Ministry of Natural Resources, Energy and Mining Government of Malawi

Integrated Resource Plan (IRP) for Malawi

Volume I - Main Report - Appendices

Draft Report - February 2017



2017-02-13









Client: Ministry of Natural Resources, Energy and Mining Government of Malawi

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in association with

Economic Consulting Associates (ECA)

and

Energy Exemplar (EE)

The IRP report is presented in the following volumes:

Volume I - Main Report

Volume I – Appendices to Main Report (this document)

Volume II - Demand Forecast

Volume III - Resource Assessment

Volume III - Appendices to Resource Assessment

0	2017-02-13	Draft Report for Client review	Study Team	Task Managers	Paul Lewington / Per Morten Heggli
Version	Date	Description	Prepared by	Checked by	Approved by

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Appendix I -

Generation Expansion Plan by Scenario

19 19 5.5 16.0 Installed Capacity (MW) otal installed capacity Generic Biomass -ower Songwe Existing hydro **Generic Wind** Hamilton Falls Kammwamba **Mpatamanga** Kholombidzo Generic Coal Kapichira III -ufu higher SSD (HFO) **MSD (LFO) Tedzani IV** Mapanga Pamodzi Kanengo -ilongwe Mznzn

-154 0.0 0.0 -67 51 Total generation Demand Net interchange Generation (GWh) Generic Biomass Lower Songwe Existing hydro Generic Wind Hamilton Falls Generic Solar Kammwamba Mpatamanga Kholombidzo Generic Coal Kapichira III Fufu higher SSD (HFO) Tedzani IV MSD (LFO) Mapanga Pamodzi Lilongwe Kanengo Mznzn

																			÷		÷	Ť		
2035	1621	290	0	0	0	0	120	100	1001	163	0	က	806	1358	417	902	746	894	8137	326	16887	16799	88	0.0
2034	1610	290	0	0	0	0	120	122	1233	163	0	2	837	1370	420	902	746	894	6103	326	15145	15350	-205	0.0
2033	1614	273	0	0	0	0	120	156	1724	163	0	4	829	1370	420	902	746	894	4068	326	13613	14014	-401	0.0
2032	1590	273	0	0	0	0	120	94	1383	163	0	က	878	1375	422	606	749	896	4080		12933	12781	152	0.0
2031	1604	255	0	0	0	0	120	133	1923	163	0	4	848	1370	420	902	746	894	2034		11420	11645	-225	0.0
2030	1575	255	0	0	0	0	120	375	1923	163	-	0	903	1370	420	905	746	894			9659	10597	-938	0.0
2029	1575	237	0	0	0	0	06	399	1923	163	-	51	903	1370	420	902	746				8785	2096	-822	0.0
2028	1575	238	0	0	0	0	06	233	1928	163	0	က	902	1375	422	606	749				8590	8744	-154	0.0
2027	1575	220	0	0	0	0	06	159	1921	163	0	4	905	1370	420	902					7730	7951	-221	0.0
2026	1579	220	0	0	0	0	06	97	1923	163	0	9	903	1381	424						6785	7223	-438	0.0
2025	1580	202	0	0	0	0	09	96	1923	163	0	4	883	1360							6272	9229	-284	0.0
2024	1582	203	0	0	0	0	09	64	1763	163	0	က	892	1375							6104	5943	162	0.0
2023	1575	185	0	0	0	0	09	9	1417	163	0	0	903	1370							2679	5382	297	0.0
2022	1634	185	0	0	0	0	09	75	1739	163	-	2	792								4654	4867	-213	0.0
2021	1624	167	0	0	0	0	30	42	1596	163	0	4	810								4437	4396	41	0.0
2018 2019 2020	1629	132	0	0	0	0	30	25	1089	163	0	4	804								3904	3971	-67	0.0
2019	2057	97	17	က	က	4	30	79	320	163	45	89									2493 2917	3444	-517	10.2
2018	2057	79	170	51	51	82															2493	2936	0	443.3
2017	1902	56	80	48	56																2081	2501	0	
Generation (GWh)	Existing hydro	Generic Solar	Kanengo	Lilongwe	Mznzn	Mapanga	Generic Wind	Generic Biomass	Kammwamba	Tedzani IV	MSD (LFO)	SSD (HFO)	Kapichira III	Mpatamanga	Hamilton Falls	Fufu higher	Kholombidzo	Pamodzi	Generic Coal	Lower Songwe	Total generation	Demand	Net interchange	Unserved energy 419.6

Generation (GWh)	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
Existing hydro	1902	2057	2057	1629 1624		1634	1575	1582	1582	1695	1703	1706	1703	1705	1704	1703	1688	1676	1667	1684
Generic Solar	56	79	26	132	167	185	185	203	202	220	220	238	237	255	255	273	273	290	290	291
Kanengo	80	170	09	0	0	-	0	0	0	0	0	0	0	0	0	-	N	က	4	4
Lilongwe	48	51	15	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-
Mzuzu	56	51	15	0	0	0	0	0	0	0	0	0	0	0	0	0	-	-	-	-
Mapanga		85	29	0	0	-	0	0	0	0	0	0	0	0	0	-	N	က	4	4
Generic Wind			30	30	30	09	09	09	09	06	06	06	06	120	120	120	120	120	120	120
Generic Biomass			79	52	42	75	9	64	96	111	138	200	200	201	195	225	233	274	361	295
Kammwamba			320	1089	1596	1739	1417	1763	1923	1497	1490	1491	1512	1502	1510	1517	1585	1705	1718	1591
Tedzani IV			163	163	163	163	163	163	163	163	163	163	163	163	163	163	163	163	163	163
Kapichira III				804	810	792	903	892	889	229	662	199	662	658	658	699	691	713	720	710
Mpatamanga							1370	1375	1370	1370	1370	1375	1370	1370	1367	1378	1370	1370	1358	1386
Hamilton Falls																423	420	420	417	425
Fufu higher																	902	902	902	606
Kholombidzo																		747	746	749
Pamodzi																			894	968
Lower Songwe																			326	326
Generic Coal																				2040
Total generation	2081	2493	2896	3900	4433	4651	2679	6102	6285	5824	5837	5923	5938	5975	5972	6474	7454	8391	9694	11594
Demand	2501	2936	3444	3971	4396	4867	5382	5943	9229	7223	7951	8744	2096	10597	11645	12781	14014	15350	16799	18370
Net interchange	0	0	-517	-71	37	-216	297	159	-270	1399	2114	- 2821	- 3669	-4621	-5672	-6305	-6556	-6950	-7090	-6758
Unserved energy	419.6	419.6 443.3	30.9	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	77	4.4	8.5	15.4	17.5

