Selected ‘Starter Kit’ energy system modelling data for Uruguay (#CCG)

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Data Note

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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 energy system modelling, causing delays. Therefore, this article provides data that can be used to create a simple zero order energy system model for Uruguay, 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 three stylized scenarios (Fossil Future, Least Cost and Net Zero by 2050) 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 Uruguay
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.5498103 [35].

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 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].

Data Description

The data provided in this paper can be used as input data to develop an energy system model for Uruguay. 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 as Supplementary Materials. Appendix figure A3 for Uruguay 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 Uruguay 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 2	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 3	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 Uruguay
Table 9	A table showing estimated fossil fuel reserves in Uruguay
Figure 4	A graph showing a final electricity demand projection for Uruguay from 2015–2050

1.1 Existing Electricity Supply System

The total power generation capacity in Uruguay is estimated at 5106.11 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.

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

	Estimated Installed Capacity (MW)			
Electricity Generation Technology	2015	2016	2017	2018
Biomass Power Plant	425.3	425.3	425.3	425.3
Oil Fired Gas Turbine (SCGT)	905.2	905.2	905.2	905.2
Gas Power Plant (CCGT)	570.34	570.34	570.34	570.34
Gas Power Plant (SCGT)	54.0	54.0	54.0	54.0
Solar PV (Utility)	227.0	227.0	227.0	227.0
Large Hydropower Plant (Dam) (>100MW)	1538.0	1538.0	1538.0	1538.0
Onshore Wind	1384.0	1384.0	1384.0	1384.0
Off-grid Solar PV	0.56	1.14	1.72	2.27

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 are based on the data used in the South America Model Base [7] and are applicable to South America. Projected cost reductions for renewable energy technologies were estimated by applying the cost reduction trends from a 2021 IRENA report focussing on Africa [8] to these South America-specific current cost estimates. These projections are presented in Table 3. Where technologies were not included in SAMBA, namely diesel generation technologies, medium hydropower plants and decentralised solar PV with storage, costs were estimated based on values from other reports by the IRENA [8,9]. The cost and performance of parameters of fossil electricity generation technologies are assumed constant over the modelling period. Country-specific capacity factors for solar PV, wind and hydropower technologies in Uruguay were sourced from Renewables Ninja and the PLEXOS-World 2015 Model Dataset [3,10,11], as well as an NREL dataset [12]. Capacity factors for other technologies were sourced from SAMBA [7] and are applicable to South America. 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	1905.0	13.0	25	0.35	0.66
Coal Power Plant	2500.0	40.0	40	0.43	0.85
Geothermal Power Plant	3796.47	100.0	20	0.11	0.85
Light Fuel Oil Power Plant	1200.0	15.0	25	0.35	0.85
Oil Fired Gas Turbine (SCGT)	1400.0	25.0	25	0.35	0.85
Gas Power Plant (CCGT)	1260.0	20.0	30	0.57	0.85
Gas Power Plant (SCGT)	583.0	10.0	30	0.38	0.85
Solar PV (Utility)	1791.02	23.28	25	1.0	0.17
CSP with Storage	5797.0	57.97	40	0.35	0.4
Large Hydropower Plant (Dam) (> 100MW)	2939.0	88.17	60	1.0	0.52
Medium Hydropower Plant (10-100MW)	2500.0	75.0	60	1.0	0.52
Small Hydropower Plant (< 10MW)	3499.0	104.97	60	1.0	0.52
Onshore Wind	1582.33	63.29	30	1.0	0.27
Offshore Wind	3928.19	157.13	25	1.0	0.31
Nuclear Power Plant	6318.0	189.54	40	0.35	0.85
Light Fuel Oil Standalone Generator (1kW)	750.0	23.0	20	0.42	0.4
Solar PV (Distributed with Storage)	4320.0	86.4	24	1.0	0.17

Table 3
Projected costs of renewable energy technologies for selected years to 2050. [7,8,9]

