



Tower Resilience Study

Summary Report

Prepared for AusNet Services

Prepared by Beca Pty. Ltd.

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Revision History

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Executive Summary

AusNet Services is evaluating the long-term resilience of its Victorian transmission network with support from Beca Pty Ltd. This report focuses on three key areas: assessing structural resilience against severe wind events, identifying strengthening requirements for extreme wind conditions, and comparing the costs of line strengthening to the financial impacts of unplanned outage events.

A total of 12 lines have been identified by AusNet as priority lines for assessment at 500 kV, 330 kV and 220 kV.

The assessment determines the maximum wind speeds that above-ground structures can withstand before exceeding utilisation limits and evaluates the scale of strengthening required for towers to withstand synoptic and downdraft wind events with Average Recurrence Intervals (ARI) of 1000 years (46 m/s) and tornado conditions (60 m/s). Additionally, a high-level cost comparison analysis examines the estimated costs of strengthening versus the cost of unplanned outages cause by extreme wind events.

Assessments were conducted using AS/NZS 7000 and AS/NZS 1170.2 design standards, without applying load or strength reduction factors. The cost-benefit method used in this report employs a risk-based cost calculation. This approach assesses base reliability and associated risk cost for each line by focussing on the weakest tower within the line and the probability of it seeing an ARI wind event.

The table below provides an overview of the findings, including site-specific ARI achieved, strengthening recommendations based on positive return benefit/cost ratios, and associated costs.

An initial assessment found that the 330 kV MSS-DDTS 1 & 2 lines may only withstand low wind speeds, consistent with previous AusNet studies. Given that historical tower failures on these lines have been rare, further investigation into tower performance is warranted. Accordingly, benefit/cost ratios and strengthening costs for these lines have not been evaluated at this stage.

Line	Lowest maximum site-specific Average Recurrence Interval (ARI) achieved (years)	Average maximum site-specific ARI achieved (years)	Level of strengthening based on benefit/cost ratio > 1 (ARI, years)	Corresponding no. of towers to be strengthened	Corresponding tower strengthening cost (\$)
500 kV					
LYPS-HWTS 1	25	427	1000	25	4.7M
LYPS-HWTS 2	25	401	1000	28	5.4M
LYPS-HWTS 3	50	426	250	15	3.3M
SMTS-SYTS 1	25	662	1000	42	6.0M
SMTS-SYTS 2	50	541	100	6	1.2M
SYTS-MLTS 1	50	279	100	21	4.3M
SYTS-MLTS 2	50	280	100	21	4.4M
MLTS-CRTS-MOPS-HYTS/APD	1000	1000	N/A	-	-
330 kV					
MSS-DDTS 1	Further review required				
MSS-DDTS 2	Further review required				
220 kV					
BATS-BETS	100	663	250	6	1.3M
BETS-KGTS	25	184	50	2	659.0K

The results of this analysis should be considered as one factor among many when making investment decisions regarding tower resilience.

1 Introduction

AusNet Services (AusNet) is assessing the long-term resilience of its Victorian transmission network and has engaged Beca Pty Ltd (Beca) for support in overlaying tower structural assessments, probability of severe winds and network element criticality to develop a long-term resilience assessment of the network.

The assessment undertaken by Beca focuses on three key areas:

- 1. Resilience Assessment:** Evaluation of the maximum wind speed that each structure for the selected transmission lines can withstand before the utilisation of a structural component (excluding redundant members) exceeds 100% of its calculated strength.
- 2. Strengthening Assessment:** High-level assessment of the structure strengthening that would be required (if any) to withstand the wind speed corresponding to an Average Recurrence Interval (ARI) of 1000 years (regional wind speed of 46 m/s) and tornado events (60 m/s).
- 3. Cost Analysis Assessment:** High level comparison of tower strengthening cost versus cost of unplanned outage due to an extreme wind event.

The transmission lines included in the assessment are listed in Table 1-1 and are located as shown in Figure 1-1.

The assessment conducted focuses solely on the analysis of the above-ground structure. The evaluation of foundations has been excluded from the loading, strengthening, and costing analyses. This approach was agreed upon with AusNet, as foundation failure is considered unlikely to be the primary cause of an unplanned line outage.

Table 1-1 - Assessed transmission lines

Voltage	Line	Line Full Name:
500 kV	LYPS-HWTS1	LOY YANG P.S. - HAZELWOOD T.S.
	LYPS-HWTS2	LOY YANG P.S. - HAZELWOOD T.S. NOTHERN LINE ON SOUTHERN EASEMENT
	LYPS-HWTS3	LOY YANG P.S. - HAZELWOOD T.S. SOUTHERN LINE ON SOUTHERN EASEMENT
	SMTS-SYTS1	SOUTH MORANG T.S. TO SYDENHAM T.S. NO1
	SMTS-SYTS2	SOUTH MORANG T.S. TO SYDENHAM T.S. NO2
	SYTS-MLTS1	SYDENHAM TS TO MOORABOOL T.S. NO1
	SYTS-MLTS2	SYDENHAM TS TO MOORABOOL T.S. NO2
	MLTS-HYTS/APD	MOORABOOL T.S. TO ALCOA PORTLAND
330 kV	MSS-DDTS-1	MURRAY S.S. - DEDERANG T.S. LINE NO1
	MSS-DDTS-2	MURRAY S.S. - DEDERANG T.S. LINE NO2
220 kV	BATS-BETS	BALLARAT – BENDIGO
	BETS-KGTS	BENDIGO – KERANG

Figure 1-1 - Transmission lines assessed



2 Design Basis Report

A Design Basis Report, detailing the standards, criteria, methodology and assumptions used for the assessment is included in Appendix A. This report was agreed with AusNet prior to proceeding with the assessment.

The Design Basis Report also specifies the tower types utilised for each line and identifies which types have been included in the assessment.

3 Summary of the methodology

A summary of the structural assessment methodology applied in the analysis is outlined below. Refer to section 4 of the Design Basis Report (Appendix A) for a detailed methodology.

