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

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Carla Cannone (c.cannone@lboro.ac.uk)
STEER Centre, Department of Geography, Loughborough University https://orcid.org/0000-0002-1214-8913
Lucy Allington (lallington9@gmail.com)
STEER Centre, Department of Geography, Loughborough University https://orcid.org/0000-0003-1801-899X
Ioannis Pappis
KTH Royal Institute of Technology https://orcid.org/0000-0001-7537-5470
Karla Cervantes Barron
University of Cambridge https://orcid.org/0000-0001-9185-3022
Will Usher
KTH Royal Institute of Technology https://orcid.org/0000-0001-9367-1791
Steve Pye
University College London https://orcid.org/0000-0003-1793-2552
Edward Brown
STEER Centre, Department of Geography, Loughborough University https://orcid.org/0000-0002-0722-9348
Mark Howells
STEER Centre, Department of Geography, Loughborough University; Imperial College London https://orcid.org/0000-0001-6419-4957
Miriam Zachau Walker
University of Oxford https://orcid.org/0000-0002-4757-3688
Aniq Ahsan
University of Oxford https://orcid.org/0000-0002-6027-4818
Flora Charbonnier
University of Oxford https://orcid.org/0000-0003-3174-0362
Claire Halloran
University of Oxford https://orcid.org/0000-0002-0308-5623
Stephanie Hirmer
University of Oxford https://orcid.org/0000-0001-7628-9259
Constantinos Taliotis
KTH Royal Institute of Technology; The Cyprus Institute https://orcid.org/0000-0003-4022-5506
Caroline Sundin
KTH Royal Institute of Technology
Vignesh Sridharan
KTH Royal Institute of Technology https://orcid.org/0000-0003-0764-2615
Eunice Ramos
KTH Royal Institute of Technology https://orcid.org/0000-0001-9061-8485
Maarten Brinkerink
University College Cork https://orcid.org/0000-0002-8980-9062
Paul Deane
University College Cork https://orcid.org/0000-0002-4681-7791
Andrii Gritsevskyi
International Atomic Energy Agency
Gustavo Moura
Federal University of Ouro Preto
Arnaud Rouget
International Energy Agency
David Wogan
Asia Pacific Energy Research Centre
Edito Barcelona
Asia Pacific Energy Research Centre
Holger Rogner
KTH Royal Institute of Technology https://orcid.org/0000-0002-1045-9830
Jen Cronin
University College London https://orcid.org/0000-0002-2888-400X

Data Note

Keywords: U4RIA, Renewable energy, Cost-optimization, Taiwan, Energy policy, CCG, OSeMOSYS

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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 Taiwan, 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 Taiwan
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: http://doi.org/10.5281/zenodo.5139521

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].

1 Data Description

The data provided in this paper can be used as input data to develop an energy system model for Taiwan. 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. Figure 1 shows a zero-order model of the production of electricity by technology over the period 2020 to 2050 for a least cost energy future. This is purely illustrative. 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.

1.1 Existing Electricity Supply System

The total power generation capacity in Taiwan is estimated at 46109.64 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 Section 2.1.

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

Electricity Generation Technology	Estimated Installed Capacity (MW)			
	2015	2016	2017	2018
Biomass Power Plant	740.0	740.0	740.0	740.0
Coal Power Plant	18650.42	18650.42	18650.42	18650.42
Oil Fired Gas Turbine (SCGT)	2631.94	2631.94	2631.94	2631.94
Gas Power Plant (CCGT)	13560.64	13560.64	13560.64	13560.64
Solar PV (Utility)	842.0	842.0	842.0	842.0
Large Hydropower Plant (Dam) (>100MW)	3778.0	3778.0	3778.0	3778.0
Medium Hydropower Plant (10-100MW)	41.0	41.0	41.0	41.0
Small Hydropower Plant (<10MW)	3.0	3.0	3.0	3.0
Onshore Wind	646.64	646.64	646.64	646.64
Nuclear Power Plant	5216.0	5216.0	5216.0	5216.0
Total Capacity	46109.64	46109.64	46109.64	46109.64

