Decarbonization Pathways for Paraguay's Energy Sector

Appendices

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November 2021

Appendix A: Useful Energy by Sector in Paraguay in 2018

This appendix describes in depth the full set of assumptions underlying the 2018 baseline for useful energy in Paraguay calculated by the authors, which serves as a basis for Scenarios 1, 2, and 3 presented in Section 1.3 of the report.

While demand for electricity has increased consistently since the 1990's, electricity consumption varies by sector as well as location in urban or rural areas. In this section, each sub-sector of Paraguay is broken down by energy source and application to provide a holistic picture of electricity consumption throughout the country. The values provided in the following tables are the useful energy values of each sub-sector and fuel type. These energy values are the final amounts of energy used by each sector, reduced by the energy efficiency percentage of each sub-sector. Some fuels are more energy dense than others, and these differences are accounted for in the values below.

Residential Sector

The residential sector is divided between urban and rural residences. Urban residences have a higher access to electricity and more advanced technologies in home appliances than rural ones. Consequently, in the urban-residential sector, a high amount of energy derives from electricity. As a whole, 69.2% of energy use in this sector comes from electricity (Table 1).

Table 1: Energy Use in the Urban-Residential Sector by Application

Sector	Urban							
Useful Energy (toe)	366,552							
Applications	***LPG***	***Kerosene***	***Firewood***	***Charcoal***	***Petrol***	***Biomass Waste***	***Electricity***	**Total**
Illumination	0	4	0	0	0	0	4,705	**4,708**
Cooking	68,813	10	18,323	16,917	0	841	16,468	**121,372**
Water Heating	1,910	0	2,313	2,273	0	143	61,679	**68,318**
Heating	5	0	326	37	0	5	1,116	**1,490**
Food Preservation	0	0	0	0	0	0	63,228	**63,228**
Cooling and Vent.	0	0	0	0	0	0	57,004	**57,004**
Pumping Water	0	0	0	0	7	0	498	**505**
Other	0	0	0	5	23	0	49,899	**49,927**
TOTAL	**70,728**	**14**	**20,961**	**19,232**	**30**	**989**	**254,597**	**366,552**

Source: Prepared by authors based on BEN 2018 and BNEU 2011.

Conversely, the rural-residential sector (Table 2) relies much more heavily on firewood and charcoal for cooking. Also, the magnitude of electricity consumption is much lower for almost every application identified. However, electricity use still accounts for 51.5% of all energy use.

Table 2: Energy Use in the Rural-Residential Sector by Application

Sector	Rural							
Useful Energy (toe)	199,346							
Applications	***LPG***	***Kerosene***	***Firewood***	***Charcoal***	***Petrol***	***Biomass Waste***	***Electricity***	**Total**
Illumination	0	6	0	0	0	0	1,995	**2,001**
Cooking	24,418	0	58,224	6,150	0	370	5,459	**94,621**
Water Heating	88	0	6,740	363	0	31	19,631	**26,854**
Heating	0	0	658	35	0	0	214	**907**
Food Preservation	0	0	0	0	0	0	35,861	**35,861**
Cooling and Vent.	0	0	0	0	0	0	17,314	**17,314**
Pumping Water	0	0	0	0	0	0	1,166	**1,166**
Other	0	0	0	3	242	0	20,377	**20,622**
TOTAL	**24,506**	**6**	**65,622**	**6,551**	**242**	**402**	**102,017**	**199,346**

Source: Prepared by authors based on BEN 2018 and BNEU 2011

Commercial, Services, and Public Sectors

The commercial, services, and public sectors rely mainly on electricity for energy use, with the highest amount of energy being used for cooling and ventilation. Table 3 identifies the breakdown of energy use by application estimating the energy use by subsector. Electricity use accounts for 97.3% of all energy use in this sector.

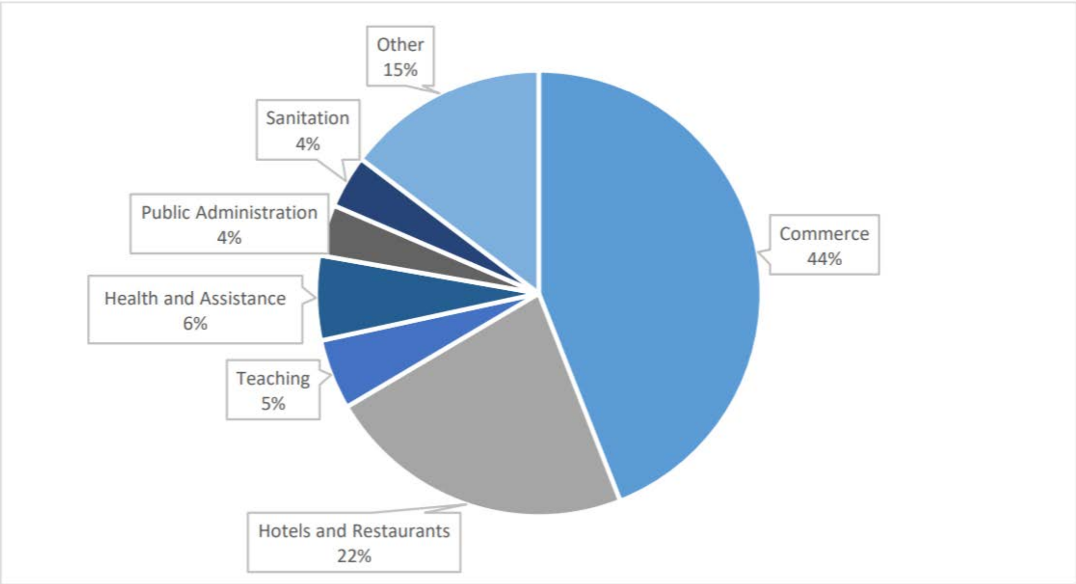
Table 3: Energy Use in the Commercial , Services, and Public Sectors by Application

Sector	Services						
Useful Energy (toe)	262,223						
Applications	***LPG***	***Motor Fuel***	***Diesel Oil***	***Firewood***	***Charcoal***	***Electricity***	**Total**
Illumination	0	0	0	0	0	9,645	**9,645**
Cooking	6,142	0	0	414	275	6,984	**13,815**
Water Heating	545	0	0	321	0	15,655	**16,521**
Heating	0	0	0	3	0	22,151	**22,154**
Food Preservation	0	0	0	0	0	55,147	**55,147**
Cooling and Vent.	0	0	0	0	0	86,980	**86,980**
Pumping Water	0	0	0	0	0	14,087	**14,087**
Driving Force	0	0	0	0	0	5,980	**5,980**
Other	41	15	1	108	0	37,556	**37,721**
Internal Transportation	47	6	100	0	0	20	**173**
TOTAL	**6,775**	**21**	**101**	**846**	**275**	**254,205**	**262,223**

Source: Prepared by authors based on BEN 2018 and BNEU 2011

Most of the total energy demand in this sector is consumed by commerce, hotels and restaurants as shown in Figure 1.

Figure 1: Energy Use in the Commercial, Services and Public Sectors by Sub-Sector



Source: Prepared by authors based on BEN 2018 and BNEU 2011.

Manufacturing Sector

Manufacturing in Paraguay continues to rely heavily on fossil fuels and biomass to generate steam and direct heat. Table 4 highlights these uses and the highest rates of consumption. Electricity use only accounts for 14.0% of energy use.

Table 4: Energy Use in the Manufacturing Sector by Application

Sector Useful Energy (toe)	Manufacture 922,333										
Applications	***LPG***	***Motor Fuel***	***Diesel Oil***	***Fuel Oil***	***Mineral Carbon***	***Petroleum Coke***	***Firewood***	***Charcoal***	***Biomass Waste***	***Electricity***	**Total**
Illumination	0	0	0	0	0	0	0	0	0	1,721	**1,721**
Steam	111	0	794	18	0	0	217,828	0	92,440	668	**311,859**
Direct Heat	611	0	96	3,052	2,780	33,460.0	233,654	7,382	10,841	9,188	**301,065**
Driving Force	0	19	614	0	0	0	0	0	178,328	108,905	**287,866**
Process Cold	0	0	0	0	0	0	0	0	0	10,967	**10,967**
Internal Transportation	21	235	1,062	0	0	0	0	0	0	288	**1,605**
Electrochemical Processes	0	0	0	0	0	0	0	0	0	16	**16**
Non-Productive Uses	16	0	0	0	0	0	0	0	0	7,218	**7,233**
TOTAL	**759**	**254**	**2,344**	**3,070**	**2,780**	**33,460**	**451,482**	**7,382**	**281,609**	**138,634**	**922,333**

Source: Prepared by authors based on BEN 2018 and BNEU 2011.

Transportation Sector

Table 5 highlights that cars are the highest consuming mode of transportation for energy overall, with diesel fuel being the most consumed fuel type.

Table 5: Energy Use in the Transportation Sector by Application

Sector	Transport							
Useful Energy (toe)	488,653							
TYPE	MODE	Petrol	Alcohol	Diesel	LPG	Aeronafta	Jet Fuel	TOTAL
Road	*Cars*	90,694	19,451	43,563	1,042	0	0	153,493
	4x4 truck (Non-commercial)	12,511	3,376	59,150	428	0	0	74,284
	Bus	0	0	36,413	0	0	0	36,413
	Minibus	1,710	313	9,181	0	0	0	11,019
	Motorcycle	19,590	3,585	0	0	0	0	23,176
	4x4 truck (Commercial use)	15,422	2,823	51,639	0	0	0	68,979
	Truck	0	0	64,955	0	0	0	64,955
	Truck tractor	0	0	38,455	0	0	0	38,455
	LAND SUBTOTAL	139,926	29,548	303,355	1,470	0	0	474,385
Fluvial	*Boats*	0	0	1,783	0	0	0	1,783
Aerial	*Planes*	0	0	0	0	999	0	999
	Jet	0	0	0	0	0	11,486	11,486
	TOTAL	139,926	29,548	305,138	1,470	999	0	488,653

Source: Prepared by authors based on BEN 2018 and BNEU 2011.

Agriculture Sector

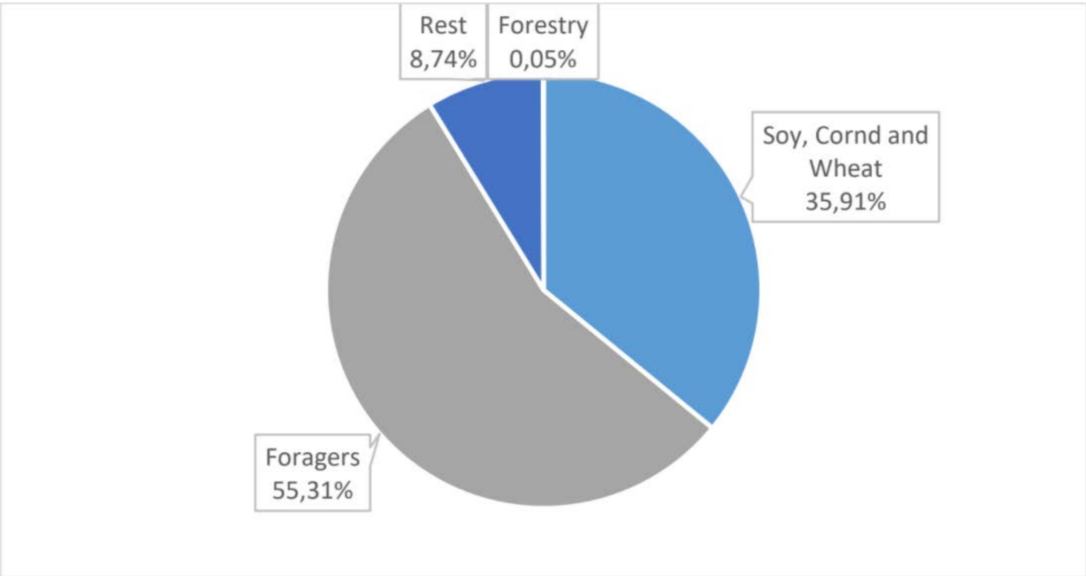
In the agriculture and forestry sector, the highest consumptions of energy use have to do with the consumption of diesel fuel used for transportation and of firewood for heating. Table 6 consolidates the energy use in these sectors while Figure 2 divides the energy use by subsector. Electricity accounts for 30.5% of all energy used.

