TRANSPOWER

North Auckland and Northland Grid Upgrade Project

Attachment M

ROAM REPORT

September 2007

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Report (Trp00010) to

TRANSPOWER

North Auckland and Northland Investment Proposal

Pre-Augmentation EUE Assessment

21 September 2007

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1) INTRODUCTION

This report provides Expected Unserved Energy (EUE) forecasts for the 'North Auckland and Northland Investment Proposal' network augmentations for the years 2012 through to 2040. The EUE forecasts were completed on the following basis:

- ROAM's 2-4-C database developed for the three optional augmentations;
- For peak demand corresponding with the prudent EC SOO demand forecast;
- With all common network augmentation and load switching out to 2040.

Option 1 – Staged installation of cross-harbour cable

Option 2 – High Temperature Conductors on Henderson-Otahuhu Line

Option 3 – Reinforcing Roskill at 220kV instead of Cross Harbour Cable

See Appendix B for the development plans for each of the above options.

2) PRE-AUGMENTATION EUE ASSESSMENT

For this assessment ROAM has applied the 2-4-C Security Constrained DC Optimal Power Flow (SC-DCOPF) simulation engine. The 2-4-C model was used for the 400kV transmission upgrade study into Auckland in 2006 to develop EUE forecasts for the Upper North Island for a range of demand, generator availability and network augmentation options.

The SC-DCOPF takes a list of transmission contingencies that must be enforced as input to the simulation. The following single credible transmission contingencies have been considered:

- HEN T5 Outage;
- HEN-SWN Outage;
- HEN-OTA Outage;
- OTA-PEN Single Circuit (220kv) Outage;
- PAK-PEN Single Circuit Outage;
- MDN T3 Outage;
- ALB T4 Outage;
- HEN-HPI Outage;
- MNG-OTA Single Circuit Outage; and
- ALB-HEN (220kv) Outage.

These contingencies were selected after running power flow analysis for the individual options. The power flow analysis took each option and applied N-1 contingencies independently. Any contingencies observed overloading the network were noted as credible, as this may very well contribute to EUE.

The SC-DCOPF dispatches generation such that all network flows will remain within 100% of their ratings following a transmission contingency without having to re-dispatch the generation. In this way the model will enforce pre-contingent load shedding to maintain the security constrained dispatch.

For this model, ROAM has taken into account the possibility of multiple line contingencies. Transpower has asked specifically for the contingency of the Henderson to Otahuhu and Henderson to Southdown circuits both failing simultaneously to be included in the study. This is possible due to the circuits sharing a single transmission tower for part of the way.

A separate sensitivity was developed for this contingency and run for the three augmentation options.

The probability of this contingency occurring is very small. When an outage did occur, the impact on EUE would depend heavily on what time of day and year and the estimated time to repair, which would in itself be dependant on to the extent of the damage which caused the outage.

For this pre-augmentation assessment flows on the transmission system are allowed to reach thermal limits on all line sections. Over-riding voltage stability limits have not been enforced as it is expected that sufficient voltage stability devices can be installed within the network to reach the thermal capacity of the system.

3) EUE OUTCOMES

3.1) ALL SECURITY CONSTRAINT CONTINGENCIES

Table 3.1.1 below shows a summary of the base cases with all security constraint contingencies considered for this study. It outlines the total EUE, number of loss of load events and average loss of load accumulated for the period 2012 to 2040. In addition to the Base Case for Option 1, 2, and 3, the generation scenario was altered by replacing Pouto Wind Farm with a base load plant in the Marsden area.

Table 3.1.1 – EUE Forecast Studies with all Security Constraint Contingencies

Case Name	Total EUE (GWh)	Number of loss of load Events (half hours)	Average loss of load (MW)
Option 1 Base	35	2200	31
Option 2 Base	660	28000	47
Option 3 Base	520	21000	50
Option 1 Base with Marsden Coal	6.1	710	17
Option 2 Base with Marsden Coal	220	17000	25
Option 3 Base with Marsden Coal	140	6700	42

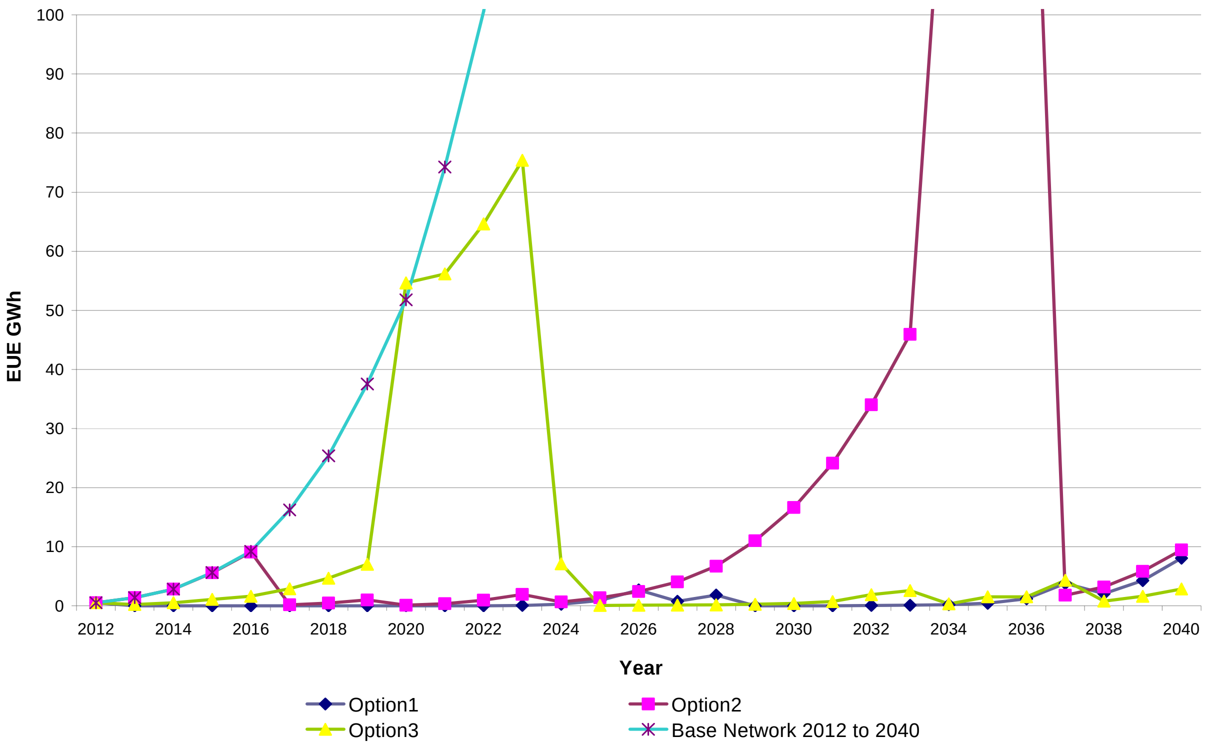
The outcomes presented in Table 3.1.1 show that the Option 1 Base with Marsden Coal case resulted in the least EUE and that the Option 2 Base case resulted in the most amount of EUE accumulated over the period 2012 to 2040.

Table 3.1.2 below shows the EUE outcomes with all contingencies considered for the three augmentation options and the base network (2012 pre-augmentation) case from 2012 to 2040. Figure 3.1.1 and Figure 3.1.2 show the corresponding graphical comparison of EUE outcomes.