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 reports by the International Renewable Energy Agency (IRENA) and the ASEAN Centre for Clean Energy (ACE) [7,8] and are applicable to Asia. Projected cost reductions for renewable energy technologies were estimated by applying the cost reduction trends from a 2021 IRENA report focussing on Africa [9] to these Asia-specific current cost estimates. These projections are presented in Table 3. 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 Taiwan 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 IRENA and ACE [7] and are applicable to Asia. 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 Section 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	2750.0	69.0	25	0.38	0.7
Coal Power Plant	1300.0	52.0	60	0.3	0.75
Geothermal Power Plant	2500.0	100.0	50	0.1	0.7
Light Fuel Oil Power Plant	1200.0	18.0	50	0.4	0.25
Oil Fired Gas Turbine (SCGT)	1344.0	18.0	50	0.4	0.25
Gas Power Plant (CCGT)	1000.0	40.0	30	0.55	0.55
Gas Power Plant (SCGT)	784.0	23.0	30	0.35	0.55
Solar PV (Utility)	1160.0	15.08	30	1.0	0.24
CSP with Storage	4965.31	120.0	35	0.33	0.3
Large Hydropower Plant (Dam) (>100MW)	1539.0	46.17	40	1.0	0.19
Medium Hydropower Plant (10-100MW)	1592.86	47.79	40	1.0	0.19
Small Hydropower Plant (<10MW)	2162.0	64.86	40	1.0	0.19
Onshore Wind	2220.09	88.8	30	1.0	0.27
Offshore Wind	2876.21	115.05	30	1.0	0.34
Nuclear Power Plant	5500.0	138.0	60	0.33	0.83
Light Fuel Oil Standalone Generator (1kW)	1500.0	38.0	20	0.42	0.4
Solar PV (Distributed with Storage)	2130.8	42.62	24	1.0	0.24

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

Renewable Energy Technology	Capital Cost ($/kW)					
	2015	2020	2025	2030	2040	2050
Biomass Power Plant	2750.0	2750.0	2750.0	2750.0	2750.0	2750.0
Solar PV (Utility)	1822.5	1160.0	828.33	745.83	608.62	608.62
CSP with Storage	7404.71	4965.31	4000.0	3223.13	3134.9	3134.9
Large Hydropower Plant (Dam) (>100MW)	1539.0	1539.0	1539.0	1539.0	1539.0	1539.0
Medium Hydropower Plant (10-100MW)	1592.86	1592.86	1592.86	1592.86	1592.86	1592.86
Small Hydropower Plant (<10MW)	2162.0	2162.0	2162.0	2162.0	2162.0	2162.0
Onshore Wind	2959.63	2220.09	1775.78	1620.71	1391.1	1391.1
Offshore Wind	3620.25	2876.21	2187.28	1773.92	1647.21	1520.5
Solar PV (Distributed with Storage)	3502.0	2130.8	1880.8	1755.8	1690.8	1625.8

1.3 Techno-economic Data for Power Transmission and Distribution

The combined losses in electricity transmission and distribution in Taiwan in 2014 are estimated based on a study by Singh and Kumar [13]. It was then assumed that combined losses would be reduced to 5% by 2050, falling in a linear fashion. Combined transmission and distribution efficiency in Taiwan is therefore assumed to reach 93.0% and 95.0% in 2030 and 2050 respectively. The combined costs of power tansmission and distribution are estimated based on a report by the Economic Research Institute for ASEAN and East Asia (ERIA) [14], which gives cost estimates for several real-life projects in ASEAN. For more detail, see section 2.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 [13,14]

Technology	Capital Cost ($/kW, 2020)	Fixed Cost ($/kw/yr, 2020)	Operational Life (years)	Combined Efficiency (2020)	Combined Efficiency (2030)	Combined Efficiency (2050)
Electricity Transmission and Distribution	306.39	6.13	50	0.92	0.93	0.95

1.4 Techno-economic Data for Refineries

Taiwan has an estimated 1230kb/d domestic refinery capacity [15]. 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 [15,16]

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 estimates based on Asia-specific cost estimates produced by the Asia Pacific Economic Cooperation (APEC) and ERIA [17.18], with an international average biomass price in 2020 assumed for imported biomass [19]. More detail is provided in Section 2.2.