Table 6: Energy Use in the Agriculture and Forestry Sectors by Application

Sector	Agro					
Useful Energy (toe)	156,479					
Applications	*LPG*	*Motor Fuel*	*Diesel Oil*	*Firewood*	*Electricity*	Total
Illumination	0	0	0	0	616	616
Tractors and Mobile Machinery	0	0	75,073	0	0	75,073
Fixed Machinery	0	1,324	142	0	28,917	30,384
Irrigation and Water Pumping	0	574	337	0	13,534	14,445
Heating	0	0	0	34,139	129	34,268
Cooling	31	0	0	0	1,661	1,693
TOTAL	31	1,898	75,553	34,139	44,858	156,479

Source: Prepared by authors based on BEN 2018 and BNEU 2011.

Figure 2: Energy Use in the Agriculture and Forestry Sectors by Subsector



Source: Prepared by authors based on BEN 2018 and BNEU 2011.

Mining and Construction Sectors

Finally, the energy use in mining and construction sectors includes both fossil fuels for transportation and electricity for certain operations. Table 7 consolidates the energy use of the mining sector as a whole while Table 8 divides energy use by application for the construction sector. The main takeaway from these sectors is the continued heavy reliance on fossil fuels for transportation. Electricity only accounts for 49.5% of energy use in the mining sector and 9.9% of use in the construction sector.

Table 7: Energy Use in the Mining Sector by Application

Sector	Mining			
Useful Energy (toe)	2,888			
Applications	**Motor Fuel**	**Diesel Oil**	**Electricity**	**Total**
Mills, Shredders and Conveyor Belts	0	0	1,531	**1,531**
Backhoes and Cargo Trucks	0	1,357	0	**1,357**
TOTAL	**0**	**1,357**	**1,531**	**2,888**

Source: Prepared by CRECE based on BEN 2018 and BNEU 2011.

Table 8: Energy Use in the Construction Sector by Application

Sector	Construction			
Useful Energy (toe)	4,248			
Applications	**Motor Fuel**	**Diesel Oil**	**Electricity**	**TOTAL**
Illumination	0	0	36	**21**
Calor	0	0	37	**22**
Driving Force Fija	21	325	603	**731**
Driving Force Móvil	12	3,189	24	**3,567**
TOTAL	**34**	**3,514**	**700**	**4,248**

Source: Prepared by CRECE based on BEN 2018 and BNEU 2011.

Appendix B: LEAP Scenarios 1, 2, and 3

This appendix describes in depth the full set of assumptions underlying the LEAP model and Scenarios 1, 2, and 3 presented in Section 1.3 of the report.

General Assumptions and Results

Economic Growth and Population

Population growth and GDP are the two critical assumptions that guide the structure of all three scenarios. For each of these, temporal variability is taken into account, including the historical trend as well as the current depreciation in GDP due to COVID-19.

The cumulative annual rate of GDP growth in Paraguay from 2018 to 2050 is assumed to be 5.39%, including an estimated GDP growth rate of 3.8% in 2021 and 2022. After this period, the economic recovery and sustained growth promotes a GDP growth rate between 5.0% and 6.0% between 2023 and 2050, continuing the upward trend of the 2009–2019 decade. This more significant growth rate is attributed to a number of competitive advantages in the agroindustry sector, higher product diversification, and higher net exports in Paraguay as well as a strong investment program in line with Paraguay's National Development Plan 2030 and in the National Energy Policy 2040, (for instance investments in improving energy and transport infrastructure, as well as education and research systems). In later years, a greater dynamism in chemical and machinery manufacturing reinforces the GDP growth rates. Table 9 summarizes GDP growth assumptions by year or period.

Table 9: GDP Growth Rate (%) Projections, 2018–2050

Year/period	GDP Growth Rate
2018	3.4
2019	-0.4
2020	-1.5
2021	4.0
2022	3.8
2023–2025	5.0
2026–2030	6.2
2031–2035	5.8
2036–2040	5.6
2041–2045	5.2
2046–2050	5.0

Source: Author's compilation based on Vice Ministry of Mines and Energy, Energy prospective study 2015-2050 (alternative scenario).

The population is normatively assumed to grow steadily based on census data from before 2018. In total, the population is expected to grow from 6.96 million in 2018 to just shy of 10 million by 2050. Similarly, the average number of people per household is expected to fall from 4 in 2018 to 3.3 by 2050, which will also support economic growth. Similarly, urbanization sees an increase from 62.5% of households in urban environments in 2018 to 75% in 2050. The increase in productivity in agriculture and further industrialization of the country will drive the urbanization.

As of 2018, 96.6% of households in Paraguay had a mobile phone, 90% had televisions and refrigerators, and 42% to 47% had air conditioning units and electric furnaces. For all of these appliances, quantity and access are expected to increase approaching 2050, with air conditioning units expected to grow at the fastest rate. Improving economic standards and a burgeoning standard of living are contributing factors to these assumed increases.

Assumptions on Biomass

In 2018, nearly 75% of the biomass extracted for energy in Paraguay derived from unsustainable sources such as native forests (see Chapter 5). As a result of this, the solid biomass in the LEAP model is unsustainable during the time periods of 2018, 2023, and 2030. After 2030, solid biomass in all three scenarios is assumed to be sustainably derived, in compliance with the targets established by the Decree No. 4056/2015 and Resolution No. 933/2020.

To verify if Paraguay has enough sustainable biomass capacity, we calculated for each proposed scenario, the required number of hectares to be cultivated for the production of firewood for direct use in Table 9, and for the production of charcoal in Table 10, all data to satisfy the demand for the year 2050.[1] From these preliminary results, the area needed for Scenarios 2 and 3 is lower to that currently projected by the PROEZA Project for 2030[2] in addition to the 193,852 hectares of forest crops currently existing in the country but it might imply land use conversion from non- energy use to energy use. This conversion will be reduced in Scenario 3 as compared to Scenario 2 given the higher replacement of biomass with electricity. Higher yields in reforestation towards 2050 (which is not taken into account in the above tables) will also dampen this conversion.

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[1] Knowing the solid biomass energy requirements, we calculated the required tons of and then, the hectares to be exploited to supply these requirements assuming constant productivity and yields of reforestation for energy purposes from 2018.
VMME-DGEA, "Producción y consumo de biomasa forestal con fines energéticos en el Paraguay," ed, 2019.

[2] « El Instituto Forestal Nacional (INFONA) coordina el Plan Nacional de Reforestación y, como parte de dicho marco, ha fijado como objetivo general 450.000 hectáreas de plantaciones forestales, de las cuales 290.000 se destinarán a la producción de madera maciza y 160.000 para fines energéticos. Estos objetivos deben alcanzarse para 2030».
FAO, *PROEZA: Pobreza, reforestación, energía y cambio climático* (National Government of Paraguay, 2017), https://www.stp.gov.py/v1/wp-content/uploads/2017/01/PROEZA-ESMF-TRAD-Espa%C3%B1ol-22-setiembre-2017.pdf.

Table 10: Firewood requirements for energy uses, in energy terms (toe), in tones and hectares to be cultivated

Scenario	Firewood Energy requirements in toe, year 2050	ton of firewood required, year 2050	Hectares to be cultivated, year 2050
Scenario 1	4,676,259	12,989,608	845,678
Scenario 2	2,959,728	8,221,465	535,252
Scenario 3	2,533,256	7,036,822	458,126

Source: Prepared by the authors.

Table 11. Charcoal requirements for energy use, in energy terms (toe). Firewood in tones and hectares to be cultivated for charcoal production

Scenario	Charcoal Energy requirements in toe, year 2050	ton of firewood required, year 2050	Hectares to be cultivated, year 2050
Scenario 1	261,115	378,428	50,076
Scenario 2	127,224	184,382	24,398
Scenario 3	309,080	447,942	59,274

Source: Prepared by the authors.

Biofuels

We also calculated for each proposed scenario, the required number of hectares to be cultivated for the production of biofuels (bioethanol, soy-bean based biodiesel) all data to satisfy the demand for the year 2050.[3]

Bioethanol

It was assumed that 80% of bioethanol will be produced with corn and the remaining 20% with sugarcane, roughly represented by the current split (see Chapter 5). Taking into account that in 2018/2019 the area cultivated with corn was 1,085,005 hectares, and for sugarcane an area of 103,000 hectares, it can be assumed that by the year 2050, the feedstock needs for bioethanol production can be fully supplied for any of the proposed scenarios, in particular if considering that improvements in yields which will reduce the number of hectares needed. However, it might imply land use conversion from food use to energy use which should be carefully investigated into.

[3] Knowing the energy requirements for bioethanol and biodiesel and the ethanol and soy-bean based diesel production productivities and yields per hectare of crops, the cultivated hectares of each crop to be used for bioethanol and biodiesel production are calculated assuming constant productivity and yields from 2018 (source: Official data from the Directorate of Agricultural Census and Statistics of the Ministry of Agriculture and Livestock. For the energy conversion ratios, the data is provided by the National Energy Balance 2018)

Table 12. Bioethanol requirements for energy use in energy terms (MJ)

Scenario	Bioethanol Energy requirements in MJ, year 2050	Ha of corn (80%) to be cultivated, year 2050	Hectares of sugarcane (20%) to be cultivated, year 2050
Scenario 1	24,252,165,765	496,791	73,955
Scenario 2	60,236,196,159	1,233,903	183,686
Scenario 3	33,935,959,947	695,158	103,485

Source: Prepared by the authors.

Biodiesel

Although several oil crops currently produced in Paraguay can be used for biodiesel production, for this calculation it is considered (as a first approximation exercise) that all biodiesel will be produced from soybean oil. Based on the results of requirements of hectares destined for soybean cultivation for biodiesel and the 3,631,000 ha cultivated in 2019/2020, [4] the cultivated area would need to be expanded. There are several private initiatives that aim to expand soybean cultivation in the western region of Paraguay, in approximately 2,000,000 ha.[5] Realizing this initiative could even supply the demand of Scenario 2, which is the one with the highest energy requirements for biodiesel production. However, this expansion could imply further deforestation, and it is not reasonable to assume that all soybeans would be used to produce biodiesel. There is potential for using residue of the livestock's animal fat (about 8% of the weight of each animal) as raw material for the production of biodiesel, in addition to other oil crops as highlighted in preliminary studies that should be updated and deepened.[6] The potential for growing jatropha, as highlighted by Law No. 4729/2012, should also be investigated closely and beyond what was done in a decade-old preliminary study.[7] Jatropha can grow on degraded lands to minimize land conversion needs.

[4] Ministerio de Agricultura y Ganadería (MAG), *Síntesis Estadísticas: Año Agrícola 2019/2020* (Asunción: MAG, September 2020), http://www.mag.gov.py/Censo/SINTESIS%20ESTADISTICAS%202019-2020.pdf.

[5] Victor Hugo Florentin, "resaltan potencial para el desarrollo de cultivos agrícolas en el Chaco" (ABC, 2021), https://www.abc.com.py/nacionales/2021/01/31/resaltan-potencial-para-el-desarrollo-de-cultivos-agricolas-en-el-chaco/; La Nación, "Existe buena expectativa para cultivo de soja en el Chaco" (La Nación, 2020), https://www.lanacion.com.py/negocios/2020/11/08/existe-buena-expectativa-para-cultivo-de-soja-en-el-chaco/.

[6] Guillermo Suouto, Paraguay explora su potencial en biocombustibles (Comunica, 2008), http://repiica.iica.int/docs/B0719e/B0719e.PDF.

[7] Hector J Causarano M (ed.), *Avances de investigación sobre Jatropha curcas en Paraguay* (San Lorenzo: FCA-UNA, 2011), http://www.agr.una.py/fca/index.php/libros/catalog/book/289.

Table 13. Biodiesel requirements for energy use, in energy terms (MJ). Hectares of soy to be cultivated for biodiesel production

Scenario	Biodiesel Energy requirements in MJ, year 2050	Hectares of soy to be cultivated, year 2050
Scenario 1	0	0
Scenario 2	66,887,328,186	5,903,803
Scenario 3	37,741,390,912	3,331,240

Source: Prepared by the authors.

The following three sections will highlight the key assumptions unique to each policy scenario and provide a look at the GHG emissions global warming potential forecast between 2018 and 2050 based on the changes associated with each scenario.

In-depth details on Scenarios

Business as Usual Scenario

The BAU scenario assumes that historical trends and behavior related to energy use and demand, intensity, and yields continue without disruption. In other words, this scenario provides insight into the consequences of policy and environmental inaction. Table 14 presents the LEAP model results for the net energy demand for this scenario in absolute quantities.

Table 14: Final Net Energy Demand by Fuel Type for BAU Scenario in kTOE

Source	2018	2023	2030	2040	2050
Electricity	1,111	1,269	1,747	2,803	4,262
Oil products	2,732	3,701	4,814	6,073	7,211
Solid Biomass	541	947	2,234	5,314	8,622
Non-sustainable solid biomass	1,622	1,421	957	0	0
Liquid biofuels	165	288	403	508	579
Solar	0	0	1	3	9
Hydrogen	0	0	0	0	0
Total	6,171	7,627	10,156	14,701	20,683

Source: Prepared by the authors.