Table 3.1.2 – EUE Forecast Studies with all Security Constraint Contingencies

System Year	System Peak Demand (MW)	EUE Base (GWh)	EUE Opt. 1 (GWh)	EUE Opt. 2 (GWh)	EUE Opt. 3 (GWh)
2012	2000	0.53	0.53	0.53	0.53
2013	2000	1.4	0	1.4	0.24
2014	2100	2.8	0	2.8	0.52
2015	2100	5.6	0	5.6	1.1
2016	2200	9.2	0	9.1	1.6
2017	2200	16	0	0.17	2.9
2018	2300	25	0	0.47	4.7
2019	2300	38	0	0.98	7
2020	2400	52	0	0.11	55
2021	2400	74	0	0.37	56
2022	2500	100	0	0.95	65
2023	2500	130	0.05	1.9	75
2024	2600	170	0.26	0.68	7.1
2025	2600	210	0.89	1.4	0.09
2026	2700	270	2.7	2.4	0.34
2027	2700	320	0.76	4	0.78
2028	2800	370	1.8	6.7	1.7
2029	2800	430	0	11	3.4
2030	2900	490	0	17	5.4
2031	2900	560	0.01	24	8.5
2032	3000	630	0.05	34	14
2033	3000	710	0.09	46	18
2034	3100	800	0.21	140	17
2035	3100	880	0.44	150	22
2036	3200	970	1.2	170	28
2037	3200	1100	3.8	1.8	38
2038	3300	1200	2.1	3.2	23
2039	3400	1300	4.3	5.8	29
2040	3400	1400	8.1	9.5	37

Figure 3.1.1 – Forecast EUE with all Security Constraint Contingencies



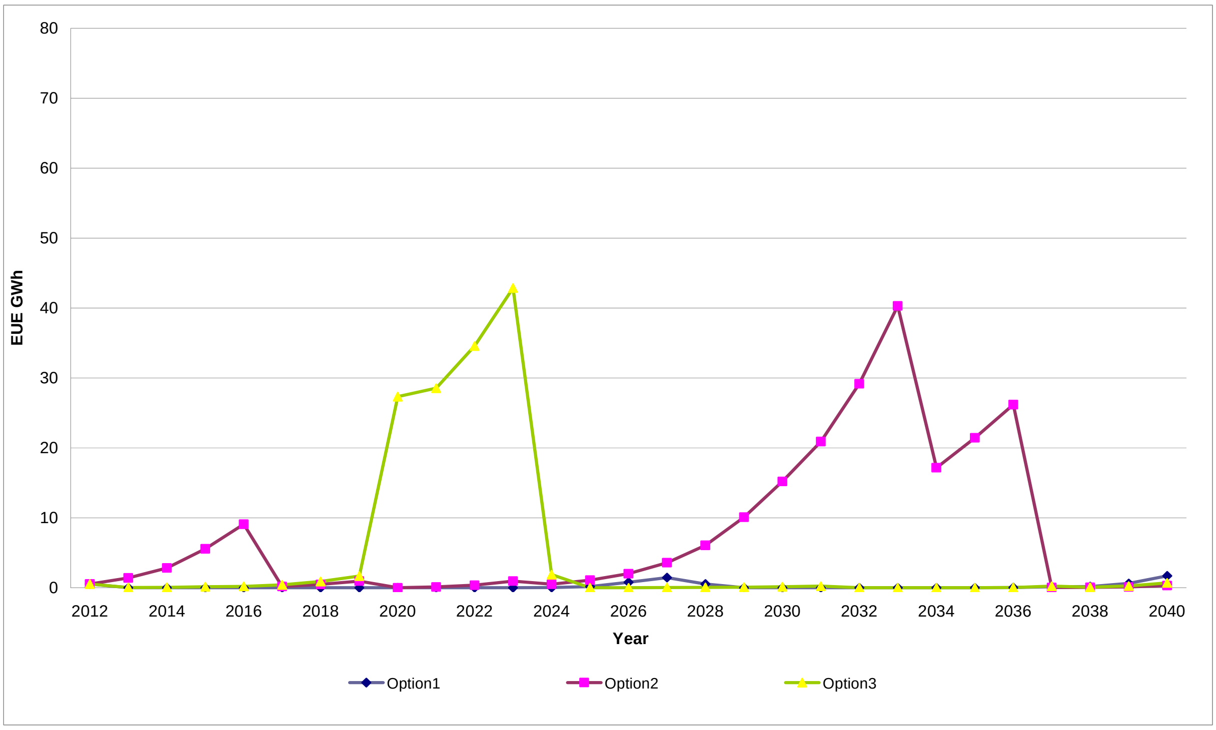
Simulation outcomes show an exponential growth in EUE for the Base Case starting 2012. By the year 2015, approximately 50GWh of EUE has been forecast. This indicates a need for network upgrade augmentations to meet the increase in energy.

It can be seen from the EUE forecast shown above that Option 1 results in the least amount of EUE apart from years 2025 to 2026 and beyond 2037. During those years, Option 3 results in the least amount of EUE. However, Option 1 has the least amount of EUE averaged over all years.

Table 3.1.3 below shows the EUE outcomes for the three augmentation options and the Base Case with Marsden Coal Replacing Pouto Wind Farm from 2012 to 2040. Figure 3.2 shows the corresponding graphical comparison of EUE outcomes.

Table 3.1.3 – EUE Forecast Studies with all Security Constraint Contingencies and Marsden Coal Replacing Pouto Wind Farm				
System State Peak Demand	**System Demand (MW)**	**EUE Opt. 1 (GWh)**	**EUE Opt. 2 (GWh)**	**EUE Opt. 3 (GWh)**
2012	2000	0.53	0.53	0.53
2013	2000	0	1.4	0.03
2014	2100	0	2.8	0.07
2015	2100	0	5.6	0.14
2016	2200	0	9.1	0.21
2017	2200	0	0.17	0.43
2018	2300	0	0.47	0.89
2019	2300	0	0.96	1.7
2020	2400	0	0.01	27
2021	2400	0	0.11	29
2022	2500	0	0.36	35
2023	2500	0	0.96	43
2024	2600	0.02	0.49	1.9
2025	2600	0.16	1.1	0
2026	2700	0.78	2	0.01
2027	2700	1.5	3.6	0.03
2028	2800	0.53	6.1	0.05
2029	2800	0	10	0.08
2030	2900	0	15	0.13
2031	2900	0	21	0.22
2032	3000	0	29	0
2033	3000	0	40	0
2034	3100	0	17	0
2035	3100	0	21	0
2036	3200	0.02	26	0.04
2037	3200	0.13	0.03	0.21
2038	3300	0.17	0.05	0.07
2039	3400	0.62	0.11	0.25
2040	3400	1.7	0.3	0.69

Figure 3.1.2 – Forecast EUE with all Security Constraint Contingencies and Marsden Coal Replacing Pouto Wind Farm



Simulation outcomes indicate that Option 1 is again expected to have the least amount of EUE for all years. It also shows that there will be a significant increase in EUE for Option 3 during years 2013 to 2024; however a significant decrease in EUE will be expected for Option 2 in the latter years 2033 to 2037 following augmentation projects.

3.2) ALL SECURITY CONTINGENCIES WITH SENSITIVITIES

Sensitivities for the three augmentations that have been taken into consideration for this study are listed in Table 3.2.1. The resulting EUE forecasts are shown in Figure 3.2.1, Figure 3.2.2 and Figure 3.2.3.