2036	363	165	19	9	9	19	09	100	258	23	19	19	112	06	163	120	300	96	200	1366	3505	3286	3251	1.1
2035	363	165	19	9	9	19	09	100	258	23	19	19	112	06	163	120	300	96	200	1093	3232	3013	2972	4.1
2034	363	165	19	9	9	19	09	100	258	23	19	19	112	06	163	120	300	96	200	820	2958	2739	2714	6.0
2033	363	155	19	9	9	19	09	100	258	23	19	19	112	06	163	120	300	96	200	546	2675	2466	2475	-0.4
2032	363	155	19	9	9	19	09	100	258	83	19	19	112	06	163	120	300	96	200	546	2675	2466	2253	9.5
2031	363	145	19	9	9	19	09	90	258	23	19	19	112	06	163	120	300	96	200	273	2382	2183	2049	6.5
2030	363	145	19	9	9	19	09	06	258	83	19	19	112	6	163	120	300	96	200		2109	1910	1859	2.7
2029	363	135	19	9	9	19	45	06	258	23	19	19	112	90	163	120	300	96			1884	1708	1668	2.4
2028	363	135	19	9	9	19	45	90	258	23	19	19	112	06	163	120	300				1788	1612	1524	5.8
2027	363	125	19	9	9	19	45	70	258	23	19	19	112	06	163	120	300				1758	1592	1391	14.5
2026	363	125	19	9	9	19	45	70	258	23	19	19	112	06	163	120					1458	1292	1268	1.9
2025	363	115	19	9	9	19	30	70	258	23	19	19	112	06	163						1313	1171	1155	1.4
2024	363	115	19	9	9	19	30	70	258	23	19	19	112	90							1150	1008	1050	-4.0
2023	363	105	19	9	9	19	30	09	258	23	19	19	112	90							1130	866	953	4.7
2022	363	105	19	9	9	19	30	40	258	23	19	19	112								1020	888	864	2.8
2021	363	92	19	9	9	19	15	30	258	23	19	19	112								985	877	781	12.2
2020	363	75	19	9	9	19	15	30	172	23	19	19	112								879	791	200	11.6
2019	363	22	19	9	9	19	15	10	43	23	19	19									298	529	614	-13.8
2018	363	45	19	9	9	10															448	403	526	-23.2
2017	351	15	10	9	9																387	372	449	-17.2
(MM																					acity	acity	load	(%) ר

Scenario 3 - Diversification - Installed Capacity (MW)

Installed Capacity (N

Existing hydro

Generic Solar

Generic Biomass

Kammwamba

edzani IV

MSD (LFO)

Generic Wind

Mapanga

_ilongwe

Mzuzu

-ower Songwe

Fufu higher

Pamodzi

Kapichira III

SSD (HFO)

Firm capa

Total installed capa

Generic Coal Kholombidzo

Hamilton Falls

Mpatamanga



																				÷	÷	Ŧ		
2035	1621	290	0	0	0	0	120	100	1001	163	0	က	806	326	902	894	1358	417	746	8137	16887	16799	88	0.0
2034	1610	290	0	0	0	0	120	122	1233	163	0	2	837	326	902	894	1370	420	746	6103	15145	15350	-205	0.0
2033	1614	273	0	0	0	0	120	156	1724	163	0	4	829	326	902	894	1370	420	746	4068	13613	14014	-401	0.0
2032	1579	273	0	0	0	0	120	20	1125	163	0	ო	868	326	606	968	1375	422	749	4080	12987	12781	206	0.0
2031	1600	255	0	0	0	0	120	119	1736	163	0	က	855	326	902	894	1370	420	746	2034	11547	11645	-97	0.0
2030	1575	255	0	0	0	0	120	349	1923	163	0	4	903	326	905	894	1370	420	747		9954	10597	-643	0.0
2029	1575	237	0	0	0	0	06	308	1923	163	0	4	901	326	902	894	1370	420			9118	2096	-489	0.0
2028	1583	238	0	0	0	0	06	168	1854	163	0	4	890	326	606	968	1375				8496	8744	-247	0.0
2027	1587	220	0	0	0	0	06	65	1548	163	0	7	879	326	905	894	1370				8050	7951	66	0.0
2026	1628	220	0	0	0	0	06	153	1694	163	0	2	803	326	902	894					6882	7223	-341	0.0
2025	1614	202	0	0	0	0	09	196	1788	163	-	24	828	326	902						6109	9229	-447	0.0
2024	1648	203	N	0	0	7	09	203	1915	163	က	32	269	326							5326	5943	-616	0.4
2023	1632	185	0	0	0	0	09	139	1780	163	0	6	795	326							5089	5382	-292	0.0
2022	1634	185	0	0	0	0	09	75	1739	163	-	2	792								4654	4867	-213	0.0
2021	1629 1624	167	0	0	0	0	30	42	1596	163	0	4	810								4437	4396	41	0.0
2020		132	0	0	0	0	30	52	1089	163	0	4	804								3904	3971	-67	0.0
2018 2019 2020 2021	2057	97	14	က	က	17	30	79	320	163	45	89									2917	3444	-517	10.2
2018	2057	79	170	51	51	85															2493	2936	0	443.3
2017	1902	26	80	48	26																2081	2501	0	419.6
Generation (GWh)	Existing hydro	Generic Solar	Kanengo	Lilongwe	Mzuzu	Mapanga	Generic Wind	Generic Biomass	Kammwamba	Tedzani IV	MSD (LFO)	SSD (HFO)	Kapichira III	Lower Songwe	Fufu higher	Pamodzi	Mpatamanga	Hamilton Falls	Kholombidzo	Generic Coal	Total generation	Demand	Net interchange	Unserved energy

Energy
Exempla
7

26.8 Installed Capacity (MW) Fotal installed capacity Reserve margin (%) Generic Biomass ower Songwe Existing hydro Hamilton Falls **Beneric Wind Sammwamba** Generic Solar **Apatamanga** Generic Coal Kholombidzo Kapichira III MSD (LFO) SSD (HFO) -ufu higher edzani IV **Japanga** Pamodzi -ilongwe **Sanengo** Nznzn

138 902 8137 746 841 417 1358 326 8.3 163 891 871 8.6 421 0.4 0. 12781 11645 351 10597 903 8743 8744 0.5 7951 1923 2.3 351 34 7223 5943 5943 0.0 5382 0.0 4396 4867 3.0 2021 0.0 1597 3971 99 0.0 3444 65.1 30 2018 2936 2493 443.3 51 51 2501 419.6 80 26 **Fotal** generation Demand Net interchange Unserved energy Generation (GWh) Generic Biomass -ower Songwe Hamilton Falls Existing hydro Generic Wind Generic Solar Kammwamba Mpatamanga Generic Coal Kholombidzo Kapichira III Fufu higher SSD (HFO) Tedzani IV MSD (LFO) Mapanga -ilongwe Pamodzi **Sanengo** Mznzn