	Capital Cost ($/kW)					
Renewable Energy Technology	2015	2020	2025	2030	2040	2050
Biomass Power Plant	1905.0	1905.0	1905.0	1905.0	1905.0	1905.0
Solar PV (Utility)	1898.79	1791.02	1683.26	1575.49	1359.96	1144.43
CSP with Storage	8652.93	5797.0	4670.0	3763.0	3660.0	3660.0
Large Hydropower Plant (Dam) (> 100MW)	2939.0	2939.0	2939.0	2939.0	2939.0	2939.0
Medium Hydropower Plant (10-100MW)	2500.0	2500.0	2500.0	2500.0	2500.0	2500.0
Small Hydropower Plant (< 10MW)	3499.0	3499.0	3499.0	3499.0	3499.0	3499.0
Onshore Wind	1620.0	1582.33	1544.65	1506.98	1431.63	1356.28
Offshore Wind	4104.0	3928.19	3752.37	3576.56	3224.93	2873.3
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 efficiency of power transmission and distribution were taken from the SAMBA dataset [7], which gives estimated efficiencies by country, including projected efficiencies to 2063. The efficiencies of transmission and distribution in Uruguay are therefore assumed to reach 96.0% and 91.0% in 2030 and 96.0% and 94.0% in 2050 respectively. The costs and operational life of transmission and distribution technologies were also taken from SAMBA, which gives estimates relevant to South America, including future projections.

Table 4
Techno-economic parameters for transmission and distribution [7]

Technology	**Capital Cost ($/kW in 2020)**	**Operational Life (years)**	**Efficiency (2020)**	**Efficiency (2030)**	**Efficiency (2050)**
Electricity Transmission	746	60	0.95	0.96	0.96
Electricity Distribution	1491	60	0.89	0.91	0.94

1.4 Techno-economic Data for Refineries

Uruguay has an estimated 50kb/d domestic refinery capacity [13]. 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 [13,14]

Technology	Capital Cost ($/PJ in 2020)	Variable Cost ($/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 estimates based on an international oil price forecast [15] for oil and oil products, the SAMBA dataset [7] for natural gas, and a report on international biomass markets [16]. More detail is provided in Sect. 2.2.

Table 6
Fuel price projections to 2050 [7,15,16]

	Fuel Price ($/GJ)					
Commodity	2015	2020	2025	2030	2040	2050
Crude Oil Imports	13.14	12.2	12.76	14.27	16.9	19.52
Crude Oil Extraction	11.95	11.09	11.6	12.97	15.36	17.75
Biomass Imports	6.16	6.16	6.16	6.16	6.16	6.16
Biomass Extraction	5.6	5.6	5.6	5.6	5.6	5.6
Coal Imports	3.2	3.55	3.64	3.73	3.9	4.26
Coal Extraction	2.91	3.23	3.31	3.39	3.55	3.87
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	3.76	4.65	5.54	6.43	8.22	10.01
Natural Gas Extraction	3.41	4.22	5.04	5.85	7.48	9.1

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 CO2 Emission Factors [17]

Fuel	CO2 Emission Factor (kg CO2/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 estimated domestic renewable energy potentials and fossil fuel reserves respectively in Uruguay.

Table A1
Definitions of the three model scenarios.

Scenario	Definition
Fossil Future	No new investments in renewable or nuclear power generation, electric stoves and heating, electric transport or energy efficiency are permitted.
Least Cost	No new investment in nuclear power is permitted. Gradual investment constraints are applied to demand-side fuel-switching and energy efficiency, whereby only up to 5% of each technology's 2050 capacity in a run without demand-side investment constraints can be invested in annually. No additional constraints are applied to find the cost-optimal solution.
Net Zero by 2050	Domestic production and imports of fossil fuels and biomass gradually decline to 0 in 2050, beginning in 2021, resulting in a gradual decline to zero carbon dioxide emissions in 2050. No new investment in nuclear power is permitted. Gradual investment constraints are applied to demand-side fuel-switching and energy efficiency, whereby only up to 5% of each technology's 2050 capacity in a run without demand-side investment constraints can be invested in annually from 2021–2039, rising to 10% from 2040–2050 to reflect greater ambition.
A3 Scenario Results for Uruguay	
The graphs below show selected results for the three modelled scenarios, including yearly electricity generation and supply capacity, fuel use in the transport sector and total annual carbon dioxide emissions for 2020–2050.	
A3.1 Electricity Generation Results	