While all fuel sources increase as Paraguay approaches 2050, oil products and solid biomass continue to increase at a significant rate. Due to the assumption that all solid biomass after 2030 is sustainably derived, the real concern in this scenario is the relatively unabated increase in oil products use, primarily in the industrial and transport sectors. As electric vehicles are never considered in this scenario, all vehicles continue to use traditional fossil fuel sources (also revealed by Table 14). As can be seen, hydrogen as a fuel is never adopted and solar energy in heating is picked up at a bare minimum. Additionally, development of liquid biofuels has moderate growth but is nothing significant when compared to the other scenarios.

Electricity demand by sector follows a similar trend. As Table 15 highlights, electricity continues to increase in each sector (aside from transport).

Table 15: Final Net Electricity Demand by Sector for Scenario 1 in GWh

Sector	2018	2023	2030	2040	2050
Residential	5,006	6,007	8,189	12,357	17,322
Commercial Services and Public Adm	4,245	4,608	6,604	11,340	18,145
Agriculture and Forestry	752	763	917	1,093	1,283
Transport	0	0	0	0	0
Industry	2,403	2,853	4,061	7,225	12,149
Mining and Construction	34	39	66	101	189
Total	12,441	14,270	19,837	32,117	49,087

Source: Prepared by the authors.

Of note is the significantly high electricity demand in the residential and commercial service sectors, a byproduct of ineffective and nonexistent energy efficiency requirements. As a result, these values in the BAU scenario are higher when compared to the other two scenarios. Another note is that industry’s electricity demand is much lower in this scenario than in the other two, catalyzed by limited adoption of electricity as a fuel source in the sector.

Scenario 2

In the residential sector, electricity replaces liquified petroleum gas, firewood, and charcoal due to a cheaper cost and overall efficiency improvements. Water heating sees a similar reduction in Liquified petroleum gas (LPG), charcoal, and firewood use, depending on income level of each household. Generally, solar energy is introduced as an alternative water heating source in this scenario while electricity is more broadly assumed to increase as a water heating energy source. In terms of general heating, a moderate increase in the use of electricity is assumed to offset the use of solid biomass and LPG.
For the commercial sector, cooking applications were more aggressively changed from biomass fuel to electric fuel. With cooking it is important to note that traditional Paraguayan culture means that it is a cultural taboo to cook with fuels other than firewood and charcoal. As a result, modest gains are assumed, yet there are many commercial sites such as hotels and restaurants where biomass continues as a main fuel source. Similar to the residential sector, water heating transitions from LPG and firewood to electricity and the introduction of solar energy. Finally, internal transportation, that is, cargo transport and other related activities, accounted for just 0.18% of energy consumption of the commercial sector in 2018, a percentage which remains unchanged in this scenario.

The industrial sector sees a radical shift from firewood use, which amounted to 41.9% of all fuel use in the sector in 2018. As in all scenarios, there is a switch of biomass consumption from unsustainable to sustainably derived after 2030. Moreover, steam production sees a switch from firewood to more electricity and solar energy. For heat generation more generally, charcoal and coking coal in metallurgical processes remain the same in this scenario while electricity use slowly replaces all other industrial processes and subsectors. Again, internal transport remains as it did in 2018 in this scenario.

In the transportation sector, three significant changes are assumed for this scenario. The first variation is that aerial transport, which accounted for 3% of energy in the transport sector, will introduce bio-SPK (synthesized paraffinic Kerosene), also known as sustainable Aviation fuel or bio jet. Given the development of the Omega Green Project in Paraguay (see Chapter 5), there are legitimate opportunities to incorporate bio jet into the aviation transport sector. As such, this scenario assumes that bio jet will comprise 2% of this subsector in 2030 and 30% by 2050 (the future of bio jet is very uncertain technologically). The second variation is that fluvial transport sees a switch from fossil fuels to electric and hydrogen fuel cell power. Finally, land transport, the largest of the transport sectors, sees the introduction of electric vehicles in this scenario, specifically automobiles, 4x4 trucks, motorcycles, and buses (listed in increasing order of penetration). Moreover, hydrogen fuel cell vehicles are introduced (for buses and in particular for cargo transportation) and engines that utilizes gasoline ethanol blends (Otto and fuel flex engines) will continue to do so although these blends transition to 100% ethanol by 2050. Thus, the sector is still, in part dependent on fossil fuels.

Adjustments in useful energy intensities[8] were also assumed in this scenario. Energy efficiency in final consumption is achieved by considering both the promotion of energy efficient habits and adopting new energy saving technologies. Both of these techniques are assumed as part of the second scenario as these methods are actively pursued in existing national policy frameworks. As expected by the consideration of the assumptions in this scenario, oil products considerably decrease over time as opposed to their sharp increase in the BAU scenario. Interestingly, the overall energy from this scenario has decreased and is nearly 5,000 ktoe lower than the BAU scenario by 2050. This is attributed to the greater useful energy intensity assumed in this scenario, meaning greater energy efficiency from population's energy use habits and newer technology adoption.

Table 16 presents the LEAP model results for the net energy demand for this scenario in absolute quantities, taking into account the results of all aforementioned assumptions.

[8] The net energy refers to the total energy consumed by appliances, artifacts or machines - for instance, the amount of fuel burned by vehicles. The useful energy gives a measure of the actual work done with such total energy - in the same example, this is the mechanical work done by vehicles. Net and Useful energy are related by efficiency as expressed by: Useful Energy = Efficiency * Net Energy. The comparison between these two types of energy indicators provides a tool to scrutinize the energy consumption in more detail. For example, in practice, the demand for useful energy in air conditioning can only be reduced by a decrease in thermal load (useful energy) or an improvement in the consumers' behavior (useful energy). In both cases, this would result in a decrease of ACs' energy consumption, which in turn would represent the underlying reason for a decrease in the demand of net energy. Intensities are obtained by divided by unit (eg: household, km etc..).

Table 16: Final Net Energy Demand by Fuel Type for the Second Scenario in ktoe

Source	2018	2023	2030	2040	2050
Electricity	1,111	1,261	1,892	3,227	5,112
Oil products	2,732	3,240	2,522	1,481	611
Solid Biomass	541	914	1,995	4,378	6,654
Non-sustainable solid biomass	1,622	1,371	855	0	0
Liquid biofuels	165	647	1,877	2,861	3,132
Solar	0	1	15	81	229
Hydrogen	0	0	14	86	171
Total	6,171	7,436	9,171	12,113	15,910

Source: Prepared by the authors.

Electricity demand by sector follows a similar trend. As Table 17 highlights, electricity continues to increase for each sector (aside from transport).

Table 17: Final Net Electricity Demand by Sector for the Second Scenario in GWh

Sector	2018	2023	2030	2040	2050
Residential	5,006	5,799	7,785	11,898	16,887
Commercial Services and Public Adm	4,245	4,539	6,322	10,276	15,716
Agriculture and Forestry	752	761	913	1,088	1,279
Transport	0	106	2,091	5,503	9,029
Industry	2,403	2,930	4,290	8,026	15,439
Mining and Construction	34	53	122	257	617
Total	12,441	14,187	21,523	37,048	58,967

Source: Prepared by the authors.

Zero Emission 2050 Scenario

The Zero Emission scenario is the ultimate goal of this report, as it promotes nearly zero carbon in the energy use sectors by 2050.

In the residential sector, electricity continues to replace biomass and LPG, however, at a much more aggressive pace than assumed in the Second scenario. Specifically, a greater amount of solar energy for water heating was assumed and LPG was eliminated entirely from the heating sector by 2030 in favor of sustainable biomass and electricity entirely. Additionally, substitution of fuel sources for illumination, water pumping, and other uses removed petroleum derivatives and assumed complete electrification by 2050.

For the commercial sector, cooking applications were more aggressively changed from biomass fuel to electric fuel, even more so than in the Second scenario. To this end, LPG is removed from cooking as a fuel by 2040 and onwards. Traditional cooking methods remain intact with the evident replacement of biomass with sustainably derived types. However, here again LPG was removed in 2040 onwards and solar energy takes a more significant presence in the water heating subsector of the commercial space.

The industrial sector sees further development and adoption of electricity and solar energy in industrial processes. In the industrial sector, LPG and other petroleum derivatives are removed by 2040. Additionally, coking coal is assumed to be fully replaced by charcoal in 2050, creating an opportunity for sustainable biomass to replace fossil fuels in higher temperature industrial processes. The Zero Emission scenario also sees internal transportation within the sector switch to either fully electric or with 100% biofuel blends by 2050.

In the transportation sector, the aerial transport continues to see the development and implementation of bio jet at a rate of 2% of this subsector in 2030 to 50% by 2050. Fluvial transport, similar to the Second scenario, continues to see a switch from fossil fuels to electric and hydrogen fuel cell power. Finally, land transport, the largest of the transport sectors, sees an even more aggressive adoption of electric and alternative fuel vehicles. Specifically, all petroleum derivatives disappear by 2050, replaced with electricity, hydrogen fuel cells, or 100% bioethanol fuel blend, a sharper contrast from the continued moderate reliance on fossil fuels seen in the Second scenario. While it would be ideal for 100% electric and hydrogen fuel cell vehicle use in 2050, the penetration of such technologies in rural settings will be difficult, and as such biofuel remains the ideal and principal alternative fuel source for remote and rural geographic regions in Paraguay.

Similar adjustments in useful energy intensities as in the second scenario were assumed and energy efficiency in this scenario remains comparable to the Second scenario with improved and more efficient appliances and policy frameworks for changing habits. The remaining portion of oil product in 2050 is the outstanding non-sustainable jet fuel for the aviation transport sector.

Table 18 presents the LEAP model results for the net energy demand for this scenario in absolute quantities, taking into account the results of all aforementioned assumptions.

Table 18: Final Net Energy Demand by Fuel Type for Second Scenario in ktoe

Source	2018	2023	2030	2040	2050
Electricity	1,111	1,359	2,125	3,712	6,047
Oil products	2,732	3,153	2,161	956	143
Solid Biomass	541	841	1,706	3,705	5,997
Non-sustainable solid biomass	1,622	1,262	731	0	0
Liquid biofuels	165	695	1,866	2,502	1,871
Solar	0	3	41	166	461
Hydrogen	0	0	66	162	230
Total	**6,171**	**7,314**	**8,697**	**11,203**	**14,749**

Source: Prepared by the authors.

Electricity demand by sector follows a similar trend as above, and as Table 19 highlights, electricity continues to increase in demand at level over 10 TWh higher than in the Second scenario by 2050.

Table 19: Final Net Electricity Demand by Sector for Second Scenario in GWh

Sector	2018	2023	2030	2040	2050
Residential	5,006	6,354	8,919	13,550	17,807

Commercial Services and Public Adm	4,245	4,551	6,284	10,205	15,496
Agriculture and Forestry	752	761	913	1,088	1,279
Transport	0	40	2,230	6,360	13,587
Industry	2,403	3,569	5,757	11,230	21,058
Mining and Construction	34	53	122	257	617
Total	12,441	15,328	24,225	42,690	69,843

Source: Prepared by the authors.

The most significant increases in electricity demand come from the transport and industry sectors, both of which have grown by more than 40% over their respective electricity demand by 2050 in the Stated Policy scenarios. The abolition of petroleum derivatives coupled with more aggressive adoption of electrified processes and machinery are the leading catalysts for this increased demand.

Appendix C: Stated Policies Scenario

This appendix describes key aspects of the Stated Policies Scenario developed in an earlier iteration of the LEAP model, as mentioned in Section 1.3 of the report.