Scenario 4 - Isolation - Annual Generation (GWh)



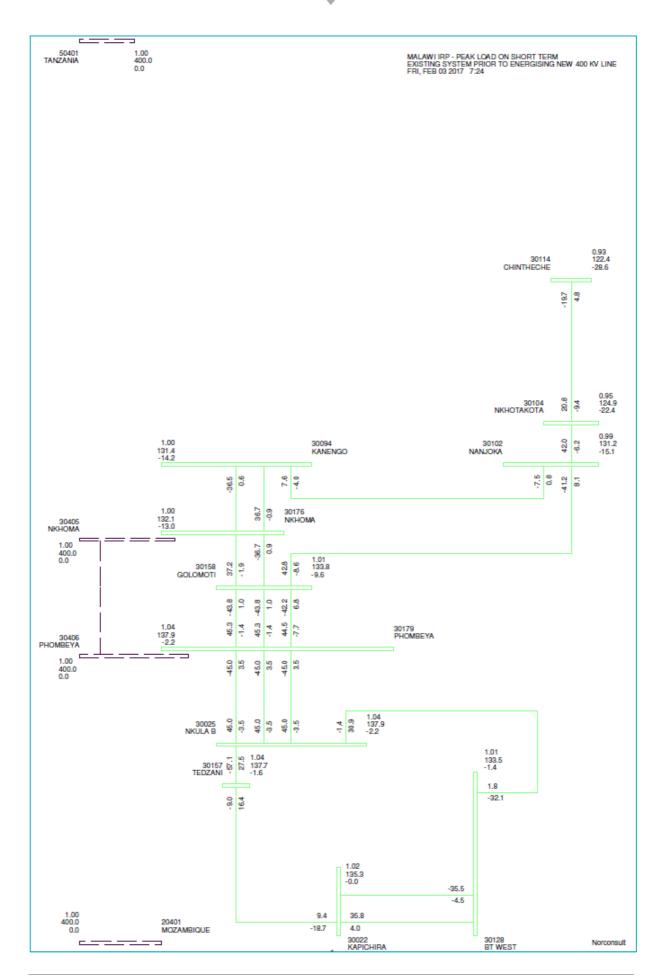


Appendix II -

Load Flow Diagrams

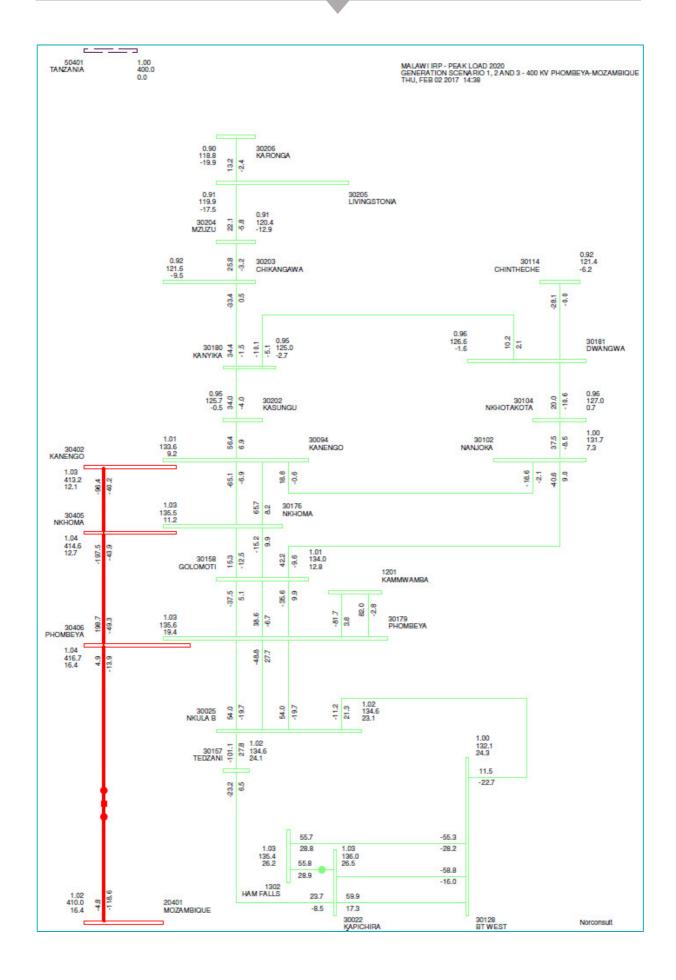
The following pages present single line diagrams for the main supply-demand scenarios. The power flow is shown at peak demand for stage 2020, 2025, 2030,2035 and 2040.

