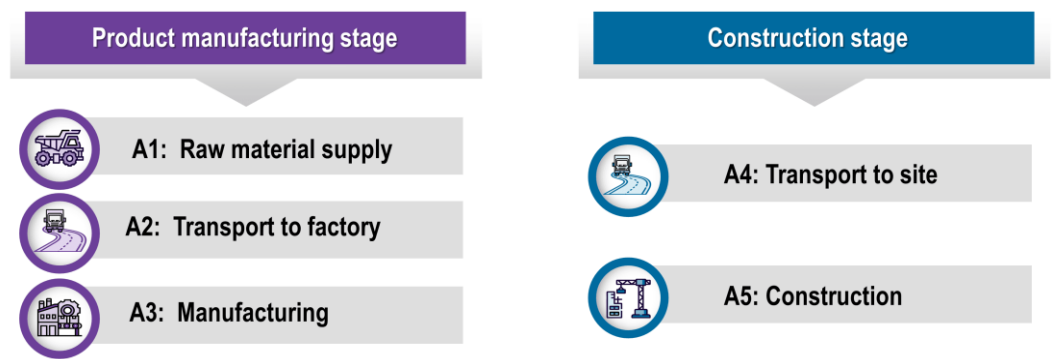
We assumed that all vegetation management expenditure was avoided in scenarios 1 and 2. In scenario 1 all assets are undergrounded, meaning that the need to manage vegetation around power lines is entirely avoided. In scenario 2 all trees of a height sufficient to require ongoing maintenance are replaced, again avoiding this ongoing cost.

Scenario 3 (grid-forming inverters) incurs the same vegetation management costs as the base case, as there is no change to either the overhead infrastructure or the tree canopy.

Scenario 4 (insulated cable) involves a temporary reduction in vegetation management expenditure as insulated cable can be operated with lower clearance from vegetation than the bare wire used in the base case. We assume that vegetation management costs reduce to 20% of the base case cost in the first year after the full roll-out of insulated cable (2028) and return to 100% of the base case cost over the next five years as vegetation starts encroaching on the newly insulated wire.

2.3.3 Embodied emissions

WT Partnership estimated the embodied emissions of each adaptation measure for this study. We focused on 'upfront' emissions, which covers the embodied emissions of materials from extraction of raw materials, through manufacture, transport and installation (Figure 2.6). Emissions from the operation of assets post-construction are excluded, as are end-of-life demolition emissions.

Figure 2.6 Lifecycle carbon analysis modules considered in this analysis

Source: WT Partnership

For the base case and the undergrounding and insulated cable scenarios we estimated the embodied emissions of conductors, poles, transformers and customer connection lines, as well as the pits, trenching and conduits involved in undergrounding. For the tree replacement scenario, we estimated the emissions involved in removing and planting a tree, as well as the net reduction in carbon embodied in the tree that results when replacing a relatively larger tree with a smaller tree. We did not estimate the embodied emissions associated with grid-forming inverters, as the key difference between grid-forming and grid-following inverters will be in software, with negligible associated emissions. As with our estimates of capital costs, we assumed that the base case embodied emissions were also incurred in the tree replacement and grid-forming inverter scenarios, as the network infrastructure replacement required in the base case is also required in these scenarios.

Our analysis broadly followed current industry guidelines for the calculation of upfront embodied emissions, however, we note that these guidelines are still preliminary and are not yet agreed industry-wide. Due to the preliminary nature of the design documentation available for the investments, the embodied emissions estimates should be treated as indicative.

- For manufacturing embodied emissions (modules A1 to A3) we have used a variety of sources, including Environmental Product Declarations, the Epic, ICM and Etool database. A variety of databases are used to ensure as broad a coverage of building materials as possible.
- A full detailed estimation of embodied emissions in stages A4 and A5 (transport of materials to site and construction, respectively) would require significant contractor input and detail surrounding construction methodology, material transport distance and wastage allowances. In the absence of these details, we have allowed for a fixed materials transport distance of 200 kilometres to and from the site, and that construction emissions are 2.5% of material manufacture and transport emissions.

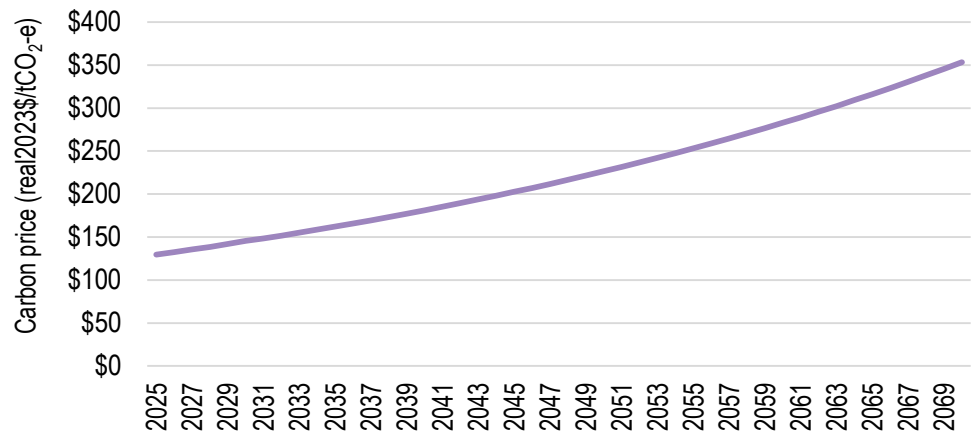
As with our estimates of capital costs, the time at which we assumed emissions were incurred varied depending on the nature of the measure:

- In the base case, emissions were assumed to be incurred progressively over the 50-year typical life of the infrastructure.
- In the undergrounding scenario, emissions were incurred over the years 2025 to 2027 in line with the construction schedule for this measure.
- In the tree replacement scenario, emissions were incurred over the years 2025 to 2027 in line with our assumed timeframe for replacing trees across the exemplar.

- In the insulated cable scenario, emissions for decommissioning bare wire conductors and replacing with insulated cable were incurred over the years 2025 to 2027, and emissions associated with periodic replacement of poles, transformers and customer connections were incurred progressively, as in the base case.

We used carbon price assumptions developed by the New South Wales Government for use in cost-benefit analysis, which are based on market carbon prices in the European Union Emissions Trading Scheme (Figure 2.7). While Australia does not have an emissions trading scheme comparable to that in place in Europe, the European carbon prices can be considered to be reflective of the society-wide costs of greenhouse gas emissions which should be reflected in a CBA.

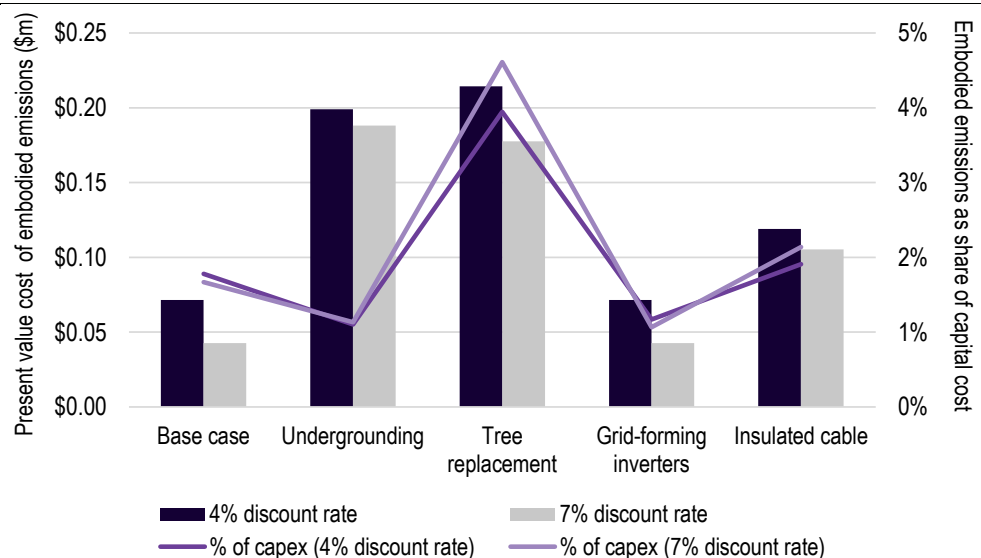
Figure 2.7 Carbon price assumptions



Source: NSW Government 2023, TPG23-08 NSW Government Guide to cost-benefit analysis, Technical note to TPG23-08: Carbon value in cost-benefit analysis, https://www.treasury.nsw.gov.au/sites/default/files/2023-03/20230302-technical-note-to-tpg23-08_carbon-value-to-use-for-cost-benefit-analysis.pdf.

Relative to the base case, the undergrounding, tree replacement and insulated cable scenarios incur a noticeable increase in embodied emissions, though the emissions cost using our assumed carbon prices is generally less than 2% of the total capital cost of each measure (Figure 2.8).

Figure 2.8 Present value of embodied emissions, total and as a share of capital cost, by scenario and discount rate



Source: ACIL Allen analysis

2.4 Estimating benefits

2.4.1 Electricity outages

A key source of benefits from the adaptation measures modelled is that they reduce power outages, particularly when the increasing effects of climate change on electricity distribution networks are considered. The discussion below details our assumptions on the level of power outages in the base case, and how these change across the adaptation scenarios.

Calibration to historical performance

We first calibrated the level of power outages in the base case to the historical performance of the exemplar sample described in section 2.2.1 across five outage cause categories:

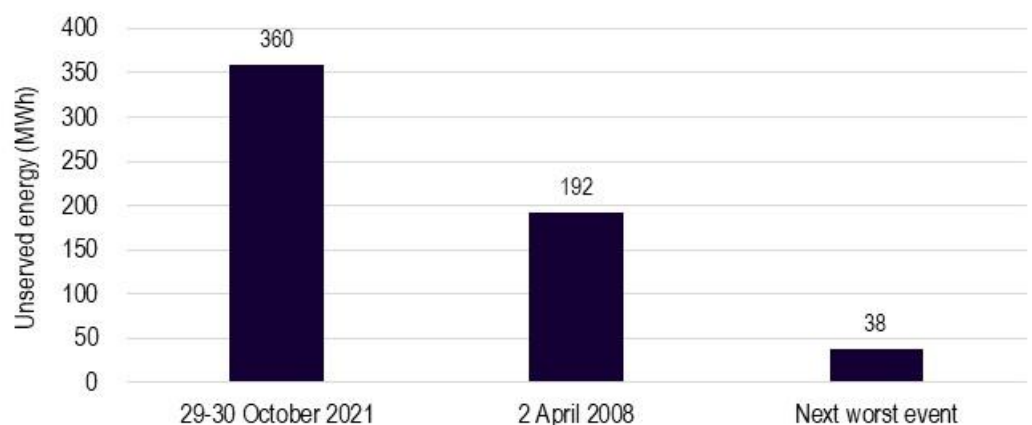
- weather and vegetation (which is of particular interest for this study as outages caused by extreme wind events are in this category)
- ‘third party’ outages, which are primarily outages caused by events such as vehicle impacts with power poles, or debris or construction equipment making contact with power lines
- animal, where animals such as possums or birds create contact between power line phases and short circuit the network
- asset failures
- planned outages for maintenance of the network.

This categorisation of outages is important as each of the network adaptation measures analysed will have different impacts on different outage types.

We analysed the level of power outages on each day over the period January 2008 to June 2022 inclusive in the exemplar sample to assess both the typical level of unserved energy and the probability and severity of major storm events that can impact the network.

