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Spatial national multi-period long-term energy and carbon planning scenarios, including temporal network security analysis. Complementing renewable energy and hydropower due to climate change

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Abstract:

As emerging countries work to balance the energy trilemma and provide secure, affordable, and environmentally sustainable energy, the link between energy, water and food and the rising demands for all are stressing the supply resource. The Republic of Ecuador is withinside the method of improvement a residential, industries and commercial demand plan which ends up in an supply call for increase, with a populace of 17.08 million population for 2018, it affords an strength boom of about 7.13% annual common until 2027, this means that our mounted strength supply should be capable of deliver all of the demand for and its annual increase, it is miles because of this that during our research we are able to examine the incorporation of recent and proposed plant life deliberate to fulfil the call for of of the residential, commercial and industries in tiers that the country is planning to make bigger way to the renewable energy withinside the efficient energy matrix, withinside the equal manner the export of energy to neighbouring international locations Colombia and Peru is proposed. However, to reap this incredible alternate we pose numerous hypotheses that describe the hypothetical demand of residential, industries and commercial call for and in addition to the development of recent renewable technology plant life. Traditional and unconventional taking gain of renewable sources in abundance which include capacity water strength, wind strength, sun strength amongst others to generate electric supply and because of the modern-day state of affairs, deepen a public and private funding settlement to reap our objective, on this manner, pleasing our biggest hypothetical cases, we are able to be capable of deliver all of the energy needs for the year 2035, making sure a strong interconnected country wide grid with its enough reserve potential and making sure that each one the residential call for is included plus the projected commercial and industry call for pleasing the big emblematic projects, that the sizable majority will directly generate new jobs, financial boom and we are able to develop as a global industrialized nation.

Keywords:

Energy planning; Electric power; Renewable energies; Ecuadorian energy matrix.

1. Introduction

This paper reviews the current state of the Ecuadorian Electric Sector, defining its structure, production, energy consumption and the legal framework on which the future expansion of the Generation System through private investment is based, as well as the concession model of certain awarded projects to the present date. The Generation planning in the Ecuadorian Electric System is based on different programs at the state level such as the Electricity Master Plan (2018-2027) [1] and the National Energy Efficiency Plan, its general objectives being to increase the generation capacity of electrical energy in an efficient and clean manner with the environment, which the Ministry of Energy and Non-Renewable Natural Resources has called 'The change of the energy matrix'.

1.1. Electricity sector main actors

The Ecuadorian electricity sector is made up of legal entities dedicated to the activities of generation, self-generation, transmission, distribution and commercialization, public lighting, import and export of electrical energy, as well as natural or legal persons who are considered consumers or end users [2, p. 20-21].

1.1.1 Generation.

Generation and/or Self-generation activities in the country are carried out by public and private companies, which must pass certain requirements to be authorized by the competent authority. Generating companies

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are those that have permission for the economic operation of one or more plants and deliver their production to one or more points of the National Transmission System, Distribution System, or isolated points. Self-generating companies are those dedicated to an industrial or commercial activity, whose electricity generation is used to supply their demand, and if applicable, the surplus can be made available to the sector. In 2019 there were 129 generation plants, of which 77 correspond to public companies and 52 plants to private companies. Now, the Electric Corporation of Ecuador Public Company maintains the largest amount of electricity production. Of the national installed generation capacity of 7,320 MW by 2020, 86% corresponds to CELEC EP, that is, 6,366.2 MW, which is distributed as follows: 27 Power Plants that correspond to 90% of the thermal park, 14 Hydroelectric Power Plants with 89% and an installed capacity of 4,498.73 MW and finally a wind power plant with 9% of a capacity of 16.5 MW.

1.1.2 Transmission.

CELEC EP - Transelectric Business Unit oversees the planning, operation, maintenance, and expansion activities of the National Transmission System, based on the energy policies established by the Ministry of Energy and Non-Renewable Natural Resources (MEM).