- The structural assessment was undertaken using Bentley software packages PLS-CADD and TOWER.
- Existing PLS-CADD line models provided by AusNet were updated with both existing available and newly developed TOWER models.
- Site-specific tower and span winds speeds were calculated in accordance with AS/NZS 1170.2, with ARI ranging from 1 to 1000 years.
- These site-specific wind speeds were applied in the PLS-CADD and TOWER models to determine the maximum wind speed each tower could withstand for each line. The wind speeds were correlated to ARI values to determine the annual reliability (annual probability of survival) for each tower location.
- TOWER models were used to estimate indicative strengthening weights required for each tower type to withstand synoptic and downdraft winds with an ARI of 1000 years and tornado winds.
- Historical data on tower strengthening project costs, supplied by AusNet, were utilised to develop high-level strengthening cost estimates for each line, corresponding to increasing ARI durations.
- AusNet also provided market costs associated with unplanned outages, as well as emergency and permanent restoration costs. These figures were used to establish high-level cost estimates per line for unplanned outages caused by line failures due to extreme wind events (risk costs).
- High-level strengthening costs were then compared against risk costs for each line to evaluate the potential reduction in risk (benefit) achieved through strengthening works (cost).

4 Summary of structure resilience and high-level strengthening assessment

Detailed summary reports for each line are provided in Appendix B. Each summary report provides the following information:

- Line specific structure number
- Structure function and type
- Site specific tower duties (i.e. wind span, weight span, deviation angle)
- Site specific structure and span synoptic wind speeds corresponding to an ARI of 1000 years
- Maximum synoptic and downdraft wind speeds (and corresponding recurrence interval) each tower can withstand before a structural member utilisation exceeds 100% of its calculated strength (excluding redundant members). Unity load factors and capacity reduction factors were applied during the assessment (refer to Design Basis Report in Appendix A for further details).
- Based on recurrence intervals calculated, structure specific annual reliabilities and annual probabilities of exceedances
- Maximum tower specific utilisations (excluding redundant members) under both synoptic and downdraft winds corresponding to an ARI of 1000 years and tornado winds to AS/NZS 7000. Maximum utilisations are given separately for leg members and other (non-leg) members.
- The number of tower members groups with utilisations exceeding 100% of calculated strengths under synoptic and downdraft winds corresponding to an ARI of 1000 years and tornado winds.
- The approximate weight of steel to strengthen the members with utilisations exceeding 100% of calculated strength under synoptic and downdraft winds corresponding to an ARI of 1000 years and tornado winds. This has been approximated by calculating the weight of members required to replace the over utilised members. Note: The feasibility of member strengthening has not been assessed.
- The list of tower member groups requiring strengthening. Tower member groups requiring strengthening for each tower type are detailed on tower utilisation diagrams provided in Appendix C.

Site specific leg footing reactions for each tower location under synoptic and downdraft winds corresponding to an ARI of 1000 years and tornado winds are also provided in Appendix E. Note site specific body and leg extensions have not been modelled so foundation loads may be approximate only.

A summary of the findings for each line are provided in the following sections.

4.1 500 kV transmission lines

(a) LYPS-HWTS 1, 2 & 3 - Loy Yang P.S. - Hazelwood T.S.

Three single circuit 500 kV lines (LYPS-HWTS 1, 2 & 3) provide a connection between the Loy Yang Power Station and the Hazelwood Terminal Station. LYPS-HWTS 2 and 3 are positioned adjacent to each other, running parallel along their entire length. All three lines are parallel and adjacent for approximately the first six towers extending out from LYPS. A summary of the findings is provided in Table 4-1.

Table 4-1 - LYPS-HWTS 1, 2 & 3 – Summary of findings

Property/Criteria	Value		
Line name	LYPS-HWTS 1	LYPS-HWTS 2	LYPS-HWTS 3
Voltage (kV)	500	500	500
N° of circuits	Single	Single	Single
Line length (km)	14.1	14.3	14.5
Total tower quantity	39	40	41
Towers assessed	36	37	38
% of towers assessed	92%	93%	93%
Lowest maximum site-specific ARI achieved (years)	25	25	50
Average maximum site-specific ARI achieved (years)	427	401	426
% of towers assessed not withstanding ARI wind speed of 1000 years	69%	76%	76%
Approximate strengthening weight required to withstand ARI wind speed of 1000 years (tonnes)	12	13	12
Approximate strengthening weight required to withstand ARI wind speed of 1000 years and tornado wind event (tonnes)	13	13	12

(b) SMTS-SYTS 1 & 2 - South Morang T.S. to Sydenham T.S.

Two single circuit 500 kV lines (SMTS-SYTS 1 & 2) connect the South Morang and Sydenham terminal stations. The two lines are positioned adjacent to each other, running parallel along their entire length. A summary of the findings is provided in Table 4-2.

Table 4-2 - SMTS-SYTS 1 & 2 - Summary of findings

Property/Criteria	Value	
Line name	SMTS-SYTS 1	SMTS-SYTS 2
Voltage (kV)	500	500
N° of circuits	Single	Single
Line length (km)	42.3	43.2
Total tower quantity	110	107
Towers assessed	104	101
% of towers assessed	95%	94%
Lowest maximum site-specific ARI achieved (years)	25	50
Average maximum site-specific ARI achieved (years)	663	541
% of towers assessed not withstanding ARI wind speed of 1000 years	40%	55%
Approximate strengthening weight required to withstand ARI wind speed of 1000 years (tonnes)	21	28
Approximate strengthening weight required to withstand ARI wind speed of 1000 years and tornado wind event (tonnes)	25	31

(c) SYTS-MLTS 1 & 2 - Sydenham T.S. to Moorabool T.S

Two single circuit 500 kV lines (SYTS-MLTS 1 & 2) connect the Sydenham and Moorabool terminal stations. The two lines are positioned adjacent to each other, running parallel along their entire length. A summary of the findings is provided in Table 4-3.

Table 4-3 - SYTS-MLTS 1 & 2 - Summary of findings

Property/Criteria	Value	
Line name	SYTS-MLTS 1	SYTS-MLTS 2
Voltage (kV)	500	500
N° of circuits	Single	Single
Line length (km)	62.9	62.9
Total tower quantity	157	157
Towers assessed	155	155
% of towers assessed	99%	99%
Lowest maximum site-specific ARI achieved (years)	50	50
Average maximum site-specific ARI achieved (years)	279	280
% of towers assessed not withstanding ARI wind speed of 1000 years	87%	86%
Approximate strengthening weight required to withstand ARI wind speed of 1000 years (tonnes)	74	74
Approximate strengthening weight required to withstand ARI wind speed of 1000 years and tornado wind event (tonnes)	75	75

(d) MLTS-CRTS-MOPS-HYTS/APD - Moorabool T.S. to Alcoa Portland

One double circuit 500 kV line connects the Moorabool Terminal Station to Alcoa Portland, via intermediate terminal stations at Cressy, Heywood, Haunted Gully and Mortlake, which connect into one or both circuits. A summary of the findings is provided in Table 4-4.

