Climate change and extreme weather event resilience

TransGrid 2023-28 revenue reset submission support

TransGrid

03 September 2021

→ **The Power of Commitment**

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Climate change and extreme weather event resilience

Dear Ralf

The attached narrative is intended to support the TransGrid 2023-28 revenue submission. It presents:

– the need to consider resilience against extreme weather events in response to climate change and the changing characteristics of the power system
– a summary of the progress TransGrid has made to date in understanding the key areas of vulnerability
– an overview of the prudent investments TransGrid proposes during the 2023-28 revenue period to understand and manage the risks to the TransGrid network due to extreme weather events, and
– a description of the work that will continue across the 2023-28 period to identify further investments that will be required in the future to prevent any decline in network resilience over time.

The narrative draws together information provided by TransGrid on activities that have already been undertaken, and proposed investments for the 2023-28 period. It also extracts key findings and information from each of the climate resilience reports prepared for TransGrid by GHD during July and August 2021. The narrative should be viewed as being subject to the same assumptions and limitations as expressed in each of the supporting GHD reports.

We hope that the narrative helps TransGrid describe to stakeholders why it is important to consider extreme weather events and to include expenditure in the 2023-28 revenue submission that will help improve the climate resilience of the NSW transmission system to these events.

Regards,

[redacted]

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1. Maintaining a resilient network

Historically TransGrid's transmission network has proven to be highly resilient, able to ride through significant events with minimum disruption to electricity supplies. The changing climate has the potential to erode resilience, and avoiding this unacceptable outcome requires focussed attention and a prudent investment program.

1.1 The changing climate

The power sector is experiencing transformational changes driven by the societal ambition to rapidly move to net-zero carbon emissions. This is seeing the fleet of dispatchable thermal generators across New South Wales being replaced by large scale variable renewable generators such as solar and wind farms, and a growing amount of embedded renewable generation, predominantly in the form of rooftop photovoltaic (PV) systems. These changes to the generation fleet will mean that in the future the generation is highly climate and weather dependent. TransGrid's transmission network will play a crucial role in connecting generation to load and in connecting large scale energy storage facilities. A highly interconnected transmission network will allow these systems to be utilised effectively to compensate for the variable nature of renewable generation. Hence, the role of the transmission network is also changing.

We expect to see the electrification of other sectors such as transport play an important role in achieving the net-zero targets. The expanded use of electricity will reinforce the need for a dependable electricity supply. It is very important that the high level of resilience delivered to date is maintained into the future.

Climate, weather, and electricity are interconnected on many levels. Renewable generators produce electricity from wind and solar irradiance, extreme temperatures increase the demand for electricity while also derating electrical plant and equipment, severe storms and bushfires have the potential to damage transmission assets and causing supply disruptions. Coupled with the changing characteristics of the generation sector, the effects of climate change have great potential to erode the resilience of the power system.

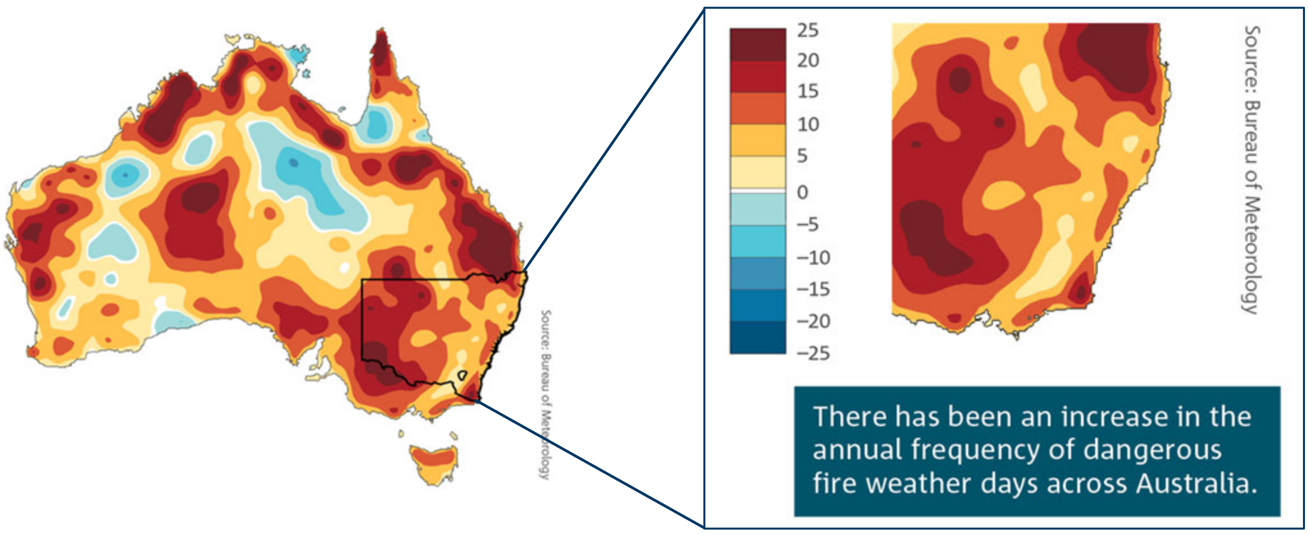


Figure 1 ***Change in the number of dangerous fire weather days from 1950 to 2010. [1, 2]***

The effects of climate change are increasingly obvious, predominantly negative, and are set to continue. An example is shown in Figure 1 where a dramatic increase in average dangerous fire weather days is illustrated. In 2020, TransGrid applied to recover costs for $55.5 million in damages caused in the 2019-20 bushfire season alone [3]. Average surface temperatures and the frequency and intensity of extreme weather events have been increasing over the past century. Climate modelling completed by the Intergovernmental Panel on Climate Change (IPCC) project that these effects will continue [4]. Fire, flood, drought, wind, storm, and extreme temperature events will continue to increase in intensity and frequency. Given the ever-growing body of evidence that indicates that the frequency and severity of extreme weather events will increase with climate change, stakeholders expect that transmission network service providers will consider the potential impact of those events on their assets and how best to manage the associated risks.