Table 8
Estimated Renewable Energy Potentials [12,18,19,20]

	Unit	Estimated Renewable Energy Potential
Solar Resource	TWh/yr	480
Onshore Wind	TWh/yr	1278.61
Offshore Wind	TWh/yr	934.53
Medium & Large Hydropower	MW	1607.2
Small Hydropower (< 10MW)	MW	207.8
Geothermal	MW	0

Table 9
Estimated Fossil Fuel Reserves [7,21]

	Proven Reserves
Coal (million tonnes)	0
Crude Oil (billion barrels)	0
Natural Gas (trillion cubic feet)	0

1.8 Electricity Demand Projection

An electricity demand projection was calculated based on the Current Policy Scenario regional demand projections of the OLADE Energy Outlook 2019 [22], which were divided by country based on historic consumption data from the International Energy Agency (IEA) [23]. Final electricity demand in Uruguay was estimated at 40.0PJ in 2016 and is forecasted to reach 61.0PJ by 2030 and 101.0PJ by 2050. For more information on the final electricity demand projection, see Sect. 2. Figure 4 below shows the final electricity demand projection.

Experimental Design, Materials, And Methods

Data were primarily collected from the reports and websites of international organizations, including the Latin America Energy Organisation (OLADE), the International Renewable Energy Agency (IRENA), the International Energy Agency (IEA), and the Intergovernmental Panel on Climate Change (IPCC). Data were also collected from the South America Model Base (SAMBA) [7]. The data sources used are detailed in this section.

2.1 Electricity Supply System Data

Data on Uruguay'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 Uruguay'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 primarily collected from the SAMBA dataset [7], which provides estimates for these parameters by technology in South America. Where estimates were not available in SAMBA, costs were extrapolated from reports by IRENA for diesel electricity generation, medium hydropower, and off-grid solar PV [8,9]. The costs of renewable energy technologies are expected to fall in the future. In order to calculate estimated cost reductions in the region, technology-specific cost reduction trends from a very recent IRENA report focussing on Africa [8] were applied to the regional current cost estimates used from SAMBA [7,8,9]. For offshore wind, the cost reduction trend was instead taken from a technology-specific IRENA report on the future of wind [25] since it is not featured in [8]. The resulting cost projections are presented in Table 3 and Figure 2. It is assumed that costs fall linearly between data points and those costs remain constant beyond 2040 when the IRENA forecasts end (except for offshore wind, where the IRENA forecast continues to 2050). Fixed costs for renewable energy technologies in each year were estimated by calculating a certain percentage (ranging from 1-4% depending on the technology) of the capital cost in that year, as done by IRENA [8].

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 average monthly capacity factors for hydropower, the average values of which are presented in Table 2. Country-specific capacity factors for offshore wind were estimated based on an NREL source that gives estimates of the potential wind power capacity by capacity factor range in each country [12], from which a capacity-weighted average was calculated. The capacity factor data were also used to estimate capacity factors for 8 time slices used in the OSeMOSYS model (see detail in Annex 1). Capacity factors for other technologies were sourced from SAMBA [7], which provides estimated capacity factors for South America. The capital costs, operational lives, and efficiencies of power transmission and distribution were also taken from SAMBA [7], which provides future projections. Techno-economic data for refineries were sourced from the IEA Energy Technology Systems Analysis Programme (ETSAP) [14], which provides generic estimates of costs and performance parameters, while the refinery options modelled are based on the methods used in The Electricity Model Base for Africa (TEMBA) [26].