Table 3.2.1 – Sensitivities

Option 1	2029 to 2033 with the same network configuration as at 2026 (before Second Pakuranga to Penrose Circuit Installed)
	PAK-PEN double circuit commissioned at the same time (2013)
Option 2	2024 to 2028 with the same network configuration as at 2023 (before High Temperature Conductor Upgrades at MNG to OTA and ALB – HEN – HPI)
	2037 to 2040 with the same network configuration as at 2036 (before Second Pakuranga to Penrose Circuit Installed)
	PAK-PEN double circuit commissioned at the same time (2017)
Option 3	2024 to 2028 with the same network configuration as at 2023 (before First Cross Harbour Cable installed)
	PAK-PEN double circuit commissioned at the same time (2013)

Figure 3.2.1 – Forecast EUE with Sensitivities for Option 1

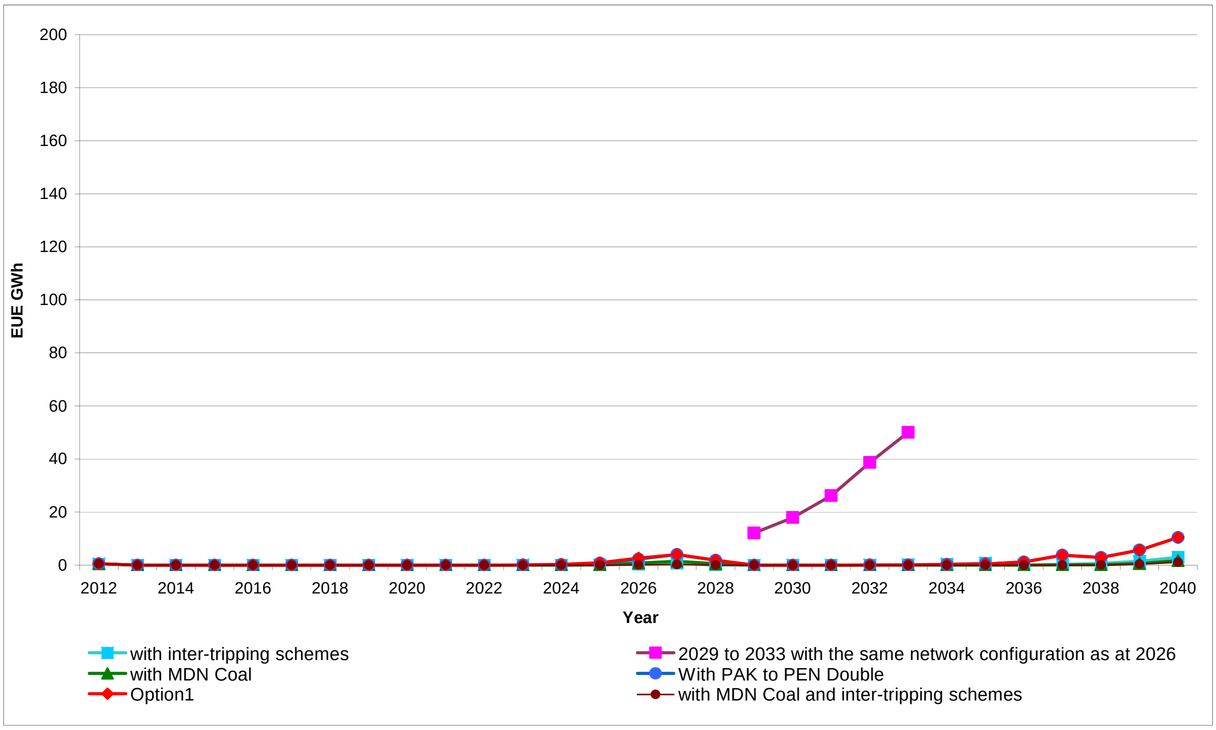


Figure 3.2.2 – Forecast EUE with Sensitivities for Option 2

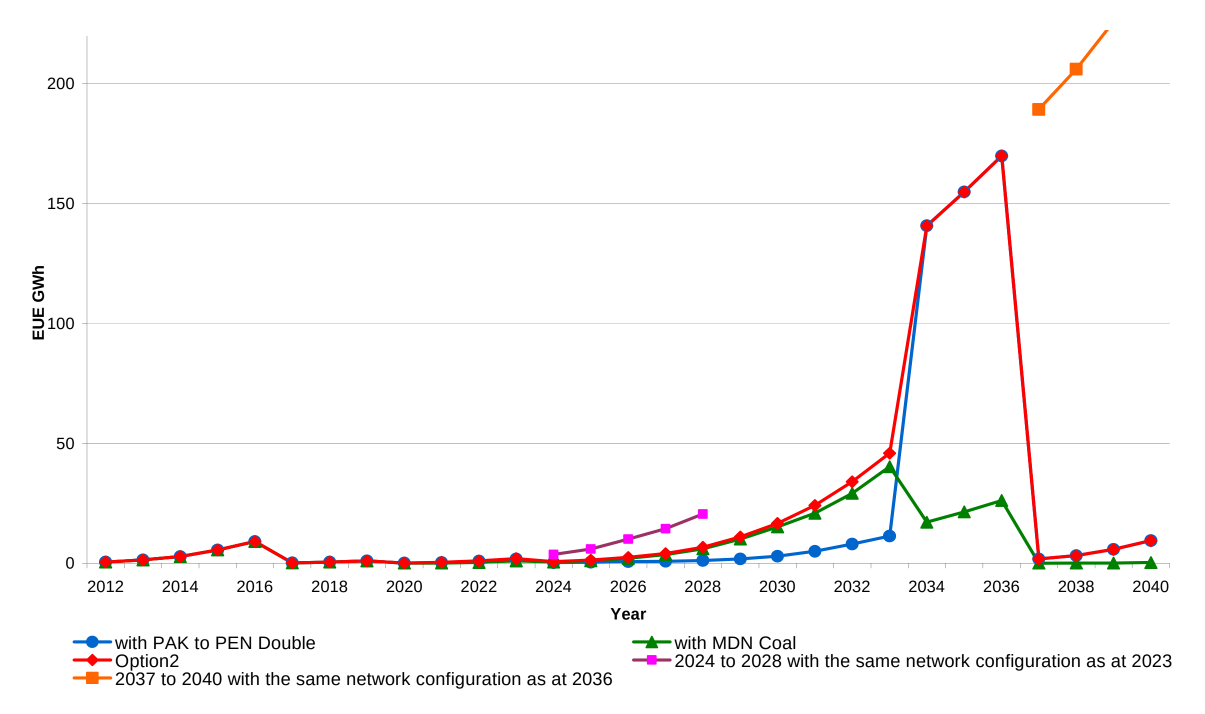


Figure 3.2.3 – Forecast EUE with Sensitivities for Option 3

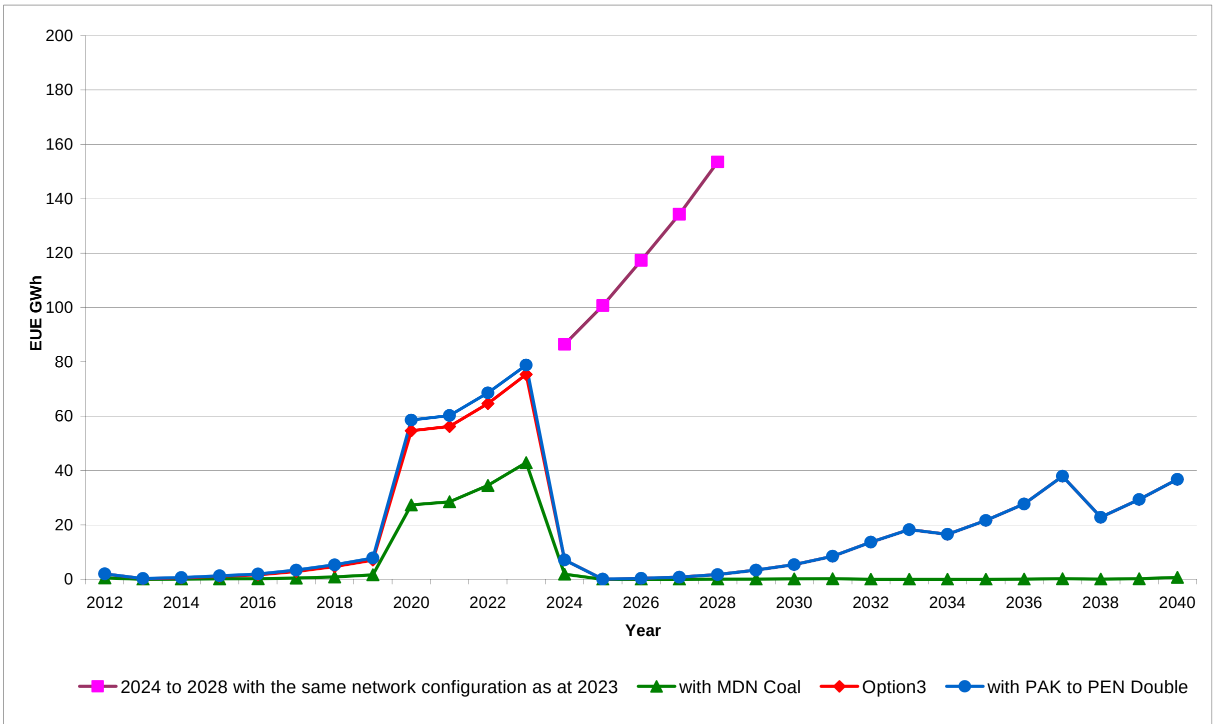


Figure 3.2.1 above shows that if the PAK-PEN 220 double circuits were to be commissioned at the same time, a slight reduction in EUE is to be expected.