Consumers depend on the transmission system to provide secure and reliable electricity supplies. The Royal Commission into National Natural Disaster Arrangements found that power outages hampered communications during bushfire events and prevented consumers from using EFTPOS to buy essential goods. It was recommended that critical infrastructure be identified, and the resilience of this infrastructure be improved [5]. Recommendation 9.4 requires governments to work with infrastructure operators to identify critical infrastructure and investigate options to improve resilience.

There are growing stakeholder and market pressures for transmission network service providers to actively respond to the risks posed by climate change. Examples include the 2017 Finkel review [6] which identified the need for improved climate and extreme weather information for the electricity sector and lead to the establishment of the Electricity Sector climate information (ESCI) project, the New South Wales Government independent inquiry into 2019-20 NSW Bushfires [7], the Royal Commission into National Natural Disaster Arrangements [5], and the Security of Critical Infrastructure Act 2018 [8] (and its 2020 amendment bill [9]). Each of these reports call for electricity network resilience against the natural and weather-related hazards of tomorrow.

1.2 Effects on the transmission network

TransGrid has drawn on research done in participation with the ESCI project to investigate the likelihood and severity of future extreme weather events. The ESCI project examined how climate models could be used to help develop a more informed view of the potential for extreme weather events over the coming decades, and case studies developed through the ESCI project identify those extreme weather events likely to pose the most significant risk to power system resilience.

TransGrid has considered the ESCI project outcomes together with vulnerability and resilience assessments undertaken by AECOM [10] and by Aurecon [11] to understand the key impacts likely to arise during extreme weather events. GHD has also undertaken a literature review and international survey to leverage global experience [12]. Table 1 summarises the key impacts that extreme weather events can have on transmission networks.

Each network impact can be broadly sorted into one of four categories.

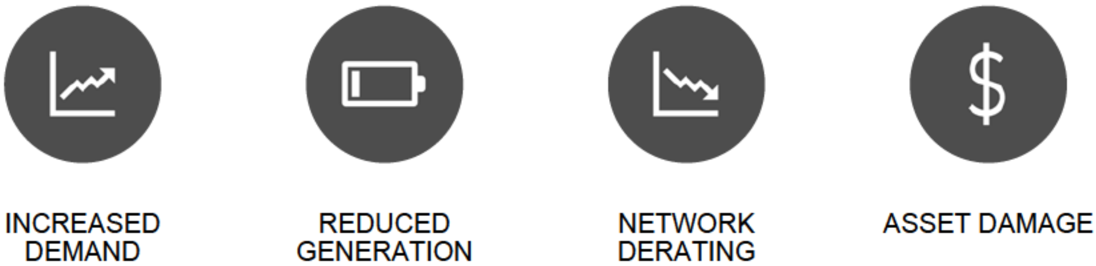


Figure 2 Broad categories of network impact of climate change

These are:

- Increased demand - extreme weather giving rise to steep increases in electricity demand and altered network utilisation. This captures both temperature-driven increases in load and reductions in the power produced by embedded generation as a result of climatic conditions. Reduced generation might arise with high ambient conditions, derating generating systems, or cloud and smoke reducing the yield of solar PV systems.
- Reduced generation - reduction in the output from large scale generation changing network utilisation. This includes any restriction in sourcing energy across the transmission network.
- Network derating - dynamic reduction in the rating of transmission network assets during periods of high ambient temperatures to avoid loading the assets to levels that can cause damage, referred to as derating.
- Asset damage - direct damage to infrastructure, such as transmission lines, from events such as high winds, storms, floods, and bushfires.

This categorisation of impacts is based on current knowledge. Over time, with greater experience of extreme weather events, other categories might be identified. It is therefore important to periodically refresh the projected climate change impacts summarised in Table 1.

Table 1 Summary of projected climate change impacts for electricity networks in Australia

Changing climate hazard	Electricity system vulnerability
Rising temperatures and increasing duration of heatwaves	Reduces generator and network capacity, increases demand, and may increase maintenance costs.
Increased frequency, severity, and extent of bushfires	Threatens most assets. There is a particularly high risk to transmission and distribution lines due to heat and smoke. The smoke and particulates can also significantly reduce the generation from large scale and embedded solar generating systems.
Increasing frequency of extreme winds	Extreme winds threaten the integrity of transmission lines, making them an important consideration for network capacity assessments and design specifications. Wind generation is sensitive to a reduction in average wind speed as well as to the frequency and magnitude of destructive gusts.
Increased variability or reduction in rainfall, and dam inflows	Reduces the water available for hydro generation. Increases the requirement for desalination and associated energy demand. Reduced soil moisture may increase damage from lightning and reduce thermal conductivity of underground power lines.
Compound extreme events	Extremes in multiple climate variables occurring simultaneously or in close sequence can cause substantial disruption. These events can be exacerbated by associated non-climatic factors such as infrastructure or staff fatigue.

An obvious and immediate effect of extreme weather events is direct damage in the form of felled lines, towers, and other asset losses. Costs to repair infrastructure are significant, as is the potential impact on the market and supply reliability while repairs are completed. The Quarterly Energy Dynamics report published by AEMO in April 2020 identified that three power system events including damage to transmission lines as a result of storms and bushfires during January 2020 added $229 million to the system costs [13].

Other issues are less apparent. One example is that a transformer's working life is a function of temperature and loading. Operating at an overall higher temperature reduces the transformer's life expectancy. Substation equipment, such as switchgear, has a specified maximum operating temperature. If this is exceeded, damage can occur. Similarly, a transmission line's working life will be reduced if operated at maximum capacity during heatwaves. This can be mitigated by applying dynamic line ratings to account for weather conditions. Traditionally a set of static weather assumptions have been used to determine static seasonal transmission line ratings. During extreme heatwaves, the ambient temperature can exceed that assumed when setting the static line ratings. Operating the line to the static ratings during extreme heatwaves risks causing accelerated degradation of the asset.

