Annex - Summary of all Input Data and Assumptions

<u>Input Data</u>

The data used in this analysis of Egypt can be found in CCG's Starter Data Kit (SDK), generated by Allington *et al.,* (2021), in addition to the full country dataset published on Zenodo (Allington *et al*., 2023). The capital and fixed costs for Egypt's power plants are listed in Annex 1 and are sourced from CCG's SDK.

Annex 1. Capital and Fixed Costs for Egypt's Power Plants. Source: Brinkerink & Deane, 2020, IRENA, 2021, IRENA, 2018a, IRENA, 2019, Staffell & Pfenninger, 2016b, Staffell & Pfenninger, 2016a, IRENA 2020b, from CCG's SDK.

OSeMOSYS Code	Technology	Capital Cost ($/kW in 2020)	Fixed Cost ($/kW in 2020)	Operational Life (years)	Power Plant Efficiency	Average Capacity Factor
PWRBIO001	Biomass Power Plant	2500	75	30	0.35	0.5
PWRCOA001	Coal Power Plant	2500	78	35	0.37	0.85
PWRGEO	Geothermal Power Plant	4000	120	25	0.8	0.79
PWROHC001	Light Fuel Oil Power Plant	1200	35	25	0.35	0.8
PWROHC002	Oil Fired Gas Turbine (SCGT)	1450	45	25	0.35	0.8
PWRNGS001	Gas Power Plant (CCGT)	1200	35	30	0.48	0.85
PWRNGS002	Gas Power Plant (SCGT)	700	20	25	0.3	0.85
PWRSOL001	Solar PV (Utility)	1378	17.91	24	1	0.36
PWRCSP001	CSP without Storage	4058	40.58	30	1	0.45
PWRCSP002	CSP with Storage	5797	57.97	30	1	0.45
PWRHYD001	Large Hydropower Plant (Dam) (> 100MW)	3000	90	50	1	0.54
PWRHYD002	Medium Hydropower Plant (10-100MW)	2500	75	50	1	0.54
PWRHYD003	Small Hydropower Plant (<10MW)	3000	90	50	1	0.54
PWRWND001	Onshore Wind	1489	59.56	25	1	0.22
PWRWND002	Offshore Wind	3972.4	158.9	25	1	0.4
PWRNUC	Nuclear Power Plant	6137	184.11	50	0.33	0.85
PWROHC003	Light Fuel Oil Standalone Generator (1kW)	750	23	10	0.16	0.3
PWRSOL002	Solar PV (Distributed with Storage)	4320	86.4	24	1	0.36

The estimated installed capacity 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 generation values, sourced from CCG's SDK and shown in Annex 2.

Annex 2. The Estimated Installed Capacity for Power Generation. Source: Brinkerink & Deane, 2020, Brinkerink et al., 2021, Byers et al., 2018 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

Values for Egypt's electricity transmission and distribution were sourced from Pappis *et al.,* 2019 used in the SDK and are shown in Annex 3. Fuel price projections to 2050 are displayed in Annex 4, and were sourced from EIA, 2020 and IRENA 2018.

Annex 3. The Capital Cost, Operational Life and Efficiency of Electricity Transmission and Distribution. Source: Pappis et al., 2019.

Technology	Capital Cost ($/kW in 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

Annex 4. 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

<u>Assumptions</u>

Scenario Configuration Assumptions (Researcher)

Least Cost Scenario

The Least Cost scenario assumed that there wouldn't be any policy interventions in the energy sector in order to generate a control scenario in which to compare scenarios that would have policy interventions; however, this may not be the most accurate representation of reality. Reduced timeslices (from 96 to 8) have been applied to increase the speed of model operation and to reflect the level of energy data granularity that is available for Egypt. 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 (This was increased to 2% for the 60BY2035 scenario). These four constraints were applied to all scenarios for consistency.

Fossil Fuel Future Scenario

Removing capital investment into renewable energy technologies throughout the entire modelling period constrained the model to only use fossil fuel technologies.

Net Zero by 2050

Historical emissions between 2015 and 2019 were used to calculate the average percentage increase in CO_2 emissions, shown in Annex 5, which was then extrapolated until 2030 (Annex 6). The peak in emissions was set to occur in 2030 which is based on the assumption that Egypt, as a middle-low income country, may not be able to immediately reduce their emissions. This peak value was then linearly decreased to 0 by 2050 (Annex 6). It is acknowledged that in reality, carbon dioxide emissions may peak beyond 2030, and that the increase could be exponential rather than linear. A linear approach was taken to be conservative.

Annex 5. Calculating the Average Percentage Increase between 2015 and 2019 for Historical Carbon Dioxide Emissions. Values sourced from ClimateWatchData, n.d..

Year	Carbon Dioxide Emissions (Mt)	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%

Annex 6. The 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 to give 2031 value.
2031	300.32	Linear decrease of 15.8065 Mt per year
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	

ISES2035, IRENA2030 and 60BY2035 Scenarios

Storage technologies were removed in the ISES2035, IRENA2030 and 60BY2035 scenarios as they are not mentioned in the national strategies that the renewable scenarios reflect.

For ISES2035 and IRENA2030, the technology capacity percentages were sourced from the EU and Egyptian Government, and IRENA, respectively. The biofuel capacity was increased to 2% for the 60BY2035 scenario, in comparison to 1.4% for all other scenarios. This was due to increasing the capacity of all renewable technologies for this scenario, and it was assumed that biofuels in this context are a renewable form of energy. Another assumption across the ISES2035, IRENA2030 and 60BY2035 scenarios was to split wind technology capacity percentages into 60% onshore and 40% offshore based on the assumption of available space for these technologies in Egypt. Annex 7 shows the technology capacity percentages and sources for the ISES2035, IRENA2030 and 60BY2035 scenarios.

Annex 7. Sourced and Custom Technology Capacity Percentages.

Scenario	Technology Capacity Percentages	Source
ISES2035	14% Wind 22% Solar PV 3% CSP 2% Hydropower 16% Coal 3.3% Nuclear (1.4% Biofuels assumption)	EU 2015, NREA, 2020
IRENA2030	18.4% Wind 21.3% Solar PV 8.3% CSP 4% Hydropower 1.4% Biofuels	IRENA, 2018b
60BY2035	20% Wind 24% solar PV 9% CSP 5% Hydropower 2% Biofuels	Research percentages – assumptions taken to increase the capacity of renewable energy technologies

Model Assumptions

Within the model, if specific input data cannot be sourced at the national level, certain parameters, such as the capacity factors for power plants, have been assumed by the researcher to be similar to other Northern African countries and sourced from international organisations such as the IEA and IRENA.

OSeMOSYS also considers 2070 as the end of the world as the last timeslice due to the model's preparation to cease production in the last year of the modelling period (2070). This suggests that the model results for 2070 may not be an accurate representation of reality and should be approached with caution.

<u>Methodology</u>

A summary of how to re-run the analysis can be found on the open-access data site Zenodo Repository, along with all six model files needed to re-run the model for these scenarios (Gibson, 2023).

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