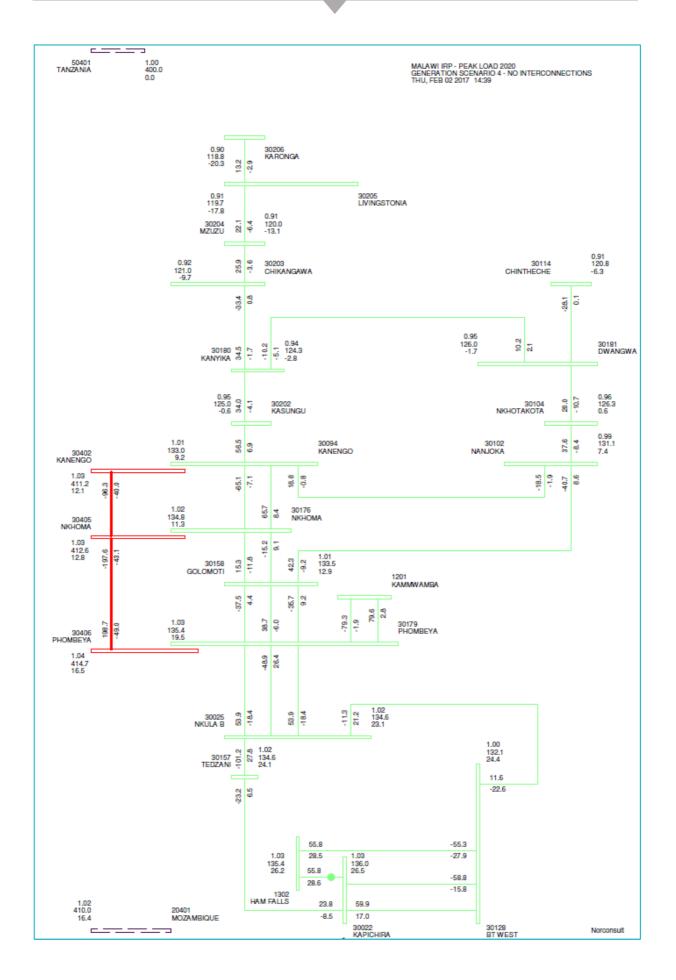


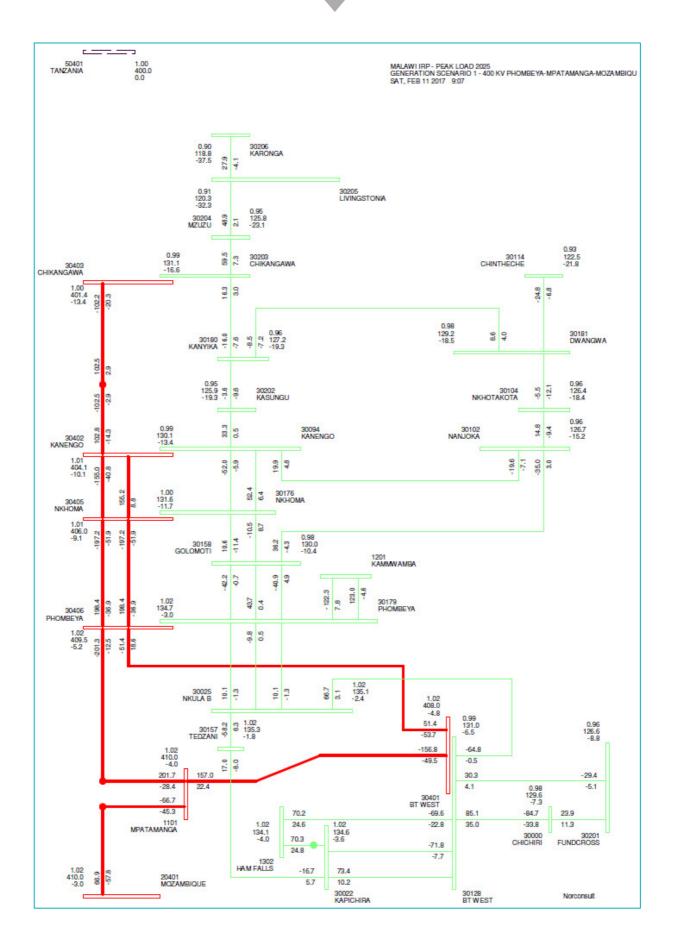


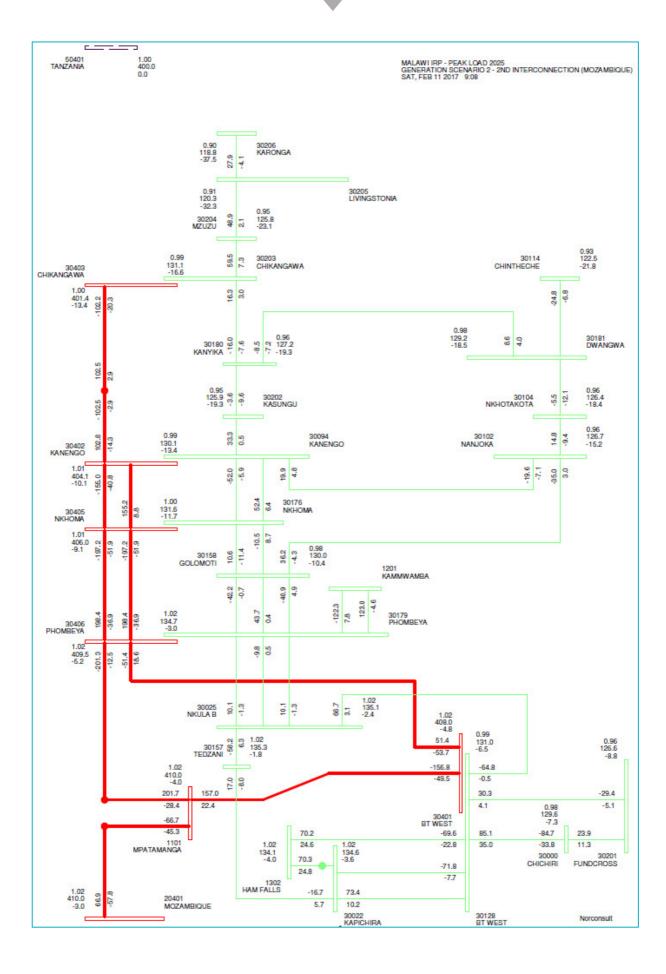






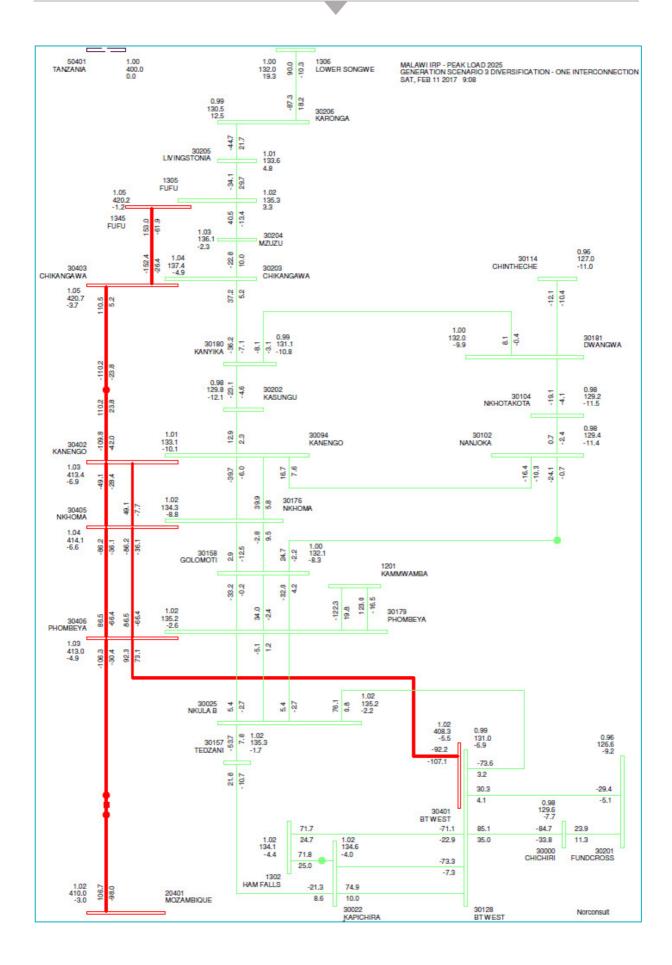


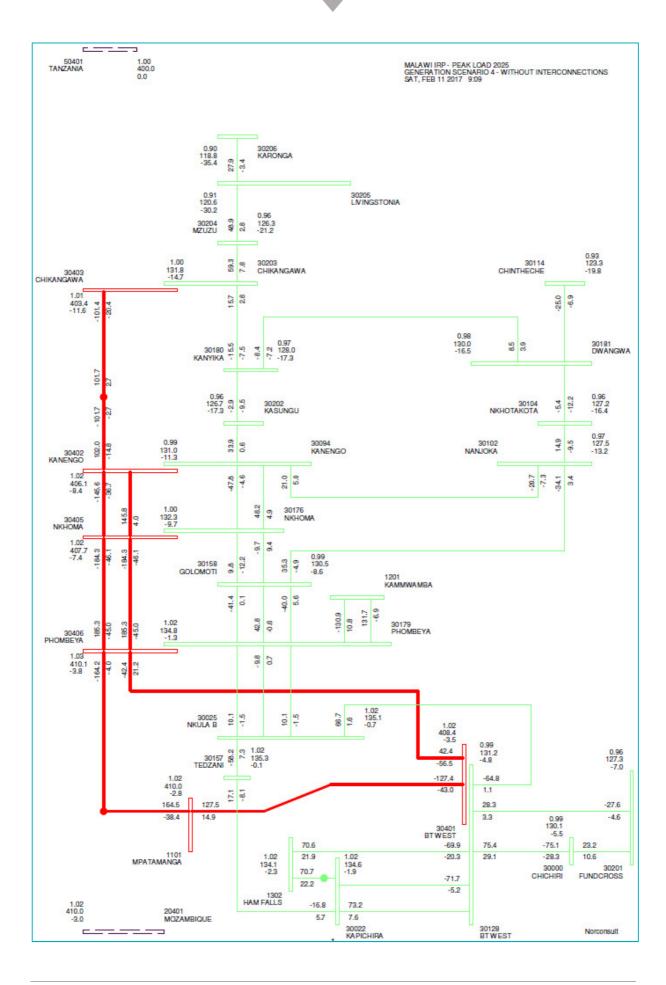


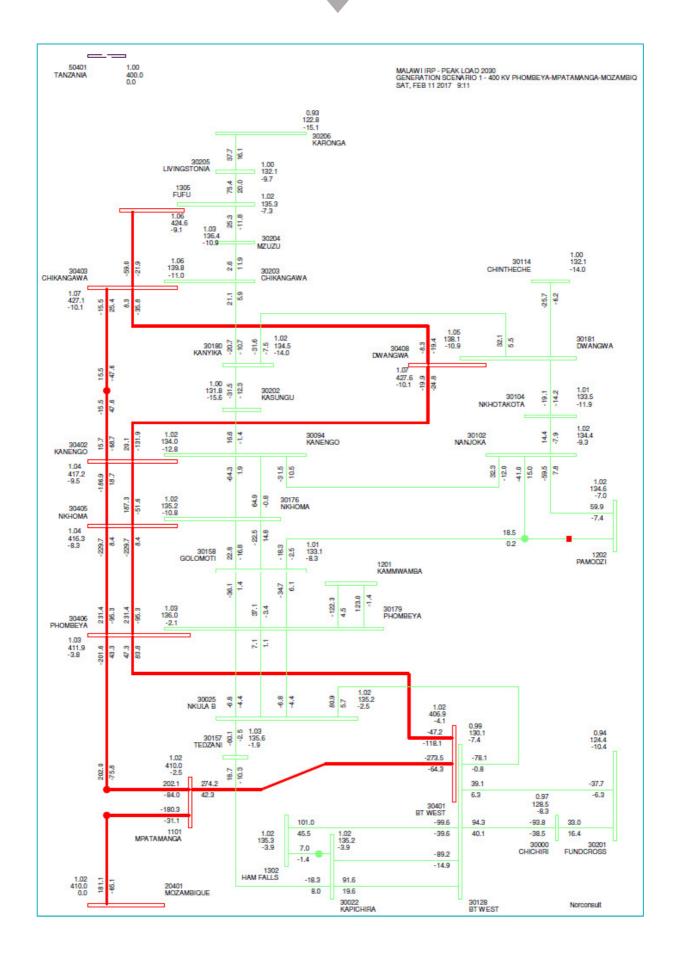