1.1.3 Commercial and Distribution units.

The distribution and commercialization of electrical energy is carried out by state companies corresponding to eleven (11) Business Units of the National Electricity Corporation Public Company, additionally there are nine (9) companies established as public limited companies, which act according to current regulations. The energy consumption of the distribution companies in 2019 can be seen in Figure 1.

1.1.4 International links

The Ecuadorian Electric System currently has two International Interconnections of a legal nature, one with Colombia through a 230 kV link, and another with Peru through charge block transfers.

1.2. Structure of the electricity sector

Figure 2 shows the interrelation of the actors in the electricity sector with the other control agencies. The Ecuadorian electricity sector is made up of a governing body that is the MEM, which through the Vice-Ministry of Electricity and Renewable Energy, is the entity responsible for meeting the country's electricity energy needs, through the formulation of the pertinent regulations, development plans and sectoral policies for the efficient use of its resources.

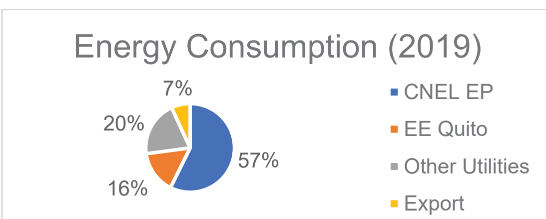

Figure 1 Energy consumption 2019 [1]

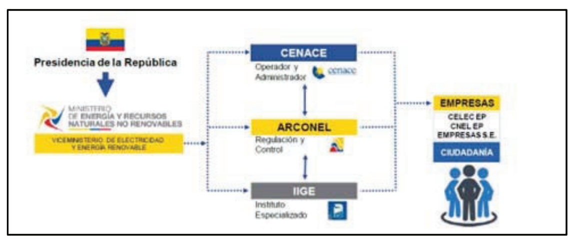

Figure 2. Structure of the Ecuadorian electricity system [1].

The National Electricity Operator (CENACE) is a strategic technical body attached to the MEM, which will act as technical operator of the National Transmission System (NTS) and is the commercial administrator of the energy block transactions, and responsible for the continuous supply of electricity at the lowest possible cost, preserving the global efficiency of the sector [2].

Executive Decree 1036 issued by the Presidency of the Republic of Ecuador established the merger of the Mining Regulation and Control Agency (ARCON), the Hydrocarbons Regulation and Control Agency (ARCH) and the Electricity Regulation and Control Agency (ARCONEL) [3] into one single entity called: Agency for the Regulation and Control of Energy and Non-Renewable Natural Resources (ARC) since July 1, 2020. By provision of the Organic Law of 'Public Electricity Service' (PES), it corresponds to ARCONEL, in its legal nature (Art. 14) regulate and control the activities related to the public electric power service and the general public lighting service, safeguarding the interests of the consumer or end-users, having among its attributions the issuance of the regulations to which the electric companies; CENACE and consumers or end users; whether these are public or private, observing the energy efficiency policies, for which they are obliged to provide the information that is required, the same that are previously approved and issued by its Board of Directors.

The Geological and Energy Research Institute (IIGE), created by Executive Decree No. 399 of May 15, 2018, through the merger of two institutes focused on research into energy efficiency, renewable energy, geology, mining, and metallurgy. With the creation of the IIGE, scientific research regarding earth sciences is strengthened, which will improve institutional capacities by generating a specialized human and technical resource, with greater scope for scientific work, technological development, and local innovation.

Electricity Corporation of Ecuador (CELEC EP) is a public company, dependent on the MEM, which was born in 2009 after the nationalization and unification of various companies in the sector. Its objective is the generation and transmission of Electric Power. National Electricity Corporation (CNEL EP) is a public company established in 2008, to provide public services of distribution and commercialization of electrical energy.

