Selected 'Starter Kit' energy system modelling data for Angola (#CCG)

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Abstract

Energy system modelling can be used to assess the implications of different scenarios and support improved policymaking. However, access to data is often a barrier to starting energy system modelling in developing countries, thereby causing delays. This article therefore provides data that can be used to create a simple zero order energy system model for Angola, which can act as a starting point for further model development and scenario analysis. The data are collected entirely from publicly available and accessible sources, including the websites and databases of international organizations, journal articles, and existing modelling studies. This means that the dataset can be easily updated based on the latest available information or more detailed and accurate local data. These data were also used to calibrate a simple energy system model using the Open Source Energy Modelling System (OSeMOSYS) and two stylized scenarios (Fossil Future and Least Cost) for 2020–2050. The assumptions used and results of these scenarios are presented in the appendix as an illustrative example of what can be done with these data. This simple model can be adapted and further developed by in-country analysts and academics, providing a platform for future work.

Specifications Table

Subject	Energy
Specific subject area	Energy System Modelling
Type of data	Tables
	Graphs
	Charts
	Description of modelling assumptions
How data were acquired	Literature survey (databases and reports from international organisations; journal articles)
Data format	Raw and Analysed
Parameters for data collection	Data collected based on inputs required to create an energy system model for Angola
Description of data collection	Data were collected from the websites, annual reports and databases of international organisations, as well as from academic articles and existing modelling databases.
Data source location	Not applicable
Data accessibility	With the article and in a repository. Repository name: Zenodo. Data identification number: v1.0.0. Direct URL to data: https://doi.org/10.5281/zenodo.4650810

Value Of The Data

- These data can be used to develop national energy system models to inform national energy investment outlooks and policy plans, as well as to provide insights on the evolution of the electricity supply system under different trajectories.
- The data are useful for country analysts, policy makers and the broader scientific community, as a zero-order starting point for model development.
- These data could be used to examine a range of possible energy system pathways, in addition to the examples given in this study, to provide further insights on the evolution of the country's power system.
- The data can be used both for conducting an analysis of the power system but also for capacity building activities. Also, the methodology of translating the input data into modelling assumptions for a cost-optimization tool is presented

here which is useful for developing a zero order Tier 2 national energy model [1]. This is consistent with U4RIA energy planning goals [2].

1 Data Description

The data provided in this paper can be used as input data to develop an energy system model for Angola. As an illustration, these data were used to develop an energy system model using the cost-optimization tool OSeMOSYS for the period 2015–2050. For reference, that model is described in Appendix A and its datafiles are available in the Supplementary Materials. Appendix figure A3 for Angola is repeated below. This is purely illustrative. It shows a zero-order model of the production of electricity by technology over the period 2020 to 2050 for a least cost energy future. Using the data described in this article, the analyst can reproduce this, as well as many other scenarios, such as net-zero by 2050, in a variety of energy planning toolkits.

The data provided were collected from publicly available sources, including the reports of international organizations, journal articles and existing model databases. The dataset includes the techno-economic parameters of supply-side technologies, installed capacities, emissions factors and final electricity demands. Below shows the different items and their description, in order of appearance, presented in this article.

Item	Description of Content
Table 1	A table showing the estimated installed capacity of different power plant types in Angola for 2015–2018
Table 2	A table showing techno-economic parameters for electricity generation technologies
Table 3	A table showing capital cost projections for renewable energy technologies up to 2050
Figure 1	A graph showing capital cost projections for renewable energy technologies from 2015–2050
Table 4	A table showing cost and performance parameters for power transmission and distribution technologies
Table 5	A table showing cost and performance data for refinery technologies
Table 6	A table showing fuel price projections up to 2050
Figure 2	A graph showing fuel price projections from 2015–2050
Table 7	A table showing carbon dioxide emissions factors by fuel
Table 8	A table showing estimated renewable energy potential in Angola
Table 9	A table showing estimated fossil fuel reserves in Angola
Figure 3	A graph showing a final electricity demand projection for Angola from 2015–2070

1.1 Existing Electricity Supply System

The total power generation capacity in Angola is estimated at 1725.1 MW in 2018 [3,4,5,6]. The estimated existing power generation capacity is detailed in Table 1 below [3,4,5,6]. The methods used to calculate these estimates are described in more detail in Sect. 2.1. Data on the installation year of each power plant can be found in the country dataset published on Zenodo.