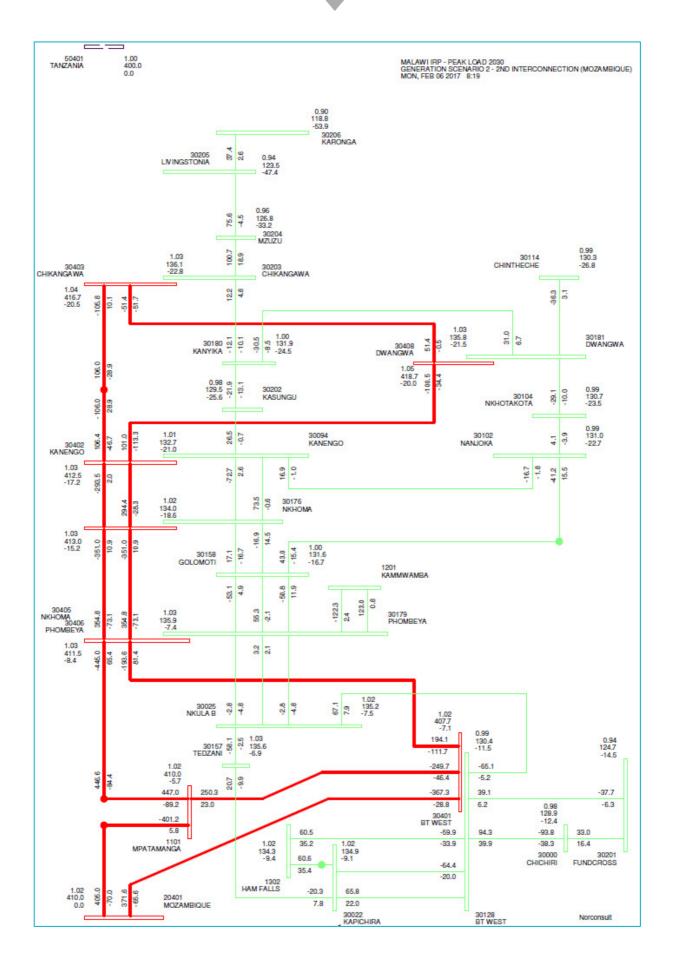






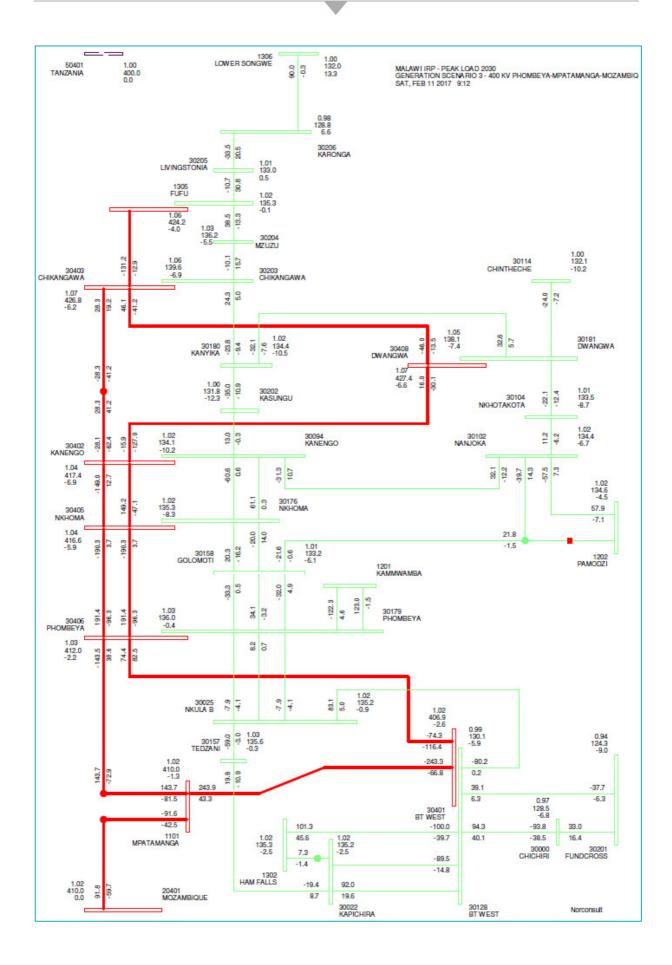


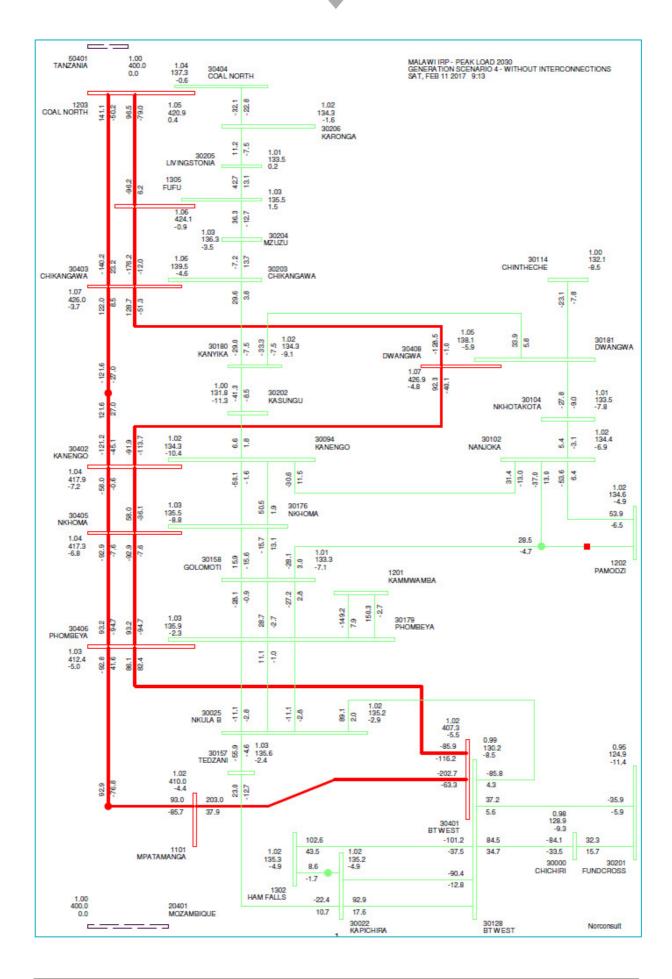






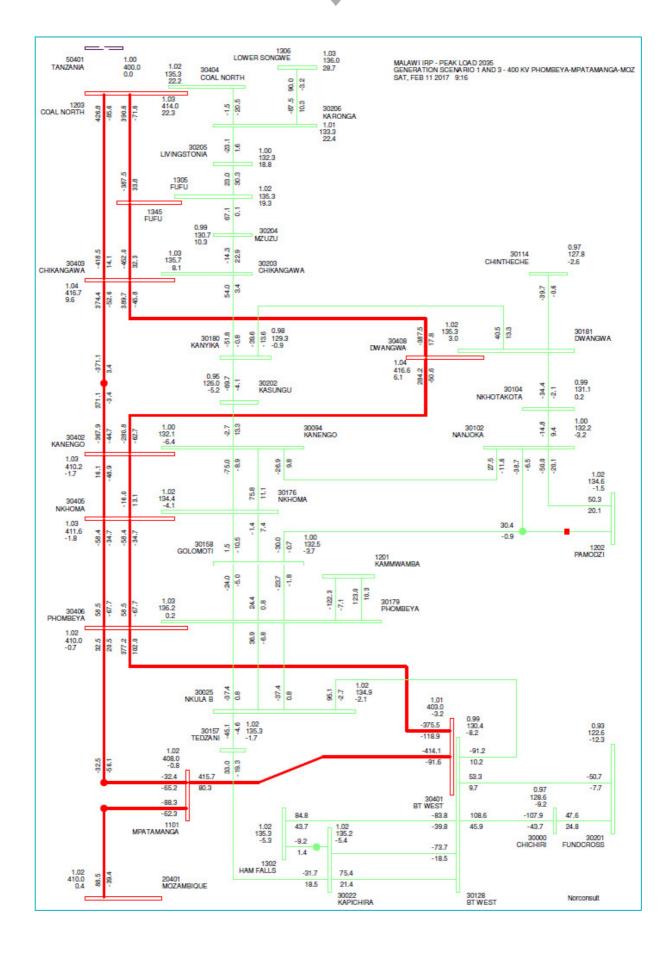


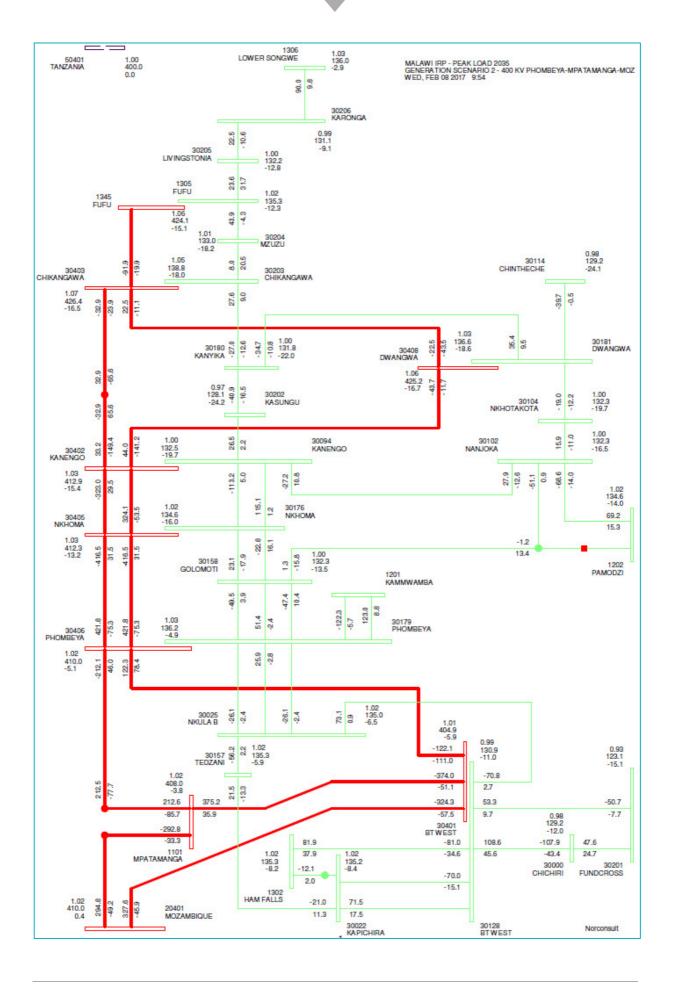






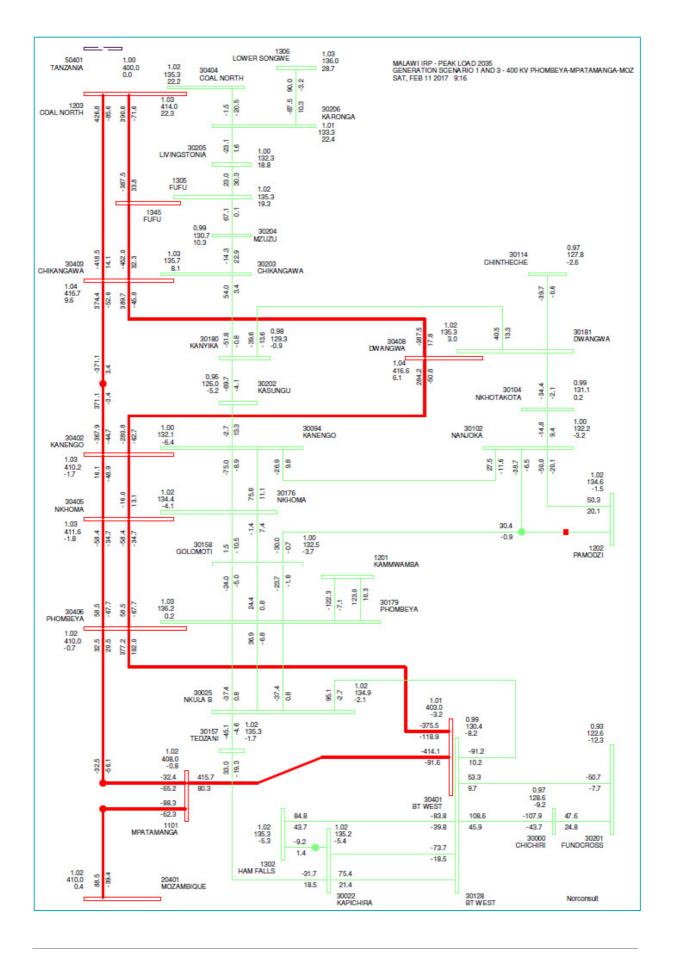