This analysis showed that two major weather events, 2 April 2008 and 29-30 October 2021, caused significantly more unserved energy than was observed on any other day. Figure 2.9 shows that customers in the exemplar sample experienced 5-10 times the unserved energy on these two days compared to the next worst energy loss event. The median amount of unserved energy in the exemplar sample per day is only 0.015 megawatt-hours, or over 10,000 times less than what was experienced on 2 April 2008.

Figure 2.9 Unserved energy in the exemplar sample on major storm days



Source: ACIL Allen analysis

Accordingly, we further categorised outages as:

- **extreme**, which are major weather events that cause particularly widespread and longer-duration outages, reflecting the severity and duration of power outages observed on 2 April 2008 and 29-30 October 2021.
- **routine**, which reflects the typical level of power outages on all other days analysed, and consists of common and relatively localised outages, which are typically of relatively short duration.

As extreme outage events are weather driven, only vegetation and weather outages were categorised as extreme.

The results of this analysis are summarised in Table 2.5.

Table 2.5 Unserved energy by outage category in the base case, 2025

Outage category	Routine		Extreme	
	Annual unserved energy (MWh)	Share of unserved energy	Unserved energy per extreme weather event (MWh)	Share of unserved energy
Vegetation and weather	0.94	34%	5.13	100%
Third party	0.26	9%	0	0%
Animal	0.28	10%	0	0%
Asset failure	1.04	37%	0	0%
Planned	0.26	9%	0	0%

Note: vegetation and weather outages increase over time due to assumed increases in tree cover, in line with the *Living Melbourne* strategy

Source: ACIL Allen analysis of the exemplar sample

We have scaled the amount of unserved energy to reflect growing population density in the area served by the exemplar feeder. We analysed the rate of population and dwelling growth in eastern and south-eastern Melbourne to extrapolate likely trends in outages. The number of dwellings grew faster than population between the 2016 and 2021 censuses (1.5% per year and 0.8% per year), so we grew the volume of unserved energy by the average of these estimates (1.2% per year).

Effects of climate change

After calibrating the level of power outages in our model to the historical performance of our exemplar sample, we adjusted the expected level of outages to reflect the effects of climate change and, in particular, increasing extreme wind events. Climate change is likely to increase the effects of extreme wind on the overhead electricity distribution infrastructure in our exemplar and so the level of extreme outages in our base case has been increased to reflect this impact. This means that adaptation measures that reduce the effects of extreme wind on this infrastructure, and therefore reduce power outages, will have a larger effect and deliver a greater economic benefit than if climate change was not occurring.

To do this we analysed both historical and projected wind data to assess how the severity of extreme wind events may change in future due to climate change.

- Historical data was sourced from the Bureau of Meteorology, using data from three weather stations (Moorabbin Airport, Scoresby and Viewbank) to approximate the conditions of the exemplar region.^{xix} Analysis found a strong link between extreme wind and extreme outage events, with both April 2008 and October 2021 incidents being the two highest recorded wind speeds over the analysed period.

- Projected wind data was drawn from the Victorian Climate Projections^{xx} under Representative Concentration Pathways (RCPs) 4.5 and 8.5, examining locations across eastern and south-eastern Melbourne.

The analysis indicates that there is little change in forecast median wind speeds under both RCPs. By contrast, our analysis of downscaled projection data of our exemplar area (eastern and south-eastern Melbourne) does suggest some increase in the severity of extreme events, with forecast maximum wind speeds expected to grow slightly in the coming decades under the RCP 4.5 scenario.² However, these projections vary by location and are subject to some uncertainty – as noted in the Victorian Climate Projections technical report, extreme wind speeds could decrease in the future for some areas of Victoria.^{xxi}

Despite the uncertainty noted above, our analysis assumes that both the severity and frequency of extreme wind events will increase in the future relative to observed historical outcomes. Based on the distribution of projected wind speeds, we assumed that the probability of observing an extreme event in a particular year is 19%³, which is a significant increase on both the historical observation rate of extreme wind events, and the Victorian Climate Change Projections model predictions for historical years (the model produces projections from 2006). The impact of extreme winds is non-linear with wind speed and inherently difficult to predict, but the increased maximum winds speeds observed in the Victorian Climate Projections supports an assumption of increased weather and vegetation related outages. The literature did not directly support a specific value, and we assumed a 20% increase to allow for this factor.

Value of customer reliability

As is common in the electricity industry, we estimated the economic cost of power outages by multiplying the unserved energy (a volume of energy) by the value of customer reliability, or VCR (expressed as a dollar value per unit of unserved energy). We have used the Australian Energy Regulator's (AER's) published VCR estimates for this analysis. More information on how the AER estimates the VCR is provided in Box 2.2.

Our core estimates for this analysis reflect direct costs only. This is because of the relatively small-scale nature of our exemplar – reducing power outages for about 1,900 electricity customers is not likely to make a material impact to the level of traffic congestion or disruption to essential services that will arise across a wider area in the event of large and widespread outages. Further, these social costs are not relevant to routine outages, which only affect small numbers of customers at any one time. However, if adaptation measures were applied very broadly, they may start to avoid these wider social costs from extreme outages. To capture this effect we have applied a social cost multiplier to the cost of extreme outages as a sensitivity in section 3.3.

The AER's VCR estimates distinguish between:

- the season of outage (summer and winter)
- time of outage (peak and off-peak)

² Counter-intuitively, projections under RCP 8.5 do not forecast a rise in extreme wind occurrences, despite having higher global emissions concentrations. As a key focus of this study is on the effect of increasing wind severity on electricity distribution networks, we used RCP 4.5 as the base case in this modelling. Outcomes under the RCP 8.5 scenario are reflective of sensitivity analysis with lower severity of extreme wind events (see section 3.3).

³ This is based on nine wind events in forty-seven projection years (from 2023 to 2070) that were of equal or greater intensity than wind events during the historical projection period (2006 to 2022). The projections did not indicate a clear pattern of increasing probability over time, so this increased probability was held constant throughout the model period.

- the type of user affected, distinguishing between residential, commercial and industrial customers, with commercial and industrial customers further disaggregated into small and large businesses.

Box 2.2 Estimating the value of customer reliability

Direct costs

The value of customer reliability reflects the cost to customers of a power outage, and therefore the benefit or value they would experience from more reliable supply. These costs include direct costs, such as food spoiling in a refrigerator, and opportunity costs, such as lost sales or production for businesses that must stop operating during a power outage.

The AER estimates the value of customer reliability through a mix of approaches:

- Residential and small business customers are surveyed to understand their willingness to pay to avoid hypothetical outages of different types (these techniques are called choice modelling and contingent valuation in the economic literature).
- Large business customers are directly surveyed to elicit information on the direct costs they experience during a power outage.

Social costs

As such, the AER’s estimates only reflect the direct costs of power outages to electricity consumers, and do not pick up some broader issues that may arise during widespread and/or long-duration outages. Examples of these wider social costs include:

- traffic congestion and diversion of policing resources due to failure of traffic lights
- disruptions to essential services such as public transport, mobile and fixed-line telecommunications, and water and sewerage systems
- safety issues such as people being trapped in elevators, increased risk of crime due to failed streetlights, and inoperable fire alarms
- reliance on back-up power for essential services such as hospitals and prisons.

Source: AER 2019, *Values of Customer Reliability Review – Final decision*, <https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/values-of-customer-reliability/final-decision>; AER 2022, *Values of Customer Reliability – Update*, <https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/values-of-customer-reliability/update-0>; ACIL Allen 2020, *Value of Customer Reliability for Widespread and Long Duration Outages*, <https://www.aer.gov.au/networks-pipelines/guidelines-schemes-models-reviews/values-of-customer-reliability/aer-position>.

We analysed the historical pattern of power outages to estimate the share of outages by season and time of day, and used the exemplar demand patterns in Table 2.2 to pro-rate the amount of unserved energy across different customer category types.

The AER’s VCR estimates also vary by the duration of the outage and so we used data from our exemplar sample to estimate differences in the likely duration of outages for routine and extreme outages (Table 2.6), with extreme weather events causing relatively more long duration outages than routine events.^{xxii}

Table 2.6 Distribution of outage duration, by outage type

	0-1 hours	1-3 hours	3-6 hours	6+ hours
Routine	41%	29%	19%	12%
Extreme	12%	16%	16%	56%

Source: ACIL Allen analysis of exemplar sample

We also adjusted the value of extreme outages to reflect their geographic reach. The standard VCRs assume a reasonably localised power outage. However, when an extreme wind event occurs and an outage is more widespread (for example, as occurred in Victoria on 2 April 2008 and 29-30 October 2021), people cannot easily mitigate the cost of the outage by travelling from the area

without power to, for example, stay with family or friends who have power, or to purchase goods and services from shops that have power.

We increased the cost of extreme outages by 10% to reflect the cost of widespread outages as estimated in two studies. One study estimated how much electricity customers were willing to pay to avoid an outage that covered three provinces in Austria, compared to a localised outage in that customer’s street,^{xxiii} and the second study estimated customers’ willingness to pay to avoid an outage that affected the whole country.^{xxiv} Our adjustment is calibrated to a level reflective of outage events that affect customers over an area with a radius of between 5 and 85 kilometres. This is consistent with the geographic spread of the April 2008 and October 2021 events, which primarily affected metropolitan Melbourne.

Together, these factors support the overall VCR estimates for each customer category set out in Table 2.7. Routine outages have a higher cost per unit of unserved energy than extreme outages. This is because outages have a ‘once-off’ effect and cease to get worse over longer periods – for example, once food has spoiled due to a lack of refrigeration, no further food loss costs are incurred, even if an outage continues for a long time. This means that when the total costs of an outage are averaged over its entire duration, the average cost per unit of unserved energy is higher for shorter (routine) outages than for longer (extreme) outages.

Table 2.7 Value of customer reliability, by customer and outage type (\$/kWh)

Heading	Routine	Extreme
Residential	\$32.2	\$22.8
Commercial	\$81.6	\$38.9
Industrial	\$133.0	\$62.1

Note: These estimates include direct costs to electricity users only. Routine outages are assumed to be localised, while the VCR for extreme outages is increased to reflect its more widespread geographic reach. Social costs are captured as a sensitivity in section 3.3.

Source: ACIL Allen analysis

Effects of increasing tree canopy

The level of unserved energy resulting from vegetation and weather changes in the base case will increase not only because of climate but also because the level of tree cover in the exemplar area is likely to increase over time due to policy actions by local governments. In turn, this increased tree canopy will increase the level of both routine and extreme vegetation and weather outages, all else being equal.

This effect is captured through an outage ‘severity factor’ for weather and vegetation outages (it is not applied to other outage categories). The effect of increasing tree cover was captured by assuming that the level of tree canopy increases in line with targets set out in the *Living Melbourne* study, which has been endorsed by the vast majority of local governments in the Melbourne metropolitan area,^{xxv} while some non-metropolitan councils have adopted similar objectives.^{xxvi} This study indicates that the total level of tree canopy in the exemplar area is likely to increase from 20% in 2015 to 30% by 2050. We increased weather and vegetation outages in line with this relative increase in tree canopy.

Effect of adaptation measures

Each of the adaptation measures reduces the severity of an outage event in different ways. Table 2.8 summarises the reduction factors by outage cause and adaptation measure that we have assumed based on our knowledge and experience of the electricity distribution network and adaptation measures analysed.