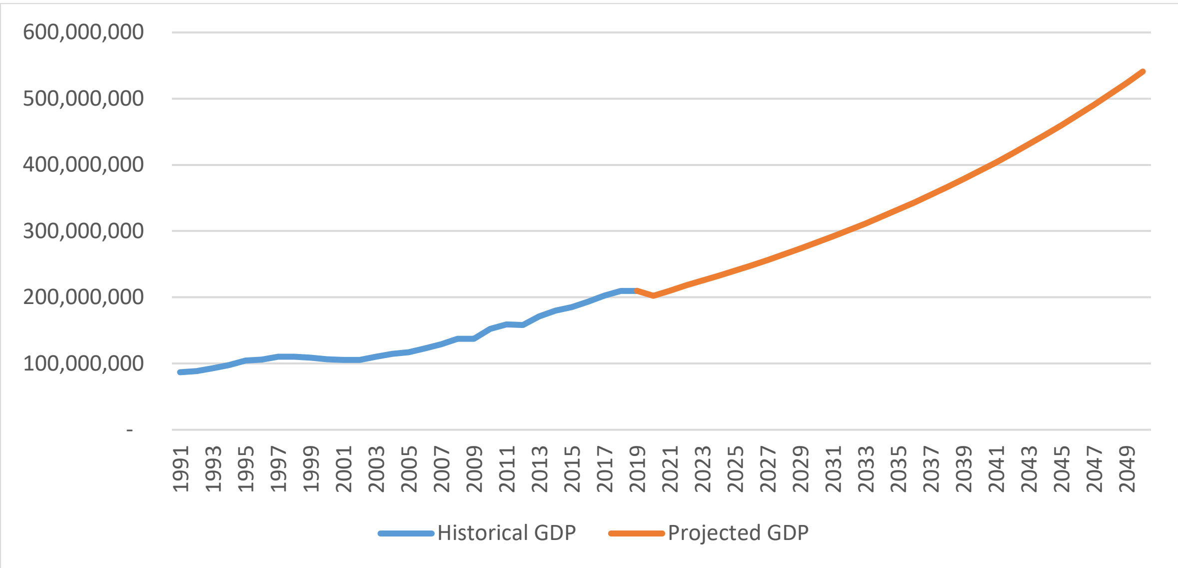
Key Assumptions

Key assumptions involve the drivers behind the evolution of each sector's energy demand. By characterizing the evolution of key assumptions, the evolution of demand can be estimated. The key assumptions variables for the model are the GDP and the population (Figures 2 & 4, respectively), then, the activity levels are calculated based on them.

Gross Domestic Product (GDP)

The projection from 2019 on, based on growth rate estimations made by the Central Bank of Paraguay (BCP) follows the historical GDP trend. The conservative annual growth rate is of 3.3%.

Figure 3: Gross Domestic Product Projection



Source: Prepared by the authors based on Central Bank of Paraguay data.

The following evolution of Growth Value Added shares of the sectors is considered:

Table 20: Share of GVA among sectors

Sector	Historical Values			Projected Values		
	1991-2000	2001-2010	2011-2018	2019-2030	2031-2040	2041-2050
Agriculture and forestry	8.2%	10.5%	12.0%	12.7%	13.1%	13.5%
Mining and Construction	7.5%	6.0%	6.8%	7.0%	7.0%	7.0%
Industry	25.1%	22.2%	20.4%	19.5%	19.1%	18.9%

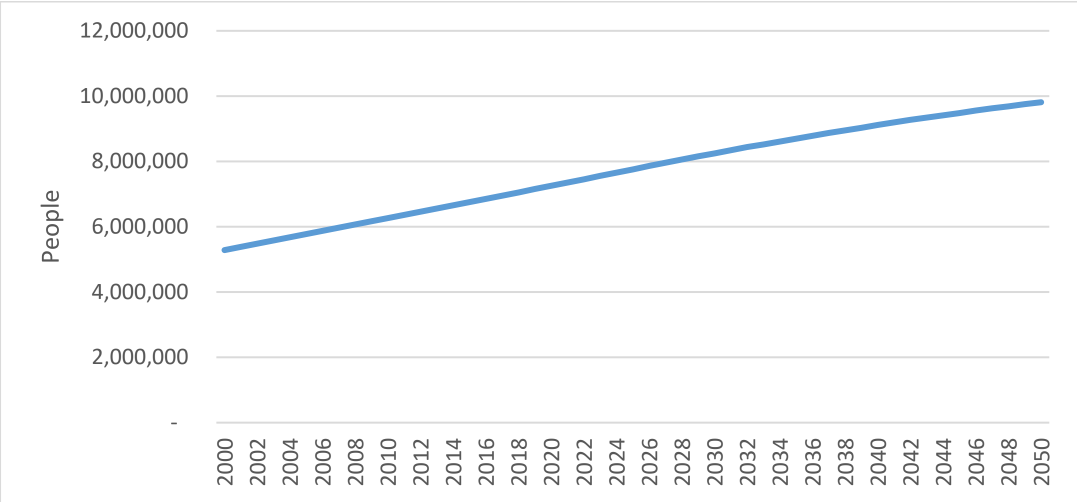
Commercial and Services	45.8%	46.7%	47.1%	47.5%	47.5%	47.5%

Source: Prepared by the authors based on data from Central Bank of Paraguay.

Population

Population projections as well as the forecast of the number of households by rural and urban areas follow those of official documents of the General Directorate of Statistics and Census (DGEEC) just like in the LEAP model described in Appendix B.

Figure 4: Projection of the Population



Source: Prepared by the authors based on DGEEC

Policies considered

Policy measures for the Residential sector include:

- Change of share of energy sources according to their uses/applications. This relates to the change of technology, *e.g.* for cooking purposes, change from LPG or Wood to electric ovens.
- Reduction of useful energy intensity requirements. This could be given by an improved behavior of users regarding energy consumption in order to reduce energy wastes, *e.g.* reduction in the refrigeration energy intensity.
- Reduction net energy intensity requirements. This could be given thanks to technological advances improving the efficiency of equipment and artifacts.

Policy measures for the Transport sector include:

- Introduction of hybrid and electric vehicles.
- Improvements in the efficiency of internal combustion engines.
- Reduction of fuel consumption in the public transport subsector, due to improvements in the drivers' behavior.

In 2018, electrical losses raised to 24.5 %, where 19.2% correspond to distribution losses and 5.4% to transmission loses. According to the National Energy Policy (PEN 2040), the objective is to reduce distribution losses by 12 % in the mid-term. Therefore, as policy measure, the reduction of electrical losses by 17% in 2030 is considered (12% distribution + 5% transmission). By 2050, it is expected for total losses to be 14%, where distribution and transmission losses are 10% and 4%, respectively. The introduction of a new hydropower plant (Corpus Christi HPP) is assumed to expand the power system's generation capacity.

No policy was considered for the other energy end use sectors therefore their useful energy intensity remain based on the useful energy of the base year (2018), as described in Appendix A.

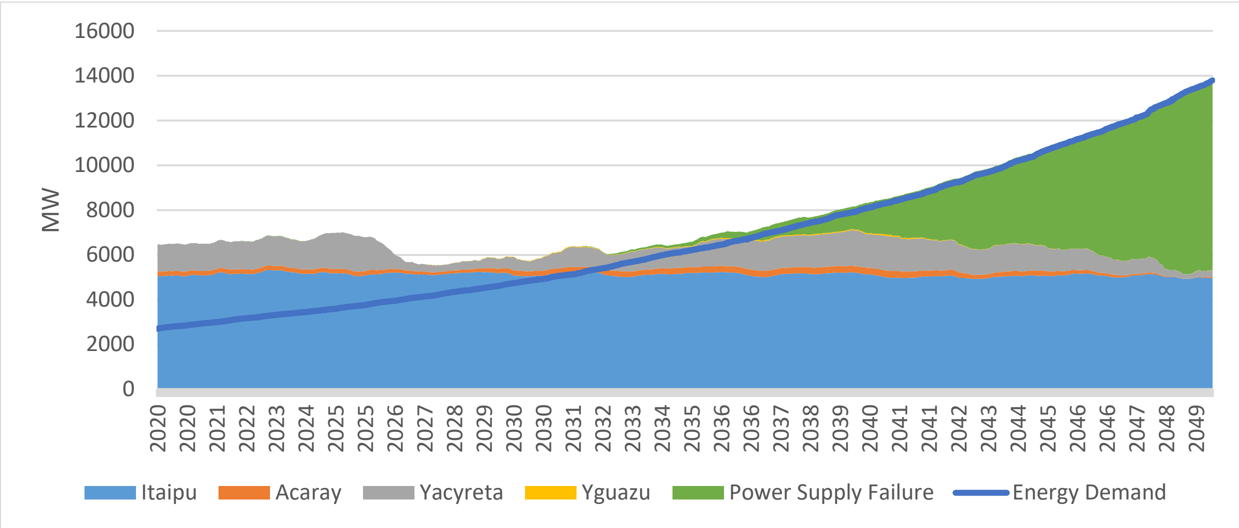
Appendix D: SimSEE simulations

Closed Market Scenarios

Business-as-Usual Scenario

In the Business-as-Usual (BAU) scenario, the electricity supply is that of 2020 and is fixed to 2050: supply resources include the dams of Acaray, Yguazú,[9] Itaipú, Yacyretá and Aña Cua as this is already under construction (it is added to Yacyretá's generation capacity). The demand growth rate is set at 5.46% within Paraguay throughout the period. **Given this constant energy demand growth, the BAU scenario anticipates the supply crunch in 2030 but it remains manageable until 2037 where non supplied energy starts to be greater than 1%**. 100%-probability of insufficient generation dispatch at peak demand should be expected by 2043. Figure 5 presents the yearly-equivalent moving-average of weekly power dispatch for the peak level of demand.

Figure 5: Peak Demand Power Balance for Business-as-Usual Scenario (Closed Market)



Source: Prepared by the authors.

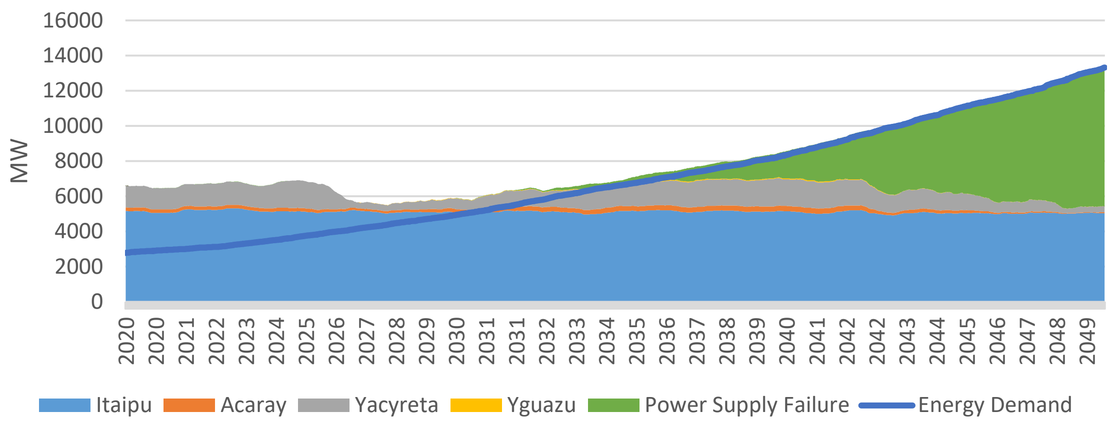
Net-Zero Pathway

This scenario takes into account the energy demand growth assumptions accounted for by the Net-Zero Pathway scenario introduced in Chapter 1. For transmission and distribution losses, reduction assumptions are 15.5% in 2040 and 15% in 2050 in line with the National Energy Policy. As a result of these inputs, the Net-Zero Pathway scenario anticipates the supply crunch to first occur in 2029 and 100%-probability of insufficient generation dispatch should be expected by 2043. These values are very similar to the BAU scenario because of the combination of increased final consumption and reduction in electric losses. Nevertheless, growth rates during the time horizon are different. For instance, this scenario includes higher growth rates at the beginning of the period, resulting in higher

[9] Yguazu is an existing dam upriver from Acaray. Its main purpose now is to control the water inflow to the Acaray power plant but ANDE has plans to install turbines and generation units, and to convert it into a proper power plant so it is included in this model.

absolute demand, even though electricity losses are reduced. Figure 6 presents the yearly-equivalent moving-average of weekly power dispatch for the peak level of demand.

Figure 6: Peak Demand Power Balance for Net-Zero Pathway Scenario (Closed Market)



Source: Prepared by the authors.