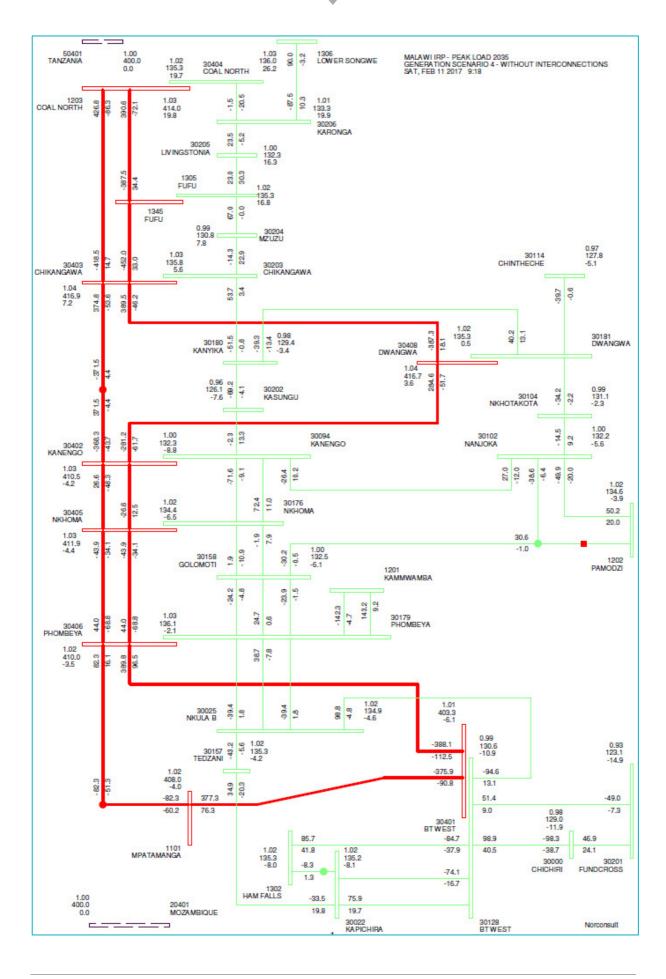


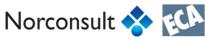
















Appendix III - Cost Estimate - Transmission Grid

Transmission line and substation cost estimates are presented on the following pages (price level as of January 2017). Cost estimates reflect economic costs based on international competitive bidding and includes equipment, transport, construction/erection and commissioning etc. - i.e. equipment installed and ready for operation, but excludes any taxes and duties and financing costs.