Table 2.8 Share of outages avoided, by cause and by adaptation measure

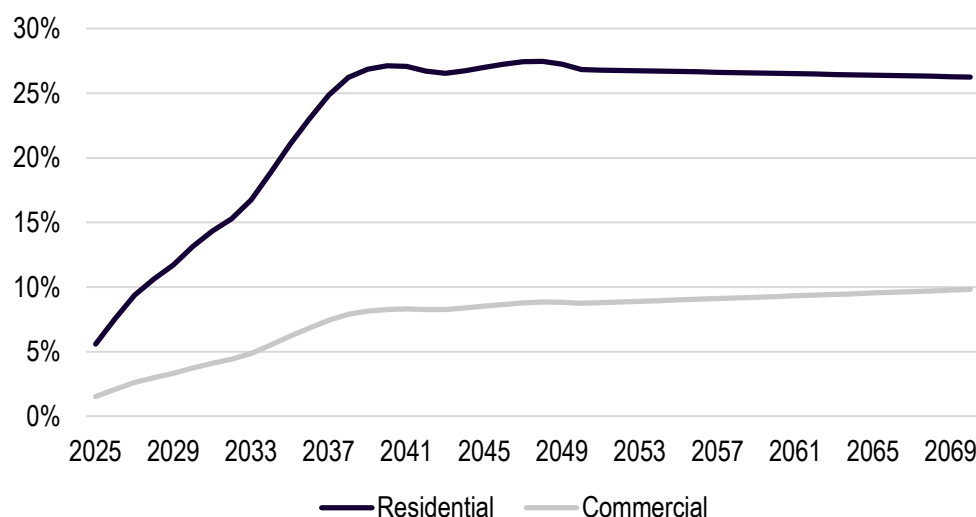
Outage cause	Routine / Extreme	Undergrounding	Tree replacement	Grid-forming inverters	Insulated cable
Vegetation/ weather	Routine	100%	67%	See Figure 2.10	50%
	Extreme	100%	80%	See Figure 2.10	25%
Third party	Both	100%	0%	See Figure 2.10	0%
Animal	Both	100%	80%	See Figure 2.10	100%
Asset failure	Both	80% initially, decreasing to 0% over 20 years	0%	See Figure 2.10	50% initially, decreasing to 0% over 20 years
Planned	Both	0%	0%	See Figure 2.10	0%

Notes: Tree replacement is assumed to be more effective in preventing extreme weather outages, as large and high-hanging branches are removed, which are a major cause of outages in storms. Conversely, insulated cable is assumed to be less effective on major storm days as cables remain close to large branches, which can be brought down in major storms. Undergrounding and insulated cable measures involve installing new infrastructure, which is assumed to reduce asset failure outages. As shown in the table, the reductions in outages are greatest initially but asset failures return to base case levels over time as these new assets age.

Source: ACIL Allen analysis

The share of power outages avoided by grid-forming inverters increases over time in line with the increasing stock of these inverters (Figure 2.10). Grid-forming inverters will be very effective in avoiding outages for those customers that install them, with our analysis indicating that typical battery and solar system capabilities will be sufficient to avoid over 90% of all outages, given that most outages are of relatively short duration. However, the share of customers with batteries is quite low, with Australian Energy Market Operator forecasts indicating that this share is likely to be around 6% by 2025 and increase to about 28% by 2050 (see section 2.3.1, page 16).

Figure 2.10 Share of outages avoided by grid-forming inverters, by customer type



Source: ACIL Allen analysis

Maladaptation

ACIL Allen, with support from technical advisors GHD, considered the potential for the adaptation measures analysed to cause ‘maladaptation’, that is, an increase in other power outage types as a side-effect of addressing outages from extreme wind.

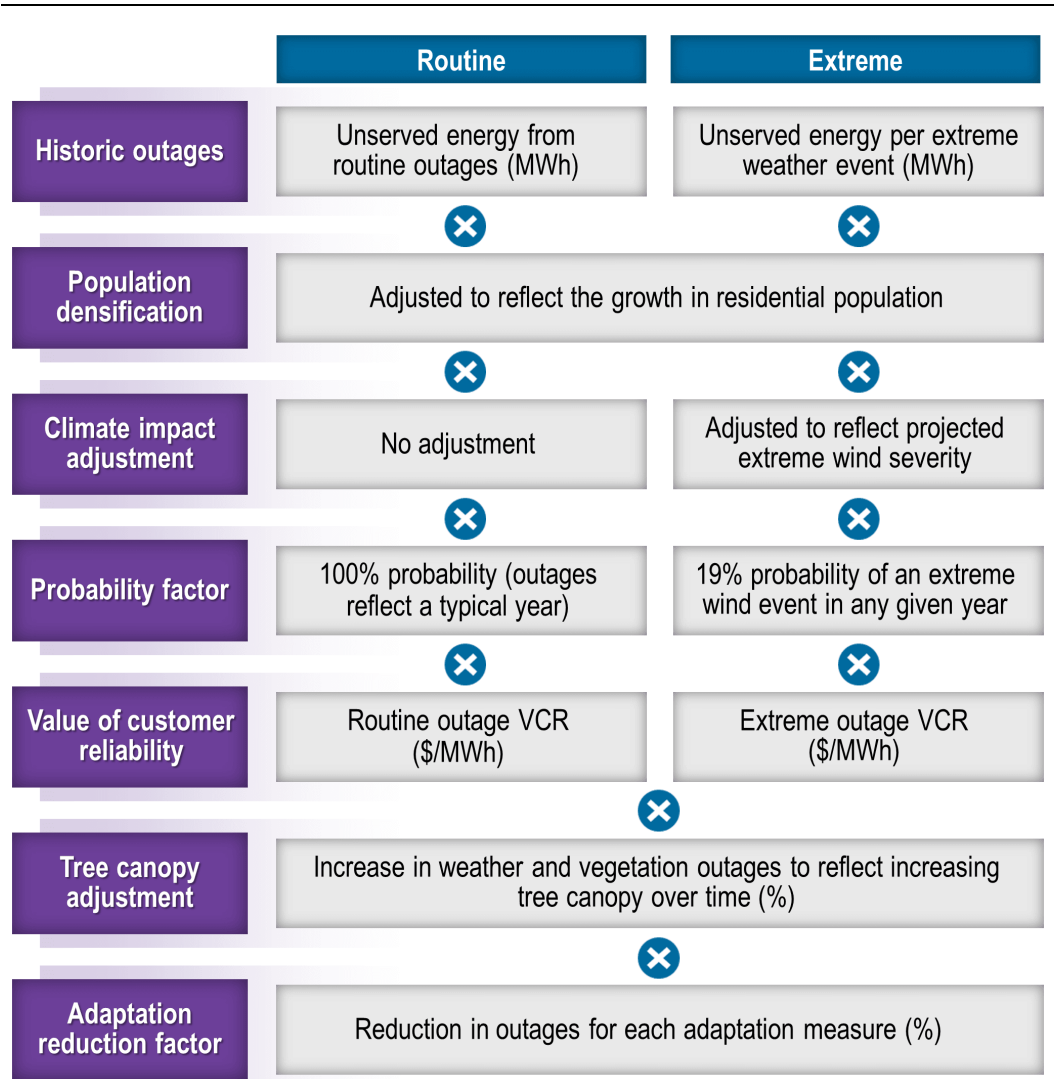
Three maladaptation risks were identified, and all three were assessed to be immaterial to our analysis of overall outages, such that no specific allowance was necessary for these modes of failure:

- Underground cables could fail due to flooding. We assessed that underground cables generally have no issues with flooding, provided that the cable insulation is not also damaged.
- Underground cables could fail due to dry soil cracking and moving. Current practice is to surround cables with stabilised sand when trenching, which isolates the cable from ground movements that may occur due to changes in soil conditions.
- ‘Dig-ins’ can occur, which is where digging equipment damages underground cables. We assessed the rate of dig-ins reported in distribution network performance reporting and found that this caused less than 0.1% of all outages for the CitiPower network, which has a relatively high proportion of underground cable.

Summary

An overview of our power outage cost quantification method is shown in Figure 2.11. The total annual cost of power outages is the sum of the annual routine outage cost and the probability-weighted extreme outage cost.

Figure 2.11 Power outage cost quantification method



Source: ACIL Allen analysis

2.4.2 Health effects of changes to tree canopy

As discussed in section 2.3.2, several of the adaptation measures analysed would change the extent of tree canopy that can be sustained in the vicinity of power lines. In turn, the extent of tree canopy has a significant impact on the temperature in a local area and can significantly reduce temperatures on hot days. It follows that increased tree canopy would reduce the impact of high temperatures and so improve the health of residents in the modelled exemplar area.

The health benefits of increased vegetation cover and the health costs of decreases in vegetation cover are calculated on the following basis:

- Just over 5,000 residents live in the area served by our exemplar feeder, calculated as 1,760 residential electricity customers multiplied by an average of 2.6 people per household.^{xxvii}
- Eastern and south-eastern Melbourne experiences about 38 days over 30°C per year, based on Bureau of Meteorology data.
- A 10% increase in the share of land covered by tree canopy is assumed to reduce the land surface temperature by 1.13°C.^{xxviii}
- The health benefit from cooling is assumed to be \$2.90 for each degree reduction per person per day above 30°C.^{xxix}

As noted in section 2.4.1 (on page 26), we estimated that the base level of tree canopy cover in 2015 was 20%, based on a weighted average of local government areas in eastern and south-eastern Melbourne, and assumed this would increase to 30% by 2050 in-line with local government-specific targets set out in the *Living Melbourne* strategy.^{xxx} Further, we estimated that 23% of all tree canopy is affected by electricity infrastructure, calculated as 80% of the canopy located in infrastructure corridors (which are primarily roads) and a small share (20%) of residential and parkland tree canopy.^{xxxi}

We further adjusted our estimates of health effects based on the Victorian Climate Projections RCP 4.5, which predict an increasing number of days over 30°C.⁴

Relative to the base case:

- Undergrounding (scenario 1) increases the extent of tree canopy, as the potential for conflict between power lines and trees is removed. We have assumed that undergrounding can support a 20% increase in the tree canopy affected by electricity distribution networks. This is equivalent to a 1.0% to 1.4% increase in the total tree canopy in the study area.⁵
- Tree replacement (scenario 2) significantly reduces the tree canopy, as large trees with significant shading effects are moved and replaced with lower-growing species that provide less shade. We have assumed that this results in a 50% reduction in the tree canopy affected by electricity distribution networks (a 2.6% to 3.4% reduction in the total tree canopy for the study area).
- There is no change in tree canopy associated with installing grid-forming inverters (scenario 3).
- Use of insulated cable (scenario 4) increases the extent of tree canopy, as insulated cables can be in closer proximity to vegetation with lower likelihood of causing power outages. We assumed that use of insulated cables supports a 10% increase in the tree canopy affected by

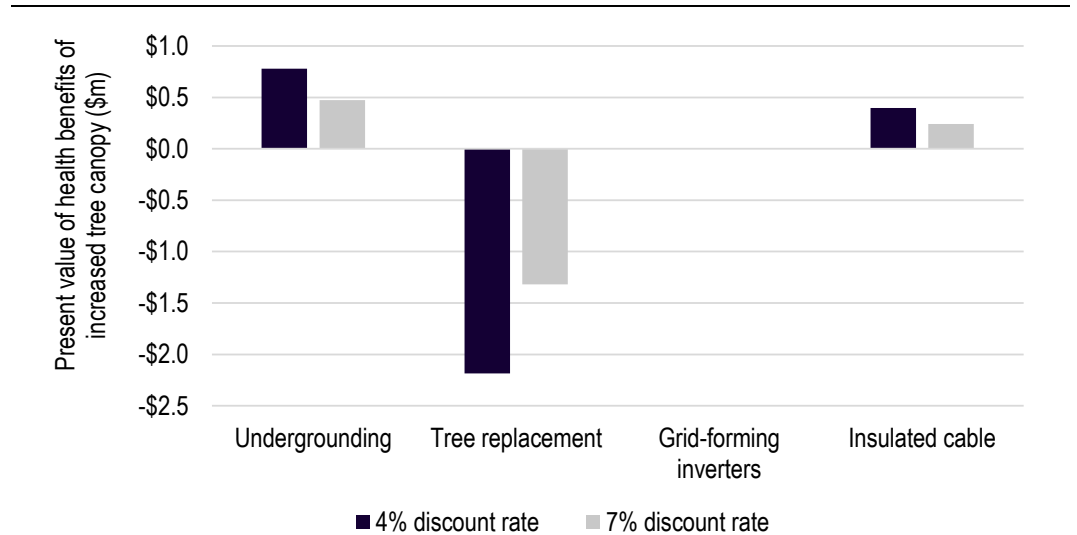
⁴ We tested outcomes under RCP 8.5 and found that this effect was not material.