3.3) ALL SECURITY CONTINGENCIES WITH INTER-TRIPPING SCHEMES FOR OPTION 1

It is observed in the above results that a network augmentation can sometimes cause an increase in EUE. This was due to the SC-DCOPF optimizing the generation dispatch in order to satisfy a myriad of different network configurations. Careful consideration is needed when 'operating' the different combinations of the three options over the 29 years and with the various security contingencies.

The cause of the loss of load for each security contingency for Option 1 was investigated by conducting analysis on a year by year basis using our power flow program. Several inter-tripping schemes were discovered which could alleviate the loss of load for certain network configurations and contingencies. These schemes are listed in Table 3.3.1 and the corresponding results in Table 3.3.2.

Table 3.3.1 – Inter-Tripping Scheme Proposal to Alleviate EUE

Security Contingency	Inter-tripping Scheme proposed	Proposed Year of Installation
HEN-SWN Outage	Hobson Street to Penrose Series Reactor Changed to 12.4 Ohms	2024
HEN-OTA Outage	Hobson Street to Penrose Series Reactor Changed to 12.4 Ohms	2024
PAK-PEN Outage	Mt Roskill to Penrose OOS	2028
PAK-PEN Outage	Otahuhu to Pakuranga Single Circuit OOS	2037

Table 3.3.2 – Option 1 with all Security Constraint Contingencies Scenarios

Case Name	Total EUE (GWh)	Number of loss of load Events (half hours)	Average loss of load (MW)
Option 1 Base	35	2200	31
Option 1 Base with MDN Coal	6.1	710	17
Option 1 Base with Proposed Inter-Tripping Schemes	18	1300	28
Option 1 Base with Proposed Inter-Tripping Schemes up to 2036[1]	3.3	490	13
Option 1 Base with MDN Coal and Proposed Inter-Tripping Schemes	2.5	340	15

[1] Up to 2036, no single year has more than 1 GWh of EUE.

Actual EUE values from year 2012 to 2040 are shown in Table 3.3.3 and the corresponding graphical comparison of these values with different scaling are shown in Figure 3.3.1 and Figure 3.3.2.

Table 3.3.3 – EUE Option 1 Forecast Study with all Security Constraint Contingencies Scenario Comparison

System State Peak Demand	System Demand (MW)	EUE Opt. 1 (GWh)	EUE Opt. 1 with Proposed Schemes (GWh)	EUE Opt. 1 with MDN Coal and Proposed Schemes (GWh)
2012	2000	0.53	0.53	0.53
2013	2000	0	0	0
2014	2100	0	0	0
2015	2100	0	0	0
2016	2200	0	0	0
2017	2200	0	0	0
2018	2300	0	0	0
2019	2300	0	0	0
2020	2400	0	0	0
2021	2400	0	0	0
2022	2500	0	0	0
2023	2500	0.05	0.05	0
2024	2600	0.26	0.01	0
2025	2600	0.89	0.07	0.01
2026	2700	2.7	0.42	0.09
2027	2700	0.76	0.84	0.24
2028	2800	1.8	0	0
2029	2800	0	0	0
2030	2900	0	0	0
2031	2900	0.01	0.01	0
2032	3000	0.05	0.05	0
2033	3000	0.09	0.12	0
2034	3100	0.21	0.34	0
2035	3100	0.44	0.85	0
2036	3200	1.2	0.04	0
2037	3200	3.8	1.1	0.03
2038	3300	2.1	1.9	0.11
2039	3400	4.3	4.1	0.35
2040	3400	8.1	7.8	1.1

Figure 3.3.1 – Forecast EUE Comparison Option 1

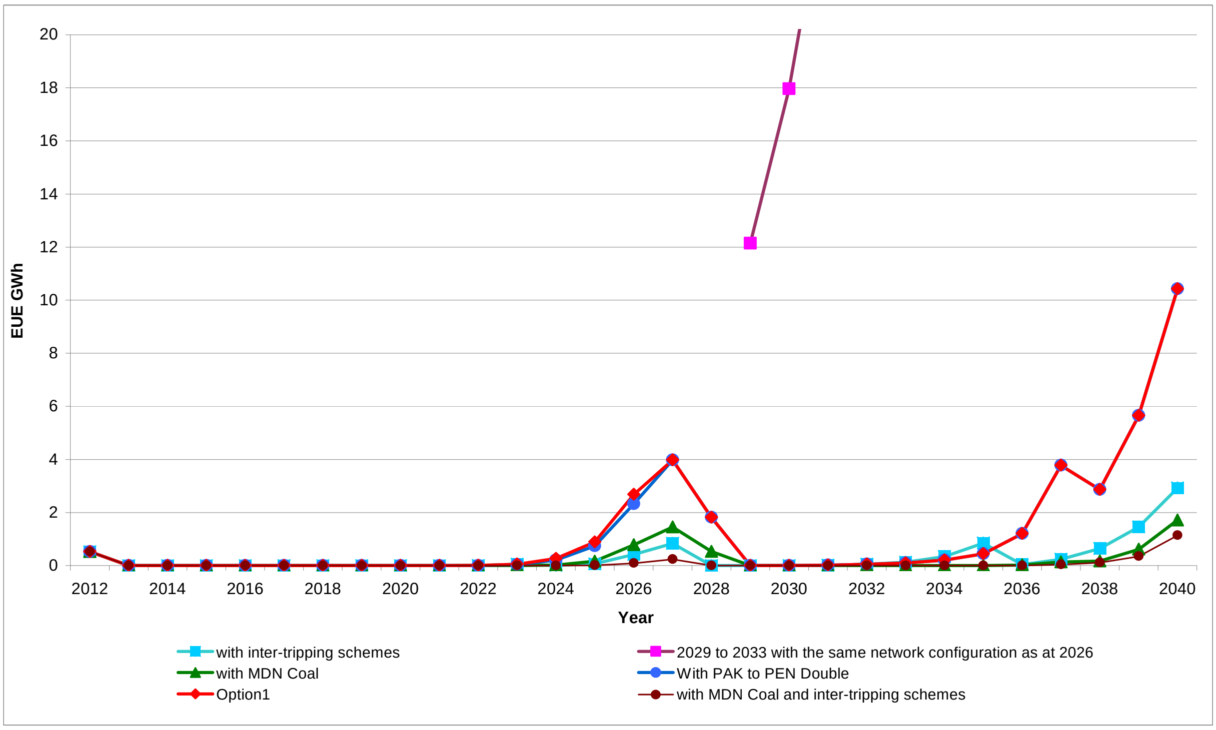
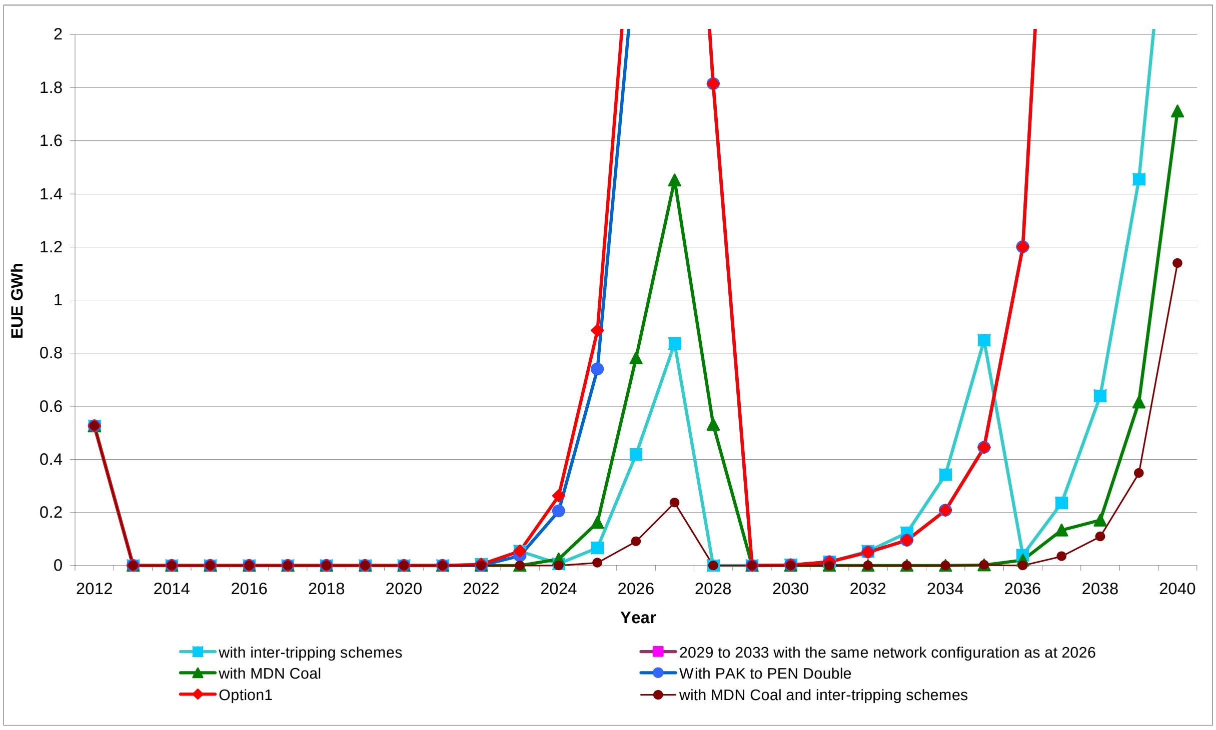