Table 6: Fuel price projections to 2050 [17,18,19]

Commodity	Fuel Price ($/GJ)					
	2015	2020	2025	2030	2040	2050
Crude Oil Imports	6.27	13.95	15.12	16.29	19.84	21.33
Crude Oil Extraction	5.7	12.68	13.75	14.81	18.03	19.39
Biomass Imports	5.55	5.55	5.55	5.55	5.55	5.55
Biomass Extraction	1.34	1.34	1.34	1.34	1.34	1.34
Coal Imports	2.38	3.03	3.09	3.15	3.53	3.61
Coal Extraction	2.16	2.72	2.77	2.82	3.18	3.25
Light Fuel Oil Imports	6.83	15.21	16.49	17.77	21.64	23.26
Heavy Fuel Oil Imports	5.99	13.3	14.43	15.55	18.94	20.35
Natural Gas Imports	5.71	9.98	10.17	10.37	10.72	10.75
Natural Gas Extraction	5.16	8.98	9.16	9.34	9.65	9.67

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 [20]

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 Taiwan.

Table 8: Estimated Renewable Energy Potentials [12,21,22]

	Unit	Estimated Renewable Energy Potential
Solar PV	TWh/yr	36.1
Onshore Wind	TWh/yr	1888.6
Offshore Wind	TWh/yr	73
Medium & Large Hydropower	MW	25700
Geothermal	MW	714

Table 9: Estimated Fossil Fuel Reserves [17]

	Proven Reserves
Coal (million tonnes)	0.0
Crude Oil (billion barrels)	0.0
Natural Gas (trillion cubic metres)	0.0

1.8 Electricity Demand Projection

Final electricity demand in Taiwan was estimated at 849.79 PJ in 2016 and is forecasted to reach 917.63 PJ by 2030 and 901.37 PJ by 2050 in a Business as Usual (BAU) scenario according to the APEC Energy Supply and Demand Outlook 7th Edition [17]. Figure 4 below shows the final 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 Asia Pacific Economic Cooperation (APEC), the Economic Research Institute for ASEAN and East Asia (ERIA), the International Energy Agency (IEA), and the Intergovernmental Panel on Climate Change (IPCC). The data sources used are detailed in this section.

2.1 Electricity Supply System Data

Data on Taiwan'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 [23]. 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. Cost, efficiency and operational life data in Table 2 were collected from reports by IRENA and ACE [7,8], which provide estimates for these parameters by technology in ASEAN and other Asian countries. 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 [9] were applied to the current Asia-specific cost estimates [7,8]. 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 [9]. The resulting cost projections are presented in Table 3 and Figure 2. It is 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). 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 [9].

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 [22], 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 a reports by IRENA [7], which provides estimated capacity factors for ASEAN. The combined capital costs of power transmission and distribution are estimated based on an ERIA report which gives estimated capital costs for 9 projects in ASEAN [14], with an average value used. The fixed operational cost is assumed to be 2% of the estimated capital cost, as done by ERIA [14]. The combined losses of transmission and distribution in 2014 were sourced from a study by Singh and Kumar [13], and it was then assumed that combined losses would fall to 5% by 2050 in a linear fashion from 2014. Techno-economic data for refineries were sourced from the IEA Energy Technology Systems Analysis Programme (ETSAP) [16], 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 [25].

2.2 Fuel Data

Fuel prices for crude oil, diesel, fuel oil, natural gas and coal were taken from the APEC Energy Outlook 7th Edition [17], which provides cost estimates by fuel from 2016 to 2050. APEC provide different natural gas and coal prices for net importers, exporters, and neutral countries, with the relevant prices used for the country. The domestic biomass price was estimated from an ERIA report that gives a local average in Thailand [18], since this was the most region-specific cost estimate that could be sourced. The imported biomass price is an international average taken from a 2021 biomass markets report by Argus Media [19].

2.3 Emissions Factors and Domestic Reserves

Emissions factors were collected from the IPCC Emission Factor Database [20], which provides carbon emissions factors by fuel. The domestic wind resources were collected from an NREL dataset, which provides estimates of potential yearly generation by country [12]. Other renewable energy potentials were sourced from national studies [21,22]. Estimated domestic fossil fuel reserves were sourced from the APEC Energy Outlook 7th Edition [17], which provides estimates of reserves by country. Although Taiwan may have some domestic coal resources, an estimate could not be sourced since reserves have not been estimated since production stopped in 2001 [17].

2.4 Electricity Demand Data

The final electricity demand projection is based on the BAU projection from the APEC Energy Outlook 7th Edition [17], which provides total demand estimates for every five years from 2015 to 2050, with demand assumed to change linearly between these data points.

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. Edward Brown: Funding Acquisition. 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. Jennifer Cronin: Writing - Review & Editing.