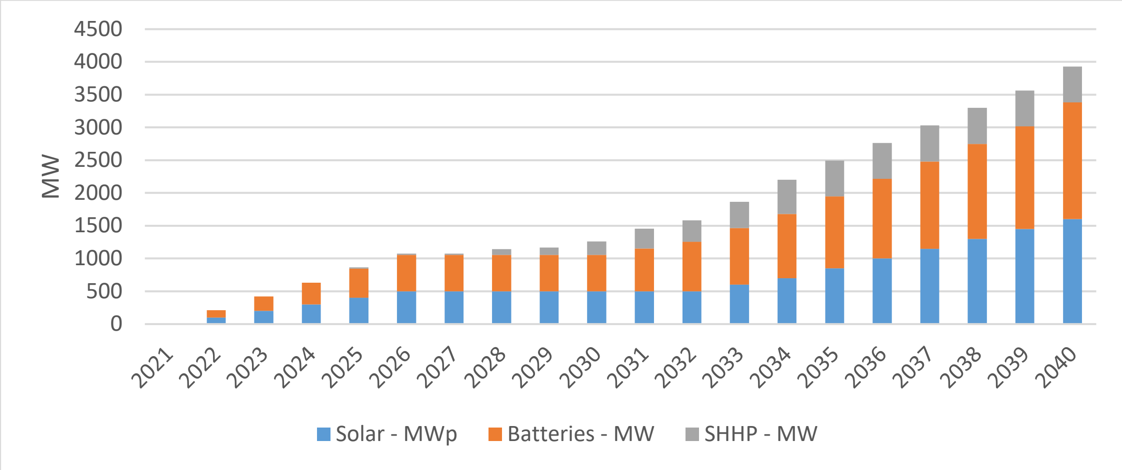
ANDE Master Plan 2021–2040

This scenario combines the ANDE Master Plan 2021–2040 electricity generation expansions for energy supply with the energy demand assumptions used in the plan. More specifically, the new Master Plan foresees the development of 550 MW of domestic hydropower plants, 1600 MW potential from solar PV units, and 7100 MWh of battery storage potential (see Figure 7). The growth rate used in this scenario is set to the Master Plan assumption of 4.88%, lower than the 5.46% assumed in the BAU scenario and lower than the electricity demand of the zero-emission scenario as well.

For this reason, the supply crunch year of this scenario is slightly ahead of that of the original ANDE Master Plan 2021–2040. **This scenario anticipates the supply crunch to first occur in 2033 for peak demand.** Despite the addition of battery storage, it remains difficult to address the supply crunch because the large chronological discrepancy in Paraguay's peak load (at night) and supply (solar peaks at noon). Moreover, the master plan's scope ends in 2040 so the growing supply crunch after 2040 is self-evident. The expected not-supplied energy drops to less than 0.01% of demand in 2033, and to 3% in 2040 thanks to the master plan's investment. 100%-probability of insufficient generation dispatch at peak demand is reached by 2047, four years later than the base-scenario only.

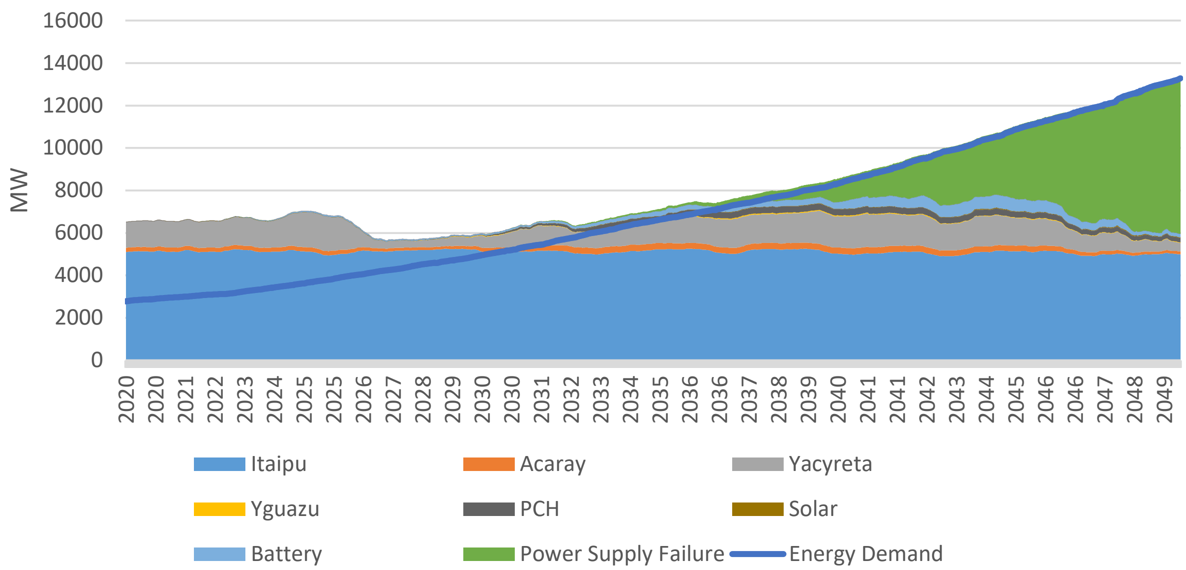
Figure 8 presents the power supply and peak demand for this scenario in MW by year.

Figure 7: Aggregated Capacity in ANDE's Master Plan 2021-2040



Source: Prepared by the authors.

Figure 8: Peak Demand Power Balance for ANDE Master Plan Scenario (Closed Market)



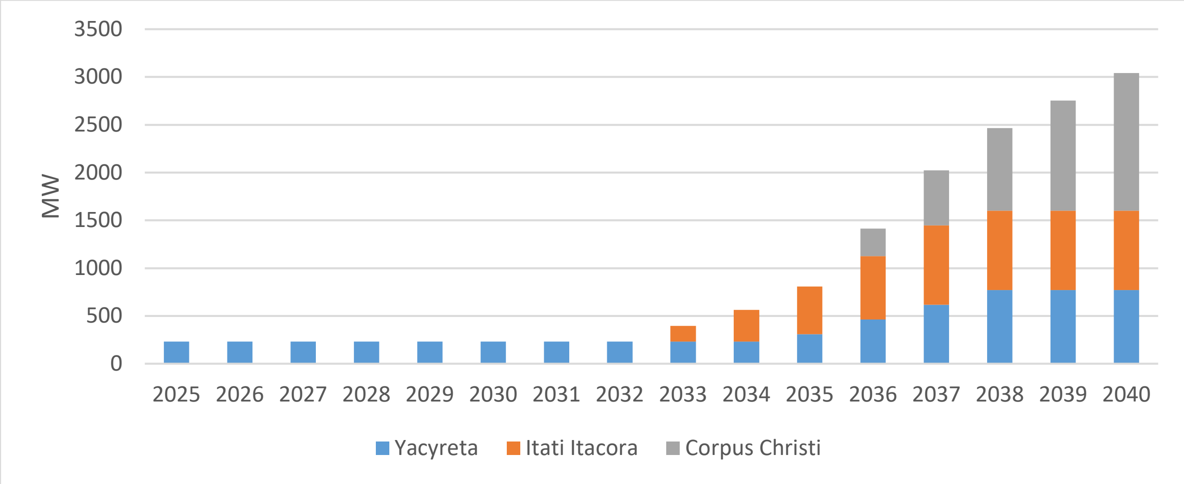
Source: Prepared by the authors.

ANDE Master Plan 2021–2040 with Binationals

This scenario has the same underlying assumptions as the previous scenario. However, in addition to solar (combined with battery storage) and mini-hydropower as new generation sources, this scenario also assumes the expansion of the Yacyretá and the construction of the Itatí Itacorá and Corpus Christi hydropower facilities, which add 3000 MW. Figure 9 highlights the magnitude of these additional generation capacities by year.

This scenario assumes that generators come online progressively and that after 2030, investments in solar PV and batteries are disregarded in favor of binational hydropower generation project development.

Figure 9: Aggregated Capacity of New Binational Hydropower Plants

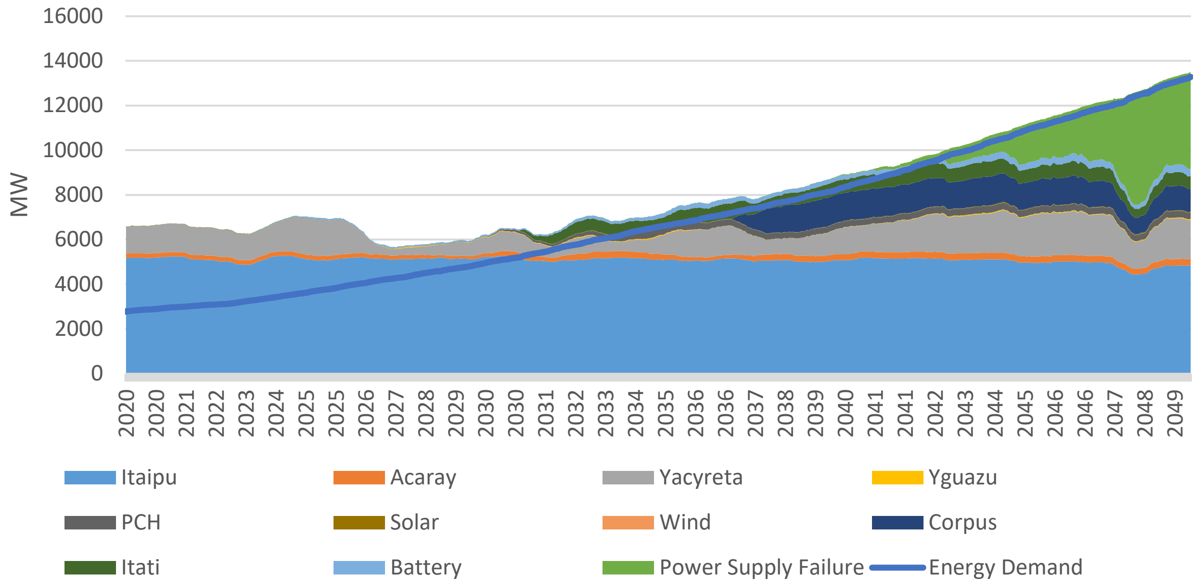


Source: Prepared by the authors.

As a result of these additional generation sources, increasing firm energy output to 79,000 GWh by 2040, this binational hydropower facility scenario is expected to push significant occurrences of the supply crunch to 2044. The first occurrence of supply failure starts in 2031 but disappear again thanks to the progressive coming online of the bi-nationals as planned by the 2021-2040 Master Plan. However, when Corpus Christi starts to operate in 2036–2040, Itaipú loses some generation output. The reason is that the creation of Corpus Christi's reservoir, downriver from Itaipú, determines the rise of the river level in Itaipu's discharge, thus reducing the height of the water level difference upstream and downstream the Itaipú dam.

The not-supplied energy would be 0.03% of demand by 2033, rising to 15% by 2050. These additional investments would help reduce power dispatch failure as compared to the previous scenarios, but the failure probability would still be high for the peak demand level after 2040, reaching 95% by 2050. Figure 10 presents the yearly-equivalent moving-average of weekly power dispatch for the peak-level of demand.

Figure 10: Peak Demand Power Balance for ANDE Master Plan with Binational Hydropower Plants Scenario (Closed Market)

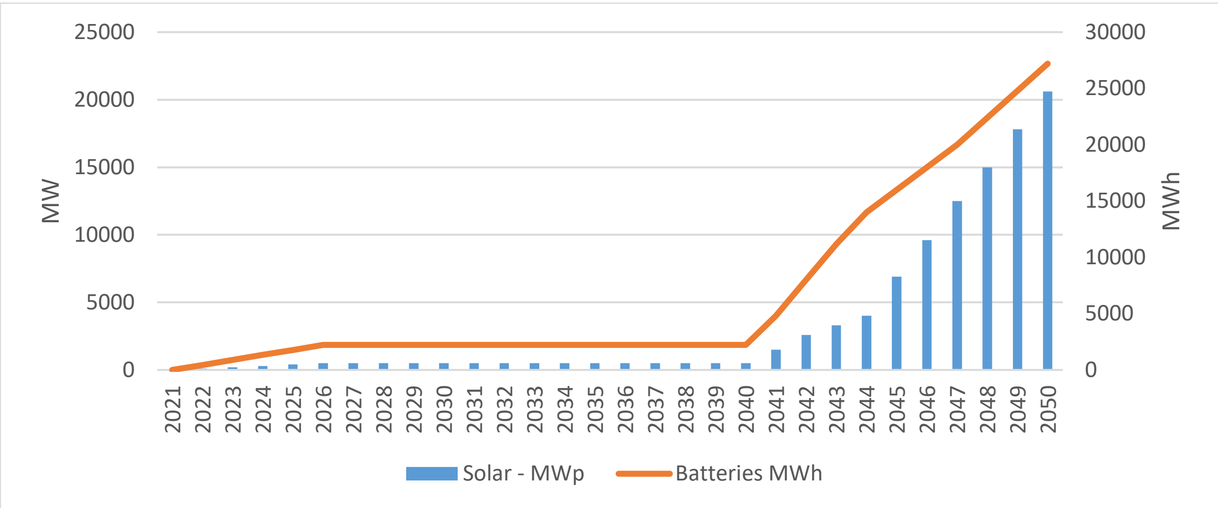


Source: Prepared by the authors.

