Re-running the analysis: Egypt

This research modelled six scenarios using OSeMOSYS to identify the technologies and target improvements that are needed to upscale RETs within Egypt's energy sector. These scenarios included a reference 'Least-Cost' scenario, a Fossil Fuel Future scenario, a Net Zero CO_2 emissions by 2050 scenario and three renewable target scenarios based on Egypt's current and potential future policies: ISES2035, IRENA2030, 60BY2035.

Least-Cost

For the Least-Cost scenario, reduced timeslices have been applied and technologies and commodities needed to meet transport demand have been removed as including these produced results with a much higher fossil fuel capacity to fulfil a higher power demand than is possible in Egypt. The technology that represents transmission imports in the power sector (PWRTRNIMP) has also been removed to investigate how Egypt will meet electricity demand domestically. In addition, the biomass power plant (PWRBIO001) technology was constrained to 1.4% of 2030 electricity demand based on IRENA's 2018 analysis to reduce its domination of Egypt's electricity generation. These four constraints were applied to all scenarios for consistency.

LC (REFERENCE) MODEL PARAMETER CHANGES
Changed default Discount Rate from 0.05 to 0.1 Reduced Timeslices 96→8 • Yearsplit value changed to 0.125 (1/8) • Changed all power plant Capacity Factors from 96→8 • Changed Specified Demand Profile for RESELC, COMELC and INDELC from 96→8 Removed transport • Accumulated Annual Demand changed to 0 for TRAMCY, TRACAR, TRABUS • Capacity to Activity Unit (time independent variable) to 0 for DEMTRAEVC, DEMTRAMCYELC, DEMTRACARELC, DEMTRABUSELC, DEMTRAMCYGSL, DEMTRACARGSL, DEMTRABUSGSL, BSTOPCAR, BSTOPBUS Removed PWRTRNIMP • Total Technology Annual Upper and Lower Limits to 0 for PWRTRNIMP PWRBIO constrained to 1.4% of 2035's energy demand (to avoid domination) • Total Technology Annual Activity Lower and Upper Limits changed to values in Appendix 1.1.

Fossil Fuel Future

To form the Fossil Fuel Future (FFF) scenario, a further constraint was added to the LC scenario: new capital investment into RETs was removed.

FFF SCENARIO MODEL PARAMETER CHANGES
Removed investment into renewables • Total Annual Max Capacity Investment to 0 between 2015 and 2070 for Wind, PV, CSP, Hydropower.

Net Zero by 2050

Historical emissions between 2015 and 2019 were used to calculate the average percentage increase in CO_2 emissions (Appendix 1.2), which was then extrapolated until 2030 to reach a peak in emissions. This peak value was then linearly decreased to 0 by 2050 (Appendix 1.3).

NZ2050 SCENARIO MODEL PARAMETER CHANGES
Limited annual emissions • Values in Appendix 1.2. inserted into Annual Emissions Limit parameter for carbon dioxide between 2015 and 2050.

Integrated Sustainable Energy Strategy 2035

The ISES2035 scenario shows Egypt's 2035 target broken down into 14% from wind, 22% from solar PV, 3% from CSP and 2% from hydropower technologies. To achieve this using OSeMOSYS, the sum of electricity demand was calculated for 2035 (Appendix 1.4), and this was multiplied by the percentage of a certain technology. The values were divided by the number of years, which were then apportioned between multiple types of power plant (Appendix 1.5). The 14% wind was split into 60% from onshore and 40% from offshore (an assumption based on the space available in the desert and at sea). These values were inserted into the model to produce the minimum percentage of electricity generation required from a certain technology by 2035.

The model produces an accurate amount of electricity generation from hydropower technologies, as the capacity is capped in Egypt at 2.8 GW due to the maximum number of dams already built on the River Nile.

To complete this scenario, the ISES 2035 target also includes a rapid increase in coal to 16% of Egypt's total electricity generation, and 3.3% of electricity generation from nuclear. The changes to OSeSMOSYS input data for the ISES 2035 scenario can be found in Appendix 1.6.