Dynamically adjusting the ratings to align with the ambient conditions avoids the risk of accelerated degradation but may result in derated lines during extreme heatwaves. This is often concurrent with increased consumer demand and reduced generator output due to derating. In worst-case scenarios, derating may increase constraints on generation during adverse weather conditions. The converse is also true, applying dynamic ratings under favourable weather conditions can improve market efficiency by allowing higher flows across transmission and reduced constraints on generation.

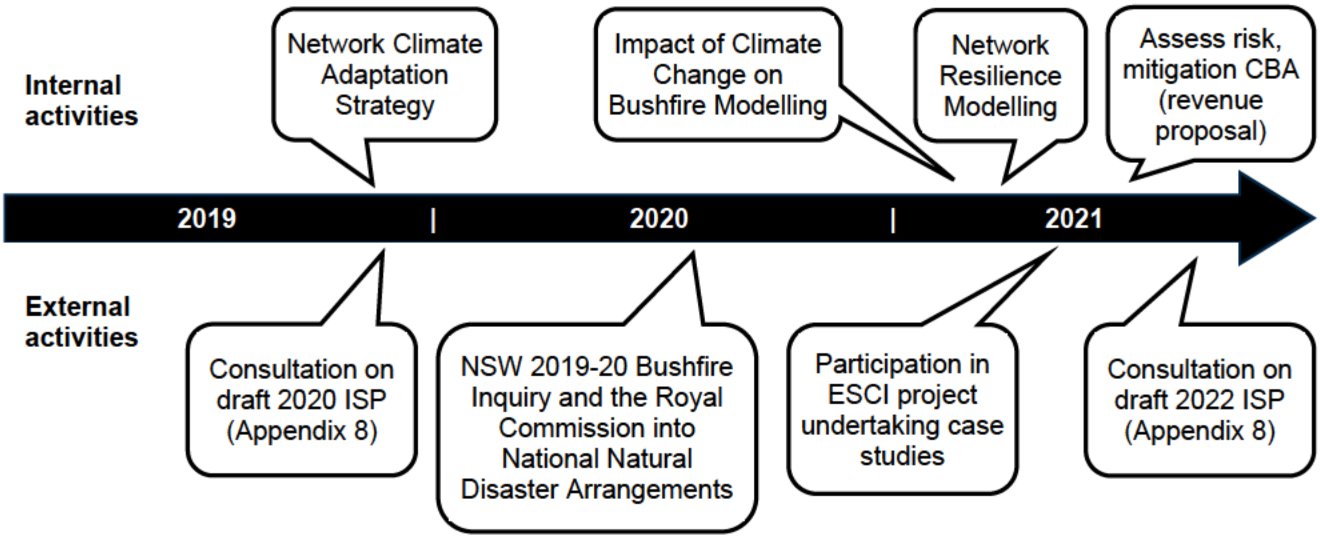
Significantly, the cost of offsetting organisational risks relating to climate change is increasing. Financial markets around the world are progressively scrutinising climate change risks. Negotiating and obtaining insurance policies for the electricity network industry is becoming prohibitively difficult and expensive. Lenders now consider climate change risk mitigation strategies adopted by organisations as part of their due diligence [14]. In addition to the financial market pressure, the business focus on climate change risk mitigation and the need for network resilience is also driven by political, legislative and industry reform intents.

It is clear that stakeholders expect transmission network service providers to proactively consider prudent measures to maintain the resilience of their networks to extreme weather events.

1.3 TransGrid action to date

TransGrid adheres to the National Electricity Rules (NER) which operationalise the National Electricity Objective (NEO) as stated in the National Electricity Law (NEL). The NEO intends to promote investment and operational efficiency for the benefit of consumers with respect to price, quality, safety, reliability of supply. Another intention of the NEO is to facilitate the security of the supply of electricity and the security of the overarching national electricity system [15]. While "climate change" is not explicitly called out in the NEL or NER, it has an irrefutable relationship with multiple focus areas of the NEO. Responding to and managing physical risks due to projected climate change is in the long-term interests of the consumers of electricity and is aligned with the intent of the NEO.

As a prudent risk manager TransGrid has recently undertaken several activities to better prepare its assets and operations to adapt and mitigate the increasing physical risks of climate change. These activities include internal business decisions and actions, and external industry participation. The final output of such activities is illustrated in Figure 3 which indicates the timing of the final output generated from each such activity.



CBA = Cost Benefit Analysis
ISP = Integrated System Plan

Figure 3 TransGrid activities to understand and mitigate the impacts of climate change (indicating the timing of the final output from each activity)

The above illustration shows only the activities focused on addressing the physical risks of climate change. They predominately relate to Asset Management, Network Planning and Operations functions. It is noted that these activities were undertaken over a period of time with some of their timelines overlapping. The above illustration only indicates the timing of the final output generated from each activity. It does not highlight other business decisions and actions being carried out by TransGrid such as developing a wider Climate Strategy, consideration of Task Force on Climate-Related Financial Disclosures (TCFD) reporting and development and approval of ESG Strategy.

In 2019, TransGrid engaged AECOM to identify regions and asset classes most exposed to severe weather. This included undertaking:

- A network climate resilience assessment covering TransGrid's network of assets.
- Review of current engineering design standards to identify climate-related design criteria and test the resilience of such criteria to the projected changes in climate.
- Development of a network climate adaptation strategy to embed climate resilience in asset planning, operation, and management functions.

In 2021 the University of Melbourne released a report, commissioned by TransGrid, to model the impacts of increased bushfire incidence and consequence due to climate change over a long-term planning horizon. TransGrid also engaged Aurecon to model the impact of natural hazards on its overhead transmission line assets to determine the probability of failure (PoF) of such assets. The outcome of this work will inform TransGrid's

Network Asset Risk Assessment model allowing a more robust assessment of risk cost associate with transmission line damage during extreme weather events.