⁵ This is calculated as the base level of tree canopy of 20% to 30%, of which 23% is affected by electricity distribution infrastructure, and which is then increased by 20%. Multiplying these factors together gives a total increase in tree canopy of 1.0% to 1.4%.

electricity distribution networks (a 0.5% to 0.7% increase in the total tree canopy for the study area).

Together, these assumptions indicate that undergrounding and insulated cable investments can deliver meaningful health benefits to residents of our modelled exemplar area due to increased tree canopy, while tree replacement is estimated to incur a significant health cost due to reduced tree canopy (Figure 2.12).

Figure 2.12 Present value of health benefits due to changes in tree canopy, relative to the base case, by scenario and discount rate



Source: ACIL Allen analysis

2.4.3 Reduced vehicle collisions with power poles

Overhead electricity infrastructure uses many street-side poles, creating a large number of potential traffic hazards. Consequently, undergrounding power lines would remove the risk of vehicle collisions with these poles, although the risk would remain that vehicles that currently collide with power poles would instead collide with trees or other fixed objects.

We estimated the cost of vehicle crashes involving power poles within our exemplar as a basis for then estimating the benefits of avoided crashes from undergrounding. To do this we first identified urban crashes involving power poles that resulted in fatalities or hospitalisations, and then translated this into a monetary cost of these crashes (Table 2.9).

Our exemplar represents about 0.11% of all the urban overhead power lines in Victoria by distance, so scaling down the total Victorian cost of crashes involving urban power poles (\$194 million) indicates that the cost of traffic crashes involving power poles in our exemplar area is about \$0.22 million per year.

The portion of these costs that will be avoided by undergrounding is difficult to quantify, as it requires assumptions about what would have happened had the vehicle not collided with a power pole. For simplicity we have assumed that undergrounding avoids 50% of these costs, or about \$0.11 million per year. Other adaptation measures do not change the number or location of power poles, and so incur the same crash costs as the base case.

Table 2.9 Cost of urban traffic crashes in Victoria involving power poles

Casualty type	Urban crashes involving power poles		Cost per crash		Total cost
	2006-2020 (count)	Annual average	2013\$	2023\$	2023\$m
Fatalities	173	11.5	\$7,425,629	\$9,615,609	\$111
Hospitalisations	3,515	234.4	\$87,988	\$113,938	\$27
Fatalities and hospitalisations					\$138
Other accidents					\$57
Victorian total					\$194

Note: 71% of costs that arise from fatalities and hospitalisations was estimated based on Economic Connections (2017). Cost per crash was estimated using the willingness to pay approach in the Australian Transport Assessment and Planning guidelines.

Sources: *Economic Connections 2017, Cost of Road Trauma in Australia*, https://www.aaa.asn.au/wp-content/uploads/2018/03/AAA-ECN_Cost-of-road-trauma-summary-report_Sep-2017.pdf; ABS 2023, *Consumer Price Index, Australia*, <https://www.abs.gov.au/statistics/economy/price-indexes-and-inflation/consumer-price-index-australia/latest-release>; *Australian Transport Assessment and Planning, Crash costs*, <https://www.atap.gov.au/parameter-values/road-transport/4-crash-costs>, Table 14, *VicRoads, Crash statistics*, <https://www.data.vic.gov.au/data/dataset/crash-stats-data-extract>.

2.4.4 Broader changes in amenity

Changes to electricity network infrastructure and nearby tree canopy can have broader impacts on amenity than are captured in section 2.4.2:

- Undergrounding electricity infrastructure (scenario 1) is likely to increase amenity for local residents and visitors, as removing overhead electricity infrastructure can improve the aesthetics of the streetscape and reduce the number of physical obstacles for pedestrians. The amenity benefit of undergrounding may also be enhanced by allowing increased tree cover, which residents and visitors typically find visually pleasing, and which may contribute to health outcomes such as improved physical health due to better conditions for walking and improved mental health^{xxxii} (these benefits are separate to the health benefits that result from increased tree canopy reducing local temperatures, which are discussed in section 2.4.2).
- Tree replacement (scenario 2) is likely to reduce the visual amenity created by large trees.
- The use of grid-forming inverters (scenario 3) is not likely to result in any changes to the streetscape or any relevant amenity changes.
- Use of insulated cable (scenario 4) can allow increased tree cover, which residents and visitors may find visually pleasing and therefore deliver amenity and health benefits.

Some relevant Australian literature examining amenity effects of electricity infrastructure and tree canopy changes is summarised in Box 2.3 on the next page.

Although the literature discussed above estimates the value of some of these amenity changes, we consider that these estimates cannot be rigorously extended to the specific circumstances of electricity distribution infrastructure in Victoria. The benefits estimated by various studies are likely to be context and location-specific, and are also sensitive to the estimation methodologies employed, meaning that using studies from other contexts to estimate amenity changes relating to the scenarios modelled in this study could be misleading. For example, house prices have increased significantly across Australia since the specific studies of the amenity benefits of undergrounding were undertaken, and it cannot be safely assumed these benefits have scaled linearly with house prices. Noting these concerns, we set out an indicative estimation of amenity benefits of undergrounding in chapter 4 to illustrate their likely materiality, and the value of further work to develop evidence applicable in contemporary Victoria.

Box 2.3 Literature analysing amenity effects of undergrounding electricity infrastructure and parkland

Undergrounding power in Western Australia

In 2011 the Economic Regulation Authority of Western Australia examined the costs and benefits of that state's ongoing policy to underground power with contributions from local governments and energy companies. It commissioned a 'hedonic valuation' study that compared house prices in areas with overhead and underground supply, while controlling for other factors that can affect house prices, and used this difference in house prices as a proxy for the amenity value that homeowners gain from having underground power supply. This study found a mean increase in house value from undergrounding of almost \$10,000 (2011 dollars), or 2.6% of the mean house price at the time.

Undergrounding power in Canberra

McNair (2009) used hedonic valuation to compare house prices in three suburbs of Canberra with a mix of overhead and underground supply. This study found that underground power increases house prices by 2.9%, or about \$11,700 per house (2009 dollars) based on the median house price in the study area.

McNair, Bennett and Hensher (2010) broadly confirmed this finding using a different estimation approach known as 'stated preference'. In this study, home-owners were surveyed on how much they valued underground power, and found they were willing to pay almost \$7,000 per household (2010 dollars).

Amenity benefits of parks in Victoria

In 2018 Infrastructure Victoria and Aither (Evangelio et al.) examined the effect of parks on house prices in Victoria using the hedonic valuation method. This study found that moving from a median or typical distance from parks to the first percentile distance from parks is associated with an increase in house prices of \$86,000. This indicates that homeowners place a significant value on the amenity benefits of parks.

Source: ACIL Allen analysis of: Economic Regulation Authority of WA 2011, *Inquiry into State Underground Power Program cost benefit study*, <https://www.erawa.com.au/cproot/9988/2/20111020%20-%20D76272%20-%20Final%20report%20-%20inquiry%20into%20State%20Underground%20Power%20Program.pdf>; McNair 2009, *House prices and underground electricity distribution lines: the case of three selected suburbs in Canberra*, https://openresearch-repository.anu.edu.au/bitstream/10440/1118/1/McNair_House2009.pdf; McNair, Bennett and Hensher 2010, *Households' willingness to pay for undergrounding electricity and telecommunications wires*, https://openresearch-repository.anu.edu.au/bitstream/10440/1115/1/McNair_Households2010.pdf; Evangelio, Hone, Lee and Prentice 2018, *What makes a locality attractive? Estimates of the amenity value of parks for Victoria*, <https://www.infrastructurevictoria.com.au/wp-content/uploads/2019/04/What-makes-a-locality-attractive-Estimates-of-the-amenity-value-of-parks-for-Victoria.pdf>.

2.4.5 Electrical safety benefits

Overhead electricity infrastructure can create a safety hazard, and so changes to this infrastructure can create welfare benefits by improving safety. Safety issues can arise due to contact between overhead infrastructure and construction or similar equipment, or when a major storm causes this infrastructure to fall over.

Energy Safe Victoria publishes annual reports on the safety performance of Victoria's electricity networks, and these include details of fatalities and major injuries that arise from contact with powerline infrastructure. ACIL Allen's analysis of these reports indicates that there have been 3 fatalities and 7 injuries from contact with urban overhead powerlines in Victoria over the last 5 years (financial years 2017-18 to 2021-22 inclusive).^{xxiii} As our exemplar represents about 0.11% of the urban overhead electrical infrastructure in Victoria by distance, this indicates that the probability of a major incident resulting in serious injury or death in our exemplar area is about 0.2% per year. As a result, we consider that the economic quantification of these safety benefits is not material to this cost-benefit analysis.

Major storms can cause electrical infrastructure to fall to the ground, potentially creating a safety hazard. That said, electrical infrastructure is designed so that contact of electrical conductors with the ground or other hazards will trigger protection equipment and normally isolate the circuit in question. In some cases, protection equipment may not operate as designed, but we are not aware

of instances where this has resulted in electrocution. Emergency services typically assess infrastructure damage in major storms and work to protect the public from potential hazards. This may include the employment of security guards to patrol the fallen infrastructure. Reducing the risk of damage to overhead electricity infrastructure will reduce the probability that emergency services or security patrols will be required to protect the public from this hazard, but the economic quantification of these benefits is not material to this analysis.

2.4.6 Animal welfare benefits

Overhead electricity infrastructure is a common cause of electrocution of birds, possums, bats and other animals that make contact with live wires and short circuit the network (this also commonly causes power outages). Some of the adaptation measures analysed in this study can significantly reduce the risk of animal electrocution, and therefore improve animal welfare:

- Undergrounding reduces the risk of animal contact with power lines to almost zero.
- Tree replacement reduces the risk of animals climbing or falling onto overhead power lines, as the trees that are taller than typical distribution infrastructure have been removed and replaced with lower-growing species.
- Grid-forming inverters have no effect on animal welfare.
- Insulated cable virtually eliminates the risk of animal electrocution due to the protective effect of the cable insulation.

We are not aware of credible estimates of either the number of animals who are harmed by power lines in the Melbourne metropolitan area or other parts of Australia, nor the monetary value that humans would put on the welfare of these animals.^{xxxiv} International studies have a high degree of uncertainty in their estimates^{xxxv} and, in any case, the findings are unlikely to translate to Australia. Therefore, we have not attempted to quantify these benefits in this study but note that animal welfare benefits could improve the investment case of several of the modelled adaptation measures beyond the estimates in this study.