ANDE Master Plan 2021–2040 with Binationals and Renewable Energy

This scenario has the same underlying assumptions as the previous scenario. However, unlike the previous scenario which assumes that development of renewable energy and battery storage is halted by 2030 in favor of binational hydropower generation, this scenario anticipates significant development of these energy types after 2040. The schedule and magnitude of renewable energy and battery development is shown in Figure 11.

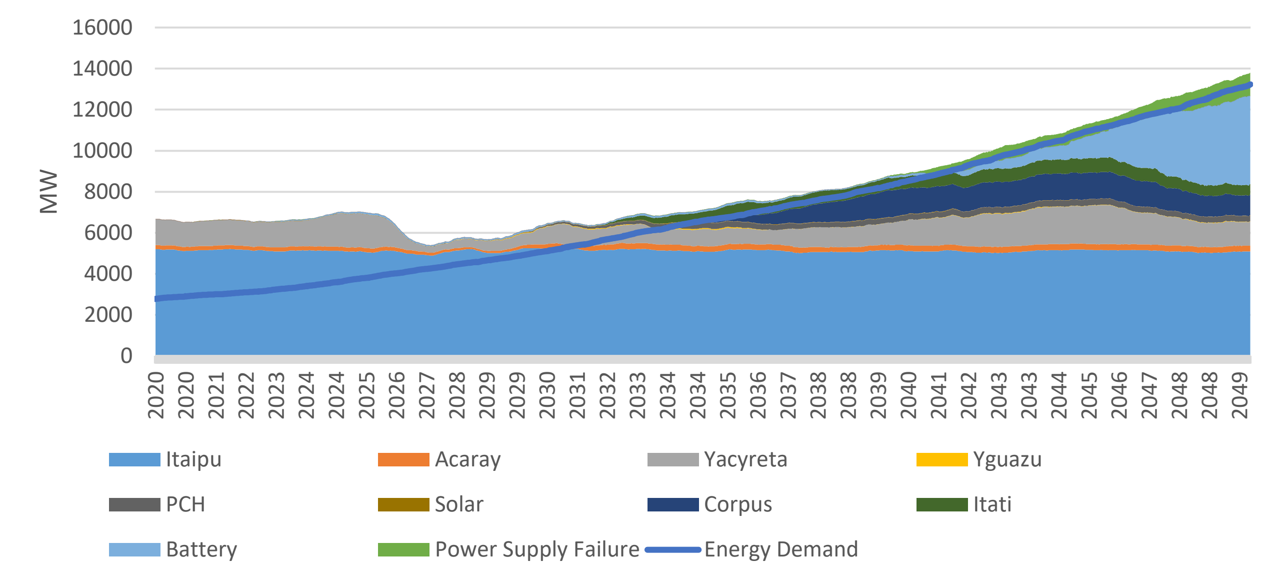
Figure 11: Aggregated Capacity of Solar PV and Batteries



Source: Prepared by the authors.

As a result of these additional generation sources, this binational hydropower and reinforced renewable energy scenario is expected to push the first occurrence of supply crunch to 2042. After this year, the not-supplied energy oscillates between 1.5% and 2.2%. As a result of solar PV and battery storage starting in 2040, there is a much greater reduction in failure for the grid system. Figure 12 presents the yearly-equivalent moving-average of weekly power dispatch for the peak-level of demand.

Figure 12: Peak Demand Power Balance for ANDE Master Plan with Binational Hydropower Plants and Renewables Scenario (Closed Market)

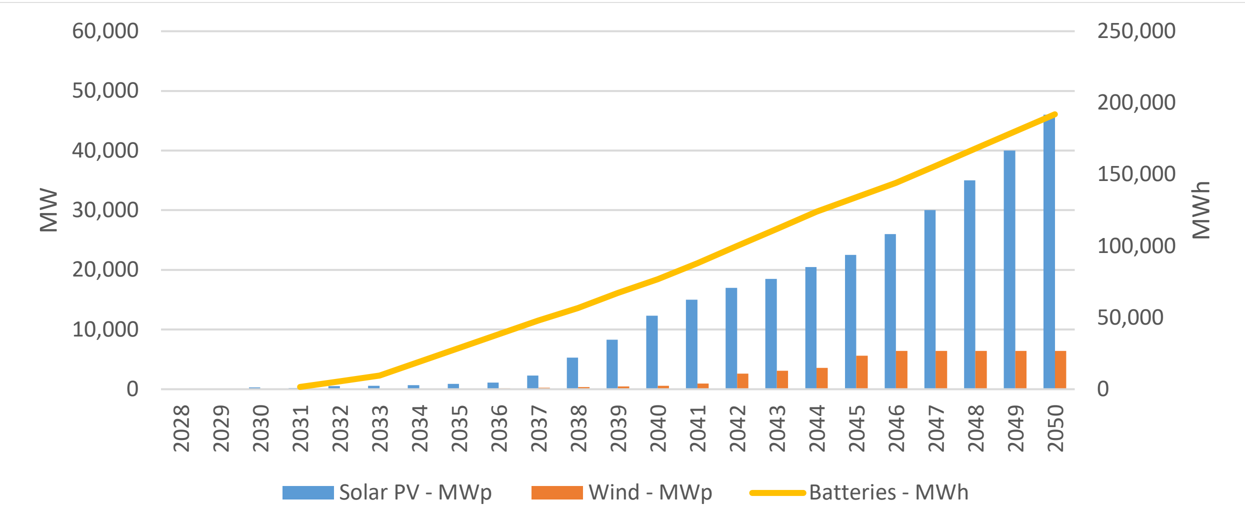


Source: Prepared by the authors.

High Investment in Renewable Energy and Batteries

This scenario relies on a schedule for high investment in renewable energy and battery generation with no investment in bi-nationals that are politically sensitive. It is important to note that since all wind potential generation is assumed to be harnessed by 2046, remaining energy sources are solar PV only. The schedule for this generation capacity, which is estimated at up to 140,000 GWh by 2050, is presented in Figure 13.

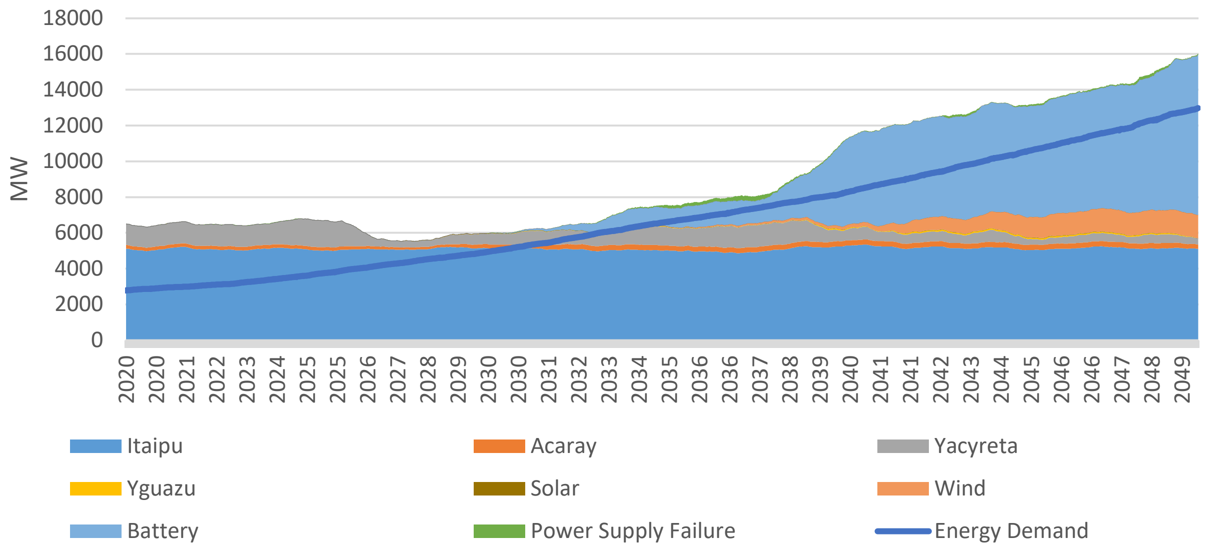
Figure 13: Aggregated Capacity of Renewables and Batteries



Source: Prepared by the authors.

While there is a significant level of new generation, batteries are installed only after 2030; this delayed start results in the first occurrence of supply crunch remaining at 2030, the same as the baseline scenario but the supply crunch remains minimum over the period: the probability of power dispatch failure is somewhat controlled, reaching to a maximum of 10%, in average, over the entire simulation period. As the SimSEE model runs at a weekly basis, the result on the daily optimization of this scenario is that the amount of battery storage required is roughly seven times larger than it should be. In any event, this oversizing of storage capacity allows for an estimate of investment and technology mix necessary to guarantee a situation of no supply crunch after 2030. Figure 14 presents the yearly-equivalent moving-average of weekly power dispatch for the peak-level of demand.

Figure 14: Peak Demand Power Balance for High Renewables Investment Scenario (Closed Market)



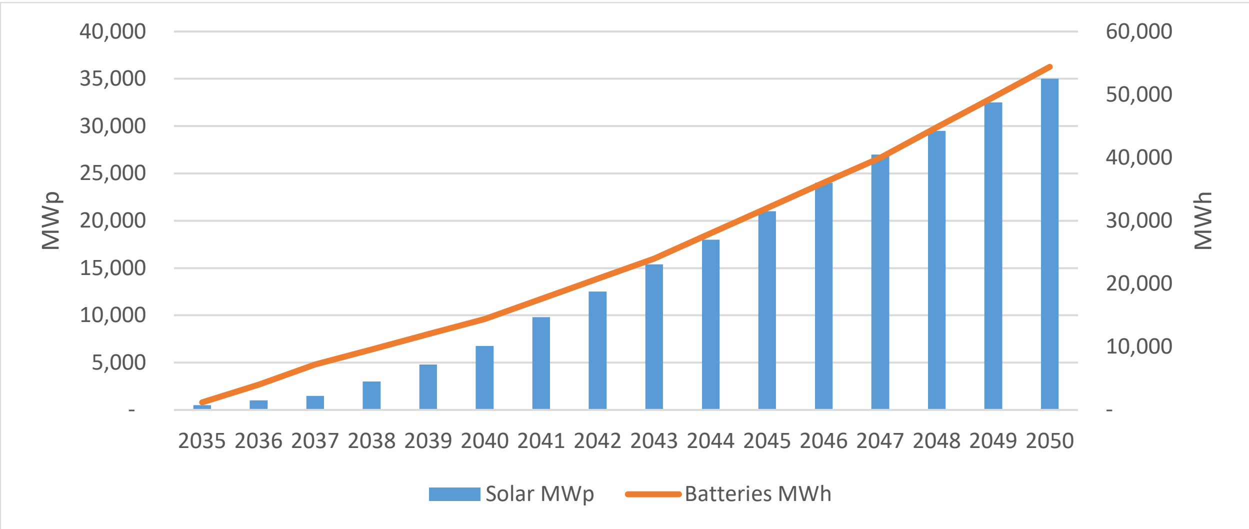
Source: Prepared by the authors.

Moderate Investment in Renewable Energy and Batteries

This scenario has the same underlying assumptions as the previous scenario. However, while the previous scenario of high renewables investment attempts to demonstrate the cost necessary to reduce not-supplied energy frequencies in the grid and marginal cost of operations, this scenario looks to address the amount of investment necessary just to reduce the expected increase in not-supplied energy. As a result, to achieve the reduction in not-supplied energy with an expected value under 5% considering the 95th percentile, the investment up to 2050 are 35,000 MW of Solar PV and 55,000 MWh of batteries, which correspond to 10,000 MW less of solar PV and almost four times less investments in batteries than in the high investment scenario.

Figure 15 highlights the magnitude of these additional generation capacities by year.