In addition to the above internal business decision and actions, TransGrid has actively participated in several external industry forums including:

- The ESCI project, where it undertook the development of two extreme weather-related case studies. The ESCI project concluded in June 2021 after 3 years and TransGrid worked collaboratively with industry peers, AEMO, BoM and CSIRO during this period.
- Consultation with AEMO during the development of the 2020 ISP. Of particular importance is Appendix 8 that details the changes that are impacting the resilience of the NEM, including climate change. TransGrid continues this activity for the development of the 2022 ISP.
- Engagement during the NSW Government independent inquiry of the devastating 2019-20 NSW bushfire. This inquiry has recommended building electricity network resilience to mitigate risk to its assets, operation and functioning of interdependent industries (especially telecommunication services and water supply).

In developing its revenue reset proposal for the 2023-28 period, TransGrid has carefully applied the knowledge gained in these engagements. This involved assessing its assets and operational vulnerability to the physical risk of changing climate and extreme weather events, especially considering the location, condition, loading, type of asset, and criticality of supply.

In 2020 AEMO commissioned Brattle Group to perform a benchmark study of overseas jurisdiction's approach to integrating climate risks into transmission network planning functions. This study observed that most jurisdictions were just beginning to develop their policies and frameworks to account for such risks and that there was a lack of comprehensive risk identification and investment planning processes worldwide. The study found that most approached climate change physical risks in an ad-hoc and reactive manner.

The above observation by Brattle Group also correlates with findings published by CIGRE in a recent technical brochure examining global practices and approached to power system resilience [16].

In July 2021, GHD Advisory undertook a literature review and phone interviews with international transmission network and system operators to investigate global practices aimed at improving transmission network resilience to the physical risks associated with extreme weather events. Our review found that while transmission network operators generally appreciate that climate change is likely to expose networks to more frequent extreme weather events, it is rare for transmission network operators to be proactively engaged in assessing the increased risk posed by extreme weather and investigating prudent mitigation options. While there are well-established measures available to improve network resilience by mitigating the risks posed by extreme weather events, little to no progress has been made in developing and applying robust frameworks for justifying such investments by most overseas network service providers and jurisdictional system operators. There is however a growing recognition of the need to consider the increased risks posed by more frequent and more extreme weather events resulting from climate change.

Giving the worldwide industry context and considering the business decisions and progress that TransGrid has made in recent years in establishing the Network Climate Adaptation Strategy and undertaking operational level risk assessment work, TransGrid is clearly leading the way when it comes to assessing and implementing options to improve network resilience to climate change. We note that this subject is of growing interest to network owners, system operators and their stakeholders. Addressing network resilience to climate change is consistent with TransGrid's broader Climate Strategy, Sustainability Strategy and its commitment to clearly define, quantify, articulate and disclose climate change risk to stakeholders. Accordingly, we consider TransGrid to be in a leading position compared to global peers.

2. Required network investments 2023-2028

2.1 Considered activities

TransGrid reviewed potential extreme weather impacts and developed several initiatives that seek to selectively address vulnerabilities to maintain acceptable levels of network risk and resilience for critical assets in the face of increasing climate change-related hazards. The literature review and international survey identified two additional initiatives worthy of inclusion, with the resulting list presenting a comprehensive set of initiatives capable of improving the resilience of the TransGrid transmission network to extreme weather events. A resilience and maturity assessment completed by GHD allowed further insights into the relative priority of the proposed initiatives [12, 17]. The resulting list of initiatives shown in Table 2 reflects the potentially cost-effective measures that TransGrid identified to maintain the resilience of the transmission network to increasingly frequent and intense extreme weather events.

Table 2 Resilience initiatives

Candidate	Scope of work
A- Compound event analysis	Developing the capability to routinely analyse compounding weather events to understand periods where an elevated security or reliability risk exist.
B- Dynamic line ratings	Implementing the continuous adjustment of transmission lines' ratings based on current weather conditions to prevent unnecessary constraints and maximise utilisation.
C- Wood pole replacements	Carrying out a replacement program for already deteriorated wood transmission poles with more resilient alternatives.
D- Polymer insulator replacements	Introducing a replacement program for non-ceramic insulators within high-bushfire risk areas. Ceramic insulators are more resilient to fire.
E- Hooked insulator replacements	Carrying out a replacement program for legacy hooked insulators in areas of high bushfire consequence.
F- Lightning resilience improvements	Several transmission lines on the QNI are identified where a lightning strike could trigger a double-circuit trip and reclosure sequence. This initiative seeks to deploy measures, such as installing surge arresters and improving tower earthing, that reduce the likelihood of a lightning flashover.
G- Asset vulnerability assessments	Introduces a program where asset condition and fault reports are captured and analysed in an ongoing way to identify trends and validate findings around vulnerability assessments.
H- Tower strengthening program	A program to strengthen key identified towers designed to legacy standards to resist higher winds in line with current day standards.
I- Deteriorated conductor replacement	Replacement works for deteriorated all-aluminium conductors to improve bushfire resilience.

GHD independently ranked each initiative using the maturity and resilience assessment framework illustrated in Figure 4. The maturity assessment applied multi-criteria analysis, rating the potential resilience benefit of each candidate initiative, and TransGrid's ability to immediately implement the initiative (maturity). Together, these criteria give a priority score. These scores are intended to be applied in conjunction with other considerations such as the cost of the initiative and any wider market benefits it might deliver outside of extreme weather periods, to make informed decisions around investments.