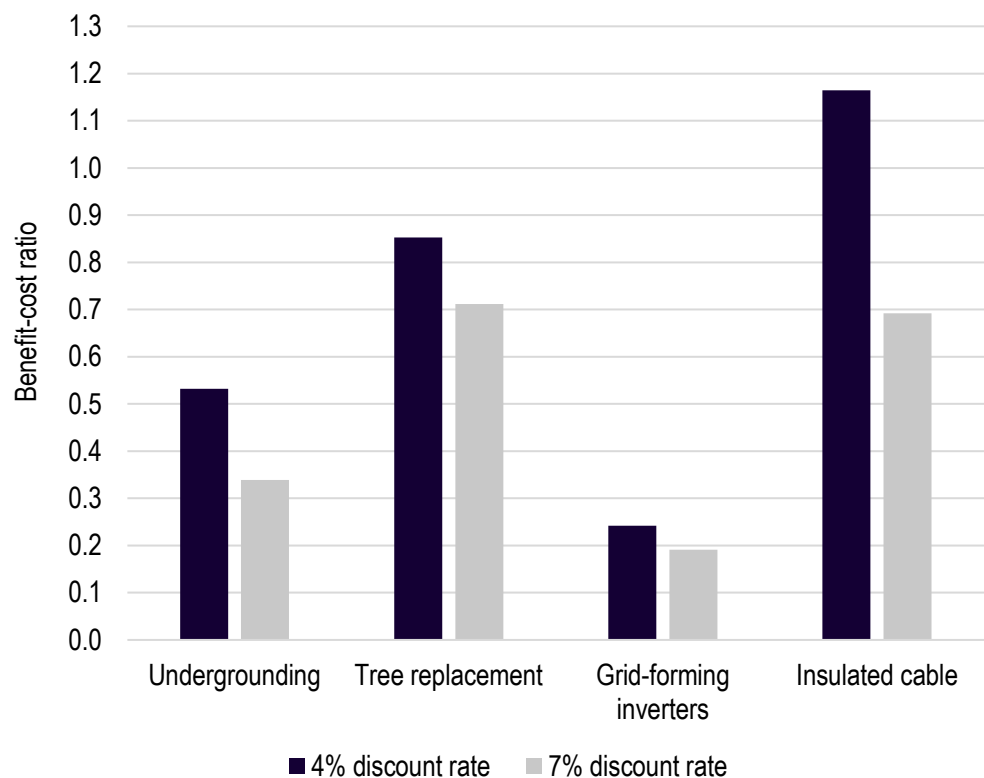
Results 3

3.1 Cost-benefit outcomes

As discussed in section 2.1, a cost-benefit analysis compares the costs and benefits of each adaptation scenario to the base case to determine the effects of each adaptation action.

Despite the modelled adaptation measures being effective in reducing electricity outages, our analysis finds that only one measure – insulated cable – achieves a BCR greater than one using a 4% discount rate, and no measure does so at a 7% discount rate (see Figure 3.1 and Table 3.1).⁶ However, the tree replacement measure has a BCR approaching one (0.85) using a 4% discount rate.

Figure 3.1 Benefit-cost ratios, by scenario and discount rate



Source: ACIL Allen analysis

⁶ As noted in section 2.1.4, a BCR of less than one indicates that the quantified benefits do not justify the projects, based on modelled assumptions and discount rates.

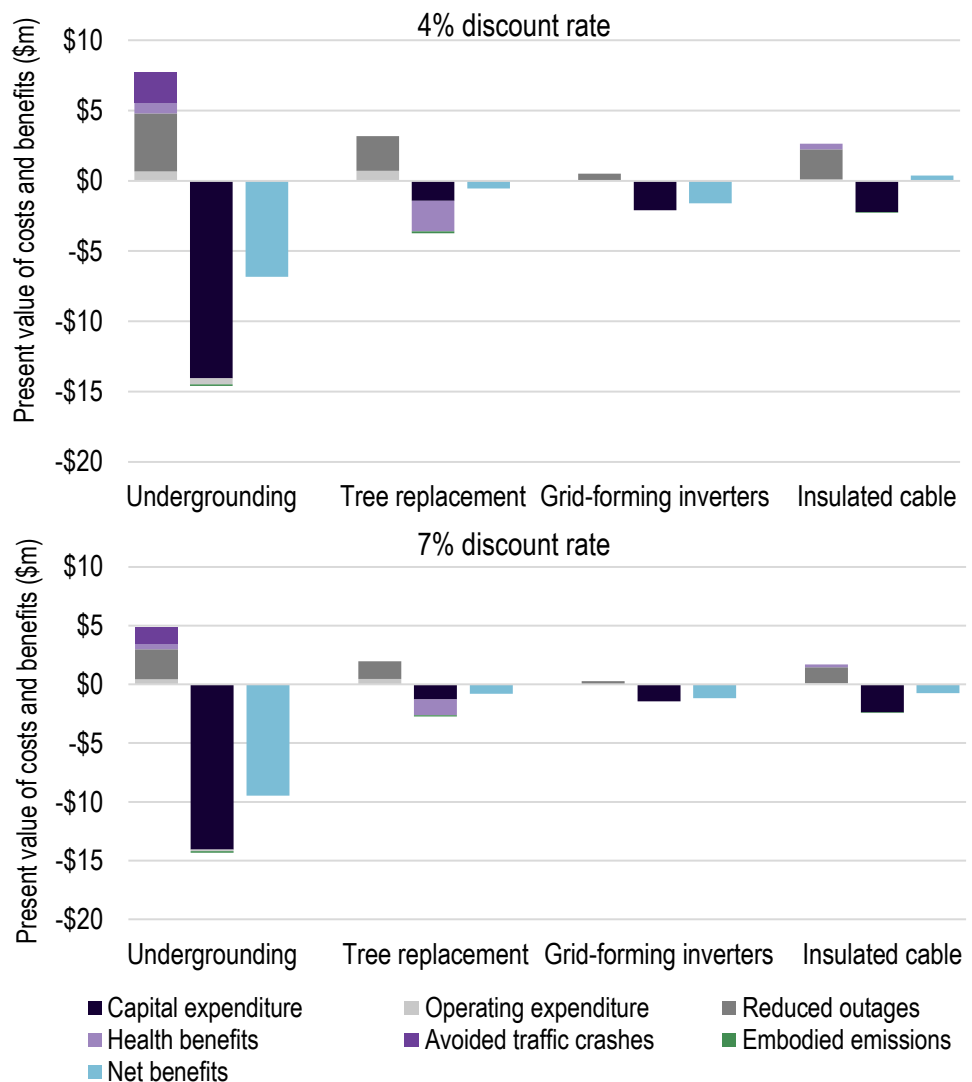
Table 3.1 Benefit-cost ratios, net present value and return on investment by adaptation scenario and discount rate

	4% discount rate		7% discount rate		Return on investment
	BCR	NPV (\$ million)	BCR	NPV (\$ million)	
Undergrounding	0.53	-\$6.8	0.34	-\$9.5	1.2%
Tree replacement	0.85	-\$0.5	0.71	-\$0.8	1.5%
Grid-forming inverters	0.24	-\$1.6	0.19	-\$1.2	-
Insulated cable	1.16	\$0.4	0.69	-\$0.8	4.7%

Note: no return on investment is presented if the value is negative (as a negative discount rate is not realistic) or not calculable (which occurs when a measure does not return a net benefit in any year of the modelling period).
Source: ACIL Allen analysis

Analysis of costs and benefits by category sheds some light on the drivers of the low BCRs for the analysed adaptation measures (Figure 3.2).

Figure 3.2 Present value of costs and benefits, by category, scenario and discount rate



Source: ACIL Allen analysis

In the case of undergrounding and grid-forming inverters, the capital expenditure on each of the adaptation measures is simply too high at this time to justify the benefits of reduced power outages due to extreme wind for our urban exemplar. The health benefits arising from increased tree cover and reduced traffic crash impacts due to undergrounding are not sufficient to change this outcome. However, as discussed in section 4.2, the unquantified amenity benefits of undergrounding could push the BCR of this measure above one.

In the case of tree replacement, the health costs of reduced tree canopy are a significant dis-benefit and drive the BCR of our exemplar below one – in the absence of this dis-benefit the measure would have a BCR of 2.1 using a 4% discount rate or 1.4 at a 7% discount rate. However, our estimated BCRs also exclude any amenity dis-benefits from replacing large trees with smaller trees (see section 2.4.4), and so are likely to over-estimate the net benefits of this measure.

3.2 Distributional outcomes

We analysed distributional outcomes across eight societal groups:

- the general base of electricity customers, which pays for costs incurred by electricity distribution businesses, separated into residential, commercial and industrial sub-categories
- local ratepayers, who incur costs for vegetation management through their local governments
- local residents, who directly benefit from reduced power outages and experience health benefits or costs due to changes in tree cover
- local commercial and industrial electricity consumers, who directly benefit from reduced power outages
- the wider community, which is affected by changes in greenhouse gas emissions and the impacts of traffic crashes.

Distributional outcomes by scenario at the 4% discount rate (Table 3.2) indicate that:

- for undergrounding and insulated cable measures, the general base of electricity consumers incurs significant costs in network investments, but the benefits are overwhelmingly realised by local residents and local electricity consumers
- for tree replacement, local ratepayers incur significant costs to implement the program and local residents experience significant health costs, while local commercial and industrial electricity customers enjoy fewer power outages and the broad base of electricity consumers incurs lower vegetation management costs
- for grid-forming inverters, the benefits and costs are incurred by the same parties, with the entities paying for the inverters also experiencing reduced power outages – but the benefits of these outages are not sufficient to pay for the inverters, so no group experiences a net benefit.

Table 3.2 Present value of net benefits by societal group (\$ million), 4% discount rate

Societal group	Under-grounding	Tree replacement	Grid-forming inverters	Insulated cable
Residential electricity customers	-\$7.8	\$0.3	\$0.0	-\$1.2
Commercial electricity customers	-\$4.8	\$0.2	\$0.0	-\$0.7
Industrial electricity customers	-\$1.4	\$0.1	\$0.0	-\$0.2
Local ratepayers	\$0.2	-\$1.2	\$0.0	\$0.0
Local residents	\$1.9	-\$1.5	-\$1.5	\$1.0
Local commercial electricity customers	\$2.0	\$1.2	-\$0.1	\$1.0

Societal group	Under-grounding	Tree replacement	Grid-forming inverters	Insulated cable
Local industrial electricity customers	\$1.0	\$0.6	\$0.0	\$0.5
Wider community	\$2.1	-\$0.1	\$0.0	-\$0.0
Total net present value (NPV)	-\$6.8	-\$0.5	-\$1.6	\$0.4

Source: ACIL Allen analysis

Distributional outcomes are similar when using a 7% discount rate as when using a 4% discount rate (Table 3.3):

- All societal groups that experience a net benefit for a given measure using a 4% discount rate experience a net benefit using a 7% discount rate, and the same is true for groups that experience a net cost.
- The net benefits and net costs for societal groups are a similar order of magnitude at the 7% discount rate as the 4% discount rate.

Table 3.3 Present value of net benefits by societal group (\$ million), 7% discount rate

Societal group	Under-grounding	Tree replacement	Grid-forming inverters	Insulated cable
Residential electricity customers	-\$7.8	\$0.2	\$0.0	-\$1.3
Commercial electricity customers	-\$4.7	\$0.1	\$0.0	-\$0.8
Industrial electricity customers	-\$1.4	\$0.0	\$0.0	-\$0.2
Local ratepayers	\$0.1	-\$1.2	\$0.0	\$0.0
Local residents	\$1.1	-\$0.9	-\$1.1	\$0.6
Local commercial electricity customers	\$1.3	\$0.7	-\$0.1	\$0.7
Local industrial electricity customers	\$0.6	\$0.4	\$0.0	\$0.3
Wider community	\$1.3	-\$0.1	\$0.0	-\$0.1
Total net present value (NPV)	-\$9.5	-\$0.8	-\$1.2	-\$0.8

Source: ACIL Allen analysis

3.3 Sensitivity testing

CBA outcomes are often very sensitive to the assumptions chosen, and these assumptions always carry a degree of uncertainty. Therefore it is common and prudent to use sensitivity testing to understand how variations in key assumptions affect the conclusions. The most important assumptions to sensitivity test are those that are material to the analysis and subject to a relatively high degree of uncertainty.