1.3. Energy production

According to the CENACE [2], in 2019 the Gross Energy produced in 2019 was 27,733.96 GWh. By origin, around 88.39% (24,513.99 GWh) was obtained from hydraulic sources, 10.14% (2,811.52 GWh) from thermal sources, and 1.45% (402.62 GWh) from renewable generation, and the remaining 0.02% (5.83 GWh) to international interconnections, as shown in Figure 3. The energy produced [2] from hydraulic sources has increased from 71.6% in 2017 to 88.39% in 2019. The Renewables gross production is distributed in 62% for Biomass, 20% Wind, 10% for Biogas and 8% for Photovoltaic Generation, as shown in Figure 4.

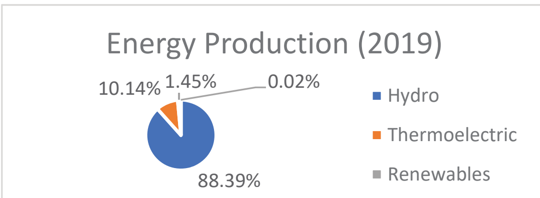

Figure 3. Energy Production by source in year 2019

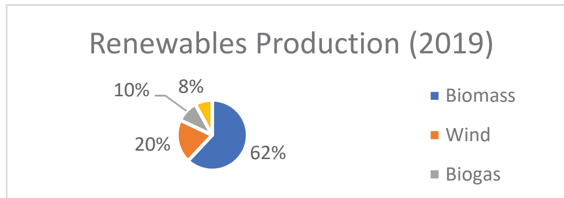

Figure 4. Renewables production in year 2019

1.4. Energy demand

The growth in energy demand in 2019 reached 8.12% compared to 2018. Table 1 includes a monthly comparative table of the energy demands of the Ecuadorian electricity sector between 2018 and 2019.

Table 1. Energy demand (GWh) 2018 and 2019 [2]

Month	2018	2019	Percent change %
January	2,064.02	2,096.56	1.58
February	1,764.59	1,946.52	10.31
March	1,970.88	2,150.00	9.09
April	1,970.93	2,117.26	7.42
May	1,999.55	2,162.90	8.17
June	1,838.77	2,000.16	8.78
July	1,862.94	2,042.18	9.62
August	1,867.16	2,034.04	8.94
September	1,845.81	1.974,23	6.96
October	1,891.27	2,040.53	7.89
November	1,870.50	2,059.80	10.12
December	1,947.52	2,129.05	9.32
Total	22,893.94	24,753.23	8.12

The per capita consumption of electricity in 2017 was 1,157.99 kWh/inhabitant, according to the National Institute of Statistics and Censuses of Ecuador.

1.5. Private Investment Opportunities

The legal framework where the opportunity for private investment in the electricity sector is based are:

- Concession Contracts (Art. 25 et seq. PES and 18 et seq. of its regulations) through MEM public selection processes.
- Projects under the Public-Private Association modality are delegated Management Contracts (PES incentives for public-private associations).
- Associative capacity of public companies to fulfil their business goals and objectives. Any type of association, strategic alliances, mixed economy companies with public or private sectors at the national or international level or within the popular and solidarity economy sector. (Art. 35 and following of the Organic Law of Public Companies).

In December 2020, through a public selection process for the concession to the private electricity generation, the renewable projects Villlonaco II and III wind farms and El Aromo photovoltaic systems (PV), with an installed capacity of 110 MW, and 200 MW, respectively, were awarded to the Spanish companies Consortium Cobra Zero-E Villonaco and Solarpackteam. These awards involve the design, construction, operation, and maintenance of new power generation projects located in the provinces of Loja (wind) and Manabí (PV).

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This research contains a number of preliminary research questions that have not been previously explored in detail, and that do not have definitive answers regarding the impact that generation projects would have on the Ecuadorian electricity sector, (i) what will Ecuador's energy planning be like and the income of the different generation projects to satisfy the energy demand during the period from 2020 to 2035?, (ii) what will be the energy production supplied by the renewable blocks in the Ecuadorian Electric System during the period from 2020 to 2035?, (iii) what will be the best scenario to satisfy the energy demand in the period 2020 to 2035?, (iv) will it be possible to supply the demand for electrical energy without having Cardenillo and Santiago hydroelectric projects?