Table 4-4 - MLTS-CRTS-MOPS-HYTS/APD - Summary of findings

Property/Criteria	Value
Line name	MLTS-CRTS-MOPS-HYTS/APD
Voltage (kV)	500
N° of circuits	Double
Line length (km)	272.8
Total tower quantity	640
Towers assessed	620
% of towers assessed	97%
Lowest maximum site-specific ARI achieved (years)	1000
Average maximum site-specific ARI achieved (years)	1000
% of towers assessed not withstanding ARI wind speed of 1000 years	0
Approximate strengthening weight required to withstand ARI wind speed of 1000 years (tonnes)	0
Approximate strengthening weight required to withstand ARI wind speed of 1000 years and tornado wind event (tonnes)	12

4.2 330 kV transmission lines

(a) MSS-DDTS 1 & 2 – Murray S.S. to Dederang T.S.

Two single circuit 330 kV lines (MSS-DDTS 1 & 2) connect the Murray and Dederang terminal stations. The two lines are positioned adjacent to each other, running parallel for their entire length. Four tower types were assessed for these lines; LS and HS, which are used for 56% of the tower on MSS-DDTS 1, and E and F, which are used for 67% of the towers on MSS-DDTS 2.

An initial assessment found that the assessed towers may only withstand low wind speeds. A high-level review of the TOWER models was undertaken to assess the accuracy of the TOWER models, including member sizes and geometry. However, no deviations from the original tower drawings were identified.

AusNet has advised that these towers have previously been identified as having sensitivity to wind loads and provided extracts of past analysis documentation.

The documentation of previous analysis included the assessment of two towers on each line, covering the four tower types (LS, HS, E, and F). The following failure conditions were noted in the documentation:

- Diaphragm horizontal edge members under axial tension or compression.
- Leg members under axial compression (in-plane or out-of-plane buckling) or tension.
- Top or bottom chord members under axial tension or compression in the crossarm.
- Other primary members (excluding redundant members).

The documentation also noted that specific diaphragms deformed beyond their elastic capacity but did not exceed their plastic capacity. An additional evaluation was previously carried out to exclude these diaphragm members from consideration, resulting in updated limiting failure wind speeds.

The wind speeds where failures were identified, as noted in the documentation, with and without inclusion of the diaphragm members, are given in Table 4-5. The ARI values corresponding to the wind speeds excluding the diaphragm members are also given.

Table 4-5 - MSS-DDTS 1 & 2 existing structure failure wind speeds from previous analysis undertaken by AusNet

Line	Site specific tower location / tower type	Failure wind speed (m/s)		Corresponding ARI (years)
		With diaphragm	Excluding diaphragm	
MSS-DDTS 1	T21 / LSU LS	25	n/a	<1
	T14 / HSU HS	14	32	~5
MSS-DDTS 2	T19 / LSU E	24	30	~3
	T23 / HSU F	24	28	~2

Tower strengthening works have also previously been undertaken by AusNet on 49 towers across both lines where towers were identified as being greater risk, such as those adjacent to road crossings.

Strengthening designs for the four towers listed in Table 4-5 have been provided by AusNet along with the failure wind speed post strengthening. Tower strengthening drawings, weights, and post-strengthening wind speeds are given in Table 4-6.

Table 4-6 - MSS-DDTS 1 tower 21, 14, and MSS-DDTS 2 tower 19, 23 strengthening details

Line	Site specific tower location / tower type	Strengthening Weight (kg)	Drawing reference:	Post strengthening failure wind speed (m/s)	Post strengthening ARI (years)
MSS-DDTS 1	T21 / LSU LS	1292	TRANS-0337659-001	45	500
	T14 / HSU HS	1305	TRANS-0337666-001	42	140
MSS-DDTS 2	T19 / LSU E	323	TRANS-0337730-001	41	95
	T23 / HSU F	323	TRANS-0337743-001	41	95

Given that these tower types have already been identified as sensitive to wind, and based on historical analysis and existing strengthening designs, further assessment of the MSS-DDTS 1 & 2 lines has been excluded from this study.

Despite the low calculated tower failure wind speeds, further assessment is warranted due to the historically rare occurrence of failure events on the MSS-DDTS 1 & 2 lines. This disparity highlights the need for a deeper investigation of the tower performance, particularly given the presence of very slender and potentially tension-only members. Additionally, it is important to note that the design standards originally applied to the MSS-DDTS 1 & 2 line towers may differ from those used in this assessment and should be considered in a separate analysis.

4.3 220 kV transmission lines

(a) BATS-BETS – Ballarat T.S. – Bendigo T.S.

A single circuit 220 kV line (BATS-BETS) connects the Ballarat and Bendigo terminal stations. A summary of the findings is provided in Table 4-7.

Table 4-7 - BATS-BETS - Summary of findings

Property/Criteria	Value
Line name	BATS-BETS
Voltage (kV)	220
N° of circuits	Single
Line length (km)	96.0
Total tower quantity	227
Towers assessed	211
% of towers assessed	93%
Lowest maximum site-specific ARI achieved (years)	100
Average maximum site-specific ARI achieved (years)	663
% of towers assessed not withstanding ARI wind speed of 1000 years	54
Approximate strengthening weight required to withstand ARI wind speed of 1000 years and tornado wind event (tonnes)	62

(b) BETS-KGTS – Bendigo T.S. – Kerang T.S.

A single circuit 220 kV line (BETS-BETS) connects the Bendigo and Kerang terminal stations. A summary of the findings is provided in Table 4-8.

Table 4-8 - BETS-KGST - Summary of findings

Property/Criteria	Value
Line name	BETS-KGST
Voltage (kV)	220
N° of circuits	Single
Line length (km)	121.6
Total tower quantity	292
Towers assessed	228
% of towers assessed	78%
Lowest maximum site-specific ARI achieved (years)	25
Average maximum site-specific ARI achieved (years)	184
% of towers assessed not withstanding ARI wind speed of 1000 years	74
Approximate strengthening weight required to withstand ARI wind speed of 1000 years and tornado wind event (tonnes)	227

5 Cost benefit analysis

A high-level comparison has been undertaken to compare the costs of strengthening works versus the costs of unplanned outages due to extreme wind events. The detailed costs and benefit/cost ratios are provided in the following sections.