Reflecting this, we have chosen the following assumptions for sensitivity testing:

- Capital costs: increasing and decreasing capital costs by 30% for all investments (this degree of cost uncertainty is a reasonable expectation for the accuracy of the ‘Class 5’ capital cost estimates⁷ that have been used in this study).^{xxxvi}

⁷ A Class 5 capital cost estimate is an early stage or concept screening estimate. See for example: GHD 2021, *ISP transmission cost database*, <https://aemo.com.au/-/media/files/major-publications/isp/2021/transmission-cost-database---ghd-report.pdf?la=en>, p. 28; and Christensen and Dysert 2005, *Cost estimate classification system – as applied in engineering, procurement and construction for the process industries*, p. 2.

- Extreme outage severity: increasing and decreasing both the frequency and the severity of power outages from extreme wind events by 20% for all scenarios, which results in a total increase in the cost of extreme outages of 44% or a total decrease of 36%.⁸
- Health costs: applying a 20% increase and a 20% decrease to the change in health costs caused by changes in tree canopy under the chosen adaptation measures.

In addition we have tested a sensitivity where we apply an additional social cost multiplier of 1.3 (that is, a 30% increase) to the high outage costs sensitivity. This sensitivity reflects that, if adaptation measures are applied widely, they may reduce a range of wider societal costs that are not likely to be fully captured within direct estimates of how households and businesses value reliability. Examples of these wider social costs include traffic congestion due to the failure of traffic lights, disruptions to essential services such as public transport, telecommunications and water and sewerage services, safety issues due to failures of equipment such as elevators, streetlights and fire alarms, and reliance on back-up power in facilities such as hospitals and prisons (see Box 2.2). We present the sensitivity analysis results for each scenario in the four tables below to assess whether outcomes for each adaptation measure are particularly sensitive to these assumptions.

Table 3.4 demonstrates that the CBA results for undergrounding are not highly sensitive to any of these assumptions. BCRs remain below 0.8 for all sensitivity-tested assumptions at the 4% discount rate, and equal to or below 0.5 at the 7% discount rate. This indicates that even quite significant changes in assumptions do not change the finding that, for urban supply areas similar to those modelled through our exemplar, undergrounding is not a cost-effective way to reduce electricity distribution network power outages from extreme wind.

Table 3.4 Sensitivity analysis of scenario 1: undergrounding

Parameter	Sensitivity	4% discount rate		7% discount rate	
		BCR	NPV (\$m)	BCR	NPV (\$m)
Core modelling results		0.53	-\$6.8	0.34	-\$9.5
Capital costs	+30%	0.41	-\$11.1	0.26	-\$13.7
	-30%	0.75	-\$2.6	0.48	-\$5.3
Extreme outage costs	+44% + social multiplier	0.78	-\$3.2	0.50	-\$7.2
	+44%	0.66	-\$5.0	0.42	-\$8.3
	-36%	0.43	-\$8.3	0.27	-\$10.4
Health costs	+20%	0.54	-\$6.7	0.35	-\$9.4
	-20%	0.52	-\$7.0	0.33	-\$9.6

Source: ACIL Allen analysis

Table 3.5 summarises the sensitivity analysis for tree replacement. Some sensitivities can push the BCR for this measure above one:

- High outage costs, with or without a social multiplier, push the BCR above one using a 4% discount rate.
- High outage costs plus a social multiplier push the BCR above one using a 7% discount rate.

This indicates that BCRs for tree replacement generally remain below one, even though there are some combinations of assumptions and discount rates where the measure could provide a positive economic return. This indicates that, even with favourable assumptions, tree replacement is

⁸ If the frequency and severity of extreme wind events are both 20% higher the increase in outages will not be 40% but 44% because 1.2 multiplied by 1.2 is 1.44, which is 44% higher than 1. Equally, if both factors are 20% lower the total reduction will be 36% not 40% because 0.8 multiplied by 0.8 is 0.64, which is 36% lower than 1.

unlikely to prove a consistently cost-effective way to reduce distribution network power outages from extreme wind.

Table 3.5 Sensitivity analysis of scenario 2: tree replacement

Parameter	Sensitivity	4% discount rate		7% discount rate	
		BCR	NPV (\$m)	BCR	NPV (\$m)
Core modelling results		0.85	-\$0.5	0.71	-\$0.8
Capital costs	+30%	0.77	-\$1.0	0.62	-\$1.2
	-30%	0.96	-\$0.1	0.83	-\$0.4
Extreme outage costs	+44% + social multiplier	1.43	\$1.6	1.19	\$0.5
	+44%	1.14	\$0.5	0.95	-\$0.1
	-36%	0.61	-\$1.4	0.52	-\$1.3
Health costs	+20%	0.76	-\$1.0	0.65	-\$1.1
	-20%	0.97	-\$0.1	0.79	-\$0.5

Source: ACIL Allen analysis

Table 3.6 demonstrates that the BCR and NPV of installing grid-forming inverters is very insensitive to a range of assumptions. BCRs remain below 0.5 for all sensitivities using a 4% discount rate, and below 0.4 using a 7% discount rate. This adaptation measure does not generate health benefits or costs, and so the results do not vary when we sensitivity test health benefit assumptions.

Overall, this indicates that even quite significant changes in critical assumptions are unlikely to change the finding that, at the present time, grid-forming inverters are not a cost-effective way to reduce power outages from extreme wind for urban parts of the distribution network similar to that modelled.

Table 3.6 Sensitivity analysis of scenario 3: grid-forming inverters

Parameter	Sensitivity	4% discount rate		7% discount rate	
		BCR	NPV (\$m)	BCR	NPV (\$m)
Core modelling results		0.24	-\$1.6	0.19	-\$1.2
Capital costs	+30%	0.19	-\$2.2	0.15	-\$1.6
	-30%	0.35	-\$1.0	0.27	-\$0.7
Extreme outage costs	+44% + social multiplier	0.45	-\$1.2	0.36	-\$0.9
	+44%	0.35	-\$1.4	0.27	-\$1.0
	-36%	0.15	-\$1.8	0.12	-\$1.3
Health costs	+20%	0.24	-\$1.6	0.19	-\$1.2
	-20%	0.24	-\$1.6	0.19	-\$1.2

Source: ACIL Allen analysis

Table 3.7 summarises the sensitivity analysis for insulated cable. This analysis shows that high capital costs or low base case outage costs can push the BCR of this investment below one using a 4% discount rate, whereas it is above one for the core modelling assumptions. This indicates that the investment case is sensitive to specific assumptions, and some caution must be used when interpreting the core modelling finding that this investment delivers a positive return for our modelled urban exemplar. Conversely, the measure can deliver a BCR of almost 2 if outage costs are high and the measure is applied widely to the point where it would materially reduce some of

the wider social costs of outages (as represented by our social multiplier), indicating that under more favourable assumptions the measure would deliver a significant positive return. Only one of the sensitivities has a BCR above one using a 7% discount rate, which is where both outage costs are high and the social multiplier is applied.

Table 3.7 Sensitivity analysis of scenario 4: insulated cable

Parameter	Sensitivity	4% discount rate		7% discount rate	
		BCR	NPV (\$m)	BCR	NPV (\$m)
Core modelling results		1.16	\$0.4	0.69	-\$0.8
Capital costs	+30%	0.90	-\$0.3	0.54	-\$1.5
	-30%	1.65	\$1.0	0.98	-\$0.0
Extreme outage costs	+44% + social multiplier	1.98	\$2.2	1.17	\$0.4
	+44%	1.58	\$1.3	0.93	-\$0.2
	-36%	0.83	-\$0.4	0.50	-\$1.2
Health costs	+20%	1.20	\$0.5	0.71	-\$0.7
	-20%	1.13	-\$0.3	0.67	-\$0.8

Source: ACIL Allen analysis

Discussion and conclusions

4

4.1 Further investigating the benefits of insulated cable

As discussed in chapter 3 and highlighted by sensitivity analysis, the finding that insulated cable has a BCR of greater than one using a 4% discount rate should be interpreted with some caution. However, the high BCR of this measure relative to other measures suggests a strong case for further investigation of this approach to adapt electricity distribution networks to climate change.

An important area of uncertainty is the effectiveness of insulated cable in reducing outages, and this uncertainty may be able to be reduced at relatively low cost. Some networks routinely use insulated cable for replacement of low voltage circuits, and this could provide conditions for a 'natural experiment' to better understand its reliability benefits. Comparing the reliability of network sections that have insulated cable with the rest of the network could give greater confidence on the effectiveness of insulated cable in preventing power outages. Although this examination would not include the effect of insulated cable on outages occurring in the high voltage network, it would still be valuable for informing future decisions on the use of this adaptation measure.

4.2 Amenity benefits may justify undergrounding

The low BCRs estimated in this study (see section 3.1) indicate that undergrounding power lines in areas similar to our modelled urban exemplar is unlikely to be a cost-effective way to reduce power outages from extreme wind events. This finding holds despite the inclusion of other benefit categories, such as avoided vegetation management costs, improved health outcomes due to increased tree canopy, and avoided impacts from traffic crashes.

However, considering the amenity benefits that can arise from undergrounding (see section 2.4.3) could greatly strengthen the case for undergrounding electricity distribution infrastructure, and justify investment to capture both the amenity and network resilience benefits of this approach.

We have translated the findings of Australian studies on the amenity benefits of undergrounding to the context of current day Victoria. These estimates should be treated with caution given that studies used reflect conditions in Western Australia and Canberra from over a decade ago, and amenity benefits are likely to be very context-specific.

We used three methods to estimate indicative amenity benefits from undergrounding for our exemplar:

- Method 1: indexing the 2009, 2010 and 2011 estimates to present day dollars using the Consumer Price Index and then averaging, giving an estimated amenity benefit of about \$13,000 per household.
- Method 2: using the average of the property uplift percentages identified in Western Australia and Canberra (2.6% and 2.9% respectively, giving an average of 2.75%) as a proxy for the

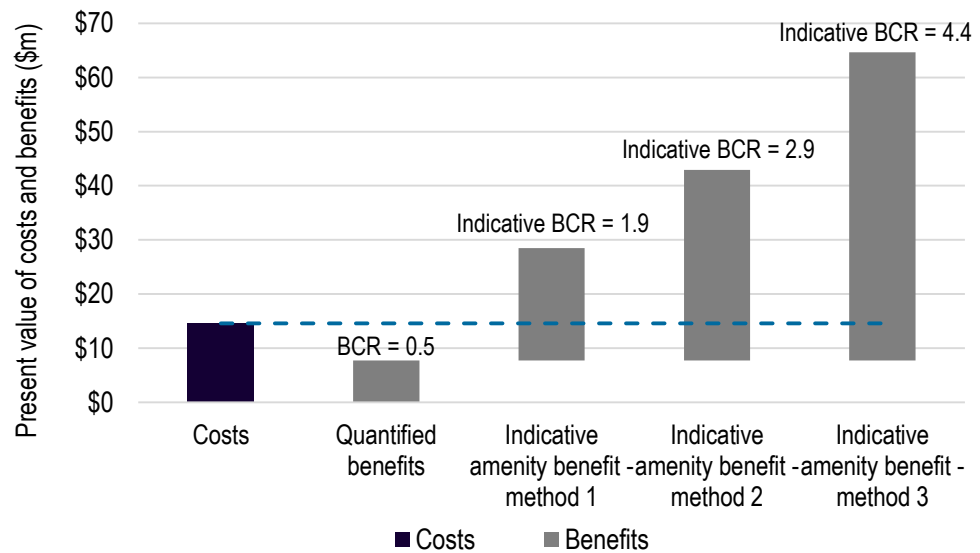
amenity value of undergrounding to local residents, and applying this uplift to the median metropolitan Melbourne house price of \$820,000 to give an amenity benefit of almost \$22,500 per household.