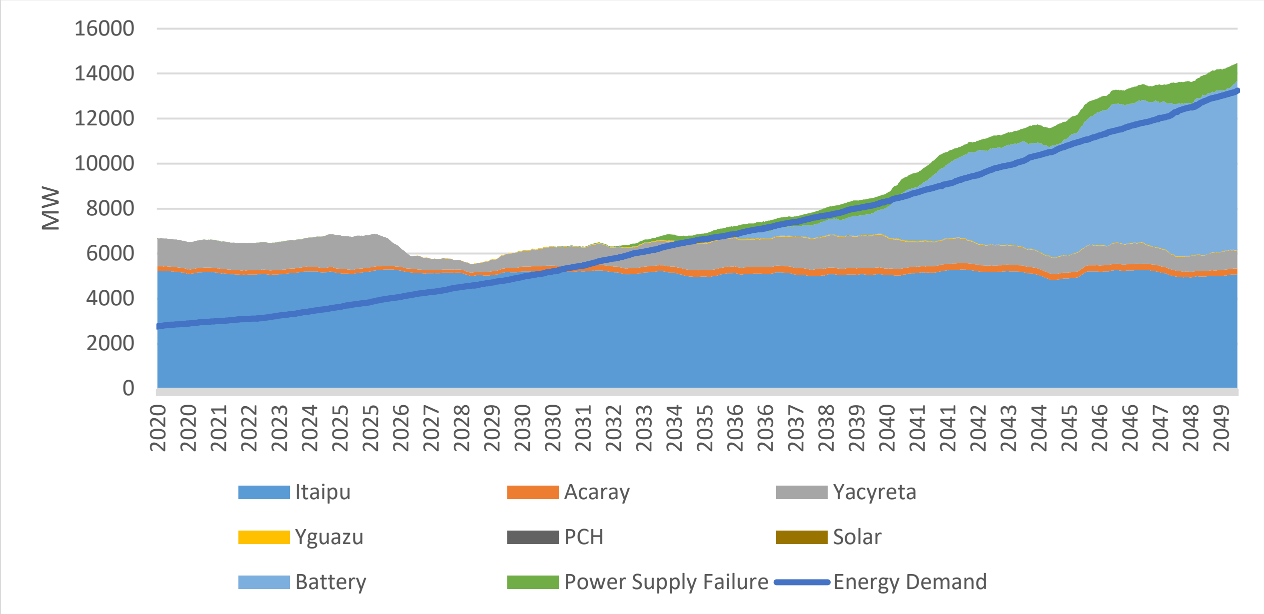
Figure 15: Aggregated Capacity of New Renewable Energy and Batteries



Source: Prepared by the authors.

While there is a significant level of new generation, its delayed start to 2030 means that generation capacity maintains current levels, just as in the previous scenario. As a result, the first occurrence supply crunch remains at 2030 but the non-supplied energy is higher than in the previous scenario. The not-supplied energy from this scenario reaches 3% by 2050. The investment in generation supply is roughly 25% higher than each year's energy demand and for lack of export outlet is wasted. Figure 16 presents the yearly-equivalent moving-average of weekly power dispatch for the peak-level of demand.

Figure 16: Peak Demand Power Balance for Moderate Renewables Investment Scenario (Closed Market)



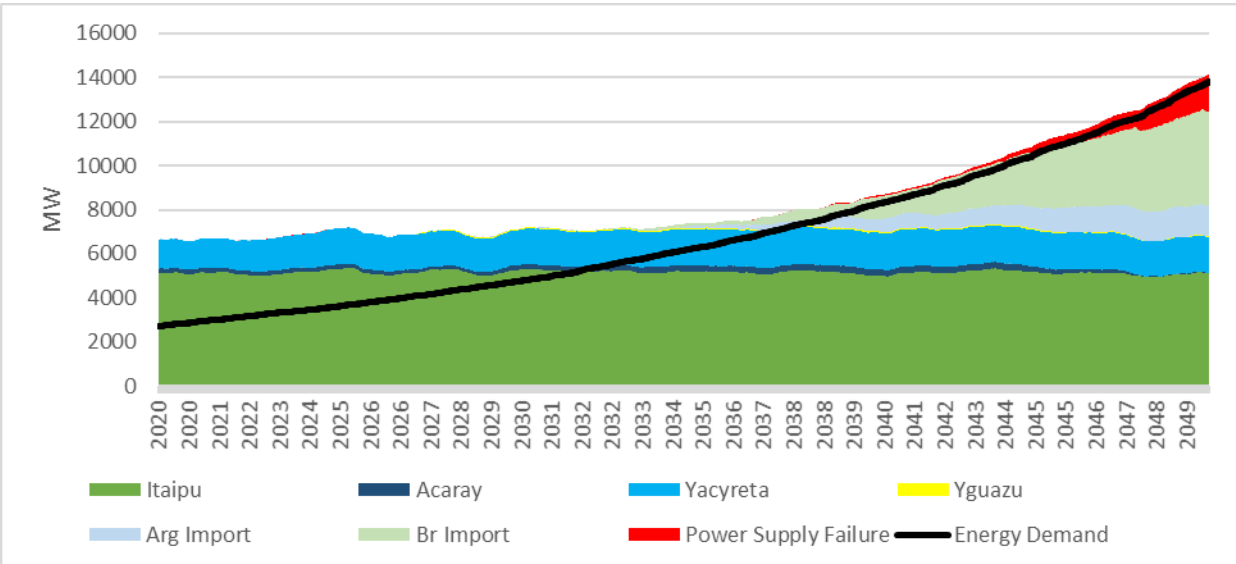
Source: Prepared by the authors.

Open Market Scenarios

Business-as-Usual Scenario

The Business-as-Usual (BAU) scenario, which assumes a demand growth projection of 5.46% for each year until 2050 and the same power supply today, sees the first occurrence of supply crunch year move from 2030 to 2038 as compared to the closed market presented in Chapter 2. Figure 17 presents the yearly-equivalent moving-average of weekly power dispatch for the peak-level of demand.

Figure 17: Peak Demand Power Balance for Business-as-Usual Scenario (Open Market)



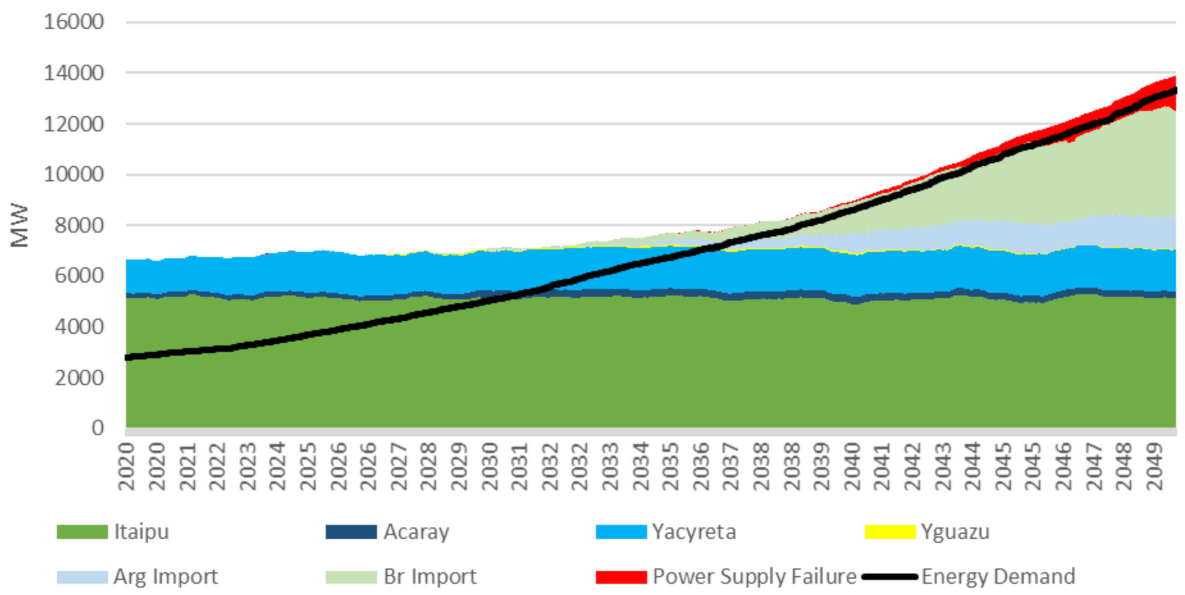
Source: Prepared by the authors.

Allowing an open market enables imports from Brazil and Argentina and they provide 55.6% of all energy demanded by 2050. With an open market, not-supplied energy would reach 0.06% and 3.2% of demand by 2040 and 2050, respectively, involving imports of 3200 GWh and 34,000 GWh, respectively. With the availability of transboundary transmission links the probability of power dispatch failure generation dispatch for the peak demand level is reduced to 60%, in average, by 2050.

Net-Zero Pathway

This scenario, which takes into account the energy demand growth assumptions accounted for by the Net-Zero Pathway scenario introduced in Chapter 1, sees a similar delay in the supply crunch, pushing it back to 2038 as well. In 2040, the not-supplied energy is reduced from 4.88% of demand in closed market to 0.6% of demand in open market. The not-supplied energy in the open market reaches 3.3% of demand by 2050. Figure 18 presents the yearly-equivalent moving-average of weekly power dispatch for the peak-level of demand.

Figure 18: Peak Demand Power Balance for Net-Zero Scenario (Open Market)



Source: Prepared by the authors.

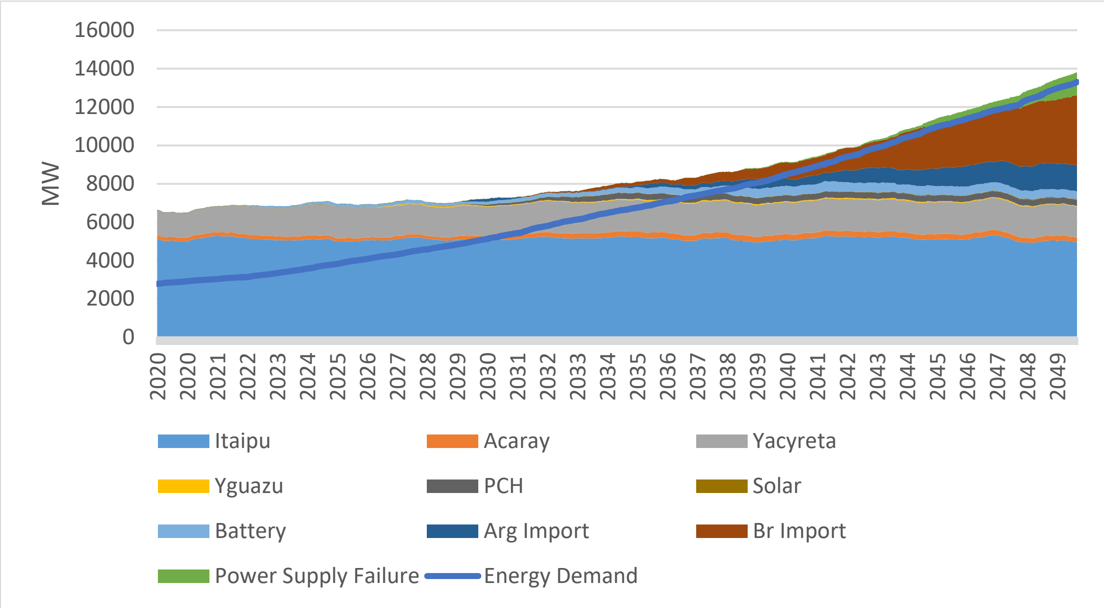
An open market enables energy imports from Brazil and Argentina and they provide 52.1% of all energy demanded by 2050. Like in the baseline scenario, the open market decreases the probability of failure to 60% by 2050.

ANDE Master Plan 2021-2040

This scenario, which also takes into account the energy demand growth assumptions accounted for by the Net-Zero Pathway scenario introduced in Chapter 1, also adheres to the planned generation capacity additions proposed in the ANDE Master Plan to 2040. As a result of an open market, the supply crunch is delayed until 2039, with Brazilian imports making a large portion of the difference. In 2040, the not-supplied energy is reduced from 3% of demand in closed market to 0.04% of demand in open market. The not-supplied energy in the open market reaches 2.4% of demand by 2050.

Figure 19 presents the yearly-equivalent moving-average of weekly power dispatch for the peak-level of demand.