5.1 Cost of tower strengthening

The cost of undertaking strengthening works for each line (as summarised in section 4) have been estimated to assist with undertaking cost-benefit analysis. Unit costs applied in developing tower strengthening costs are described in section 5.1.1, with line specific summaries provided in sections 5.1.2 to 5.1.4.

5.1.1 Unit costs

The following cost components have been allowed for in towers strengthening activities:

- Steel strengthening installation and materials
- Design costs
- Community engagement
- Landowner compensation
- Site reinstatement

All other costs have been excluded from this assessment. The unit costs provided by AusNet and utilised in the study are outlined below.

(a) Strengthening installation and materials

Based on recent cost data for strengthening works conducted on the MSS-DDTS 1 & 2 lines, the average direct strengthening cost is calculated to be approximately \$150 per kilogram of steel. This figure encompasses materials, labour, and plant costs. For the purposes of this study, an estimate of \$200/kg has been assumed, to include allowance for project and site establishment costs.

(b) Strengthening design costs

The cost of the strengthening design work is estimated to be 15% of the installation and material strengthening costs.

(c) Estimated cost of community engagement

AusNet has advised allocating \$10,000 for community engagement related to strengthening works for each strain-strain section. The costs have been applied as follows:

- For a line requiring the strengthening of a single tower, a cost of \$10,000 is applied.
- For each additional tower requiring strengthening, an incremental cost of \$1,000 is applied, up to a maximum total of \$10,000 per strain-strain section on the line.

(d) Estimated cost of landowner compensation and site reinstatement

AusNet has provided the following cost guidelines for landowner compensation and site reinstatement, based on previous tower reinforcement projects. These costs vary according to land use, with the specific land use at each tower location supplied by AusNet.

The unit costs are allocated per strain-strain section. To determine the cost per individual tower requiring strengthening, AusNet has advised to divide the values by the average number of towers per strain-strain section for each line.

Table 5-1 - Landowner compensation and site reinstatement for strain-strain section

Land use	Landowner compensation	Site reinstatement
Farming – cropping	\$500,000	\$150,000
Farming – animal	\$350,000	\$100,000
Farming – general	\$300,000	\$125,000
Commercial (i.e., crushed rock, car yard, etc.)	\$500,000	\$100,000
Private	\$150,000	\$75,000
Crown land	Nil	\$75,000

5.1.2 500 kV transmission lines

Tower strengthening costs for the eight 500 kV transmission lines assessed are given in the following sections. Further strengthening cost details are provided in Appendix D.

(a) LYPS-HWTS 1, 2, & 3 – Loy Yang P.S. - Hazelwood T.S.

The number of towers requiring strengthening, along with the estimated strengthening weights and costs to withstand each ARI level for individual LYPS-HWTS lines, are presented in Table 5-2 to Table 5-4. Combined values for all three lines are given in Table 5-5.

Table 5-2 - LYPS-HWTS 1 - Estimated Cost of Strengthening – Individual line

Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	1	2	12	16	24	25	30
	% of towers	-	3%	6%	33%	44%	67%	69%	83%
Estimated strengthening required (kg)		-	800	1,600	6,800	9,100	11,900	12,000	12,500
Estimated strengthening cost (\$)		-	239.0K	469.0K	2.4M	3.3M	4.6M	4.7M	5.3M

Table 5-3 - LYPS-HWTS 2 - Estimated Cost of Strengthening – Individual line

Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	2	5	11	15	24	28	30
	% of towers	-	5%	14%	30%	41%	65%	76%	81%
Estimated strengthening required (kg)		-	1,700	3,500	6,400	8,300	11,700	12,100	12,300
Estimated strengthening cost (\$)		-	514.5K	1.2M	2.4M	3.3M	4.9M	5.4M	5.5M

Table 5-4 - LYPS-HWTS 3 - Estimated Cost of Strengthening – Individual line

Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	0	5	13	15	22	28	31
	% of towers	-	0%	14%	35%	41%	59%	76%	84%
Estimated strengthening required (kg)		-	0	3,500	7,600	8,300	10,000	11,100	11,400
Estimated strengthening cost (\$)		-	0.0	1.2M	2.9M	3.3M	4.3M	5.1M	5.4M

Table 5-5 - LYPS-HWTS 1, 2, & 3 - Estimated Cost of Strengthening – Combined lines

Combined Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	3	12	36	46	70	81	91
	% of towers	0.0%	2.7%	10.9%	32.7%	41.8%	63.6%	73.6%	82.7%
Estimated strengthening required (kg)		-	2,500	8,600	20,800	25,700	33,600	35,200	36,200
Estimated strengthening cost (\$)		-	753.5K	2.9M	7.8M	9.8M	13.8M	15.2M	16.2M

(b) SMTS-SYTS 1 & 2 – South Morang T.S. to Sydenham T.S. No. 1 & 2

The number of towers requiring strengthening, along with the estimated strengthening weights and costs to withstand each ARI level for individual SMTS-SYTS lines, are detailed in Table 5-6 and Table 5-7. Combined values for both lines are summarised in Table 5-8.

Table 5-6 - SMTS-SYTS 1 - Estimated Cost of Strengthening – Individual line

Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	1	6	22	30	40	42	85
	% of towers	-	1%	6%	21%	29%	38%	40%	82%
Estimated strengthening required (kg)		-	600	4,800	13,600	16,900	20,400	20,600	24,900
Estimated strengthening cost (\$)		-	163.0K	1.2M	3.7M	4.8M	6.0M	6.0M	8.7M

Table 5-7 - SMTS-SYTS 2 - Estimated Cost of Strengthening – Individual line

Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	0	6	30	42	52	56	84
	% of towers	-	-	6%	30%	42%	51%	55%	83%
Estimated strengthening required (kg)		-	-	4,500	18,100	24,200	27,200	27,600	30,400
Estimated strengthening cost (\$)		-	-	1.2M	5.4M	7.2M	8.2M	8.4M	10.0M

Table 5-8 - SMTS-SYTS 1 & 2 - Estimated Cost of Strengthening – Combined lines

Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	1	12	52	72	92	98	169
	% of towers	0%	0%	6%	25%	35%	45%	48%	82%
Estimated strengthening required (kg)		0	600	9,300	31,700	41,100	47,600	48,200	55,300
Estimated strengthening cost (\$)		0.0	163.0K	2.4M	9.1M	12.0M	14.2M	14.4M	18.7M

(c) SYTS-MLTS 1 & 2 – Sydenham T.S. to Moorabool T.S. No. 1 & 2

The number of towers requiring strengthening, along with estimated strengthening weights and costs to withstand each ARI level for individual SMTS-MLTS, lines are detailed in Table 5-9 and Table 5-10.