- Method 3: proxying the amenity value of undergrounding to local residents as 2.75% of the median house price in eastern and south-eastern Melbourne (and which is therefore more reflective of the exemplar modelled in this study), giving an amenity benefit of just over \$36,000 per household.

If we apply each of these estimates to the 1,572 residential customers served by overhead connections in our exemplar, we calculate further amenity benefits of \$21 million to \$57 million for our exemplar.

Noting the need for caution, including these indicative amenity benefits suggests very significant net benefits from undergrounding (Figure 4.1).

Figure 4.1 Present value of costs and benefits of undergrounding using a 4% discount rate, including indicative estimates of amenity benefits



Source: ACIL Allen analysis

This finding is somewhat supported by the observation that the Western Australian, South Australian and Northern Territory governments have supported electricity undergrounding over many decades (Box 4.1).

From 1995 to 2012 the Victorian Government operated an undergrounding policy, the Powerline Relocation Scheme, until it was discontinued as funding was reprioritised to support bushfire prevention by electricity networks in the wake of the 2009 Black Saturday fires.^{xxxvii} Under this policy, the Victorian Government would provide up to 50% of the cost of undergrounding for projects that met the application criteria, and local governments and electricity distribution companies made co-contributions.^{xxxviii} Additionally, since the 1990s it has been standard for all new residential developments in Victoria to have underground power supply.^{xxxix}

Overall, if the amenity benefits of undergrounding are significant in Victoria, these investments could be cost-effective in a range of locations, and so prove a practical way for electricity distribution networks to adapt to climate change. Importantly, undergrounding also complements the objectives of many local governments to increase tree canopy, which is itself a valuable adaptation to a warming climate.

Box 4.1 State and territory undergrounding policies**Western Australia**

The Western Australian Government established the State Underground Power Program (SUPP) in 1996, largely in response to major power outages from a 1994 storm. The SUPP has undergrounded over 100,000 properties over multiple funding rounds.

A 2011 review of the SUPP by the Economic Regulation Authority of WA found that the program had delivered net benefits to that point, with the largest single benefit category being improved amenity value for home-owners (\$749 million in benefits out of a total of \$817 to \$858 million).

The Economic Regulation Authority of WA recommended that the State Government reduce contributions to projects in high-income areas, as most of the benefits are captured by relatively wealthy home-owners. But it also recommended that the project be continued.

From 2024 the WA Government will implement a re-branded Targeted Underground Power Program, with a greater focus on areas with ageing network infrastructure, and on lower-income areas that have been under-represented in the program to date.

South Australia

The South Australian Government established the Power Line Environment Committee in 1990, bringing together energy network, transport, local government, tourism and community interests to coordinate undergrounding projects. The projects were funded through mandatory contributions from the monopoly distribution network operator, and project-specific contributions from local governments.

Unlike the SUPP, the Power Line Environment Committee has focused on undergrounding major transport routes and community and tourism hubs, rather than general residential areas.

The Power Line Environment Committee has delivered \$231 million of projects in a mix of metropolitan and regional locations from program start until 2019-20.

Northern Territory

New residential developments in the Northern Territory have been required to have underground power since the late 1970s, reflecting in part the impacts of Cyclone Tracy in 1974.

In addition the NT Government has funded a range of undergrounding programs, including:

- supply to nine Darwin schools in 2019
- \$60 million in 2022 to underground targeted parts of the Darwin high voltage network.

Source: WA Government, *State Underground Power Program 2022-23*, <https://www.wa.gov.au/government/document-collections/state-underground-power-program-2022-23>; Essential Services Commission of South Australia, *Power Line Environment Committee resources*, <https://www.escosa.sa.gov.au/industry/electricity/plec/plec-resources>; NT Government, *Budget 2022: undergrounding high voltage power network begins*, <https://ntrebound.nt.gov.au/news/2022/budget-2022-undergrounding-high-voltage-power-network-begins>; Power and Water Corporation, *Undergrounding power supply to Darwin schools*, <https://www.powerwater.com.au/about/projects/current-projects/undergrounding-power-supply-to-darwin-schools>.

4.3 Interaction with network re-investment

Our CBA assumes that the existing overhead network infrastructure is of mixed age and is replaced periodically over its expected life of 50 years. This gradual rate of replacement reduces the capital cost of network infrastructure in the base case in present value terms. However, if network re-investment is required more urgently than we have assumed, the cost of base case investment increases in present value terms and the case for investing in undergrounding or insulated cable is strengthened.

Urgent network re-investment might be required if a particular part of the network has much older infrastructure than the network as a whole. If, for example, an entire network area's infrastructure has aged to the point where it needs to be replaced within ten years, using a 4% discount rate the BCR:

- of undergrounding improves from 0.53 to 0.72 (excluding the indicative amenity benefits estimated in section 4.2)
- of insulated cable improves from 1.2 to 2.3.

This indicates a good case for upgrading infrastructure to be more climate resilient at end-of-life, rather than simply replacing it like-for-like. However, we note that the age of infrastructure in any given area will generally vary due to ongoing maintenance and replacement (for example, due to storms, vehicle impacts or asset failures), and it will be relatively uncommon to find specific areas with distinctly ageing infrastructure that requires widespread and urgent replacement.

Another circumstance that could improve the economics of undergrounding or insulated cable is if rapid increases in electricity demand outstrip the capacity of existing network assets, and so drive significant re-investment. Such rapid increases in electricity demand were last seen in the late-1990s and early-2000s when Australian households and businesses rapidly installed air-conditioning with associated growth in peak summer demand. (Since the late-2000s peak electricity demand growth has generally been muted, largely because of improved thermal efficiency of homes, improving energy efficiency of appliances and rapid uptake of rooftop solar photovoltaic generation.)

While peak demand growth has been muted in recent years, there is a high likelihood of significant increases in demand throughout Victoria's electricity distribution networks over coming decades from two main sources: electric vehicles and the electrification of household heating.^{xi} Electric vehicles represent a potential step-change in household electricity demand and will increase loads at the low and high voltage level across all distribution networks. And the electrification of household heating could see winter electricity demand peak at higher levels as increasing gas prices cause households to switch their heating from gas to reverse-cycle air-conditioners.

The scale and speed of these sources of demand growth is highly uncertain, and there is significant potential for smart demand management to reduce the need for network investment to accommodate these loads. However, the potential need to accommodate electric vehicles and heating electrification also creates an opportunity to better adapt these networks to the effects of climate change by insulating or undergrounding power lines where reinvestment is required.

4.4 Potential Victorian Government actions to facilitate undergrounding

The lack of widespread undergrounding in Victoria could suggest that households and local governments do not value the benefits sufficiently to pay for them. Or, more likely, it reflects that undergrounding is a complex exercise requiring coordination across a range of beneficiaries – including local home-owners and businesses, visitors, local governments, electricity distribution network businesses and state government entities – and that raises difficult questions about who should pay. This complexity acts as a major barrier to undergrounding existing electricity infrastructure. The complexity of undergrounding is demonstrated by a recent case study involving the Bayside City Council, which covers inner south-east bayside suburbs of Melbourne such as Brighton and Sandringham (Box 4.2).

This complexity, and the successful experience of the Western Australian and South Australian governments in coordinating the multiple parties involved in undergrounding projects (see Box 4.1), suggests an important coordination role for the Victorian Government to facilitate undergrounding.

Box 4.2 Bayside City Council's undergrounding power policy

During 2022 Bayside City Council developed a draft policy on undergrounding power lines. This policy set out the council's in-principle support for undergrounding, and noted a range of benefits including:

- aesthetic improvements to the streetscape and increased tree coverage
- improved power reliability
- reduced costs to maintain tree clearances around power lines
- removal of potential traffic hazards.

The council also surveyed residents to obtain their views and found that 81% per cent of residents surveyed were in favour of undergrounding.

Despite this support, the draft policy was not adopted by Council due to disagreements over the best approach to funding projects. The four options considered in the draft policy were:

- direct funding as part of council-funded capital works
- Victorian Government grants (noting that such a program is not presently in place)
- increased rates for benefiting home-owners
- direct payment by benefiting home-owners through negotiation with electricity networks.

Source: Bayside City Council, *Undergrounding powerlines*, <https://yoursay.bayside.vic.gov.au/powerlines>

Our analysis highlights a few principles and priorities for future Victorian Government actions to support undergrounding:

- There is a significant knowledge gap in Victoria on the amenity benefits of undergrounding. The Victorian Government could support comprehensive studies of this value, such as through hedonic pricing or contingent valuation methodologies. If these studies confirm the broad findings of past Western Australian and Canberran studies, the case for undergrounding in primarily residential areas in Victoria would be greatly strengthened.
- When amenity benefits are included, the majority of benefits of undergrounding accrue to home-owners.
- Though the majority of benefits of undergrounding accrue to home-owners, other parties do benefit:
 - People who work in the area or who visit will benefit from improved amenity.
 - Electricity network businesses benefit from undergrounding through reduced vegetation management expenditure and reduced capital expenditure on replacing ageing assets (as undergrounding delivers an entirely new set of assets).
 - Local governments benefit from undergrounding through reduced vegetation management expenditure.
 - To the extent that undergrounding reduces the health impacts of future heatwaves and the human impact of some traffic crashes, the primary health system will experience lower costs.
- Systems and processes for undergrounding can be standardised across multiple local governments, to simplify processes for electricity distribution network businesses (who work across many local government areas) and deliver efficiency benefits from avoiding individual local governments having to 'reinvent the wheel'.

4.5 Using real options to reduce uncertainty on costs and benefits

While the results in chapter 3 do not indicate that investment in electricity distribution networks is generally a cost-effective way to address the effects of extreme wind in an urban supply area, a 'real options' perspective (see Box 4.3) highlights several areas where further consideration of these options will be valuable.

Box 4.3 Real options analysis

Real options is an analytical framework that seeks to accommodate the effects of uncertainty on economic decision-making and recognises that deferring or staging major investment decisions to gain more information can create benefits that are not captured in a static scenario analysis. For example:

If a company committed \$10 million to an investment with a 50% probability of returning \$20 million and a 50% probability of returning nothing, the expected value of the investment is zero.

However, if that same company committed \$2 million to facilitate the same investment of \$10 million quickly if market circumstances moved in a favourable direction it would have a:

- 50% probability of incurring a loss of \$2 million, in the event that market circumstances were not favourable and the investment was not taken
- 50% probability of incurring a benefit of \$8 million, in the event that market circumstances were favourable and the investment was taken.

The probability-weighted value of the total investment taking a real options perspective is \$3 million, compared to \$0 under a static scenario approach.

Source: ACIL Allen analysis

The key factors that could increase the value of the analysed adaptation measures under a real options perspective is where information increases over time to support more targeted investment decisions. In turn, the most valuable information will relate to the most uncertain cost or benefit categories, such as:

- the amenity value of undergrounding investment (not quantified in this study, but indicatively estimated in section 4.1 above)
- the effectiveness of insulated cable in preventing power outages in major storm events
- increased temperatures and the effect of tree canopy on health costs
- increased impacts of extreme wind on network outages
- the cost premium of grid-forming inverters over grid-following inverters.