2. Methodology

2.1. Data availability

In this chapter we will review the technical information available by the control agencies of the Ecuadorian electricity sector such as MEM, CENACE and ARC, which will serve as input data for our modelling in the Long Emissions Analysis Platform (LEAP).

For the operational data, the CENACE 2019 Annual Report was used, for the forecast load and generation projection, the Electricity Master Plan 2018-2027 issued by the MEM was used, for certain specific data the System Data (SISDAT) Database was used, and the Annual and Multiannual Statistics of the Ecuadorian Electricity Sector 2018, Resolution ARCONEL – 069/16.

2.2. Historic production

The historical production for the year 2019 of the generation plants of the Ecuadorian Electric System was obtained from the CENACE Annual Report 2019, specifically in annex 2.3 (Net production by generation company [GWh] 2019). As shown in Table 2.

Within the report issued by CENACE, the power plants or generation units whose historical production in 2019 is zero have not been considered. This situation occurs because the effective capacity in hydroelectric generation that Ecuador currently has increased considerably in recent years, causing the lower capacity thermal plants to not be required in daily dispatches, other plants do not have the authorization of the governing bodies to participate in the Ecuadorian electricity sector, even though these plants are currently operational, additionally there is another group of plants that are intervened by the Ecuadorian state, whose equipment and components are deteriorating due to lack of operation and maintenance. Table 3 shows a summary of the companies with the drawbacks.

2.3. Energy Capacity

The energy capacity of the power plants and/or generation units was obtained by means of the Statistical Information Reports of the Ecuadorian Electricity Sector available in the SISDAT database of ARC as shown in Table 4.

Table 2. Production by generation company [2]

Power Plant	Jan.	Feb.	March	April	May	June	July	Aug.	Sept	Oct.	Nov.	Dec.
C. F. Altgenotec	0.09	0.09	0.1	0.1	0.09	0.07	0.09	0.11	0.08	0	0	0
C. F. Brineforcorp	0.11	0.12	0.14	0.13	0.1	0.07	0.06	0.09	0.09	0.07	0.1	0.13
C. H. Minas San Francisco	28.57	14.42	38.89	52.63	7.29	6.49	38.39	38.49	12.88	17.95	25.09	25.6
C.H. Minas San Francisco	21.28	40.52	26.09	21.72	43.64	11.21	28.39	38.49	12.88	17.95	25.09	25.6
C. H. Coca Codo Sinclair	565.86	483.61	544.62	536.66	533.94	524.1	370.12	524.1	550.7	572.52	584.541	591.15
C. H. Manduriacu	12.95	16.73	20.39	15.14	18.24	14.65	11.95	11.31	7.66	5.28	14.36	19.3
C.H. Manduriaco	12.35	16.73	19.23	14.72	17.92	14.9	9.1	4.17	5.85	12.89	13.48	19.37
C. E. Villonaco	6.52	4.59	6.21	4.84	4.93	8.74	9.68	11.49	8.8	5.31	3.28	4.25
C. H. Delsitanisagua	39.84	19.68	19.13	0	11.12	12.7	8.68	0	0	23.15	28.08	33.71
C. H. Delsitanisagua	27.88	26.9	17.02	14.71	16.83	11.13	12.29	0	0	23.61	31.35	35.03
C. H. Delsitanisagua	21.25	14.61	13.71	31.51	13.35	17.63	11.92	0	0	22.44	25.74	31.84
C. H. Alazán	1.14	2.54	2.68	2.64	1.76	1.5	2.61	2.16	2.82	2.8	2.19	2.16
C. T. Jaramijó	20.99	19.05	21.29	22.35	21.32	21.14	22.92	19.13	13.04	24.15	9.38	9.38
C. T. Manta 2	2.96	3.06	3.16	4.54	5.23	4.02	4.39	3.44	2.38	4.15	4.06	4.52
C. T. Miraflores	0	0.01	0	0	0	0	0.01	0	0	0.01	0	0.01
C. T. Miraflores	0.13	0.3	0.24	0.21	0.3	0.1	0	0.01	0.01	0.02	0.02	0.01
C. T. Miraflores	0.14	0.36	0.29	0.26	0.29	0.1	0	0.01	0.01	0.02	0.02	0.01
C. T. Miraflores	0	0.01	0	0	0	0	0.01	0	0	0.01	0	0.01
C. T. Miraflores	0.04	0.23	0.22	0.05	0.23	0.01	0	0	0.01	0.02	0.02	0.01
C. T. Miraflores	0.04	0.15	0.14	0.23	0.19	0.03	0	0.01	0.01	0.02	0.02	0.01