Combined values for both lines are summarised in Table 5-11.

Table 5-9 - SYTS-MLTS 1 - Estimated Cost of Strengthening – Individual line

Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	0	21	59	90	131	135	143
	% of towers	-	-	14%	38%	58%	85%	87%	92%
Estimated strengthening required (kg)		-	-	15,400	38,700	56,800	72,400	73,200	74,100
Estimated strengthening cost (\$)		-	-	4.3M	10.6M	15.7M	20.6M	20.9M	21.4M

Table 5-10 - SYTS-MLTS 2 - Estimated Cost of Strengthening – Individual line

Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	0	21	65	89	130	134	143
	% of towers	-	-	14%	42%	57%	84%	86%	92%
Estimated strengthening required (kg)		-	-	15,700	42,300	56,200	72,300	73,100	74,100
Estimated strengthening cost (\$)		-	-	4.4M	11.8M	15.7M	20.7M	20.9M	21.4M

Table 5-11 - SYTS-MLTS 1 & 2 - Estimated Cost of Strengthening – Combined lines

Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	0	42	124	179	261	269	286
	% of towers	0%	0%	14%	40%	58%	84%	87%	92%
Estimated strengthening required (kg)		0	0	31,100	81,000	113,000	144,700	146,300	148,200
Estimated strengthening cost (\$)		0.0	0.0	8.7M	22.4M	31.4M	41.3M	41.8M	42.8M

(d) MLTS-CRTS-MOPS-HYTS/APD – Moorabool T.S. to Alcoa Portland

As detailed in Table 5-12, none of the towers assessed for the MLTS to APD lines were found to withstand ARI wind speeds below 1000 years. The number of towers requiring strengthening, along with estimated strengthening weights and costs, is provided exclusively for tornado events.

Table 5-12 - MLTS-CRTS-MOPS-HYTS/APD - Estimated Cost of Strengthening

Estimated cost of strengthening							
Description		Average recurrence interval (years)					
		100	200	250	500	1000	Tornado
Regional wind speed (VR) (m/s)		41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	-	-	-	-	-	21
	% of towers	-	-	-	-	-	3%
Estimated strengthening required (kg)		-	-	-	-	-	11,900
Estimated strengthening cost (\$)		-	-	-	-	-	3.2M

5.1.3 330 kV transmission lines

(a) MSS-DDTS 1 & 2 – Murray S.S. to Dederang T.S.

The strengthening costs for the towers along the two 330 kV transmission lines will be determined using a separate investigation given the identified disparity between the failure wind as per historical analysis and the historical performance of the lines.

5.1.4 220 kV transmission lines

Tower strengthening costs for the two 220 kV transmission lines assessed are given in the following sections. Further strengthening cost details are provided in Appendix D.

(a) BATS-BETS – Ballarat T.S. – Bendigo T.S.

The number of towers requiring strengthening, along with the estimated strengthening weights and costs to withstand each ARI level for the BATS-BETS line, are detailed in Table 5-13.

Table 5-13 - BATS-BETS - Estimated Cost of Strengthening

Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	0	0	1	6	41	121	209
	% of towers	-	-	-	0%	3%	19%	57%	99%
Estimated strengthening required (kg)		-	-	-	1,400	5,100	22,500	61,100	91,300
Estimated strengthening cost (\$)		-	-	-	362.4K	1.3M	6.1M	17.3M	26.8M

(b) BETS-KGTS – Bendigo T.S. – Kerang T.S.

The number of towers requiring strengthening, along with the estimated strengthening weights and costs to withstand each ARI level for the BETS-KGTS line, are detailed in Table 5-14.

Table 5-14 - BETS-KGTS - Estimated Cost of Strengthening

Estimated cost of strengthening									
Description		Average recurrence interval (years)							Tornado
		25	50	100	200	250	500	1000	
Regional wind speed (VR) (m/s)		37.3	39.3	41.1	42.9	43.4	45.0	46.5	60.0
Annual reliability (annual probability of survival) (%)		96.0%	98.0%	99.0%	99.5%	99.6%	99.8%	99.9%	-
Towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	No. of towers	0	2	46	154	166	210	215	215
	% of towers	-	1%	20%	68%	73%	93%	95%	95%
Estimated strengthening required (kg)		-	2,600	56,800	166,300	178,300	222,300	226,700	226,700
Estimated strengthening cost (\$)		-	659.0K	14.3M	42.2M	45.3M	56.5M	57.6M	57.6M

5.2 Cost of unplanned outage event

AusNet has provided the following to estimate the cost of unplanned outages due to extreme wind events:

- Market cost of an unplanned outage
- Emergency restoration costs
- Permanent restoration costs.

The unit costs applied are detailed as follows:

(a) Market cost of an unplanned outage

The hourly market costs of an unplanned outage (Table 5-15) and estimated restoration durations (Table 5-16) are provided below. The total market cost of an unplanned outage has been calculated by multiplying the hourly market costs by the corresponding restoration durations and is given in Table 5-18.

Table 5-15 - Market costs of unplanned outages, supplied by AusNet

Line voltage / circuit arrangement	Lines	Circuit outage	Average hourly rate (using average of 10 year NPV)
500 kV single circuit	LYPS-HWTS 1, 2, & 3	Any one circuit	\$132.20
		Any two circuits	\$241.40
		All three circuits	\$71,055.04
	SMTS-SYTS 1 & 2	Any one circuit	\$6,536.54
		Both circuits	\$15,759.07
	SYTS-MLTS 1 & 2	Any one circuit	\$40,574.74
		Both circuits	\$54,675.18
500 kV double circuit	MLTS-CRTS 1 & 2	Both circuits	\$94,516.52
	CRTS-HGTS/TRTS/MOPS	Both circuits	\$10,982,266.66
	MOPS/TRTS-HYTS	Both circuits	\$14,228,895.95
330 kV single circuit	MSS-DDTS 1 & 2	Any one circuit	\$18,437.94
		Both circuits	\$36,875.88
S220 kV single circuit	BATS-BETS	One circuit	\$56,001.49
	BETS-KGTS	One circuit	\$26,046.08

Table 5-16 - Restoration durations using Emergency Restoration Structure (ERS) and assumed tower failures per event, supplied by AusNet

Line voltage /circuit arrangement	Assumed tower failures per event	Mean time to repair (days)
500 kV single circuit	3	12
500 kV double circuit (one circuit restored)	5	17
500 kV double circuit (both circuits restored)	5	32
330 kV single circuit	3	7
220 kV single circuit	5	5

(b) Emergency and permanent replacement costs

The costs of emergency and permanent replacements of each structure type are as below (Table 5-17).