2.2 Fuel Data

Fuel price projections for crude oil were taken from a 2020 US EIA oil price forecast [15], based on which projections for LFO and HFO were estimated by increasing the price by 1/3 for LFO and reducing the price by 20% for HFO, as done in TEMBA [26]. The natural gas price forecast was taken from SAMBA, which provides country-specific forecasts to 2063 [7]. The domestic biomass price was estimated based on a report on international biomass markets [16] that includes cost estimates for biomass production in Brazil. This cost was increased by 10% to estimate a price for imported biomass, reflecting the cost of importation.

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. The domestic solar and wind resources were collected from NREL datasets, which provide estimates of potential yearly generation by country [12,18]. Other renewable energy potentials were sourced from a regional report by OLADE [19] and the World Small Hydropower Development Report [20], which provide estimated potentials by country. The large and medium hydropower potential was estimated by subtracting the small hydropower potential [20] from the estimated overall hydropower potential [19]. Estimated domestic coal and oil reserves were sourced from the SAMBA dataset [17], while natural gas reserves were sourced from the 2019 BP Statistical Review [21], which provide estimates of reserves by country.

2.4 Electricity Demand Data

The final electricity demand projection for Uruguay is based on the Current Policy Scenario of the OLADE Energy Outlook 2019 [22], which provides regional aggregated demand projections to 2040.These regional cost projections were divided by country using historical consumption data from the IEA [23], and extended to 2050 by extrapolating the growth trend to 2050.

Declarations

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. Mark Howells: Conceptualisation; Methodology; Writing – Review & Editing; Supervision. Miriam Zachau Walker: Software. Aniq Ahsan: Software. Flora Charbonnier: Software. Claire Halloran: Software. Stephanie Hirmer: Supervision; Writing - Review & Editing. Constantinos Taliotis: Conceptualisation; Writing - Review & Editing. Caroline Sundin: Conceptualisation; Writing - Review & Editing. Vignesh Sridharan: Conceptualisation. Eunice Ramos: Conceptualisation. Maarten Brinkerink: Data curation. Paul Deane: Data Curation. Gustavo Moura: Data Curation. Arnaud Rouget: Conceptualisation. Andrii Gritsevskyi: Conceptualisation. David Wogan: Conceptualisation. Edito Barcelona: Conceptualisation. Holger Rogner: Conceptualisation.

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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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Figures