Table 1
Installed Power Plants Capacity in Angola [3,4,5,6]

Power Generation Technology	Estimated Installed Capacity (MW)			
	2015	2016	2017	2018
Light Fuel Oil Power Plant	327.8	327.8	327.8	327.8
Oil Fired Gas Turbine (SCGT)	23.0	23.0	23.0	23.0
Gas Power Plant (SCGT)	419.62	419.62	419.62	419.62
Solar PV (Utility)	14.0	14.0	14.0	14.0
Large Hydropower Plant (Dam) (>100MW)	849.4	849.4	849.4	849.4
Medium Hydropower Plant (10-100MW)	71.0	71.0	71.0	71.0
Off-grid Solar PV	12.87	13.38	13.38	13.38
Off-grid Hydropower	6.86	6.86	6.86	6.86

1.2 Techno-economic Data for Electricity Generation Technologies

The techno-economic parameters of electricity generation technologies are presented in Table 2, including costs, operational lives, efficiencies and average capacity factors. Cost (capital and fixed), operational life and efficiency data were collected from reports by the International Renewable Energy Agency [7,8,9] and are applicable to all of Africa. These cost data include projected cost reductions for renewable energy technologies, which are presented in Table 3. The cost and performance of parameters of fossil electricity generation technologies are assumed constant over the modelling period. In this analysis only fixed power plant costs are considered, which capture variable operation and maintenance costs. Country-specific capacity factors for solar PV, wind and hydropower technologies in Angola were sourced from Renewables Ninja and the PLEXOS-World 2015 Model Dataset [3,10,11]. Capacity factors for other technologies were sourced from the International Renewable Energy Agency [8,12] and are applicable to all of Africa. Average capacity factors were calculated for each technology and presented in the table below, with daytime (6am – 6pm) averages presented for solar PV technologies. For more information on the capacity factor data, refer to Sect. 2.1.

Table 2
Techno-economic parameters of electricity generation technologies [3,7,8,9,10,11,12]

Technology	Capital Cost ($/kW in 2020)	Fixed Cost ($/kW/yr in 2020)	Operational Life (years)	Efficiency	Average Capacity Factor
Biomass Power Plant	2500.0	75.0	30	0.35	0.5
Coal Power Plant	2500.0	78.0	35	0.37	0.85
Geothermal Power Plant	4000.0	120.0	25	0.8	0.79
Light Fuel Oil Power Plant	1200.0	35.0	25	0.35	0.8
Oil Fired Gas Turbine (SCGT)	1450.0	45.0	25	0.35	0.8
Gas Power Plant (CCGT)	1200.0	35.0	30	0.48	0.85
Gas Power Plant (SCGT)	700.0	20.0	25	0.3	0.85
Solar PV (Utility)	1378.0	17.91	24	1.0	0.32
CSP without Storage	4058.0	40.58	30	1.0	0.45
CSP with Storage	5797.0	57.97	30	1.0	0.45
Large Hydropower Plant (Dam) (>100MW)	3000.0	90.0	50	1.0	0.52
Medium Hydropower Plant (10-100MW)	2500.0	75.0	50	1.0	0.52
Small Hydropower Plant (< 10MW)	3000.0	90.0	50	1.0	0.52
Onshore Wind	1489.0	59.56	25	1.0	0.11
Offshore Wind	3972.4	158.9	25	1.0	0.12
Nuclear Power Plant	6137.0	184.11	50	0.33	0.85
Light Fuel Oil Standalone Generator (1kW)	750.0	23.0	10	0.16	0.3
Solar PV (Distributed with Storage)	4320.0	86.4	24	1.0	0.32

Table 3
Projected costs of renewable energy technologies for selected years to 2050. [7,9]