Figure 3.3.2 – Forecast EUE Comparison Option 1 Zoomed In



3.4) ALL SECURITY CONTINGENCIES WITH INTER-TRIPPING SCHEMES FOR OPTION 2

The cause of the loss of load for each security contingency for Option 2 was investigated by conducting analysis on a year by year basis using our power flow program. Several inter-tripping schemes were discovered which could alleviate the loss of load for certain network configurations and contingencies. These schemes are listed in Table 3.4.1 and the corresponding results in Table 3.4.2.

Table 3.4.1 – Inter-Tripping Scheme Proposal to Alleviate EUE

Security Contingency	Inter-tripping Scheme proposed	Proposed Year of Installation
HEN-SWN Outage	Mt Roskill to Penrose OOS	2034
HEN-OTA Outage	Mt Roskill to Penrose OOS	2034
PAK-PEN Outage	Otahuhu T4 OOS	2024 to 2034 (not needed after 2nd PAK to PEN Circuit Installed)

Table 3.4.2 – Option 2 with all Security Constraint Contingencies Scenarios

Case Name	Total EUE (GWh)	Number of loss of load Events (half hours)	Average loss of load (MW)
Option 2 Base	660	28000	47
Option 2 Base with MDN Coal	220	17000	25
Option 2 Base with Proposed Inter-Tripping Schemes	140	12000	23
Option 2 Base with Proposed Inter-Tripping Schemes and MDN Coal	71	8300	17

Actual EUE values from year 2012 to 2040 are shown in Table 3.4.3 and the corresponding graphical comparison of these values with different scaling are shown in Figure 3.4.1 and Figure 3.4.2.

Table 3.4.3 – EUE Option 2 Forecast Study with all Security Constraint Contingencies Scenario Comparison				
System State Peak Demand	**System Demand (MW)**	**EUE Opt. 2 (GWh)**	**EUE Opt. 2 with Proposed Schemes (GWh)**	**EUE Opt. 2 with MDN Coal and Proposed Schemes (GWh)**
2012	2000	0.53	0.53	0.56
2013	2000	1.4	1.4	1.4
2014	2100	2.8	2.8	2.8
2015	2100	5.6	5.6	5.6
2016	2200	9.1	9.1	9.1
2017	2200	0.17	0.17	0.19
2018	2300	0.47	0.47	0.64
2019	2300	0.98	0.98	1.1
2020	2400	0.11	0.11	0.34
2021	2400	0.37	0.37	0.93
2022	2500	0.95	0.95	1.9
2023	2500	1.9	1.9	0.96
2024	2600	0.68	0.3	0.11
2025	2600	1.4	0.49	0.23
2026	2700	2.4	0.84	0.43
2027	2700	4	1.3	0.81
2028	2800	6.7	2.1	1.5
2029	2800	11	3.6	2.7
2030	2900	17	6.1	4.6
2031	2900	24	10	6.7
2032	3000	34	15	11
2033	3000	46	22	16
2034	3100	140	4.8	0.03
2035	3100	150	6.6	0.06
2036	3200	170	8.9	0.09
2037	3200	1.8	3.4	0.03
2038	3300	3.2	5.4	0.09
2039	3400	5.8	8.6	0.32
2040	3400	9.5	13	1.1