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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Figures

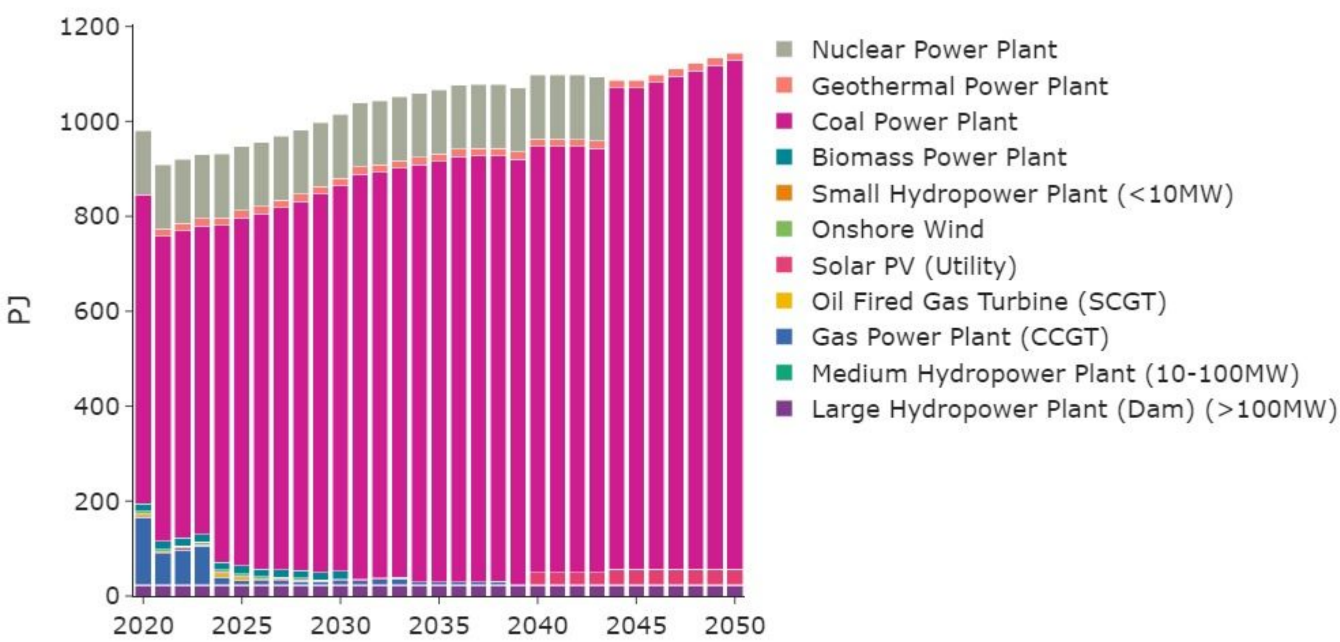

Figure 1

An illustrative example of a zero-order least-cost energy scenario for Taiwan produced using the data presented in this paper.