Power Generation Technology	Capital Cost ($/kW)					
	2015	2020	2025	2030	2040	2050
Biomass Power Plant	2500.0	2500.0	2500.0	2500.0	2500.0	2500.0
Solar PV (Utility)	2165.0	1378.0	984.0	886.0	723.0	723.0
CSP without Storage	6051.0	4058.0	3269.0	2634.0	2562.0	2562.0
CSP with Storage	8645.0	5797.0	4670.0	3763.0	3660.0	3660.0
Large Hydropower Plant (Dam) (>100MW)	3000.0	3000.0	3000.0	3000.0	3000.0	3000.0
Medium Hydropower Plant (10-100MW)	2500.0	2500.0	2500.0	2500.0	2500.0	2500.0
Small Hydropower Plant (<10MW)	3000.0	3000.0	3000.0	3000.0	3000.0	3000.0
Onshore Wind	1985.0	1489.0	1191.0	1087.0	933.0	933.0
Offshore Wind	5000.0	3972.4	3020.9	2450.0	2275.0	2100.0
Solar PV (Distributed with Storage)	6840.0	4320.0	3415.0	2700.0	2091.0	2091.0

1.3 Techno-economic Data for Power Transmission and Distribution

The techno-economic parameters of transmission and distribution technologies were taken from the Reference Case scenario of The Electricity Model Base for Africa (TEMBA) [13]. According to these data, the efficiencies of power transmission and distribution in Angola are assumed to reach 95.0% in 2030. In the following table, the techno-economic parameters associated with the transmission and distribution network are presented.

Table 4
Techno-economic parameters for transmission and distribution technologies in Angola [13]

Technology	Capital Cost ($/kW in 2020)	Operational Life (years)	Efficiency (2020)	Efficiency (2030)	Efficiency (2050)
Electricity Transmission	365	50	0.95	0.95	0.95
Electricity Distribution	2502	70	0.94	0.95	0.95

1.4 Techno-economic Data for Refineries

Angola has an estimated 65 tb/d domestic refinery capacity [14]. In the OSeMOSYS model, two oil refinery technologies were made available for investment in the future, each with different output activity ratios for Heavy Fuel Oil (HFO) and Light Fuel Oil (LFO). The technoeconomic data for these technologies are shown in Table 5.

Table 5
Techno-economic parameters for refinery technologies [14,15]

Technology	Capital Cost ($/kW in 2020)	Variable Cost ($/GJ in 2020)	Operational Life (years)	Output Ratio
Crude Oil Refinery Option 1	24.1	0.71775	35	0.9 LFO : 0.1 HFO
Crude Oil Refinery Option 2	24.1	0.71775	35	0.8 LFO : 0.2 HFO

1.5 Fuel Prices

Assumed costs are provided for both imported and domestically-extracted fuels. The fuel price projections until 2050 are presented below. These are generic estimates based on an international oil price forecast [16] and cost estimates for Africa [8]. A detailed explanation of how these estimates were calculated is provided in Sect. 2.2.

Table 6
Fuel price projections to 2050 [16,8]

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

1.6 Emission Factors

Fossil fuel technologies emit several greenhouse gases, including carbon dioxide, methane and nitrous oxides throughout their operational lifetime. In this analysis, only carbon dioxide emissions are considered. These are accounted for using carbon dioxide emission factors assigned to each fuel, rather than each power generation technology. The assumed emission factors are presented in Table 7.

Table 7
Fuel-specific CO_2 Emission Factors [17]

Fuel	CO_2 Emission Factor (kg CO_2/GJ)
Crude oil	73.3
Biomass	100
Coal	94.6
Light Fuel Oil	69.3
Heavy Fuel Oil	77.4
Natural Gas	56.1

1.7 Renewable and Fossil Fuel Reserves

Tables 8 and 9 show Angola's estimated domestic renewable energy potentials and fossil fuel reserves respectively.