			Scen 4	2018					Scen 4								
	n convice by	ice by	Scen 3	2018			14	יב הא	Scen 3	2019	2019	2019	2019	-	-		
	a o a	111 361	Scen 2	2018			1	iii seivice oy	Scen 2	2019	2019	2019	2019	2026	2026	2026	
			Scen 1	2018					Scen 1	2019	2019	2019	2019	-			
	Cost	estimate	[MUSD]	Sunk			Cost	estimate	[MUSD]	79.7				71.2			
		Towertype		Y Tower DbCkt				Towertype		Varies SgCkt	/ Tower	/ Tower	Y Tower	Varies SgCkt	VTower	YTower	
		Circuits		1 γ				Circuits		1 \	1	1 \	1 γ	1 \	1	1 γ	
	Conductor	ting.	adkı	2x Bluejay				Colludo	adkı	3x Tern	3x Tern	3x Tern	3x Tern	3x Tern	3x Tern	3x Tern	
ES	Distance	Lim)	[WIII]	173		RS	of sector	Distance	[KIII]	210	110	45	55	215	110	105	
COMMITTED LINES		Transformers	No. Ratio MVA	1 400/132 200		INTERCONNECTORS		Transformers	No. Ratio MVA								
		Ctatio	Status	New				Charles	Status	Existing				Existing			
	ubstations	Ę	01	Nkhoma			ubstations	Ļ	01	Phombeya	Border	Cassapa T	Phombeya	Blantyre West	Border	Blantyre West	
	Lines and Substations	Transformers	No. Ratio MVA	1 400/132 200			Lines and Substations	Transformers	No. Ratio MVA	1 400/220 200							
		Charter		New				Charter) status	New				Existing			
		200		Phombeya					HOIL	Matambo	Matambo	Border	Cassapa T	Mozambique2	Mozambique2	Border	
	Voltage	Voltage	[ww]	008	9		1/0	VOICABE	[kv]				000	004			



Voltage [kV]												l	l				
[kv]			Lines and Substations	bstations			٦	Distance	Conductor				Cost		In service by	, d	
	From	Status	Transformers No. Ratio MVA	욘	Status	Transformers No. Ratio M	Ž	[km]		Circuits	Tower type		estimate [MUSD]	Scen 1	Scen 2	Scen 3	Scen 4
400	Nkhoma	Existing		Kanengo	New		200	8 09	3x Tern	1	YTower	SgCkt	52.6	2020	2020	2020	2020
	Kanengo	Existing		Chikangawa	New	1 400/132	200	280	3x Tern	1		SgCkt	111.0	2022	2022	2022	2022
	Phombeya	Existing		Blantyre West	New	2 400/132	200	8 09	3x Tern	1	YTower	SgCkt	52.6	2023	2023	2023	2023
	Mpatamanga	Power plant		Blantyre West	Existing			50	3x Tern	1	YTower	SgCkt	21.9	2023	2023	2026	2023
	Mpatamanga	Existing		Cassapa T				15 3	3x Tern	1	YTower	SgCkt	7.8	2023	2023	2026	2023
	Mpatamanga 2	Existing		Cassapa T 2				15 3	3x Tern	1	YTower	SgCkt	7.8	2023	2023	2026	
	Cas sapa T			Phombeya	Existing			9 09	3x Tern	1	YTower	SgCkt	22.0	-	-	-	2023
	Nkhoma 2	Existing		Kanengo 2	Existing			8 09	3x Tern	1		SgCkt	25.1	2023	2023	2023	2023
	Chikangawa	Existing		Fufu (Higher)	New	1 400/132	200	160	3x Tern	1		SgCkt	73.0	2027	2033	2025	2028
	Kholombidzo	Power plant		Phombeya	Existing			15 3	3x Tern	1		SgCkt	10.9	2028	2034	2030	2031
	Kanengo	Existing		Dwangwa	New	1 400/132	200	200	3x Tern	1	YTower	SgCkt	85.7	2028	2028	2028	2028
	Dwangwa	Existing		Chikangawa	Existing			85 3	3x Tern	1	YTower	SgCkt	33.0	2030	2030	2030	2030
	Chikangawa	Existing		Coal North	New			270	3x Tern	1	YTower	SgCkt	96.7	2031	2036	2031	2029
	Fufu (Higher)	Existing		Coal North	Existing			110	3x Tern	1	YTower	SgCkt	40.9	2031	2036	2031	2029
	2nd circuit on existing lines:	ig lines:															
	Phombeya	Existing		Nkhoma	Existing			173	2x Bluejay	1	Built already	DbCkt	21.7	2021	2021	2021	2021
	Kanengo	Existing		Kasungu	New	1 132/66	20	120	1x Parakeet	1		SgCkt	29.5	2019	2019	2019	2019
	Kasungu	Existing		Kanyika	New	1 132/66	20	40	1x Parakeet	1	One shield wire	SgCkt	17.1	2019	2019	2019	2019
	Kanyika	Existing		Chikangawa	Existing	1 132/66	20	120	1x Parakeet	1	One shield wire	SgCkt	24.5	2019	2019	2019	2019
	Phombeya	Existing		Kammwamba	Power plant			15 2	2x Parakeet	2	One shield wire	DbCkt	8.2	2019	2019	2019	2019
	Tedzani IV	Power Plant		Tedzani	Existing			1 1	1x Parakeet	1		SgCkt	2.0	2019	2019	2019	2019
	Chikangawa	Existing		Mznzn	New	1 132/66	20	75 1	1x Parakeet	1		SgCkt	22.9	2020	2020	2020	2020
	Mznzn	Existing		Livingstonia	New	1 132/66	20	115 1	1x Parakeet	1	One shield wire	SgCkt	28.6	2020	2020	2020	2020
	Livingstonia	Existing		Karonga	New	1 132/66	20	105	1x Parakeet	1	One shield wire	SgCkt	27.0	2020	2020	2020	2020
	Dwangwa	New	1 132/66 50	Kanyika	Existing			75 1	1x Parakeet	1	One shield wire	SgCkt	22.5	2020	2020	2020	2020
132	Kapichira	Existing		Kap.ext	Power plant			1 1	1x Parakeet	2	One shield wire	DbCkt	4.3	2020	2020	2020	2020
	Kap.ext.	Existing		Hamilton*				5 1	1x Parakeet	2	One shield wire	DbCkt	1.2	2020	2020	2020	2020
	Hamilton*			Blantyre West	Extension			35 1	1x Parakeet	2		DbCkt	13.7	2020	2020	2020	2020
	Hamilton	Power plant		On Kapichira-BI.W.				1 1	1x Parakeet	1	One shield wire	SgCkt	2.0	2026	2032	2029	2026
	Fufu (Higher)	Power plant		On Mzuzu-Livingst.				4 1	1x Parakeet	1	One shield wire	SgCkt	2.8	2027	2033	2025	2028
	Pamodzi	Power plant		On Golomoti-Nanjoka				1 1	1x Parakeet	1	One shield wire	SgCkt	2.0	2030	2035	2026	2027
	Pamodzi	Power plant		Nanjoka	Existing			35 2	2x Parakeet	1	One shield wire	SgCkt	8.0	2030	2035	2026	2027
	Karonga	Existing		"Coal North"	Existing				1x Parakeet	1		SgCkt	9.9	2031	2036	2030	2030
	Lower Songwe	Power plant		Karonga	Existing			50 1	1x Parakeet	1	One shield wire	SgCkt	9.5	2033	2035	2023	2034