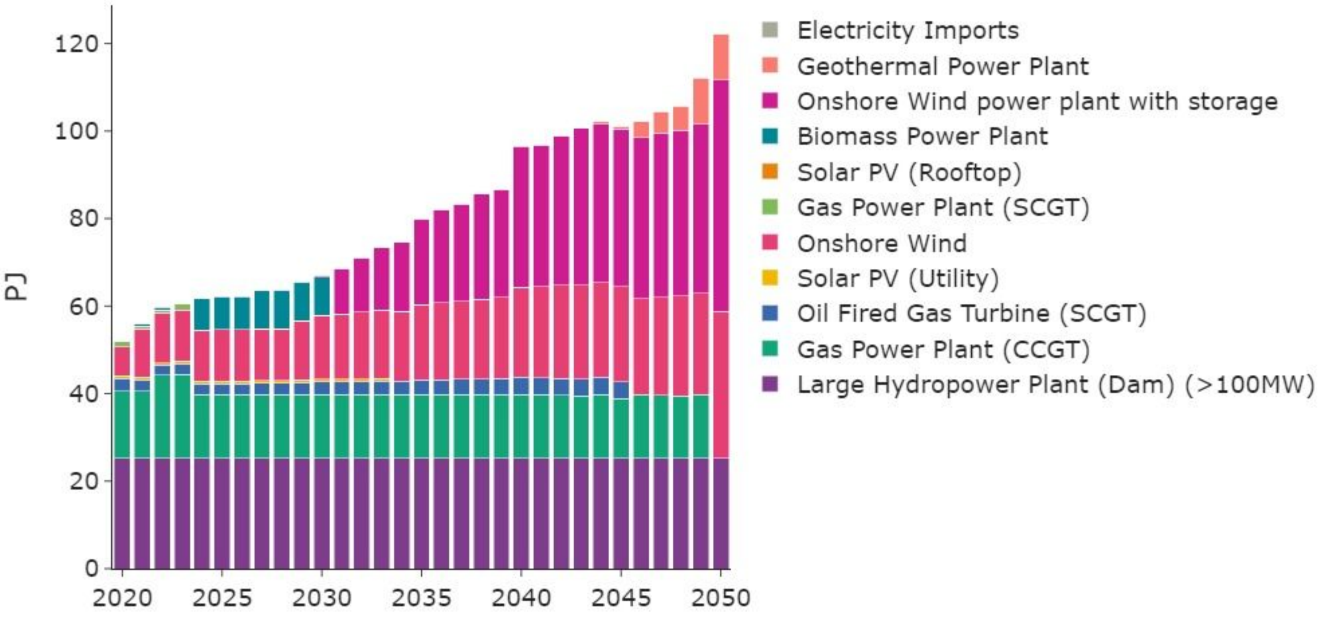

Figure 1

An illustrative example of a zero-order least-cost energy scenario for Uruguay’s electricity production produced using the data presented in this paper.