Table 8
Estimated Renewable Energy Potentials in Angola [18,19,20]

	Unit	Estimated Renewable Energy Potential
Solar PV	TWh/yr	13319
CSP	TWh/yr	9786
Wind (CF 20%)	TWh/yr	202
Wind (CF 30%)	TWh/yr	0
Wind (CF 40%)	TWh/yr	0
Hydropower	MW	7209
Small Hydropower (< 10MW)	MW	600
Geothermal	MW	0

Table 9
Estimated Fossil Fuel Reserves in Angola [21,22]

	Estimated Reserves
Total Recoverable Coal (mil. short tons, 2017)	0.0
Crude Oil Proven Reserves (billion barrels, 2019)	8.38
Natural Gas Proven Reserves (trillion cubic feet, 2019)	14.91

1.8 Electricity Demand Projection

Electricity demand in Angola was estimated at 42.8 PJ in 2018 and is forecasted to reach 110.71 PJ by 2030 and 448.61 PJ by 2050 [23] in a reference scenario. Figure 3 below shows the electricity demand projection.

2 Experimental Design, Materials, And Methods

Data were primarily collected from the reports and websites of international organizations, including the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA), and the Intergovernmental Panel on Climate Change (IPCC). Additionally, data were sourced from The Electricity Model Base for Africa (TEMBA), an existing OSeMOSYS model of African electricity supply [13].

2.1 Electricity Supply System Data

Data on Angola's existing on-grid power generation capacity, presented in Table 1, were extracted from the PLEXOS World dataset [3,4,5] using scripts from OSeMOSYS global model generator [24]. PLEXOS World provides estimated capacities and commissioning dates by power plant, based on the World Resources Institute Global Power Plant database [5]. These data were used to estimate installed capacity in future years based on the operational life data in Table 2. Data on Angola's off-grid renewable energy capacity were sourced from yearly capacity statistics produced by IRENA [6]. Cost, efficiency and operational life data in Table 2 were collected from reports by IRENA [7,8,9], which provide generic estimates for these parameters by technology. These reports also provide projections of future costs for renewable energy technologies. These data are presented in Table 3 and Fig. 1, where it was assumed that costs fall linearly between the data points provided by IRENA and that costs remain constant beyond 2040 when the IRENA forecasts end (except for offshore wind, where the IRENA forecast continues to 2050).

Country-specific capacity factors for solar PV, onshore wind and hydropower were sourced from Renewables Ninja and the PLEXOS-World 2015 Model Dataset [3,10,11]. These sources provide hourly capacity factors for 2015 for solar PV and wind, and 15-year averages monthly capacity factors for hydropower. Country-specific capacity factors for offshore wind were sourced from the TEMBA dataset [23], which provides capacity factor estimates for 8 time slices. Average capacity factors are presented in Table 2. These data were also used to estimate capacity factors for the 8 time slices used in the OSeMOSYS model (see detail in Annex 1). Capacity factors for other technologies were sourced from reports by IRENA [8,12], which provide generic estimates for each technology. The costs and efficiencies of power transmission and distribution were sourced from TEMBA reference case [23], which provides generic cost estimates and country-specific efficiencies which consider expected efficiency improvements in the future. Techno-economic data for refineries were sourced from the IEA Energy Technology Systems Analysis Programme (ETSAP) [15], which provides generic estimates of costs and performance parameters, while the refinery options modelled are based on the methods used in TEMBA [13].

2.2 Fuel Data

The crude oil price is based on an international price forecast produced by the US Energy Information Administration (EIA), which runs to 2050 [16]. The price was increased by 10% for imported oil to reflect the cost of importation. The price of imported HFO and LFO were calculated by multiplying the oil price by 0.8 and 1.33 respectively, based on the methods used in TEMBA [13]. The prices of coal, natural gas and biomass were sourced from an IRENA report [8], which provides generic estimates for costs to 2030. Again, a linear rate of change was assumed between data points from IRENA, and the forecast was extended to 2040 using the rate of change between 2020 and 2030. Prices were then assumed constant after 2040. The cost of domestically-produced biomass was increased by 10% to estimate a cost of imported biomass.