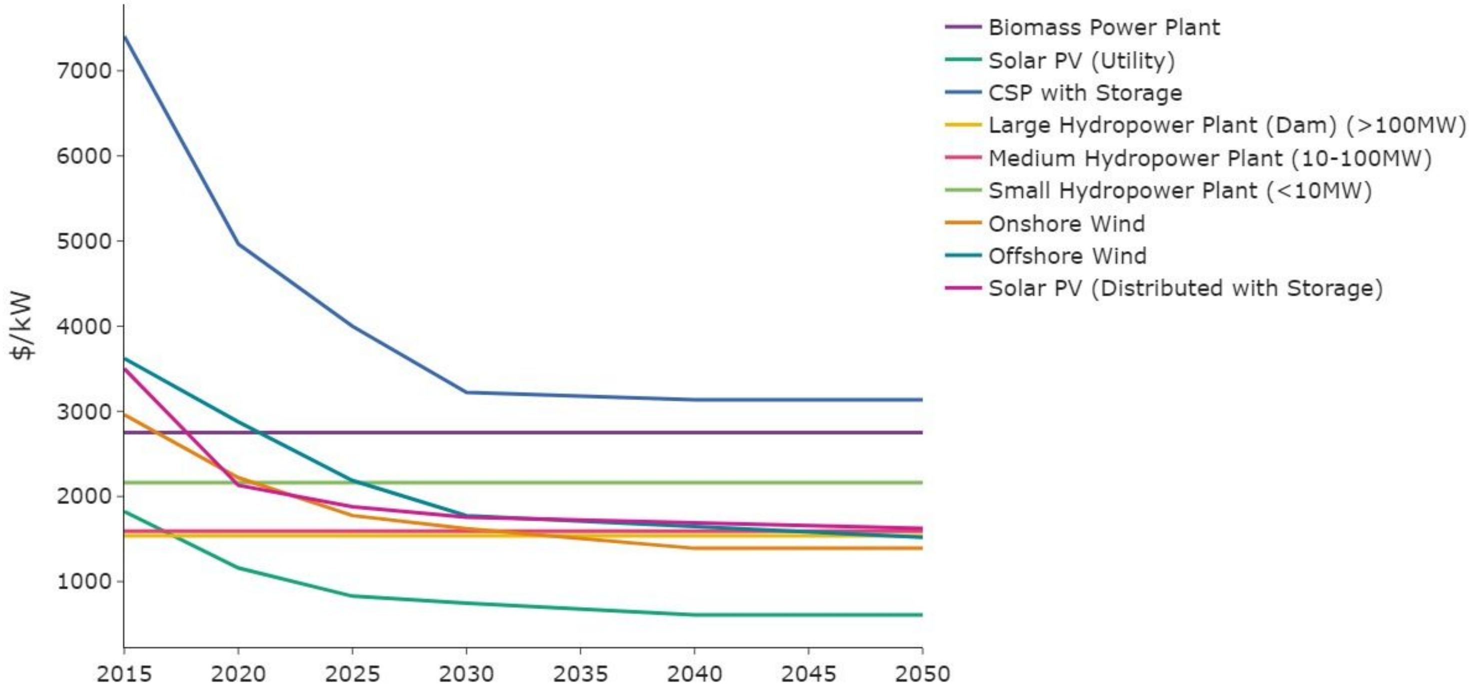

Figure 2

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

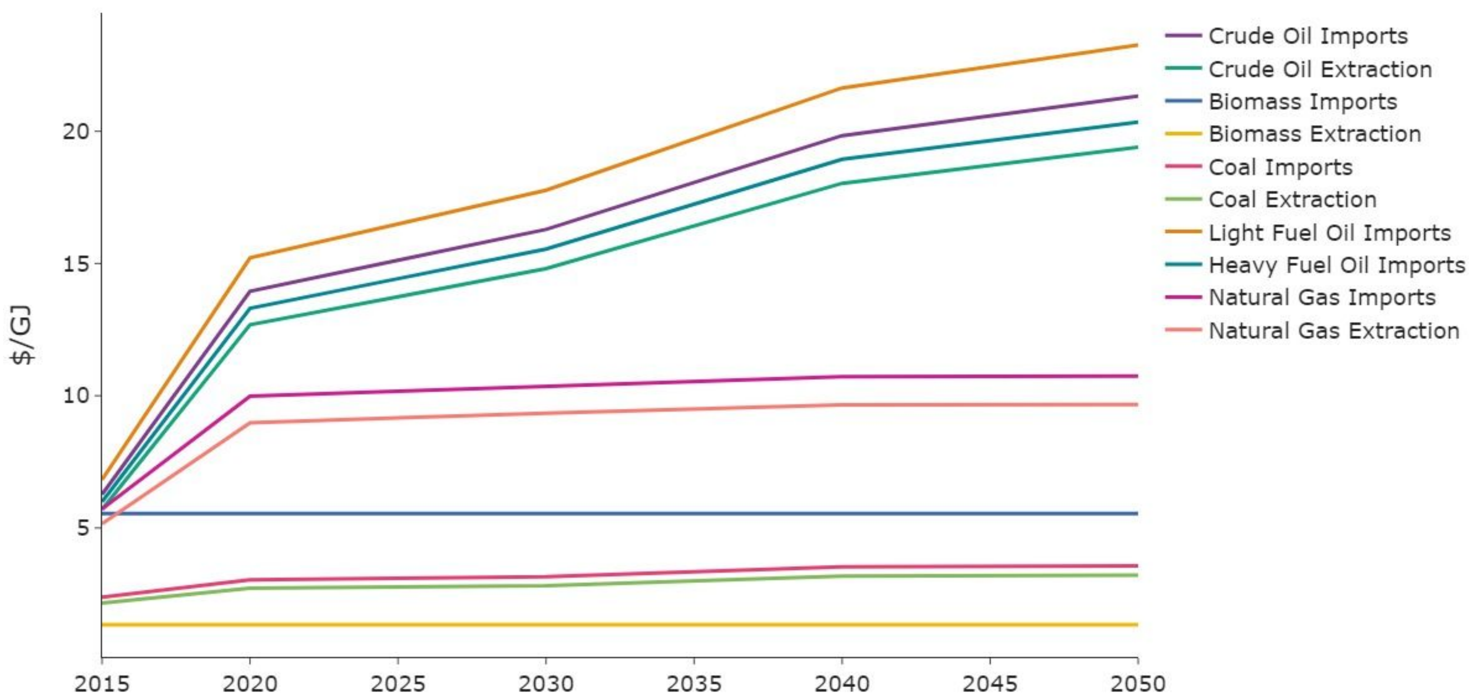

Figure 3

Fuel price projections to 2050 [17,18,19]