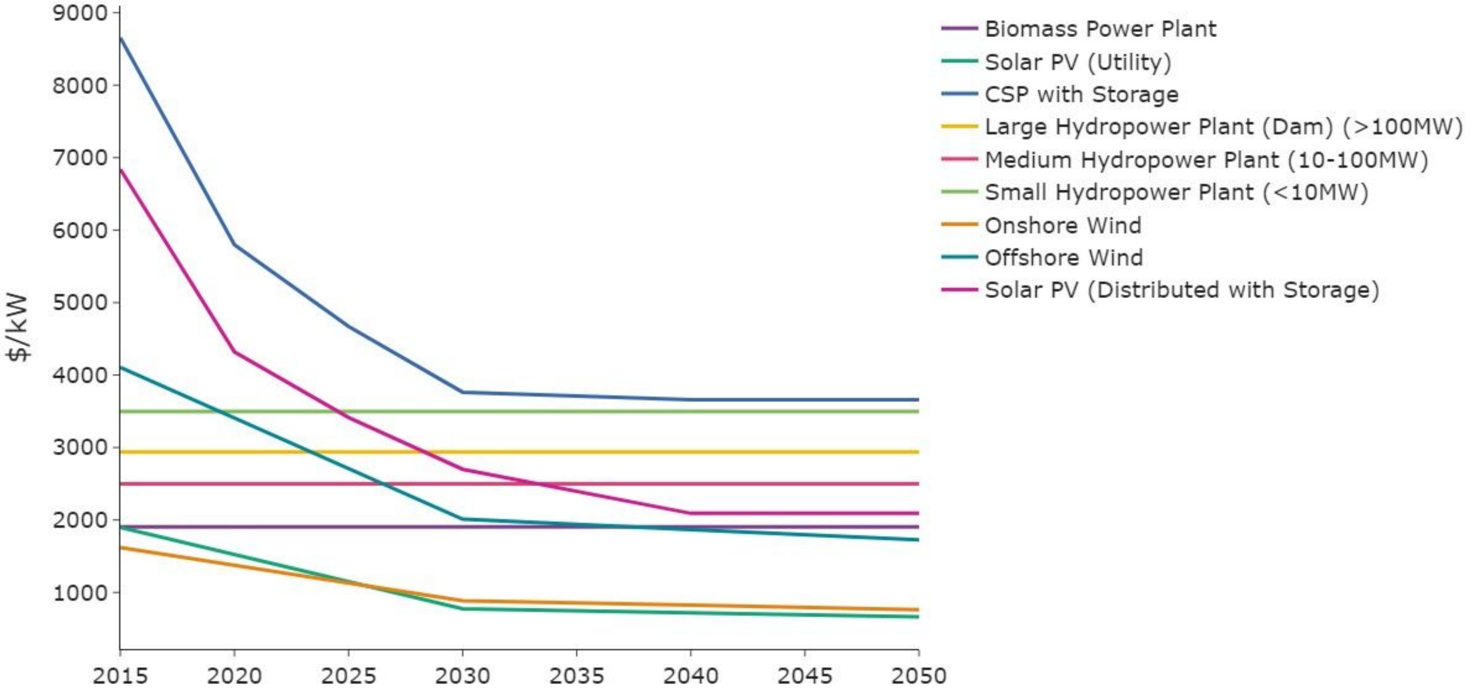

Figure 2

Projected costs of renewable energy technologies for selected years to 2050 [7,8,9]

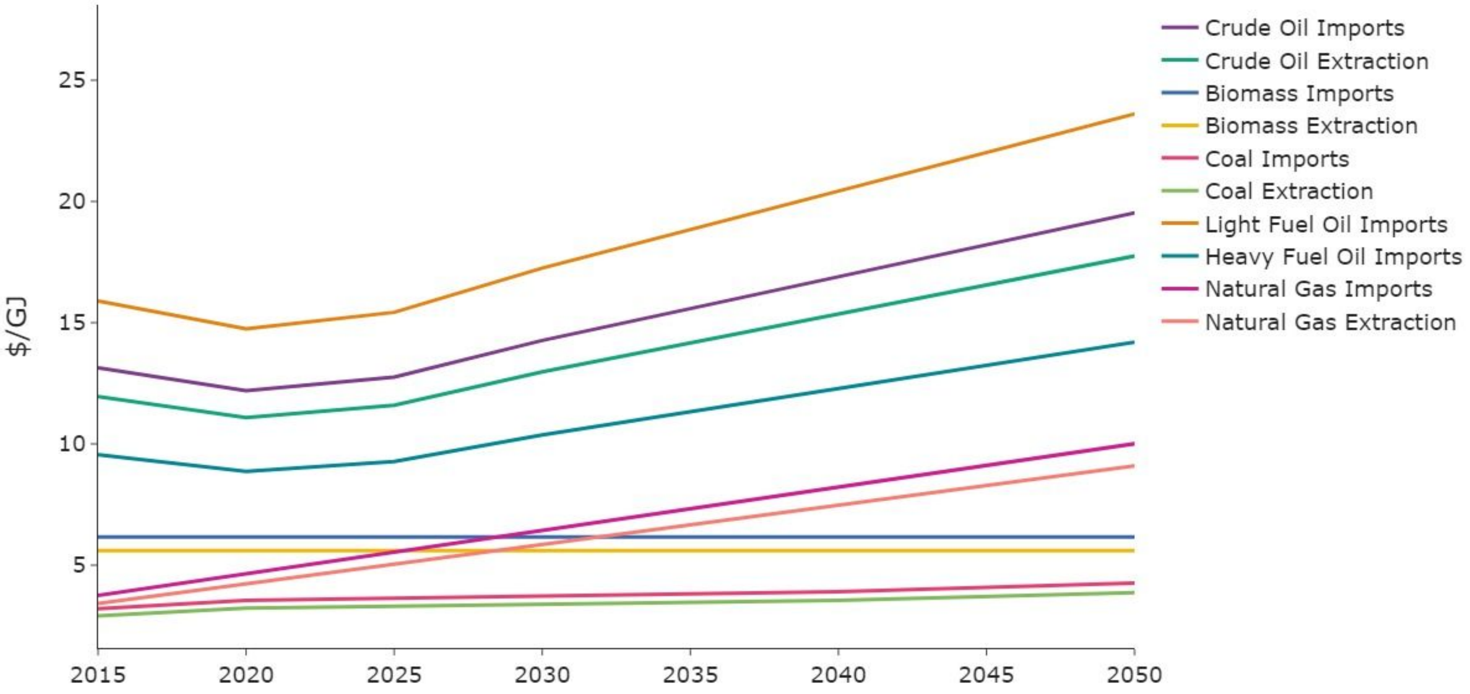

Figure 3

Fuel price projections to 2050 [7,15,16]