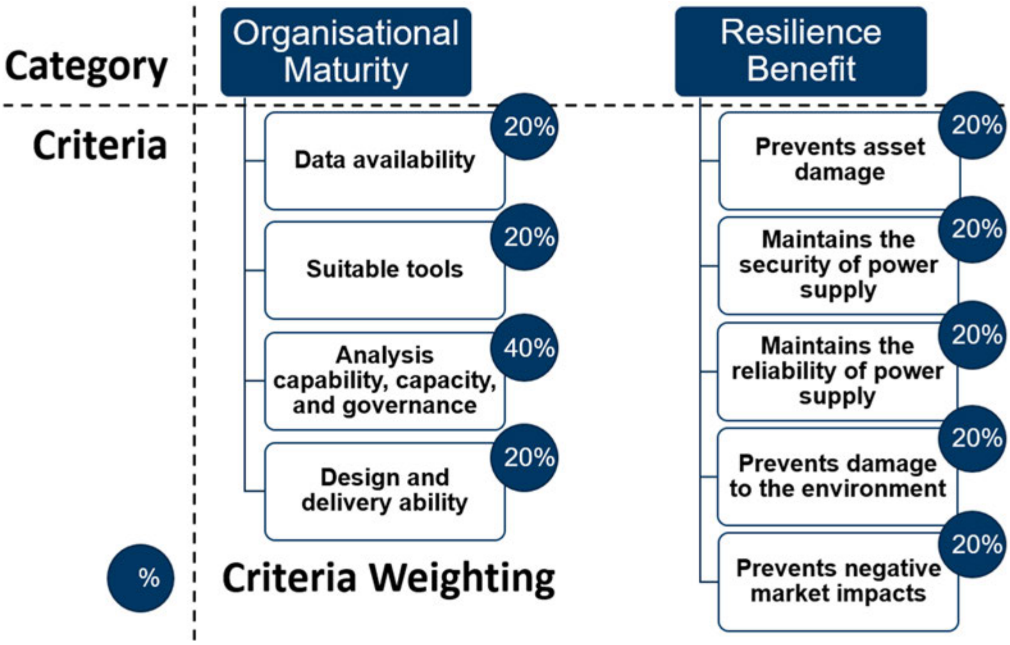


Figure 4 Maturity and resilience assessment framework - scoring categories with associated weighting

The maturity framework helps to identify those initiatives which can be implemented immediately (high maturity) and those where further work is required to improve the maturity. The scoring process implemented in the framework helps identify the sort of investment that is required to improve maturity.

A lower maturity score and high resilience score indicates that there is merit in undertaking further work during the 2023-28 revenue period to improve maturity which will increase confidence that any identified investments to improve resilience will be cost-effective. A high maturity score indicates that TransGrid is confident of being able to identify the parts of the network where the proposed initiative should be deployed and to efficiently deliver the necessary works.

Scores indicated that candidate A, compound event analysis, offers potentially very high resilience benefits, however, it is also the least ready for immediate implementation. It would be prudent to work on weak areas of organisational maturity to better position TransGrid for future implementation as discussed in section 3.1. All other candidates are more mature meaning that they can be undertaken now and could help to enhance network resilience.

2.2 Revenue proposal inclusions

Of the nine candidate initiatives that TransGrid initially considered and explored, it has carefully selected two initiatives to include in its upcoming 2023-28 revenue reset submission. The selection process involved considering the following factors for each candidate initiative:

- Costs and benefits analysis, including resilience benefits and wider market benefits
- Opportunities for expenditure optimisation (i.e. targeted expenditure to tackle highest risks first, efficiently leveraging other expenditure programs and exploring potential Capex/Opex trade-offs)
- Organisational maturity (i.e. representing business experience and confidence to deploy the candidate initiative while considering the existence and quality of data, tools, systems and resourcing capacity and capability).

This is illustrated in the following diagram.

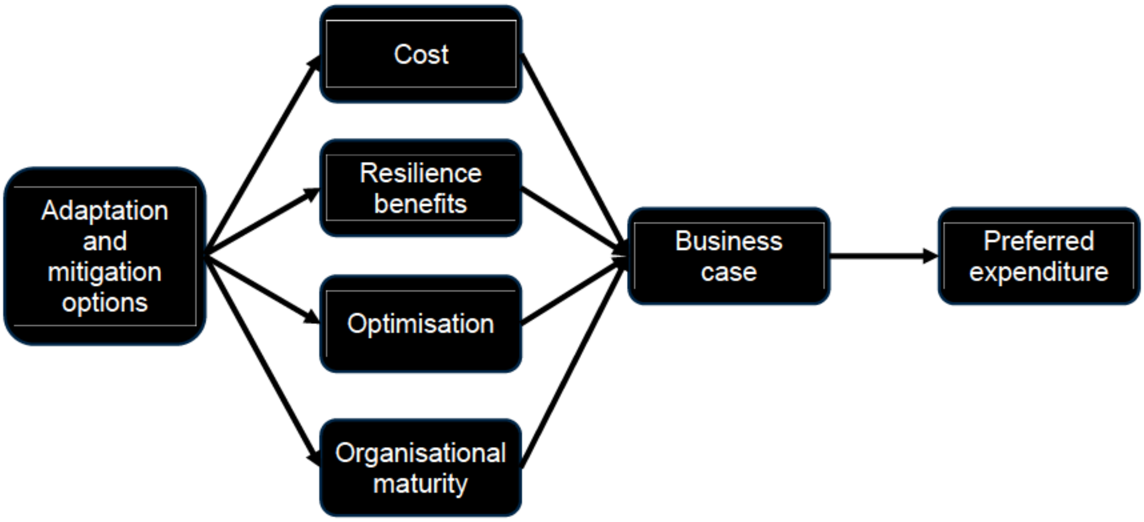


Figure 5 *Short-listing and solution development*

This rigour in developing its expenditure business cases demonstrates the conscious decision TransGrid has made through each step to only proceed with those initiatives that are prudent, efficient and meet the NEO criteria. In other words, TransGrid is proposing only those initiatives that are absolutely necessary and must be deployed in the next five years. It has avoided burdening the end consumers with unnecessary or early expenditure.

Proactively investing to increase network resilience is clearly beneficial for both TransGrid and consumers. It is prudent to make these resilience improvements, especially when considering that their costs are diminutive when compared with TransGrid's typical capital and maintenance expenditure.