2.3 Emissions Factors and Domestic Reserves

Emissions factors were collected from the IPCC Emission Factor Database [17], which provides carbon emissions factors by fuel. Domestic renewable energy potentials for solar PV, CSP and wind were collected from an IRENA-KTH working paper [18], which provides estimates of potential yearly generation by country in Africa. Other renewable energy potentials were sourced from a regional report by IRENA [19] and the World Small Hydropower Development Report [20], which provide estimated potentials in MW by country. Estimated domestic fossil fuel reserves are from the websites of The World Bank and US EIA [21,22], which provide estimates of reserves by country.

2.4 Electricity Demand Data

The final electricity demand projection is based on data from the TEMBA Reference Scenario dataset [23], which provides yearly total demand estimates from 2015–2070 under a reference case scenario.

3 Ethics Statement

Not applicable.

4 Credit Author Statement

Lucy Allington: Data curation; Investigation; Methodology; Writing – original draft; Visualisation. Carla Cannone: Data curation; Investigation; Software; Formal analysis; Visualisation. Ioannis Pappis: Data curation; Investigation; Validation; Writing - Review & Editing. Karla Cervantes Barron: Data Curation; Software; Visualisation. William Usher: Software; Supervision. Steve Pye: Supervision; Project Administration; Writing – Review & Editing. Edward Brown: Funding Acquisition; Conceptualisation. Mark Howells: Conceptualisation; Methodology; Writing – Review & Editing; Supervision. Constantinos Taliotis: Conceptualisation; Writing – Review & Editing. Caroline Sundin: Conceptualisation; Writing – Review & Editing. Vignesh Sridharan: Conceptualisation. Eunice Ramos: Conceptualisation. Maarten Brinkerink: Data curation. Paul Deane:

Declarations

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Declaration of Competing Interests

The authors declare that they have no known competing financial interests or personal relationships which have or could be perceived to have influenced the work reported in this article.