In the case of the amenity benefit of undergrounding, investing a small amount of money to gain better information on these benefits would have significant value (as discussed in section 4.2). If studies establish that the amenity benefits of undergrounding are large, the relatively small amount of money invested in these studies could potentially support investment to unlock multiple billions of dollars of benefits.⁹

In the case of insulated cable's effectiveness in major storm events, as discussed in section 4.1, there may be scope for further investigation of the effectiveness of insulated cable to provide valuable information to support future decisions on the use of this adaptation measure.

Further monitoring for improvements in climate data would be beneficial to refine the case for all adaptation measures. Refined projections on the frequency and severity of extreme wind would reduce the uncertainty around the potential benefits of these measures.

Though the cost premium for grid-forming inverters relative to grid-following inverters was projected for this study to be too high for them to deliver a net benefit from reduced power outages, it is possible that their cost may fall faster than assumed in this analysis. Monitoring trends in the cost of this equipment could highlight where the case for investment has improved, and updated cost-benefit analysis may be justified.

⁹ Gross amenity benefits of about \$13,000 per household translate to net benefits of over \$9,000 per household (reflecting the cost of undergrounding net of the other benefits identified in this study). If this benefit translated to half of Victoria's 2.4 million occupied private dwellings, the aggregated net benefits would exceed \$11 billion.

4.6 Methodological lessons for climate adaptation analyses

Cost-benefit analysis of climate adaptation measures for infrastructure must address a number of complexities and uncertainties. This study is no exception, and our experience in analysing adaptation measures to combat the effects of extreme wind on the electricity distribution network is likely to have lessons for analyses of other climate hazards and other infrastructure sectors.

Some particularly difficult methodological issues we have encountered in this study include:

- the uncertainty of climate change impacts, and sensitivity of these impacts to assumptions on global emissions concentration pathways
- the interaction between adaptation measures as both mitigating the impacts of climate change, but also contributing to climate change through embodied emissions
- the sensitivity of the benefits of adaptation measures to the scale at which they are applied
- the risk that adaptation measures will reduce the impact of the identified hazard (extreme wind), but cause maladaptations that create new risks to the operation of the infrastructure
- the difficulty of estimating some particularly uncertain costs or benefits.

Uncertainty of climate change impacts

Climate change will have long-lasting and uncertain impacts on infrastructure, and so these impacts are particularly difficult to quantify. Even where climate change has created a clear trend, such as towards increasing average temperatures or bushfire risk, there is significant year-to-year variability in outcomes around this trend and uncertainty in terms of both the probability and severity of extreme weather events in any given year.

These uncertainties have been particularly acute for this analysis due to our focus on extreme wind. Compared to extreme heat or bushfires, where there is a clear relationship between climate drivers and outcomes, the effect of climate change is particularly uncertain and location-specific. As noted in section 2.4.1 (page 23), the *Victorian Climate Projections* forecast declining severity of extreme wind in some Victorian locations, and increasing severity in others.

In our exemplar, these projections indicated increasing severity and frequency of extreme winds under a moderate emissions trajectory (RCP 4.5, broadly consistent with strong global action to curb greenhouse gas emissions) but, counter-intuitively, no clear impact under a high emissions trajectory (RCP 8.5).

This highlights the uncertainty of extreme wind outcomes, and a need for caution in interpreting the results of this study. We used sensitivity analysis to examine the possibility that climate change will have a much lower impact on the severity and frequency of extreme wind than assumed in our core assumptions.

Impact of adaptation measures on climate change

Several of our adaptation measures created material embodied emissions through investment in new infrastructure (the undergrounding and insulated cable scenarios), or through replacing large mature trees with smaller trees (the tree replacement scenario). This illustrates a broader challenge in adapting infrastructure to climate change – the act of replacing or upgrading infrastructure will typically create embodied emissions and exacerbate the problem the investments are responding to.

Our analysis of embodied emissions is specific to the infrastructure analysed and indicates that, broadly speaking, the embodied emissions of our proposed adaptation measures are not sufficiently large to prevent their adoption (see section 2.3.3). This finding may not translate to other infrastructure types or other adaptations. Electricity distribution infrastructure has a specific

mix of materials that differs to that used in, for example, roads, bridges, dams or even electricity transmission infrastructure. For example, wooden poles and all-aluminium conductors are common in electricity distribution networks, whereas electricity steel towers and steel-reinforced aluminium conductors are common in electricity transmission networks.

Therefore it is important that case-specific assessments of embodied emissions are undertaken for other infrastructure sectors and adaptation measures.

Scale of application

Our approach to estimating the value of customer reliability reflects the fact that some benefits of electricity network adaptation depend on how widely the measures are implemented. Strictly speaking, the broader social benefits that arise from continuity of supply to transport infrastructure and other essential services are small if the measure is implemented only in our single hypothetical exemplar, but these benefits will be much larger if the measure were to be implemented widely. This uncertainty was addressed by assessing outcomes under a sensitivity with a social multiplier applied to the value of avoided outages (section 3.3).

Other infrastructure adaptation studies could face similar issues. The effectiveness of adaptation measures to improve the resilience of network-based infrastructure, such as transport or telecommunications infrastructure for example, is particularly likely to be sensitive the scale at which these measures are applied. Studies of such infrastructure that adopt a case study approach may need to consider the effects of applying measures widely, as we have done for this study through the social benefits multiplier.

Maladaptation risks

In analysing measures that can adapt electricity distribution infrastructure to reduce the risk of extreme wind, we also considered the possibility that this could create exposure to new risks (see the discussion in section 2.4.1 on page 27). In particular, some of these risks are themselves affected by climate change, such as the risk of flooding or extremely dry soil causing damage to underground cables.

Our analysis did not indicate that maladaptation risks were material to the performance of the infrastructure considered in this study. However, this may not be true of other infrastructure adaptations in other sectors, and it is important that maladaptation risks are carefully considered on a case-by-case basis in infrastructure adaptation analyses.

Uncertain cost or benefit categories

Many cost-benefit analyses must estimate highly uncertain costs or benefits, but these difficulties can be particularly acute for infrastructure climate adaptation analyses. This is because of both the long duration over which costs and benefits of long-lived infrastructure must be assessed, and the particularly uncertain nature of climate impacts (discussed above on page 47).

In addition to these effects, which are likely to be common to most infrastructure adaptation studies, this study required estimation of several particularly uncertain cost and benefit categories.

- The amenity benefits of undergrounding are potentially large but highly uncertain. As illustrated in Figure 4.1, these benefits could plausibly move undergrounding from a BCR of well below one to 2 or more. As is discussed in section 2.4.4, the approach we took to manage this uncertainty was to exclude these potential benefits from the core CBA but present indicative amenity benefits to illustrate their importance.
- Estimating the number of trees that were sufficiently large and close to power lines to require replacement under the tree replacement scenario required visual analysis of randomly sampled areas from which our exemplar sample was drawn. Such visual inspection is

inherently subjective and uncertain, as specialised arboreal assessment or on-site inspection was beyond the scope of this analysis (our assessment was done using Google Maps Street View). Changes in the areas sampled could also lead to variations in results.

- Assumptions around the future decrease in the cost premia applying to grid-forming inverters relative to typical grid-following inverters are particularly uncertain due to the rapid change in this technology, particularly for small-scale inverters. It is possible that the cost premium could decline to a point where this technology becomes the default application for small-scale solar and battery inverters. However, forecasting the probability or potential timing of such a point is inherently difficult. This uncertainty is best managed through a real options approach involving a 'watching brief' on cost trends for this technology (see section 4.5), rather than an early commitment to investment.

Translating assumptions to other studies

In many cases the sources used in our study reflect costs and benefits that are specific to electricity distribution infrastructure and the effects of extreme wind, while in other cases a broad range of studies will be able to use similar assumptions. These similarities and differences are set out in Box 4.4.

Box 4.4 Extending ACIL Allen’s methodology to other infrastructure adaptation cost-benefit analyses

Discount rates

We adopted standard Victorian discount rates for this study, which would be common to a range of Victorian infrastructure CBAs. However, ACIL Allen notes that the NSW Government has recently issued new guidance on discount rates to reflect lower interest rates over recent years, and it is possible that the Victorian Government will update its guidance in future.

Climate data

Climate impacts on extreme wind vary by location and are subject to some uncertainty. We used the *Victorian Climate Projections* to estimate wind impacts for our exemplar area, and this study indicates that extreme wind events could decrease in some Victorian locations. This means that the findings for our exemplar will not necessarily extend to other locations.

Value of power outages

We used network regulatory information notices collated by electricity distribution networks and published by the Australian Energy Regulator (AER), and values of customer reliability (VCR) developed by the AER. While the VCR analysis is relevant to all electricity outages, including those arising due to issues in the generation or transmission of power, our detailed analysis of the causes and durations of outages is specific to electricity distribution networks.

Health benefits from increased tree canopy

We used analysis developed by the NSW Government on the value of ‘green infrastructure’ to calibrate costs and benefits from changes in tree canopy. The parameters identified in that study and used here would be of relevance to a range of projects that affect tree canopy, including clearing canopy to make space for new infrastructure, or developing new parkland to mitigate urban heat island effects.

Reduced traffic crash impacts

We calibrated the cost of traffic crashes involving power poles based on crash statistics from VicRoads and crash cost estimates from the Australian Transport Assessment and Planning guidelines. These estimates would not typically be needed for an energy sector analysis, but may be relevant to analyses of other infrastructure, particularly transport infrastructure.

Capital expenditure

Our capital expenditure estimates were bespoke and specific to the adaptation measures modelled. However, urban electricity distribution infrastructure is relatively standardised across Australia, and our cost estimates could inform other studies involving similar infrastructure in other jurisdictions.

Operating expenditure

Our operating expenditure estimates were bespoke and reflect the specific infrastructure modelled. However, urban electricity distribution infrastructure is relatively standardised across Australia, and so our estimates could be used to inform analyses of urban distribution infrastructure in other jurisdictions. Similarly, our vegetation management costs could be informative for other studies of areas similar to the exemplar, that is, a well-treed Australian urban area with primarily overhead electricity distribution infrastructure.

Embodied emissions

Our embodied emissions estimates were bespoke and specific to the adaptations modelled. However, urban electricity distribution infrastructure is relatively standardised across Australia, and so these estimates could inform other studies involving similar infrastructure in other jurisdictions.

We used the recent (April 2023) guidance from the NSW Government on carbon prices, which builds on current day prices in the European Union Emissions Trading Scheme. However, there are a range of other possible sources to benchmark carbon prices for infrastructure CBAs.

Sources: NSW Government 2023, TPG23-08 NSW Government Guide to cost-benefit analysis, Technical note to TPG23-08: Carbon value in cost-benefit analysis, https://www.treasury.nsw.gov.au/sites/default/files/2023-03/20230302-technical-note-to-tpg23-08_carbon-value-to-use-for-cost-benefit-analysis.pdf; CSIRO, GenCost project data, <https://data.csiro.au/collection/csiro:44228>; Infrastructure and Transport Ministers 2020, Australian Transport Assessment and Planning Guidelines: PV5 environmental parameter values, <https://www.atap.gov.au/parameter-values/environment/index>; Economic Connections 2017, Cost of Road Trauma in Australia, https://www.aaa.asn.au/wp-content/uploads/2018/03/AAA-ECON_Cost-of-road-trauma-summary-report_Sep-2017.pdf; Australian Government, Australian Road Deaths Database, <https://www.officeofroadsafety.gov.au/data-hub/fatalities-data#accordion-58>; Australian Government, Severe Injuries Dashboard, <https://www.officeofroadsafety.gov.au/data-hub/serious-injuries-data#accordion-76>; VicRoads, Crash statistics, <https://www.data.vic.gov.au/data/dataset/crash-stats-data-extract>.

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