Table 5-17 - Emergency and permanent restoration costs, supplied by AusNet

Line voltage / circuit arrangement	Emergency restoration	Permanent restoration	
	ERS mast	Suspension tower	Strain tower
500 kV single circuit	\$678,850	\$1,733,654.80	\$1,993,703.02
500 kV double circuit	\$1,357,700	\$2,600,482.20	\$2,990,554.53
330 kV single circuit	\$577,022.50	\$1,480,398.69	\$1,702,458.49
220 kV single circuit	\$366,579	\$938,114.53	\$998,271.95

(c) Total cost of unplanned outage event

Based on the unit costs and durations provided under (a) and (b), the total estimated costs of unplanned outage events for each line are provided in Table 5-18. Further detail is provided in Appendix D.

Table 5-18 - Summary of estimated cost of unplanned outage event

Line voltage	Lines	Affected lines/circuits	Total market cost of outage (\$)	Total emergency restoration costs (\$)	Total permanent Restoration costs (\$)	Overall cost per outage event (\$)
500 kV	LYPS-HWTS 1, 2, & 3	any one line	38.1K	2.0M	5.2M	7.3M
		any two lines	88.6K	4.1M	10.4M	14.6M
		all three lines	20.5M	6.1M	15.6M	42.2M
	SMTS-SYTS 1 & 2	any line	1.9M	2.0M	2.0M	9.1M
		both lines	5.5M	2.0M	2.0M	12.7M
	SYTS-MLTS 1 & 2	any line	11.7M	2.0M	2.0M	18.9M
		both lines	15.7M	2.0M	2.0M	23.0M
	MLTS-CRTS 1 & 2		38.6M	6.8M	13.0M	58.4M
	CRTS-HGTS/TRTS/MOPS		4,481M	6.8M	13.0M	4,501M
	MOPS/TRTS-HYTS		5,805M	6.8M	13.0M	5,825M
330 kV	MSS-DDTS 1 & 2	any line	3.1M	1.7M	7.8M	12.6M
		both lines	8.4M	3.5M	15.6M	27.5M
220 kV	BATS-BETS		6.7M	1.8M	4.7M	13.2M
	BETS-KGTS		3.1M	1.8M	4.7M	9.6M

5.3 Cost benefit assessment

The estimated costs of tower strengthening, outlined in section 5.1, and the estimated costs of unplanned outage events, as detailed in section 5.2, have been used to perform a high-level cost-benefit analysis.

A summary of the cost-benefit assessment method applied in the analysis is provided below:

- The number of wind events expected to result in an unplanned outage over the remaining life of the asset has been estimated by multiplying the annual probability of failure (based on the lowest maximum ARI withstood) by the asset's remaining lifespan, which has been set at 30 years as advised by AusNet.
- The risk cost is calculated by multiplying the estimated number of wind events during the asset's remaining lifespan by the cost of a single unplanned outage event, as detailed in section 5.2. This calculation provides an estimate of the total risk cost associated with unplanned outage events over the remaining life of the asset.
- Risk costs have been determined based on the existing lowest maximum ARI withstood, and reduced risk costs have been calculated for increased ARI values up to a maximum of 1000 years.
- Total tower strengthening costs, as outlined in section 5.1, have been calculated for each ARI level based on the number of towers requiring strengthening to achieve each ARI threshold.
- The reduction in risk cost (i.e. the benefit) is divided by the cost of tower strengthening (i.e., the cost) to give a benefit/cost ratio for each ARI.

The findings for each line are detailed in sections 5.3.1 to 5.3.3.

It is acknowledged that the cost-benefit method employed for the assessment has certain limitations; however, alternative approaches were also identified as having their own constraints. One notable limitation is that the risk cost for each line is determined based on its weakest tower, which may not represent the overall resilience of the entire line. As the location of a wind event cannot be predicted, only the probability of occurrence, it is assumed that the wind event would coincide with the weakest tower on the line.

The chosen method was agreed upon with AusNet after consultations with other industry specialists. The results of the cost-benefit analysis should be considered as one factor among many in making investment decisions regarding tower resilience.

5.3.1 500 kV transmission lines

The cost-benefit analysis for the eight 500 kV transmission lines assessed is presented in the following sections. Further details are provided in Appendix D.

(a) LYPS-HWTS 1, & 2 & 3 - Loy Yang P.S. - Hazelwood T.S.

The cost-benefit analysis of individual LYPS-HWTS lines is presented in Table 5-19 to Table 5-21. Benefit/cost ratios greater than one are observed for LYPS-HWTS 1 and LYPS-HWTS 2 for ARI values up to and including 1000 years. Since both lines currently include towers incapable of withstanding an ARI of 50 years, they incur relatively high existing risk costs. Consequently, the reduction in risk costs outweighs the cost of strengthening all towers to withstand an ARI of 1000 years. In contrast, as all towers assessed on LYPS-HWTS 3 can already withstand an ARI of 50 years, this line has a lower risk cost. Therefore, for LYPS-HWTS 3, the reduction in risk costs only exceeds the strengthening costs for ARI values up to 250 years.

As noted in section 4.1(a), LYPS-HWTS 2 and 3 are positioned adjacent to each other, running parallel along their entire length, with all three lines parallel and adjacent for approximately the first six towers extending out from LYPS. Based on this, separate assessments have been conducted to evaluate the impact of an extreme wind event affecting both LYPS-HWTS 2 and 3, as well as all three lines for the initial six towers near LYPS. Refer to Appendix D for detailed findings.