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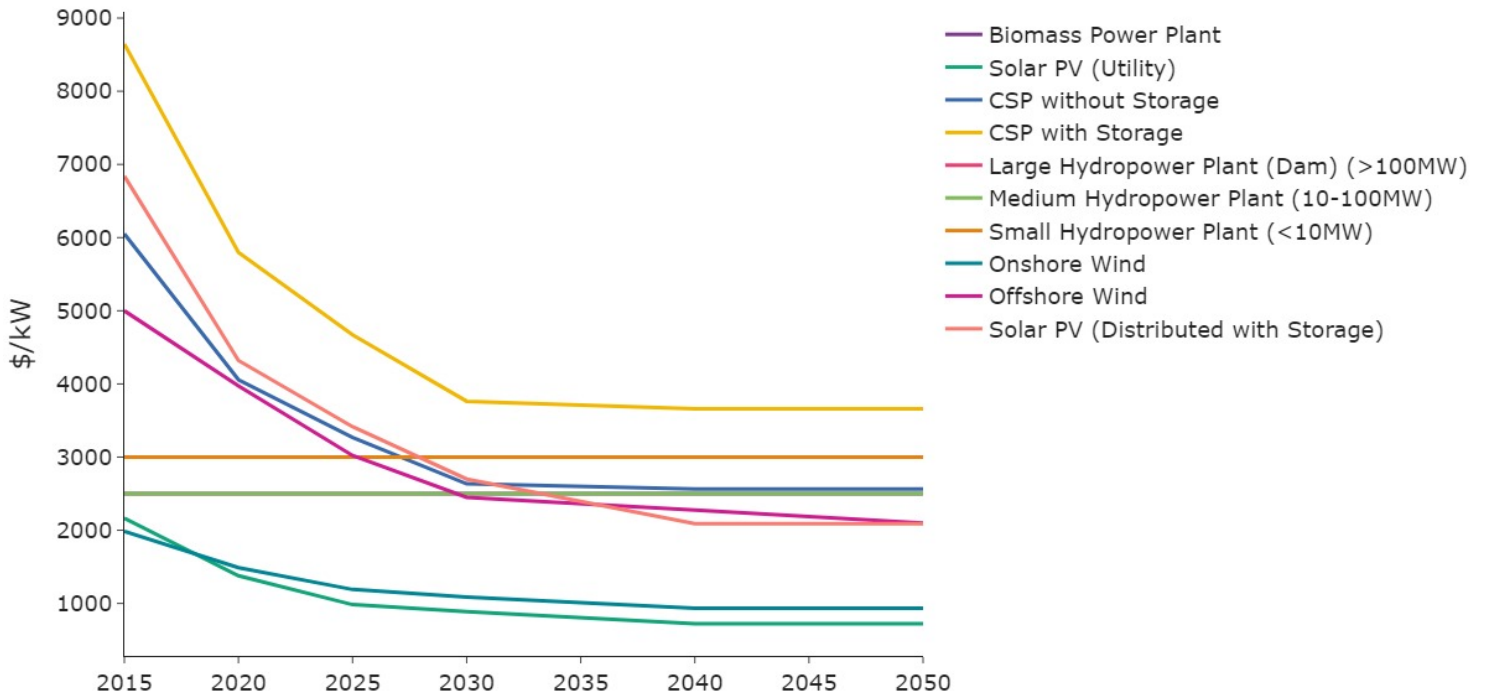
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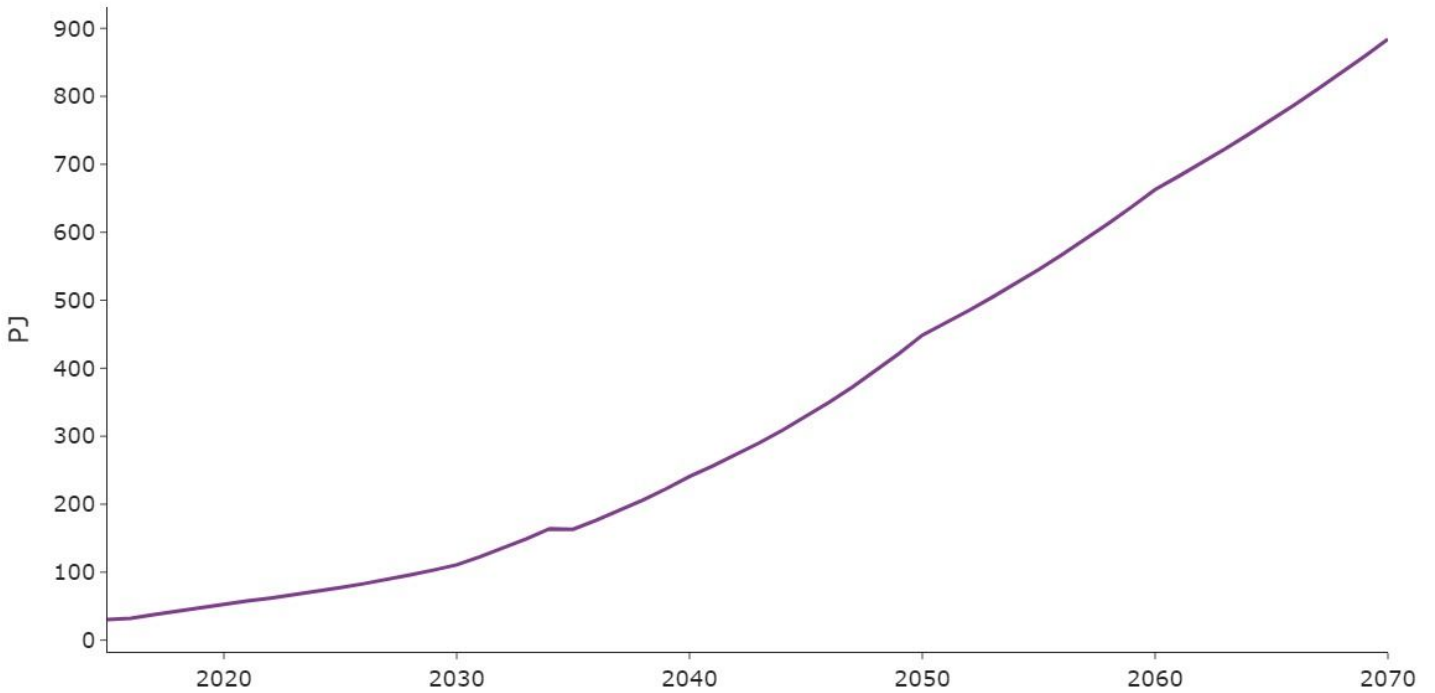
Figures