TransGrid has included the following two initiatives in the 2023-2028 revenue submission. Both initiatives were identified as mature candidates as TransGrid has a proven capability to efficiently implement each work program. These programs were preferred as they offer the best value when the cost required to implement the initiatives and the full set of benefits delivered were compared with the other initiatives:

- **Wood pole replacement program**

  TransGrid has many lines that use wood poles. Most notable is a section of the Queensland – New South Wales Interconnector (QNI) between Tamworth and Armidale. Many of these timber assets are deteriorated and already require replacement. Additionally, wood structures are significantly more vulnerable to the effects of bush fires. Wood poles combust at a low temperature when compared with concrete or steel alternatives. Replacing wood poles in targeted areas improves the transmission network's ability to ride through local bushfires and thereby increases overall network resilience.

  Replacement of wood poles with concrete or steel is a reasonably simple like-for-like substitution and one that TransGrid often completes. This indicates that TransGrid has the tools, skills, and resources necessary to immediately implement this program, achieving the benefit of maintaining a highly reliable network. While this program of work is focused on addressing asset condition issues, it also offers a network resilience benefit.

- **Expansion of dynamic line rating**

  Expanding dynamic line rating as a part of regular operations at TransGrid offers numerous benefits. When conditions are favourable, the rating of a transmission line can be increased. This has the potential to reduce congestion and allows more flexible network operation. Conversely, when conditions are unfavourable, such as on extremely hot days, lines may be derated, preventing overheating and maintaining the service life of the asset. Implementing this initiative has a resilience benefit in that it may reduce asset damage, but it also has significant market advantages as unnecessary constraints may be avoided.

  TransGrid has an existing program for dynamic ratings on some transmission lines and, as such, has most of the data, tools, and capabilities necessary to implement this program and therefore it is appropriate to introduce this program in the 2023-2028 revenue period.

TransGrid proposes to install weather monitoring stations to provide dynamic lines ratings for a limited number of additional transmission circuits. These lines are expected to experience contingency events that exceed current static thermal ratings and where the flow on those circuits is unlikely to be restricted by other criteria such as stability considerations. This program provides a prudent level of expenditure as it targets those transmission circuits where dynamic line ratings are expected to deliver the greatest benefit. Some of the benefits delivered include reduced constraints placed on renewable generation and a decreased risk of overheating transmission circuits when operating under extreme temperature conditions with little or no wind.

While only these two initiatives have been selected for the upcoming revenue period, all the other candidates, summarised in Table 2 above, offer resilience benefits. The data, tools, and organisational capabilities should be continued to be developed and each initiative should be considered for the following revenue period.

The traditional approach to determining the prudent operating and replacement capital expenditure for a transmission network relies on using historical data to set efficient expectations of future expenditure. However, this is not a reasonable approach for maintaining network resilience in a changing climate, as climate models typically show that historical weather patterns are not a good predictor of future weather patterns. Climate change models show that extreme weather events are becoming more frequent and more severe, and it is therefore expected that a step-change in expenditure will be required to maintain sufficient network resilience to these events.

The expenditure identified by TransGrid for the two initiatives should be treated as a legitimate request to address network vulnerabilities that have a resilience benefit in addition to market congestion, safety, environmental and supply security benefits. By supporting the proposed step-change in expenditure, the AER will be supporting TransGrid to make prudent and proactive investments that will improve the resilience of the transmission system to extreme weather events and deliver savings to customers over the longer term by reducing the magnitude and likelihood of pass-through events.

TransGrid will be supplying business cases for the selected projects as part of the supporting material for their upcoming revenue submission.

In addition to the two identified Capex programs, TransGrid also considers it prudent to increase Opex to refine and augment existing asset management and capacity planning processes to integrate within those activities' exploration of further opportunities for investment programs to improve network resilience. This is described further in Sections 3.1, 3.2 and 3.3.

3. Future activities and challenges

It is important that TransGrid continues to investigate opportunities to maintain a highly resilient New South Wales transmission network in response to the projected impacts of climate change. While there are costs involved in undertaking these activities, they are necessary and will enable TransGrid to identify emerging resilience issues and select the appropriate adaptation strategies to avoid any unnecessary short-term costs to repair the network as well as a degradation in resilience over time. The future work can be grouped into three key themes:

- Developing and refining compound event analysis
- Ongoing assessment of vulnerability and mitigations options
- Development of and reporting against key resilience metrics

These additional activities do not replace the capacity planning and asset management work that TransGrid undertakes, they complement those activities by focusing on additional measures needed to keep an appropriate focus on the resilience of the transmission network.

In addition, TransGrid also needs to keep abreast of the latest climate forecasting and maintain the ability to downscale regional climate models to produce the more granular climate forecasts to inform prudent and efficient risk management decisions.

It also needs support related, broader initiatives including:

- working with other network service providers, stakeholders and the AER to navigate the existing NEM regulatory framework and identify an effective way to ensure required resilience improvement investments can be justified and included in regulated network expenditure plans. This topical challenge is discussed in Section 3.4
- working with governments to identify critical infrastructure and investigate options to improve resilience as recommended by the Royal Commission into National Natural Disaster Arrangements [5].
- providing annually updated bushfire management plans as recommended by the NSW Bushfire Inquiry [7].
- harmonising network resilience management and reporting to address resilience to extreme weather, cyber security risks and other malicious acts consistent with requirements in the Security of Critical Infrastructure Act [8, 9].
- supporting AEMO to complete power system frequency risk reviews with the last review to be completed by July 2022 (NER obligation defined in clause 5.20A).
- supporting AEMO to complete the general power system risk review every two years with the first review completed by 31 July 2023 (NER obligation defined in clause 11.138).

3.1 Compound event analysis

Compounding weather events refer to a sequence of overlapping climate hazards that have the potential to amplify the stress on the power system and adversely impact reliability and resilience. Compound events have occurred in recent years through the combination of extreme heat combined with widespread bushfires, followed by storms and catastrophic winds. Another example of a compound event is the set of circumstances that led to the South Australian blackout in 2016. Key factors that contributed to the blackout included extreme winds damaging transmission lines, low power system inertia, the unexpected reduction in output from a number of windfarms and the trip of the interconnector to preserve system stability.

In the 2020 Integrated System Plan (ISP), AEMO identified the potential risk to power system resilience posed by compound weather events.