Figure 3.4.1 – Forecast EUE Comparison Option 2

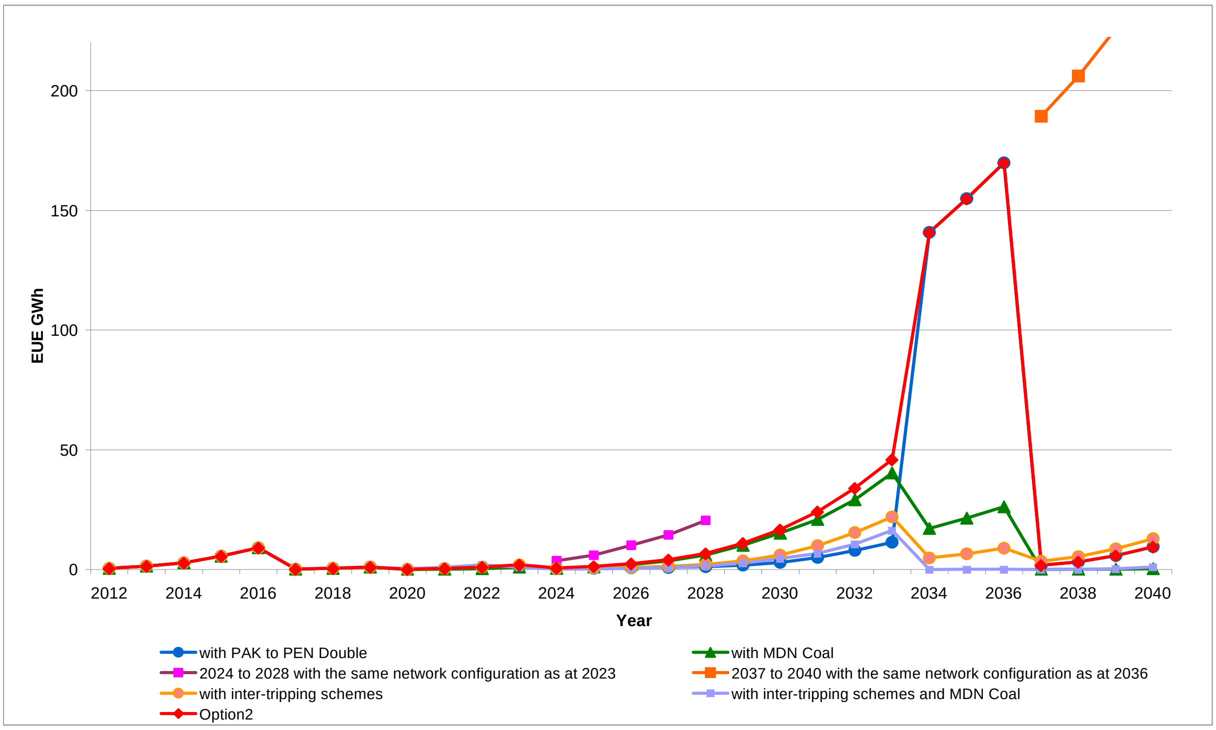
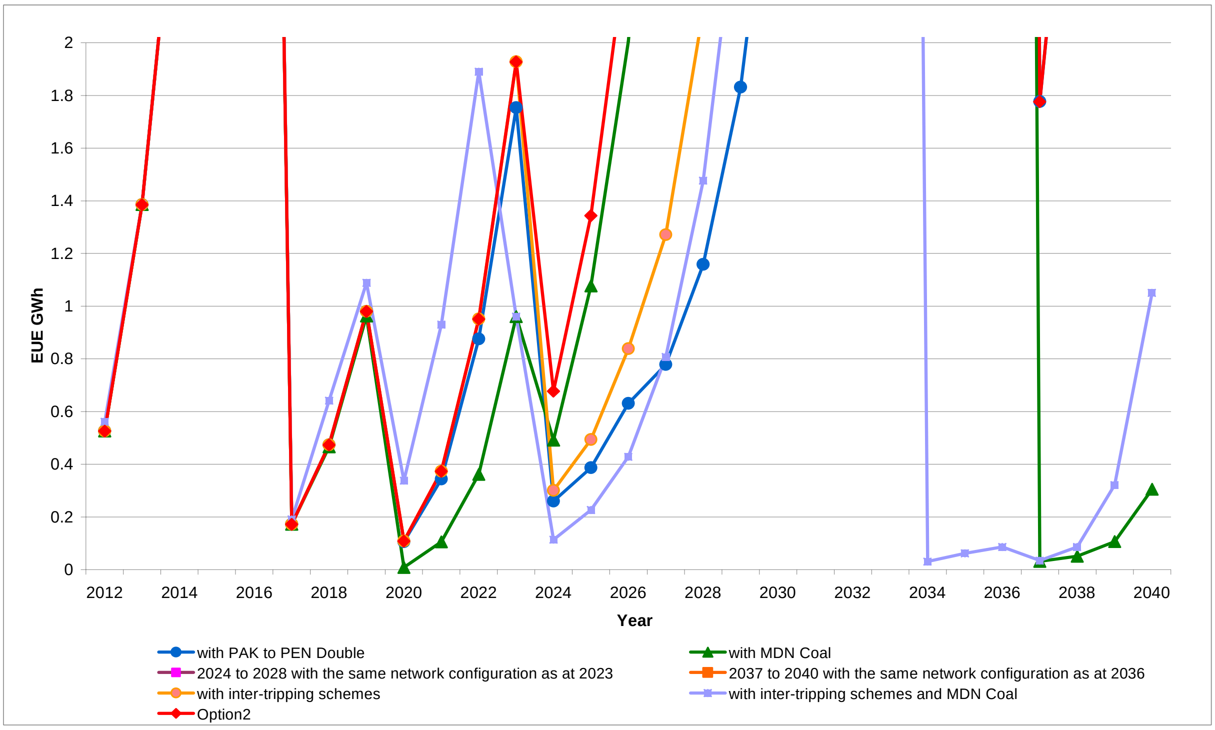


Figure 3.4.2 – Forecast EUE Comparison Option 2 Zoomed In



3.5) *ALL SECURITY CONTINGENCIES WITH INTER-TRIPPING SCHEMES FOR OPTION 3*

The cause of the loss of load for each security contingency for Option 3 was investigated by conducting analysis on a year by year basis using our power flow program. Several inter-tripping schemes were discovered which could alleviate the loss of load for certain network configurations and contingencies. These schemes are listed in Table 3.5.1 and the corresponding results in Table 3.5.2.

Table 3.5.1 – Inter-Tripping Scheme Proposal to Alleviate EUE

Security Contingency	Inter-tripping Scheme proposed	Proposed Year of Installation
HEN-SWN Outage	Mt Roskill to Penrose OOS	2013
HEN-OTA Outage	Mt Roskill to Penrose OOS	2013

Table 3.5.2 – Option 3 with all Security Constraint Contingencies Scenarios

Case Name	Total EUE (GWh)	Number of loss of load Events (half hours)	Average loss of load (MW)
Option 3 Base	520	21000	50
Option 3 Base with MDN Coal	140	6700	42
Option 3 Base with Proposed Inter-Tripping Schemes	42	4500	19
Option 3 Base with Proposed Inter-Tripping Schemes and MDN Coal	15	2700	11

Actual EUE values from year 2012 to 2040 are shown in Table 3.5.3 and the corresponding graphical comparison of these values with different scaling are shown in Figure 3.5.1 and Figure 3.5.2.

Table 3.5.3 – EUE Option 3 Forecast Study with all Security Constraint Contingencies Scenario Comparison				
System State Peak Demand	**System Demand (MW)**	**EUE Opt. 3 (GWh)**	**EUE Opt. 3 with Proposed Schemes (GWh)**	**EUE Opt. 3 with MDN Coal and Proposed Schemes (GWh)**
2012	2000	0.53	0.54	0.54
2013	2000	0.24	0.03	0.03
2014	2100	0.52	0.05	0.05
2015	2100	1.1	0.19	0.19
2016	2200	1.6	0.53	0.52
2017	2200	2.9	1.1	1.1
2018	2300	4.7	1.8	1.8
2019	2300	7	2.8	2.7
2020	2400	55	3.9	3.7
2021	2400	56	1.7	0.37
2022	2500	65	3.8	0.8
2023	2500	75	7.5	2.1
2024	2600	7.1	0	0
2025	2600	0.09	0	0
2026	2700	0.34	0	0
2027	2700	0.78	0.03	0
2028	2800	1.7	0.06	0.01
2029	2800	3.4	0.1	0.03
2030	2900	5.4	0.21	0.06
2031	2900	8.5	0.57	0.15
2032	3000	14	1.9	0
2033	3000	18	2.7	0
2034	3100	17	0.28	0
2035	3100	22	0.61	0
2036	3200	28	1.6	0.04
2037	3200	38	4.7	0.21
2038	3300	23	0.79	0.07
2039	3400	29	1.6	0.25
2040	3400	37	2.9	0.69