Figure 1

Projected costs of renewable energy technologies for selected years to 2050 [7,9]
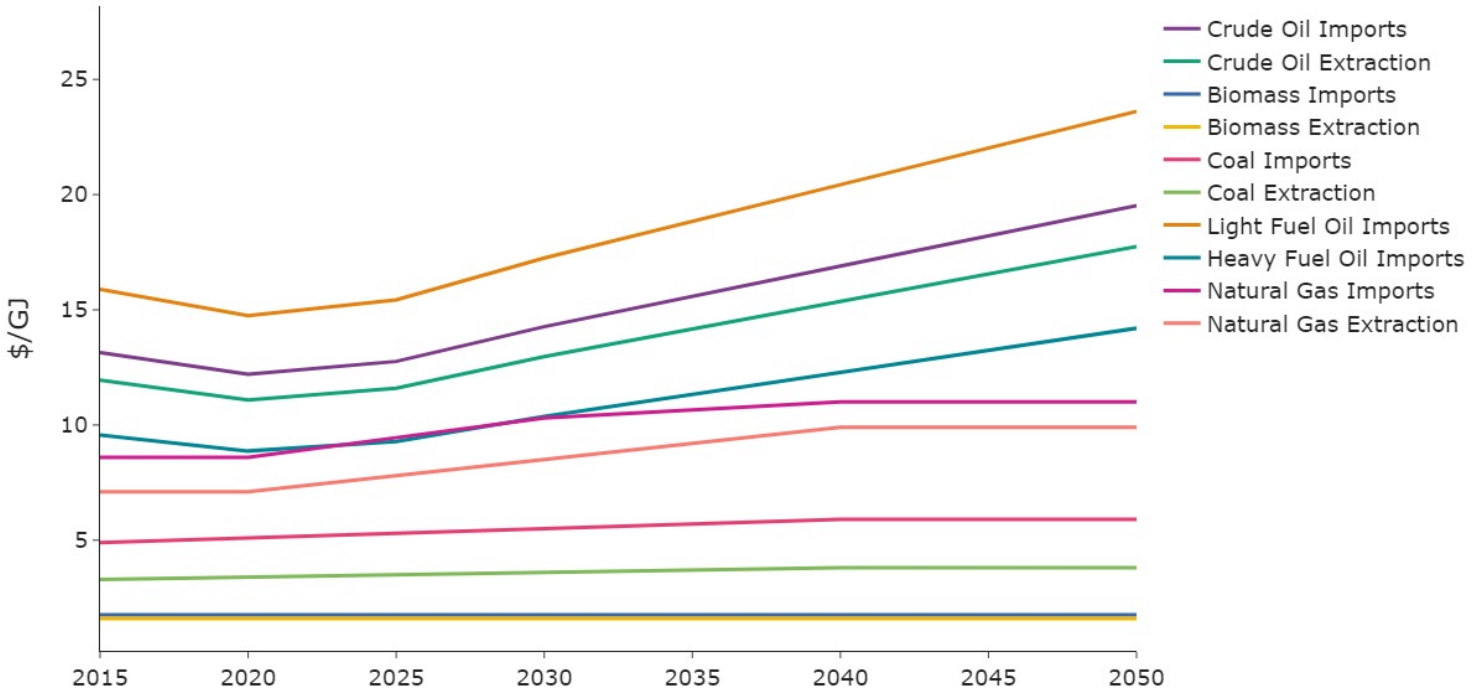
Figure 2

Fuel price projections to 2050 [16,8]

Figure 3

Electricity Demand Projection (PJ) for Angola [23]

Supplementary Files

This is a list of supplementary files associated with this preprint. Click to download.

- AngolaFossilFuture.txt
- AngolaLeastCost.txt
- Appendix.docx