GHD has reviewed the data, analysis tools and processes, and resources available within TransGrid to undertake a quantitative assessment of the risks posed by compound events [18]. That review identified that while TransGrid has many of the elements required to undertake the analysis needed to quantify the risks associated with compound events, a study of this nature has yet to occur. As a result, there was some doubt regarding TransGrid's ability to complete compound event analysis in a timely and cost-effective manner.

GHD has since worked with TransGrid to demonstrate how scenario-based contingency analysis can be used to help quantify the potential consequence of compound events. A proof-of-concept study has been completed which simulated the potential impact on the TransGrid transmission network from the following three compound weather events:

1. An east coast heatwave that results in increased demand, reduced generation capacity, and reduced ability to import power into NSW.
2. Heat and fires causing increased demand across NSW reduced generation capacity and an increased likelihood of double circuit outages.
3. Heat and storms presenting increased demand across NSW and a broad storm front across northern NSW resulting in reduced QNI import, concurrent with reduced wind generation in northern NSW.

Identifying relevant compound events was accomplished by reviewing the past decade of events captured in AEMO incident reports. The specific modelling assumptions and input data was developed by GHD in collaboration with TransGrid.

The key learnings coming from the proof of concept study include that:

- Plausible compound event scenarios can be developed by reviewing historical incident reports with climatic conditions adjusted by taking into account predictions in climate models.
- Existing contingency analysis tools such as PSSE can be used to understand the potential consequence of compound events in terms of the amount of load that may need to be shed to maintain a secure power system.
- Further refinement of the modelling process is needed to provide robust and actionable outcomes.
  - While the state-wide demand can be adjusted relatively easily to meet a particular extreme temperature scenario, further model development is required to translate that demand to a substation level.
  - Additional effort in downscaling climate models would assist in more confidently defining the likely impact on transmission assets from these compound event scenarios. Impacts can then be modelled in the simulations to understand the wider power system consequences.
  - Further iterations of the scenario-based contingency analysis should be completed to provide a more robust assessment of consequences, and to investigate the effectiveness of resilience improvement initiatives.
  - Enhanced automation of the simulation process would enable variations to the key system conditions at the time of the compound event to be studied. This would help build a more robust understanding of the sensitivity of the modelled outcomes to key inputs.

The proof of concept identified that it is possible to leverage existing analysis tools and systems, however additional power system modelling, demand forecasting, and climate forecasting resources would be required to provide TransGrid with the capacity to routinely review the expected consequence of compound weather events.

Building this additional capability into the TransGrid transmission planning processes would help quantify the risk posed by compound weather events and help explore prudent risk mitigation measures. The proof of concept developed by GHD suggests that establishing the compound weather assessment capability would require funding an additional annual Opex cost of $300k.

Having established the compound weather event modelling capability, it could also be used to assess the case for adjusting planned transmission network expansion projects to reduce their vulnerability to extreme weather.

3.2 Vulnerability assessment and solution development

In 2019 TransGrid established its network climate adaptation strategy that was supported by a network climate resilience assessment and a review of current engineering design standards, as described in Section 1.3. Collectively this body of work provides a point in time assessment of the potential vulnerability of network assets to damage caused by extreme weather events.

The vulnerability assessment was informed by insights into projected future weather conditions drawn from the climate modelling such as that undertaken via the ESCI project. Further refinement of the outcomes from the vulnerability assessment was achieved by considering available information on the location and condition of the assets. Collectively this allowed various options for improving resilience through reducing asset vulnerability to be identified. Of the options explored, TransGrid has identified two high priority work programs to undertake during the 2023-2028 revenue period:

- Wood pole replacement programs, and
- Introduction of dynamic line ratings.

While considerable work has been completed, further work is required to ensure that vulnerability assessment processes become integrated into TransGrid's routine asset management processes. Completing this additional work will help ensure that assessing resilience to climate change becomes an integral part of TransGrid's asset management processes.

The network climate adaptation strategy outlines key themes and actions to facilitate climate adaptation integration into the TransGrid Asset Management System. Once implemented these actions will establish a line of sight with climate resilience to asset management policy, strategy and objectives.

The following additional measures will be explored to further integrate effective consideration of resilience to climate change into TransGrid's routine asset management processes:

- Reviewing the TransGrid's Network Asset Strategy and Risk Management Framework to explore whether a more explicit measure of the risk posed by extreme weather events should be included
- Incorporating climate risk assessments and exploration of adaptation strategies into the early phase of planning of major Capex projects and programs
- Reviewing asset condition monitoring processes and data to identify any emerging evidence of degradation of life driven by climate changes. New trends may necessitate reviewing asset vulnerability assessments
- Introducing climate resilience into safety in design (or sustainability in design) process reviews.

3.3 Resilience metrics to monitor progress

While power system resilience is generally recognised as important, there are few uniformly accepted metrics for measuring resilience. Work recently published by CIGRE in its Technical Brochure 883 [16] has provided important guidance for establishing effective resilience metrics and the role that a set of metrics can play in helping to implement a resilience framework.

Figure 6 Resilience framework. Source: Sandia National Laboratories [19] and CIGRE [16]

TransGrid recognises the value in adopting an appropriate set of resilience metrics and plans to develop resilience metrics to enable monitoring of network resilience, by reporting against those. Resilience metrics can generally be grouped into one of the following two categories:

- Attribute-based (qualitative) metrics lead to a more judgemental analysis and provide less definitive answers to the question of how resilient TransGrid's network is. However, they are easier to collect and simpler to analyse in terms of computational efforts.
- Performance-based (quantitative) metrics lead to more objective analysis and are considered a better way of answering the question of how resilient TransGrid's network is. However, they are harder to produce and the data to be used in these analyses may not be available without some further investment in data collection.

It is noted that resilience metrics should be different to reliability metrics and should be service-based and include impacts to human and services to the community.