ISES2035 SCENARIO MODEL PARAMETER CHANGES
Added technology percentages of demand (42% by 2035) • Sum of Specified Annual Demands for COMELC, RESELC, INDELC in 2035 (Appendix 1.4) • Total Annual Technology Lower Limit and Upper Limits changed to reflect a percentage of total demand (Appendix 1.5) • Linearly increase these Upper and Lower Limits to percentage of demand (Appendix 1.6). • Upper Limit values always 0.5 above Lower Limit values Storage technologies removed • Total Technology Annual Activity Lower and Upper Limits to 0 and Residual Capacity to 0 – PWRSOL002, PWRSOL001S, PWRWND001S, PWRCSP002

IRENA's REMap 2030 Analysis

For the IRENA2030 scenario, the methodology is similar to the ISES2035 scenario, however, the total electricity demand from which to calculate the percentages for each technology is based on the 2030 demand value rather than the 2035 value (Appendices 1.7, 1.8 and 1.9).

IRENA2030 SCENARIO MODEL PARAMETER CHANGES
Added technology percentages of demand (53% by 2030) • Sum of Specified Annual Demands for COMELC, RESELC, INDELC in 2030 (Appendix 1.7) • Total Annual Technology Lower Limit and Upper Limits changed to reflect a percentage of total demand (Appendix 1.8) • Linearly increase these Upper and Lower limits to percentage of demand (Appendix 1.9). • Upper Limit values always 0.5 above Lower Limit values Storage technologies removed • Total Technology Annual Activity Lower and Upper Limits to 0 and Residual Capacity to 0 – PWRSOL002, PWRSOL001S, PWRWND001S, PWRCSP002

<u>60% Renewables by 2035</u>

In the 60BY2035 scenario, the custom percentages of each technology are broken down as follows: 20% wind, 2% biofuels, 24% solar PV and 9% CSP (and 5% hydro). The methodology is similar to both the ISES2035 and IRENA2030 scenarios above (Appendices 1.4, 1.10, 1.11).

60BY2030 SCENARIO MODEL PARAMETER CHANGES
Added technology percentages of demand (60% by 2035) • Sum of Specified Annual Demands for COMELC, RESELC, INDELC in 2035 (Appendix 1.4) • Total Annual Technology Lower Limit and Upper Limits changed to reflect a percentage of total demand (Appendix 1.10) • Linearly increase these Upper and Lower Limits to percentage of demand (Appendix 1.11). • Upper Limit values always 0.5 above Lower Limit values Storage technologies removed • Total Technology Annual Activity Lower and Upper Limits to 0 and Residual Capacity to 0 – PWRSOL002, PWRSOL001S, PWRWND001S, PWRCSP002

<u>Data sources</u>

The data used in this paper can be found in CCG's Starter Data Kit, generated by Allington *et al*. (2021). The estimated installed capacities for the power generation technologies were sourced from Brinkerink & Deane, 2020, Brinkerink *et al.,* 2021, Byers *et al.,* 2018 and IRENA, 2020a for the 2018 values (Appendix 1.12). Values for Egypt's electricity transmission and distribution were sourced from Pappis *et al.,* 2019 (Appendix 1.13). Fuel price projections to 2050 are displayed in Appendix 1.14, and were sourced from EIA, 2020 and IRENA 2018. Renewable constraints in the scenarios were based on policies from NREA (2020) and IRENA (2018a). Data source references can be found in the 'Annex – Data Inputs and Assumptions' file on Zenodo.

Appendix

Appendix 1.1. The calculated linear increase for each power plant to reach the percentage demand for each technology in 2030 for the IRENA2030 scenario.

	Electricity Demand Per Year (PJ)								
Technology	2022	2023	2024	2025	2026	2027	2028	2029	2030
PWRSOL001	15.42	30.84	46.27	61.69	77.11	92.53	107.95	123.38	138.80
PWRCSP001	6.04	12.09	18.13	24.18	30.22	36.26	42.31	48.35	54.39
PWRWND001	8.00	16.01	24.01	32.01	40.01	48.02	56.02	64.02	72.02
PWRWND002	5.34	10.67	16.01	21.34	26.68	32.01	37.35	42.68	48.02
PWRBIO001	1.04	2.08	3.13	4.17	5.21	6.25	7.29	8.34	9.38

Appendix 1.2. Calculating the average percentage increase between 2015 and 2019 for historical carbon dioxide emissions. Values sourced from ClimateWatchData, n.d..

Year	Carbon Dioxide Emissions (mton)	Calculation
2015	204.63	-
2016	208.41	2015→2016 = 1.84723648%
2017	220.46	2016→2017 = 5.78187227%
2018	226.91	2017→2018 = 2.92570081%
2019	229.70	2018→2019 = 1.22956238%
		AVERAGE INCREASE = 2.94609298%

Appendix 1.3. The calculated rise and fall of carbon dioxide emissions for Egypt. Information sourced from Climate Watch Data 2015-2019.