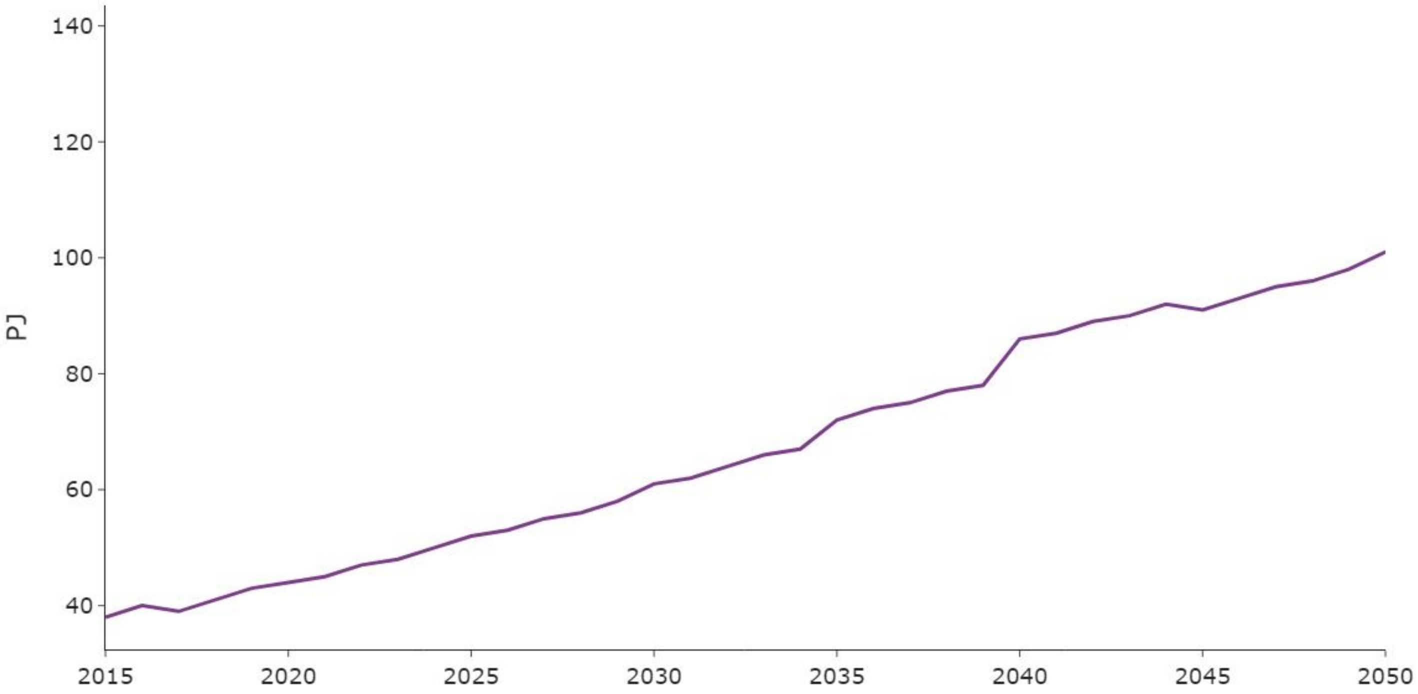

Figure 4

Final Electricity Demand Projection (PJ) [22,23]

Supplementary Files

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

- UruguayFF.txt
- UruguayLCv2.txt
- UruguayNZv2.txt
- appendix.docx