Table 5-19 - LYPS-HWTS 1 – Benefit/Cost Assessment (for individual line only)

Description	Average recurrence interval (years)						
	25	50	100	200	250	500	1000
Estimated quantity of wind events over remaining life (30 years)	1.20	0.60	0.30	0.15	0.12	0.06	0.03
Assessed towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	-	1	2	12	16	24	25
Risk Cost - Cost of unplanned outage event x Estimated quantity of wind events over remaining life (single line outage) (\$)	8.7M	4.4M	2.2M	1.1M	873.1K	436.5K	218.3K
Cost of strengthening to withstand recurrence interval wind speed (Cost) (\$)	-	239.0K	469.0K	2.4M	3.3M	4.6M	4.7M
Reduction in risk cost by undertaking tower strengthening (Benefit) (\$)	-	4.4M	6.5M	7.6M	7.9M	8.3M	8.5M
Benefit/Cost ratio	-	18.27	13.96	3.12	2.40	1.80	1.80

Table 5-20 - LYPS-HWTS 2 – Benefit/Cost Assessment (for individual line only)

Description	Average recurrence interval (years)						
	25	50	100	200	250	500	1000
Estimated quantity of wind events over remaining life (30 years)	1.20	0.60	0.30	0.15	0.12	0.06	0.03
Risk Cost - Cost of unplanned outage event x Estimated quantity of wind events over remaining life (single line outage) (\$)	8.7M	4.4M	2.2M	1.1M	873.1K	436.5K	218.3K
Assessed towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	-	2	5	11	15	24	28
Cost of strengthening to withstand recurrence interval wind speed (Cost) (\$)	-	514.5K	1.2M	2.4M	3.3M	4.9M	5.4M
Reduction in risk cost by undertaking tower strengthening (Benefit) (\$)	-	4.4M	6.5M	7.6M	7.9M	8.3M	8.5M
Benefit/Cost ratio	-	8.48	5.46	3.17	2.40	1.70	1.59

Table 5-21 - LYPS-HWTS 3 – Benefit/Cost Assessment (for individual line only)

Description	Average recurrence interval (years)						
	25	50	100	200	250	500	1000
Estimated quantity of wind events over remaining life (30 years)	1.20	0.60	0.30	0.15	0.12	0.06	0.03
Risk Cost - Cost of unplanned outage event x Estimated quantity of wind events over remaining life (single line outage) (\$)	-	4.37M	2.18M	1.09M	873.07K	436.54K	218.27K
Assessed towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	-	-	5	13	15	22	28
Cost of strengthening to withstand recurrence interval wind speed (Cost) (\$)	-	-	1.2M	2.9M	3.3M	4.3M	5.1M
Reduction in risk cost by undertaking tower strengthening (Benefit) (\$)	-	-	2.2M	3.3M	3.5M	3.9M	4.1M
Benefit/Cost ratio	-	-	1.82	1.13	1.07	0.92	0.82

(b) SMTS-SYTS 1 & 2 - South Morang T.S. to Sydenham T.S. No. 1 & 2

The cost-benefit analysis of individual SMTS-SYTS lines is presented in Table 5-22 and Table 5-23. Similar to LYPS-HWTS 1 and LYPS-HWTS 2, SMTS-SYTS 1 includes a tower incapable of withstanding an ARI of 50 years, resulting in a relatively high existing risk cost. Consequently, the reduction in risk cost outweighs the cost of strengthening all towers to withstand an ARI of 1000 years. In contrast, SMTS-SYTS 2 has all assessed towers capable of withstanding an ARI of 50 years, leading to benefit/cost ratios greater than one only up to an ARI of 100 years.

SMTS-SYTS 1 & 2 are adjacent to each other, running parallel along their entire length so, similar to the LYPS-HWTS lines, an assessment has been carried out to evaluate the impact of an extreme wind event affecting both lines. Refer to Appendix D for detailed findings.

Table 5-22 - SMTS-SYTS 1 – Benefit/Cost Assessment

Benefit / Cost Assessment							
Description	Average recurrence interval (years)						
	25	50	100	200	250	500	1000
Estimated quantity of wind events over remaining life (30 years)	1.20	0.60	0.30	0.15	0.12	0.06	0.03
Risk Cost - Cost of unplanned outage event x Estimated quantity of wind events over remaining life (single line outage) (\$)	10.9M	5.5M	2.7M	1.4M	1.1M	547.2K	273.6K
Assessed towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	-	1	6	22	30	40	42
Cost of strengthening to withstand recurrence interval wind speed (Cost) (\$)	-	163.0K	1.2M	3.7M	4.8M	6.0M	6.0M
Reduction in risk cost by undertaking tower strengthening (Benefit) (\$)	-	5.5M	8.2M	9.6M	9.8M	10.4M	10.7M
Benefit/Cost ratio	-	33.6	6.6	2.6	2.0	1.7	1.8

Table 5-23 - SMTS-SYTS 2 – Benefit/Cost Assessment

Benefit / Cost Assessment							
Description	Average recurrence interval (years)						
	25	50	100	200	250	500	1000
Estimated quantity of wind events over remaining life (30 years)	1.20	0.60	0.30	0.15	0.12	0.06	0.03
Risk Cost - Cost of unplanned outage event x Estimated quantity of wind events over remaining life (single line outage) (\$)	-	5.5M	2.7M	1.4M	1.1M	547.2K	273.6K
Assessed towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	-	-	6	30	42	52	56
Cost of strengthening to withstand recurrence interval wind speed (Cost) (\$)	-	-	1.2M	5.4M	7.2M	8.2M	8.4M
Reduction in risk cost by undertaking tower strengthening (Benefit) (\$)	-	-	2.7M	4.1M	4.4M	4.9M	5.2M
Benefit/Cost ratio	-	-	2.3	0.8	0.6	0.6	0.6

(c) SYTS-MLTS 1 & 2 - Sydenham T.S. to Moorabool T.S. No.1 & 2

The cost-benefit analysis of individual SYTS-MLTS lines is presented in Table 5-24 and Table 5-25. Benefit/cost ratios greater than one are observed for strengthening towers that are currently unable to withstand ARI values of up to 100 years.

An assessment has also been carried out to evaluate the impact of an extreme wind event affecting both lines. Refer to Appendix D for detailed findings.