Year	Carbon Dioxide Emissions (Mt)	Calculation
2015	204.63	Climate Watch Data
2016	208.41	Climate Watch Data
2017	220.46	Climate Watch Data
2018	226.91	Climate Watch Data
2019	229.70	Climate Watch Data
2020	236.47	2019 value x 102.946/100)
2021	243.44	Previous value x 102.246/100
2022	250.61	
2023	257.99	
2024	265.59	
2025	273.41	
2026	281.46	
2027	289.75	
2028	298.29	
2029	307.08	
2030	316.13 (Peak)	Linear decrease: 316.13/20 = 15.8065. 316.13-15.8065
2031	300.32	Linear decrease of 15.8065
2032	284.52	
2033	268.71	
2034	252.90	
2035	237.10	
2036	221.29	
2037	205.48	
2038	189.68	
2039	173.87	
2040	158.07	
2041	142.26	
2042	126.45	
2043	110.65	
2044	94.84	
2045	79.03	
2046	63.23	
2047	47.42	
2048	31.61	
2049	15.81	
2050	0	

Appendix 1.4. Total electricity demand calculation for the ISES 2035 and 60BY2035 scenarios.

Electricity Demand (PJ)	2035 Values
Industrial Electricity Demand (INDELC)	246.529454
Commercial Electricity Demand (COMELC)	226.753715
Residential Electricity Demand (RESELC)	396.687567
	Total = 869.970736

Appendix 1.5. The total electricity demand split into electricity demand per technology and power plant in 2035 for the ISES2035 scenario.

Total Electricity Demand (TED) 2035 (PJ)	% of TED for each technology	Electricity demand 2035 per technology (PJ)	Number of power plants to split the demand
869.970736	22 (Solar PV)	191.39356192	1 (PWRSOL001)
	3 (CSP)	26.09912208	1 (PWRCSP001)
	14 (Wind)	121.79590304	2 (PWRWND001, PWRWND002)
	16 (Coal)	139.19531776	1 (PWRCOA001)
	3.3 (Nuclear)	28.709034288	1 (PWRNUC)

Appendix 1.6. The linear increase for each power plant to reach the percentage demand for each technology in 2035 for the ISES2035 scenario.

	Electricity Demand Per Year (PJ)													
Technology	‘22	‘23	‘24	‘25	‘26	‘27	‘28	‘29	‘30	‘31	‘32	‘33	‘34	‘35
PWRSOL001	13.67	27.34	41.01	54.69	68.36	82.03	95.70	109.39	123.04	136.71	150.38	164.05	177.72	191.39
PWRCSP001	1.86	3.73	5.59	7.46	9.32	11.19	13.05	14.91	16.78	18.64	20.51	22.37	24.24	26.10
PWRWND001	5.22	10.44	15.66	20.88	26.10	31.32	36.54	41.76	46.98	52.20	57.42	62.64	67.86	73.08
PWRWND002	3.48	6.96	10.44	13.92	17.40	20.88	24.36	27.84	31.32	34.80	38.28	41.76	45.24	48.72
PWRCOA001	9.94	19.89	29.83	39.77	49.71	59.66	69.60	79.54	89.48	99.43	109.37	119.31	129.25	139.20
PWRNUC	2.05	4.10	6.15	8.20	10.25	12.30	14.35	16.41	18.46	20.51	22.56	24.61	26.66	28.71

Appendix 1.7. Total electricity demand calculation for the IRENA 2030 scenario.

Electricity Demand (PJ)	2030 Values
Industrial Electricity Demand (INDELC)	184.965384
Commercial Electricity Demand (COMELC)	170.128102
Residential Electricity Demand (RESELC)	297.625567
	Total = 652.719053

Appendix 1.8. The total electricity demand split into electricity demand per technology and power plant in 2030 for the IRENA2030 scenario.

Total Electricity Demand (TED) 2035 (PJ)	% of TED for each technology	Electricity demand 2030 per technology (PJ)	Number of power plants to split the demand
652.719053	21.264 (Solar PV)	138.796580131	1 (PWRSOL001)
	8.333 (CSP)	54.3932543949	1 (PWRCSP001)
	18.391 (Wind)	120.040284624	2 (PWRWND001, PWRWND002)
	1.437 (Biofuels)	9.37814731847	1 (PWRBIO001)

Appendix 1.9. The linear increase for each power plant to reach the percentage demand for each technology in 2030 for the IRENA2030 scenario.