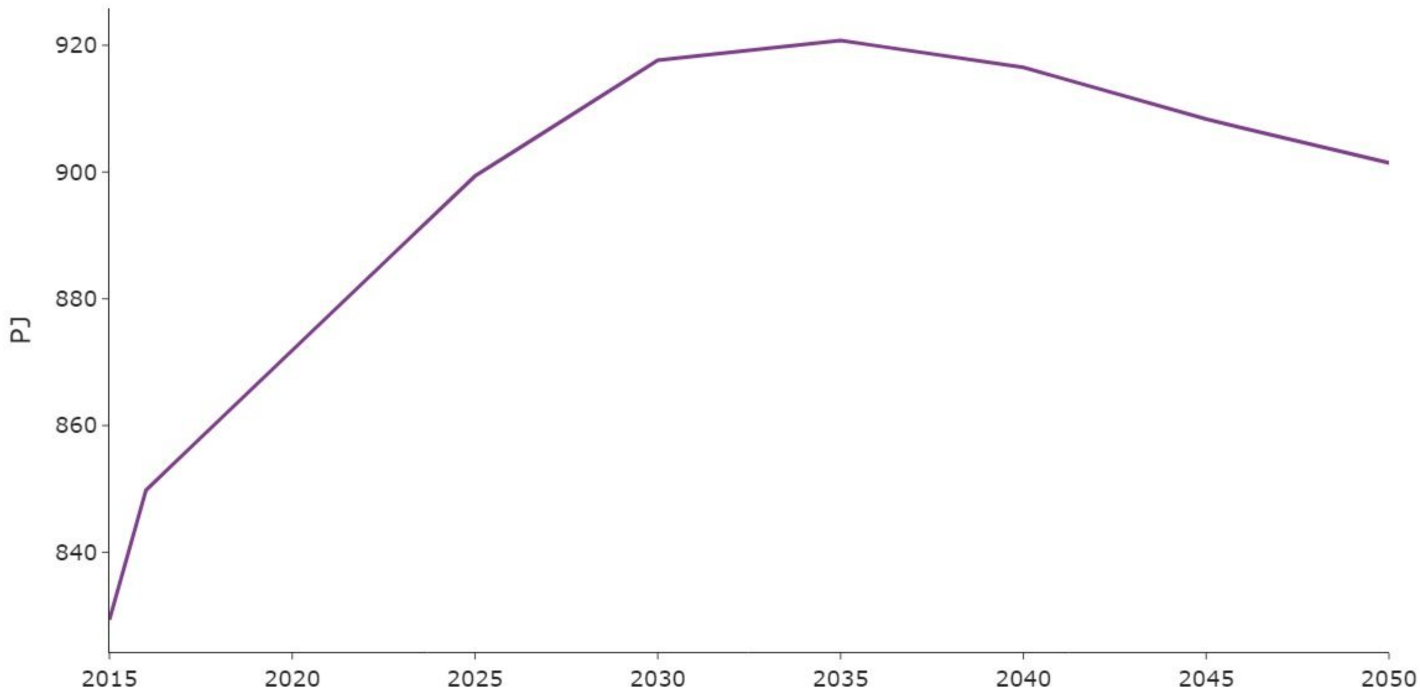

Figure 4

Final Electricity Demand Projection (PJ) [17]

Supplementary Files

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

- TaiwanSupplementaryMaterials.zip
- Appendix.docx