Figure 3.5.1 – Forecast EUE Comparison Option 3

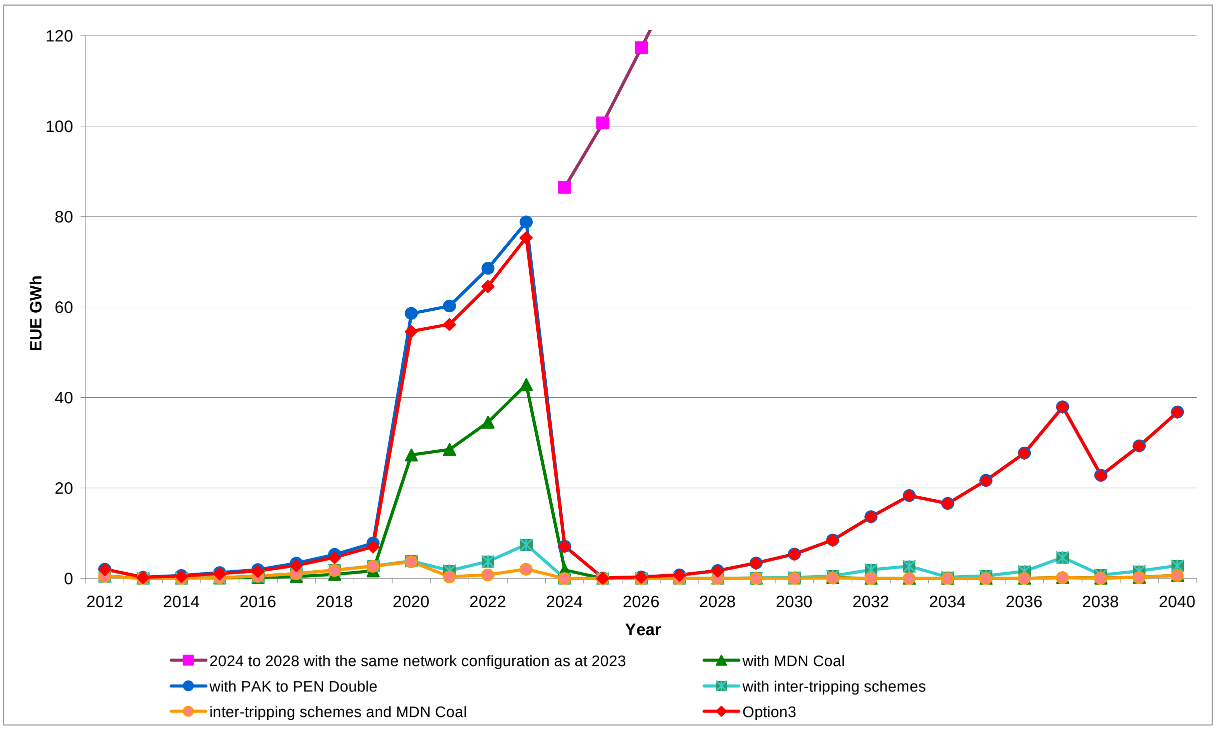
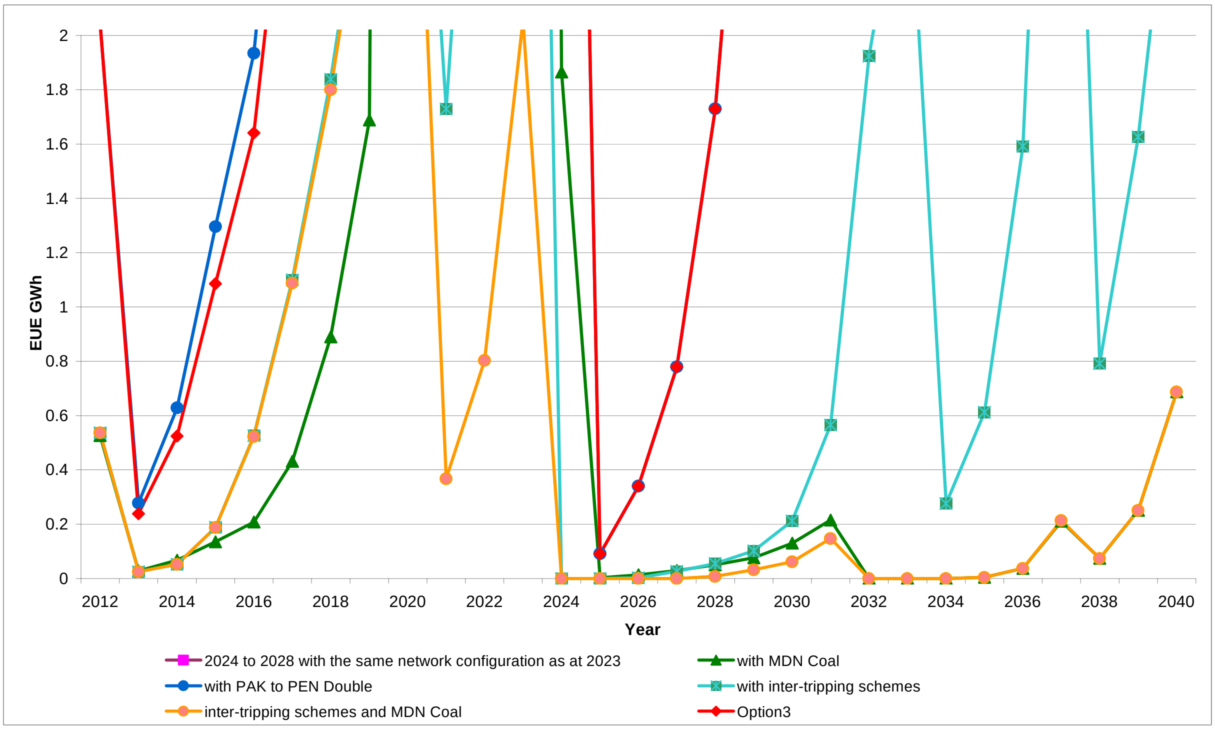


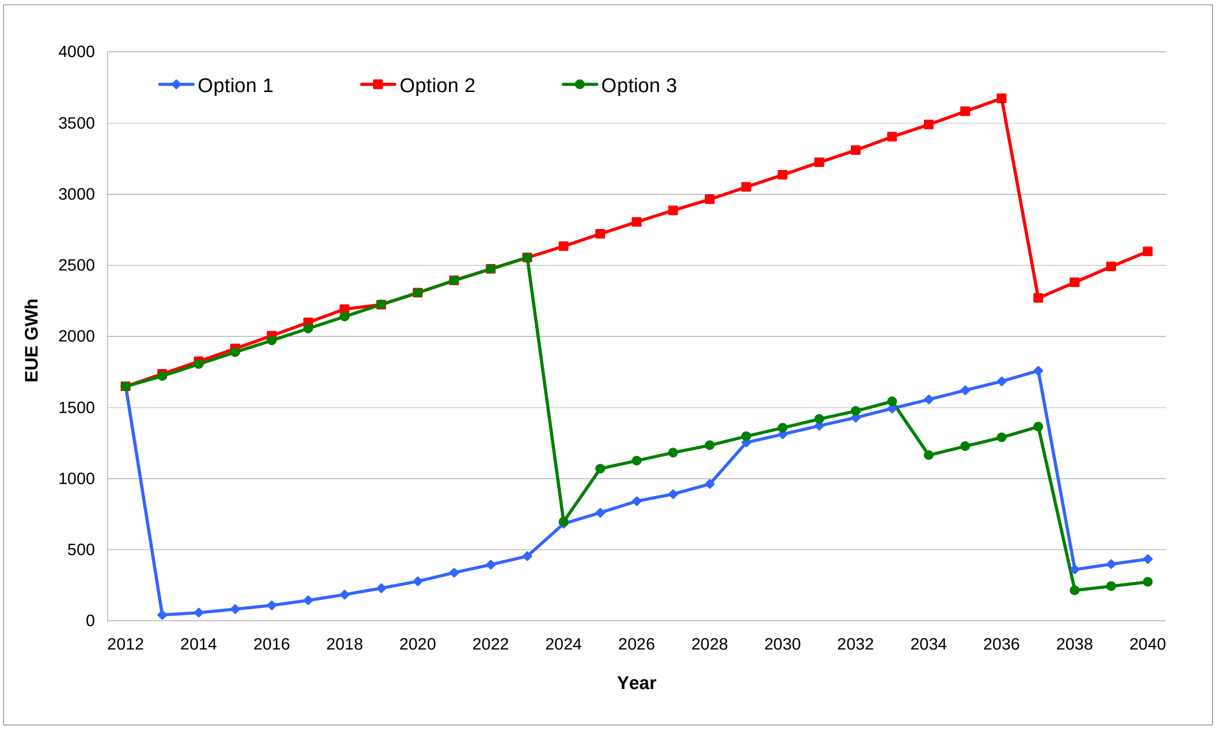
Figure 3.5.2 – Forecast EUE Comparison Option 3 Zoomed In



3.6) OTA-HEN DOUBLE OUTAGE

The OTA-HEN (Henderson to Otahuhu and Henderson to Southdown circuits) 220kV double circuit contingency is of particular interest to Transpower. It is expected that such a contingency is possible and therefore needs to be taken into consideration for this study. The resulting EUE forecasts for all three options, when including the double circuit outage as a contingency, are shown in Figure 3.6.1.