In the longer-term, the development of resilience metrics may require updating the existing Enterprise Resource Planning (ERP) and Asset Monitoring Information Platform (AMIP) systems to allow capturing and processing of appropriate asset condition, operational performance parameters and related climate data or weather events. The intention is that over a period of time the insight from such measurement will allow TransGrid to better manage and control its assets and operate in a resilient manner.

CIGRE Technical Brochure 833 also notes that power system resilience should consider the ability to deal with a range of potential threats, not just extreme weather events. Key additional threats include cyber security and physical man-made attacks on critical infrastructure. TransGrid should consider that there may be merit to harmonise the reporting and monitoring of resilience to capture all of the threats in a consistent framework. The merit of adopting a harmonised approach should be further considered taking into account the legislative requirements being established by the Australian Government via the Security of Critical Infrastructure Act 2018 (and its 2020 amendment bill and Positive Security Obligation) calling for electricity network resilience against natural and weather-related hazards of tomorrow.

3.4 Current challenges and regulatory approvals

Presently there is a lack of climate science modelling knowledge embedded within the electricity supply industry to produce forecast weather event scenarios with enough locational resolution and relevancy to impacted infrastructure and its operation. There is also a lack of climate forecast data (such as extreme wind patterns) that is directly relevant and interacts with network infrastructure. Modelling techniques to generate relevant climate forecast scenarios (such as continuous run of extreme heat days, compound weather events correlation, probabilities, spatiotemporal representation etc.) are still in their infancy and their application by transmission network services providers lacks maturity. This deficiency in forecast information combined with limited or absence of established knowledge or guidance on climate change risk assessment methodologies is impeding the uptake of such risk management approach in a routine business-as-usual fashion. These challenges were also noted in the output of the ESCI project.

Given that the climatic conditions of tomorrow will not be the reflection of the past and the challenges in forecasting climate information, it is difficult to convert historical anecdotes and records of weather-related events to data-rich knowledge and business tools to justify resilience investment decisions for tomorrow. Developing the business case to mitigate forecasted climate change risk for *ex-ante* expenditure evaluation is difficult. The cost of network resilience measure versus the risk reduction it will deliver both need to be assessed. Of these, robust estimation of the risk reduction for extreme weather events (High Impact Low Probability or HILP phenomenon) is difficult to articulate in a business case. The value of avoided or reduced detrimental impact to network assets and their operation is difficult to measure and prove.

This contrasts with the cost pass-through (*ex-post*) application, which is relatively easier to prepare and evaluate and is the current mechanism available to the industry to recover the costs associated with repairing the damage caused by extreme weather events. However, reliance on an *ex-p*ost approach is not sustainable in light of climate change projections which show extreme weather events happening more frequently and with greater intensity and/or for a longer duration. The *ex-post* approach fails to encourage proactive investment to reduce the impact of extreme weather events by improving resilience. Estimates from the building industry suggest that it is approximately four times more expensive to event manage and repair asset damages *ex-post* than proactively invest to improve resilience [20]. Any inefficiency due to a lack of strategic risk mitigation initiatives is ultimately paid for by the end-users, i.e. consumers of electricity.

The current *ex-ante* regulatory regime in Australia and its investment evaluation approach is retrospective in its outlook assessment. While this backward-looking evaluation approach may be suitable for routine expenditure plans that deal with cyclic risk management activities (for e.g. age and condition-based asset replacement expenditure evaluation, if all else remains constant), such a regime is unsuitable to evaluate forecast investments that do not follow the historical patterns and respond to changing risks. In the case of climate change risk, the past is not a wholly valid predictor of the future.

The NSW government bushfire enquiry recommends that electricity network resilience to bushfires should be improved [7]. The inquiry suggested there may be merit in reviewing the way costs for resilience improvement works are recovered. It also acknowledged the need to carefully assess resilience improvement options to ensure that there is an appropriate consideration of the trade-off between the cost of implementing the option and the resilience benefit delivered. The enquiry suggested that the cost-benefit trade-off is best addressed collaboratively by utilities and government. Meanwhile, the final report from the ESCI project notes that the support of the AER is needed for the use of climate information in investment decisions [21]. This will require regulatory acceptance of a consistent set of climate models and risk assessment frameworks.

4. Conclusion

Historically TransGrid's transmission network has proven to be highly resilient, able to ride through significant events with minimum disruption of electricity supplies. The changing climate coupled with the changing characteristics of the power system has the potential to erode resilience; avoiding this unacceptable outcome requires focussed attention and a prudent investment program. Climate change is placing stressors on the network in the form of increased demand, less predictable generation, network derating, and asset damage. Without action, these stressors will degrade the resilience of the transmission network. Additionally, costs to consumers will increase as large cost pass-through events become more frequent.

TransGrid has recently undertaken strategic and operational level risk assessment work to understand the physical risks posed by the climatic condition of tomorrow on its network assets and operations. This has demonstrated its leading position within the industry, and it is committed to clearly define, quantify, articulate and disclose its risk exposure and its mitigation measures to its stakeholders.

TransGrid assessed areas of weakness and nine resilience improvement initiatives were proposed and carefully evaluated. Two prioritised resilience initiatives were selected for the 2023-28 revenue period. These are wood pole replacements and dynamic line ratings. Other resilience initiatives are of great value and should be developed and considered for implementation as risk assessment techniques evolve and in future revenue periods.

In order to comprehensively embed its network climate adaptation strategy into its day-to-day business functions, TransGrid needs to incorporate climate-driven asset and operation impact assessment and mitigation analysis in its network planning procedures, asset management investment strategies, and its risk management framework. This will involve a long term organisation-wide commitment to establish new practices, tools, metrics, data capture and analysis methodology, evaluation approach and additional capabilities. It will also require TransGrid to take long term strategic advocacy positions to address climate risk and drive changes needed to the existing regulatory framework. This continued integration of planning for resilience into business processes will also position TransGrid to effectively support and contribute to the range of related external initiatives and new obligations discussed in section 3.

Collectively, the proposed focus on resilience should maintain a highly resilient TransGrid's transmission network meeting the expectations of New South Wales electricity users.

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