	Electricity Demand Per Year (PJ)								
Technology	2022	2023	2024	2025	2026	2027	2028	2029	2030
PWRSOL001	15.42	30.84	46.27	61.69	77.11	92.53	107.95	123.38	138.80
PWRCSP001	6.04	12.09	18.13	24.18	30.22	36.26	42.31	48.35	54.39
PWRWND001	8.00	16.01	24.01	32.01	40.01	48.02	56.02	64.02	72.02
PWRWND002	5.34	10.67	16.01	21.34	26.68	32.01	37.35	42.68	48.02
PWRBIO001	1.04	2.08	3.13	4.17	5.21	6.25	7.29	8.34	9.38

Appendix 1.10. The total electricity demand split into electricity demand per technology and power plant in 2035 for the 60BY2035 scenario.

Total Electricity Demand (TED) 2035 (PJ)	% of TED for each technology	Electricity demand 2035 per technology (PJ)	Number of power plants to split the demand
869.970736	24 (Solar PV)	208.79297664	1 (PWRSOL001)
	9 (Solar CSP)	78.29736624	1 (PWRCSP001)
	20 (Wind)	173.9941472	2 (PWRWND001, PWRWND002)
	2 (Biofuels)	17.39941472	1 (PWRBIO001)

Appendix 1.11. The linear increase for each power plant to reach the percentage demand for each technology in 2035 for the 60BY2035 scenario.

	Electricity Demand per Year (PJ)													
Technology	‘22	‘23	‘24	‘25	‘26	‘27	‘28	‘29	‘30	‘31	‘32	‘33	‘34	‘35
PWRSOL001	14.91	29.83	44.74	59.66	74.57	89.48	104.40	119.31	134.22	149.14	164.05	178.97	193.88	208.79
PWRCSP001	5.59	11.19	16.78	22.37	27.96	33.56	39.15	44.74	50.33	55.93	61.52	67.11	72.71	78.30
PWRWND001	7.46	14.91	22.37	29.83	37.28	44.74	52.20	59.66	67.11	74.57	82.03	89.48	96.94	104.40
PWRWND002	4.97	9.94	14.91	19.89	24.86	29.83	34.80	39.77	44.74	49.71	54.68	59.66	64.63	69.60
PWRBIO001	1.24	2.49	3.73	4.97	6.21	7.46	8.70	9.94	11.19	12.43	13.67	14.91	16.16	17.40

Appendix 1.12. The estimated installed capacity for Power Generation. Source: Brinkerink & Deane, 2020, Brinkerink et al., 2021, Byers et al., 2018a and IRENA, 2020a.

Power Generation Technology	**Estimated Installed Capacity (MW)**
Light Fuel Oil Power Plant	546.33
Oil Fired Gas Turbine (SCGT)	600
Gas Power Plant (CCGT)	16545.67
Gas Power Plant (SCGT)	294
Solar PV (Utility)	25
CSP without Storage	20
Large Hydropower Plant (Dam) (>100MW)	2700
Medium Hydropower Plant (10-100MW)	150
Onshore Wind	810
Off-grid Solar PV	50

Appendix 1.13. The capital cost, operational life and efficiency of electricity transmission and distribution. Source: Pappis et al., 2019.

Technology	**Capital Cost in ($/kW 2020)**	**Operational Life (years)**	**Efficiency (2020)**	**Efficiency (2030)**	**Efficiency (2050)**
Electricity Transmission	365	50	0.96	0.96	0.96
Electricity Distribution	2502	70	0.91	0.92	0.94

Appendix 1.14. Fuel price projections to 2050. Source: EIA, 2020 and IRENA 2018.

Commodity	**Fuel Price ($/GJ)**					
	2015	2020	2025	2030	2040	2050
Crude Oil Imports	13.14	12.2	12.76	14.27	16.9	19.53
Crude Oil Extraction	11.95	11.09	11.6	12.97	15.36	17.75
Biomass Imports	1.76	1.76	1.76	1.76	1.76	1.76
Biomass Extraction	1.6	1.6	1.6	1.6	1.6	1.6
Coal Imports	4.9	5.1	5.3	5.5	5.9	5.9
Coal Extraction	3.3	3.4	3.5	3.6	3.8	3.8
Light Fuel Oil Imports	15.89	14.75	15.43	17.25	20.43	23.61
Heavy Fuel Oil Imports	9.56	8.87	9.28	10.38	12.29	14.2
Natural Gas Imports	8.6	8.6	9.45	10.3	11.0	11.0
Natural Gas Extraction	7.1	7.1	7.8	8.5	9.9	9.9