Figure 3.6.1 – Forecast EUE with OTA-HEN Double Outage



Compared with Figure 3.1.1 above, it is evident that if OTA-HEN 220kV lines were taken out of the system, a large amount of EUE will occur for all three options. Comparing all three cases, Option 1 results in the least amount of EUE averaged over all years.

The failure rate for individual 220kV circuits in New Zealand is approximately 0.25 failures per annum per 100km, with a Mean Time to Repair of 280 minutes. Hence, for the 32km length of the OTA-HEN lines, the expected outage rate would be approximately once in 10 years. Well designed 220kV double circuit lines are accepted as having independent failures on each circuit for random events, such as lightning and pollution flashovers. However, any double circuit line will be vulnerable to a common mode failure such as fire, severe storms, or aircraft incident, no matter how remote.

Over a period of 35 years into the future, Option 1 is much less exposed to the effect of a double circuit outage than Option 3, and particularly less than Option 2. With Option 1 or 3, there is also the possibility of advancing the cross-harbour cable should further system experience demonstrate vulnerability to double circuit outages.

4) SUMMARY

From the analysis of the above results, Option 1 shows the most resilience across the different scenarios, providing the highest ‘supportable demand’ and therefore the lowest EUE outcomes.

The study of different generation scenarios shows a large benefit in installing a base load plant in the Marsden area as opposed to peaking plant for reliability purposes.

By observing the individual effects generated by the security contingencies following each network augmentation, operating procedures can be emulated by simulating inter-tripping schemes within the framework of the model. This has been shown to be very successful at reducing EUE for particular network augmentation options.

The combination of utilising the inter-tripping schemes with the Marsden coal generation scenario for Option 1 (Case ‘Option 1 Base with MDN Coal and Proposed Inter-Tripping Schemes ‘) produces the best outcome for EUE as shown in Table 3.3.2. ‘Option 1 Base with Proposed Inter-Tripping Schemes up to 2036’, which does not rely on Marsden, is only slightly less reliable than the best outcome up to 2036, as shown in Table 3.3.2.

Option 1 is the least vulnerable to potential major loss of load in the event of a double contingency such as the loss of both OTA-HEN 220kV lines, especially in the first 20 years, as further operating experience is gained into the reliability of the Auckland system. Option 1 is preferable in this regard, followed by Option 3 and then Option 2.

Appendix A) Generator Data

Generator unit ratings have been sourced from the Transpower 2007 APR. Where necessary these have been scaled up to represent as generated ratings for modelling in the 2-4-C dispatch engine.

Table A.1 – Generator Data for 2-4-C Simulation Studies

Node Name	Station Name	Winter Rating	Summer Rating
Marsden	Ngawha	25	25
Marsden	Pouto	300 (45 at peak)	300 (45 at peak)
Marsden	Wairau	7.2	7.2
Otahuhu	Infinite Generator 1	N/A	N/A
Otahuhu	Otahuhu CCGT	390	390
Southdown	Southdown	170 (65 at peak)	170 (65 at peak)
Marsden	Marsden Coal	300	300

Appendix B) Development Plans

The following information was extracted from the document "Opts 1,3,5 Build Plans.doc" as supplied by Transpower.

Table B.1 - Option 1: Staged installation of cross-harbour cables

Year	Augmentation
2014	One PEN-HOB-WRU-ALB 220 kV cable plus HOB and WRU GXP's
	17.5 Ohm Series reactor in HOB-PEN cable at Penrose; to match power flow between new cable and existing overhead circuits to the North Isthmus
	Take LST-ROS feeder out of service supplying all LST from HOB and PEN
	Install one new 220 kV PAK-PEN circuit (combination cable and overhead)
2019	Install 2nd WRU 250 MVA 15% 220/33 kV transformer, take Vector's 110 kV WRU supply system OOS
2025	Permanent split of Vector network between HOB and LST
	Install 2nd IC transformer at HOB
2028	Install a 2nd 220 kV PAK-PEN circuit
2029	Change HOB-PEN cable series reactor to 12.4 Ohm
2030	A 220 kV transformer feeder at ROS supplied from PEN. 220 kV cable, 250 MVA 15% transformer
2033	Install 3rd IC transformer at MDN equal to existing
2039	Install a second ALB-PEN cable parallel to first cable but not connected into HOB or WRU

Table B.2 - Option 2: High Temperature conductors on Henderson-Otahuhu Line	
Year	**Augmentation**
2013	Replace HEN T1 & T5 with two 250 MVA 7% interconnecting Tf's
2014	High temperature conductor on 220 kV HEN-OTA circuits.
2016	High temperature conductor on 110 kV MNG-ROS ccts
2018	Install the first 220 kV PAK-PEN circuit
2020	Install a third 220/110 kV transformer equivalent to and in parallel with OTA T5
	Upgrade OTA-ROS 1 & 2 with High Temp Conductor
2021	Install a second interconnecting transformer same as existing in parallel with ALB T4
2022	Upgrade 200m of ALB-HEN simplex chukar to duplex zebra 75oC
2025	Upgrade the MNG-OTA circuits to High Temp conductor
2027	Upgrade the 220 kV ALB-HEN-HPI circuits to high temperature conductor
2032	Add a third unit equivalent to the existing MDN T1 & T2 in parallel with these
2035	Add a second 220/110 kV transformer at Penrose equivalent and parallel to PEN T10
	Install a 220/110 kV transformer at ROS supplied by cable from PEN
	Build PAK-PEN 2 circuit 5 Ohm 105 MVA series reactors in ALB-HEN 1&2 circuits at Henderson
2038	High temperature conductor on 110 kV HEP-ROS 1&2

Table B.3 - Option 3 - Reinforcing Roskill at 220 kV instead of Cross Harbour Cable	
Year	**Augmentation**
2014	Install ROS ICT 1- 15% 250 MVA - with single 220 kV cable feeder from PEN
	Reinforce PEN with one 220 kV PAK-PEN cct
2021	Install ROS ICT 2
2022	Install a second ICT at ALB equivalent to ALB T4
2025	Install 1st cross-harbour cable with HOB & WRU GXP's
	2nd PAK-PEN cct
2026	Permanently split Vector 110 kV network at HOB-LST
	Install HOB ICT 2 – use ROS ICT 2
2033	Install 3rd MDN ICT equal to existing
2035	Upgrade PAK-PEN circuits to force-cooled cable/120oC overhead
	Reduce PEN reactor to 12.4 Ohms
2039	Install 2nd cross-harbour cable, direct HOB-PEN

Appendix C) Network Model for Option 1

The network model for Option 1 by 2039 is shown in the figure below. This model was obtained by employing the network snapshot provided by Transpower and modified to result in a suitable model for the study conducted. The modifications include:

- Switch out line connections to isolate only the network that are of interest
- Aggregating loads to appropriate buses
- Setting the generators to match the desired generation scenario

Figure C.1 – Oneline Diagram of Option 1 – 2039