Figure 19: Peak Demand Power Balance for ANDE Master Plan Scenario (Open Market)

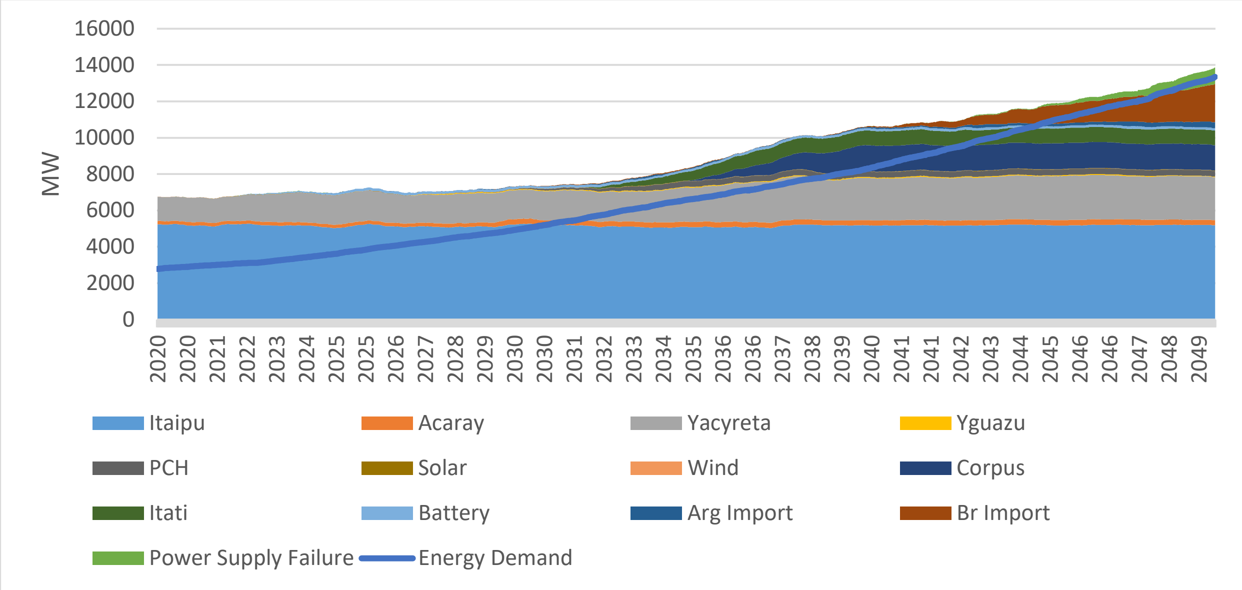


Source: Prepared by the authors.

ANDE Master Plan 2021–2040 with Binationals

The combination of the open market and the development of binational hydropower development in addition to generation expansion of the 2021-2040 Master plan delays the supply crunch to 2045. The not-supplied energy by 2040 would be much less than 0.01% of demand (from 0.03% in closed market), while by 2050 would be 1.0% (as compared to 15% in closed market), with net imports of 14, 000 GWh. Figure 20 presents the yearly-equivalent moving-average of weekly power dispatch for the peak-level of demand.

Figure 20: Peak Demand Power Balance for ANDE Master Plan with Binational Hydropower Plants Scenario (Open Market)



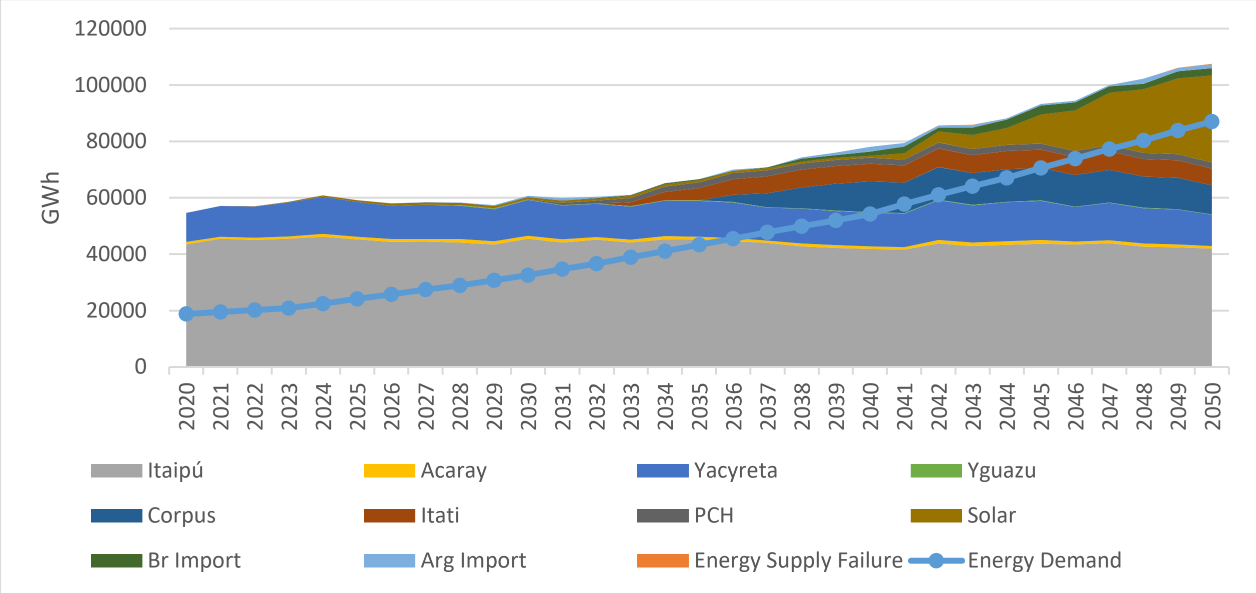
Source: Prepared by the authors.

Allowing an open market enables energy imports from Brazil and Argentina and they provide 23.0% of all energy demanded by 2050.

ANDE Master Plan 2021–2040 with Binationals and Renewable Energy and Batteries

This scenario assumes a significant ramp-up increase of solar, and battery storage technology within Paraguay after the completion of binational hydro projects starting in 2040. As a result of this generational capacity and the potential for energy imports, there is no supply crunch between 2020 and 2050, as all energy demand is met. Figure 21 presents the yearly-equivalent moving-average of weekly power dispatch for the peak-level of demand.

Figure 21: Peak Demand Power Balance for ANDE Master Plan with Binational Hydropower Plants and Renewables Scenario (Open Market)

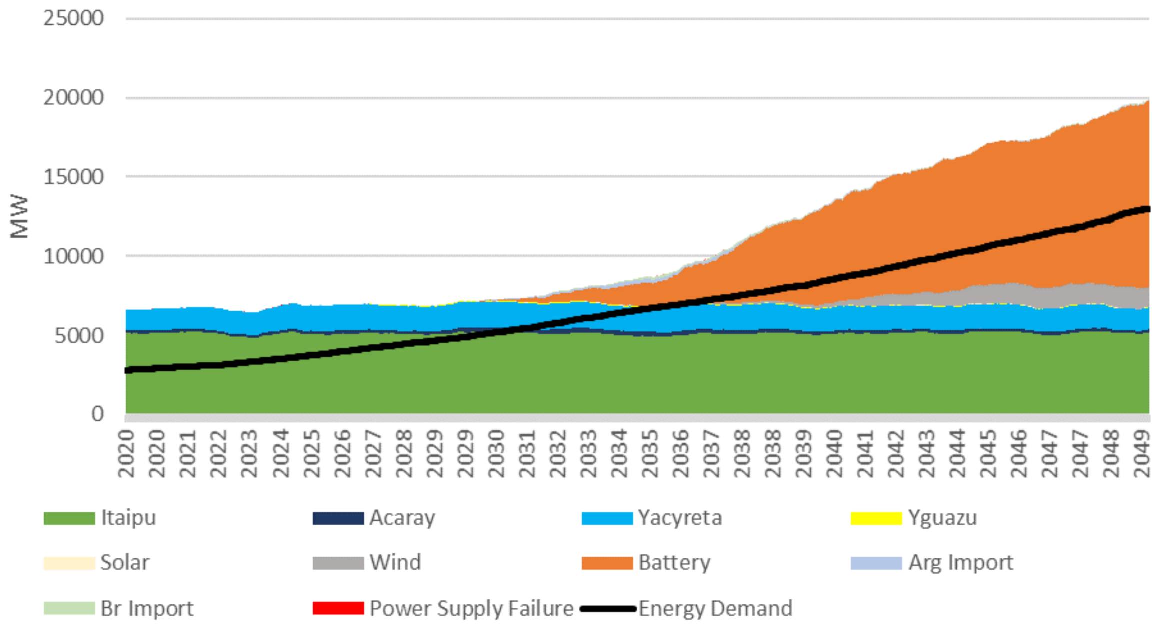


Source: Prepared by the authors.

High Renewables Investment

This scenario assumes a significant ramp-up increase of solar, wind, and battery storage technology within Paraguay between 2030 and 2050 which led to no supply crunch between 2020 and 2050, as all energy demand is met with renewable energy. The surplus from renewables in the low-demand seasons (autumn and winter) is even exported and after 2035, the energy surplus begins to accumulate due to the high penetration of renewable energies and most if is exported to the Brazilian and Argentinian markets. Unlike the previous scenario, this high access to battery storage reduces the reliance on imported energy to near zero. It is important to note the very small energy imports from Argentina and Brazil are used to supply load requirements that the investments in renewable are not able to, for instance, due to chronological mismatch between peak demands and solar irradiation or due to water inflow instability at dams' level. Figure 22 presents the yearly-equivalent moving-average of weekly power dispatch for the peak-level of demand.

Figure 22: Peak Demand Power Balance for High Renewables Investment Scenario (Open Market)



Source: Prepared by the authors.

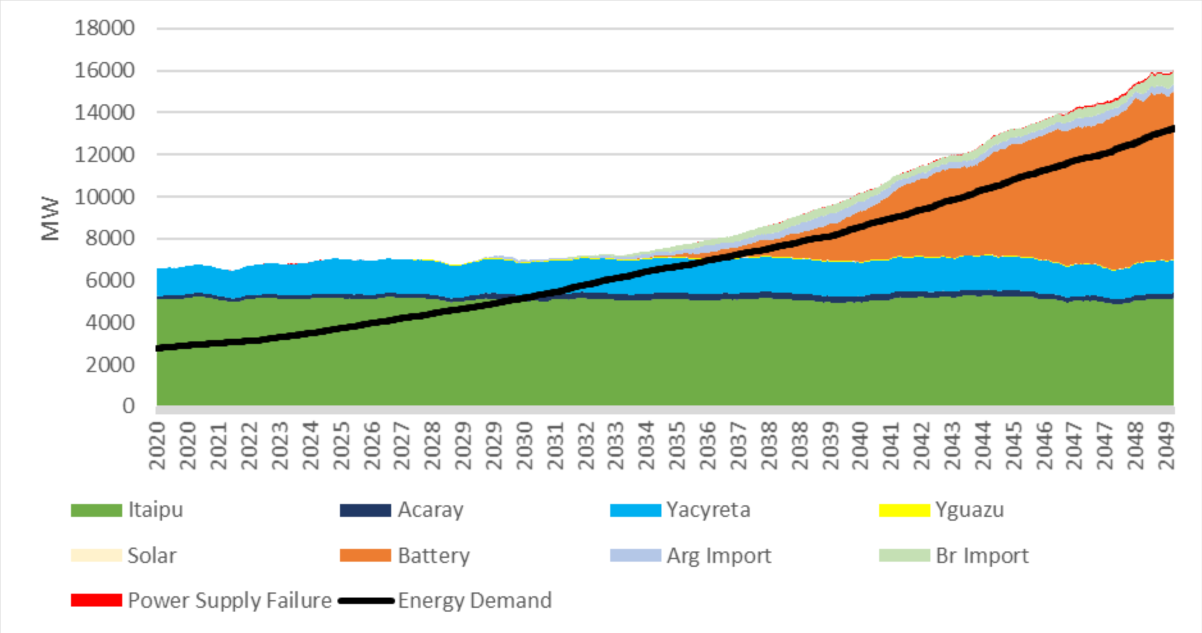
We note here that failures cannot be reduced completely even for the periods where investments in battery storage are massive. A main explanation for this is that the model itself is limited, as it optimizes the power dispatch in a weekly basis whereas the traditional operation mode of a battery is related to an intra-day optimization. In this model, the optimization involves charging the battery in weeks of lower energy demand in order to supply the storage in weeks of higher and peak demand but with the constraint of weekly energy capacity. This implies that the battery sizing here is roughly seven times what it would be if the charging/discharging cycles were intra-day. Nevertheless, this "oversizing" allows for one to estimate the amount of investment and technology mix needed to secure a situation of negligible not-supplied energy and energy surplus to export to the neighboring countries.

Moderate Renewables Investment

This final scenario assumes a moderate increase of solar, wind, and battery storage technology within Paraguay between 2030 and 2050 to reduce the amount of expected not supplied energy. As a result, there is yet again no supply crunch between 2020 and 2050 And as in the previous scenario, the reliance on imports is small but is still needed to supply the loads that cannot be met by renewable energies or by hydro-dams because of low water inflow.

Figure 23 presents the yearly-equivalent moving-average of weekly power dispatch for the peak-level of demand.

Figure 23: Peak Demand Power Balance for Moderate Renewables Investment Scenario (Open Market)



Source: Prepared by the authors.

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Please cite as:

Columbia Center on Sustainable Investment (CCSI), Quadracci Sustainable Engineering Lab at Columbia University, and Centro de Recursos Naturales, Energía y Desarrollo (CRECE). *Decarbonization Pathways for Paraguay's Energy Sector.* New York: CCSI, November 2021, http://ccsi.columbia.edu/content/paraguay-energy.

Published by the Columbia Center on Sustainable Investment, a leading applied research center and forum dedicated to the study, discussion and practice of sustainable international investment.