Table 5-24 - SYTS-MLTS 1 – Benefit/Cost Assessment

Benefit / Cost Assessment							
Description	Average recurrence interval (years)						
	25	50	100	200	250	500	1000
Estimated quantity of wind events over remaining life (30 years)	1.20	0.60	0.30	0.15	0.12	0.06	0.03
Risk Cost - Cost of unplanned outage event x Estimated quantity of wind events over remaining life (single line outage) (\$)	-	11.4M	5.7M	2.8M	2.3M	1.1M	567.7K
Assessed towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	-	-	21	59	90	131	135
Cost of strengthening to withstand recurrence interval wind speed (Cost) (\$)	-	-	4.3M	10.6M	15.7M	20.6M	20.9M
Reduction in risk cost by undertaking tower strengthening (Benefit) (\$)	-	-	5.7M	8.5M	9.1M	10.2M	10.8M
Benefit/Cost ratio	-	-	1.33	0.80	0.58	0.50	0.52

Table 5-25 - SYTS-MLTS 2 – Benefit/Cost Assessment

Benefit / Cost Assessment							
Description	Average recurrence interval (years)						
	25	50	100	200	250	500	1000
Estimated quantity of wind events over remaining life (30 years)	1.20	0.60	0.30	0.15	0.12	0.06	0.03
Risk Cost - Cost of unplanned outage event x Estimated quantity of wind events over remaining life (single line outage) (\$)	-	11.4M	5.7M	2.8M	2.3M	1.1M	567.7K
Assessed towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	-	-	21	65	89	130	134
Cost of strengthening to withstand recurrence interval wind speed (Cost) (\$)	-	-	4.4M	11.8M	15.7M	20.7M	20.9M
Reduction in risk cost by undertaking tower strengthening (Benefit) (\$)	-	-	5.7M	8.5M	9.1M	10.2M	10.8M
Benefit/Cost ratio	-	-	1.29	0.72	0.58	0.49	0.51

(d) MLTS-CRTS-MOPS-HYTS/APD - Moorabool T.S. to Alcoa Portland

As detailed in section 4.1(d), MLTS-CRTS-MOPS-HYTS/APD structures have been determined to achieve an ARI of 1000 years, hence excluded from the cost-risk-benefit assessment.

5.3.2 330 kV transmission lines

As detailed in section 4.2(a), initial assessments of the tower types used on these lines revealed that all towers have members with utilisation levels exceeding 100% for relatively low wind speeds. This finding aligns with past analyses conducted by AusNet.

Due to the very low annual reliabilities calculated and consequently high risk costs, these lines would exhibit high benefit/cost ratios. However, as noted in earlier sections, further investigation of these lines is warranted given the historically rare occurrence of failure events associated with them. Based on this, benefit/cost ratios have not been calculated at this stage.

5.3.3 220 kV transmission lines

Cost-benefit analysis for the two 220 kV transmission lines assessed are given in the following sections. Further details are provided in Appendix D.

(a) BATS-BETS - Ballarat T.S. – Bendigo T.S.

The cost-benefit analysis of the BAT-BETS line is presented in Table 5-26. The reduction in risk costs exceed the cost of strengthening towers to withstand a minimum ARI of 250 years.

Table 5-26 - BATS-BETS – Benefit/Cost Assessment

Benefit / Cost Assessment							
Description	Average recurrence interval (years)						
	25	50	100	200	250	500	1000
Estimated quantity of wind events over remaining life (30 years)	1.20	0.60	0.30	0.15	0.12	0.06	0.03
Risk Cost - Cost of unplanned outage event x Estimated quantity of wind events over remaining life (single line outage) (\$)	-	-	4.0M	2.0M	1.6M	794.6K	397.3K
Assessed towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	-	-	-	1	6	41	121
Cost of strengthening to withstand recurrence interval wind speed (Cost) (\$)	-	-	-	362.4K	1.3M	6.1M	17.3M
Reduction in risk cost by undertaking tower strengthening (Benefit) (\$)	-	-	-	2.0M	2.4M	3.2M	3.6M
Benefit/Cost ratio	-	-	-	5.5	1.9	0.5	0.2

(b) BETS-KGTS – Bendigo T.S. – Kerang T.S.

The cost-benefit analysis of the BETS-KGTS line is presented in Table 5-27. The reduction in risk costs exceed the cost of strengthening towers to withstand a minimum ARI of 50 years. A lower level of strengthening is justified for BETS-KGTS compared to BAT-BETS, as the market cost of outages of BETS-KGTS is lower (as detailed in Table 5-18) and significantly more towers would require strengthening to achieve the same reduction in risk cost.

Table 5-27 - BETS-KGTS – Benefit/Cost Assessment

Benefit / Cost Assessment							
Description	Average recurrence interval (years)						
	25	50	100	200	250	500	1000
Estimated quantity of wind events over remaining life (30 years)	1.20	0.60	0.30	0.15	0.12	0.06	0.03
Risk Cost - Cost of unplanned outage event x Estimated quantity of wind events over remaining life (single line outage) (\$)	11.6M	5.8M	2.9M	1.4M	1.2M	578.9K	289.5K
Assessed towers not withstanding recurrence interval wind speed (Towers requiring strengthening to withstand)	-	2	46	154	166	210	215
Cost of strengthening to withstand recurrence interval wind speed (Cost) (\$)	-	659.0K	14.3M	42.2M	45.3M	56.5M	57.6M
Reduction in risk cost by undertaking tower strengthening (Benefit) (\$)	-	5.8M	8.7M	10.1M	10.4M	11.0M	11.3M
Benefit/Cost ratio	-	8.8	0.6	0.2	0.2	0.2	0.2

6 Conclusions

A summary of the findings from the study is presented in Table 6-1 which outlines the lowest and average maximum site-specific ARI achieved for each line. It also specifies the level of strengthening recommended based on the assessed benefit/cost ratios.

As highlighted in the report, the cost-benefit method used for this assessment has certain limitations. Therefore, the results of the cost-benefit analysis should be viewed as one of several factors to consider when making investment decisions regarding tower resilience.

Table 6-1 - Summary of assessment findings

Line	Lowest maximum site-specific ARI achieved (years)	Average maximum site-specific ARI achieved (years)	Level of strengthening based on benefit/cost ratio > 1 (ARI, years)	Corresponding no. of towers to be strengthened	Corresponding tower strengthening cost (\$)
LYPS-HWTS 1	25	427	1000	25	4.7M
LYPS-HWTS 2	25	401	1000	28	5.4M
LYPS-HWTS 3	50	426	250	15	3.3M
SMTS-SYTS 1	25	662	1000	42	6.0M
SMTS-SYTS 2	50	541	100	6	1.2M
SYTS-MLTS 1	50	279	100	21	4.3M
SYTS-MLTS 2	50	280	100	21	4.4M
MLTS-CRTS-MOPS-HYTS/APD	1000	1000	N/A	-	-
MSS-DDTS 1	Further review required				
MSS-DDTS 2	Further review required				
BATS-BETS	100	663	250	6	1.3M
BETS-KGTS	25	184	50	2	659.0K