It was considered that the reports are of high quality and contain the fundamental information of the Ecuadorian Electric System, this information will be useful for our modelling in the LEAP software in the ‘Exogenous Production’ section.

Table3. Companies with problems in their legalization

Company	Nominal Power [MW]	Fuel
Termoguayas Generation	150	Fuel Oil 6
Electroquil	180	Diesel Gas Turbine
Intervisa Trade	105	Diesel Gas Turbine
Ulysseas	30	Naphtha

In accordance with the provisions of the Electricity Master Plan, the expansion of generation will be carried out with the following objective: Guarantee the supply of electricity in Ecuador through the optimal expansion of the electric power generation stage, in the short, medium and long term, with criteria of efficiency, sustainability, quality, continuity and security; promoting the use of renewable energy resources, in an area of sufficiency, energy sovereignty, social and environmental responsibility; considering technical, economic, financial and administrative aspects.

Table 5 details the Electricity Generation projects that are under construction, Table 6 details the Electric Power Generation projects with Enabling Titles. Table 7 details the hydroelectric projects with more than 500 MW that have a final study and design, and Table 8 presents the summary of the generation projects for the case of the productive matrix that are additional to the Base case, detailing the most probable date of commercial operation, the name of the generation project, the company or institution in charge, the current state (construction, studies, etc.), if the project is financed with public or private funds, the type of technology (hydroelectric, thermoelectric, Non-Conventional Renewable Energies, among others), the nominal power (MW), and the estimated average annual energy (GWh/year).

2.4 Generators factors of maximum availability

Resolution No. ARCONEL-069/16, in its literal 4, defines the referential availability factors:

> "…*the referential availability factors are detailed by type of technology of the generating plants, which will serve for the comparison of the monthly average availability factor; and, for the liquidation of the fixed charge or annuity*."

These Values are presented in Table 9. The referential maximum availability values indicated by the resolution do not consider the Generation systems with renewables, for this reason due to the availability of their primary energies such as wind and solar energy, in our modelling we will enter the value of 100%. for this type of technology.

Table 4. Energy Capacity of National Grid Generators

Company	Investment	Power Plant	Type	Power subtype	Energy Type	Nominal Power (MW)	Effective Power (MW)	Nominal Power to public service (MW)
Algenotec	Private	Algenotec	Solar	Fotovoltaic	Renewable	0.936	0.936	0.936
Brineforcorp	Private	Brineforcorp	Solar	Fotovoltaic	Renewable	0.999	0.999	0.999
CELEC–Coca Codo Sinclair	Public	Manduriacu	Hydro	Hydro	Renewable	63	65	63.36
CELEC–Coca Codo Sinclair	Public	Coca Codo Sinclair	Hydro	Hydro	Renewable	1,500	1,476	1,500
CELEC- Electroguayas	Public	Trinitaria	Thermoelectric	Turbovapour	Non-renewable	133	133	133
CELEC- Electroguayas	Public	Gonzalo Zevallos (Vapour)	Thermoelectric	Turbovapour	Non-renewable	146	140	146
CELEC- Electroguayas	Public	Gonzalo Zevallos (Gas)	Thermoelectric	Turbogas	Non-renewable	26.265	20	26.265
CELEC- Electroguayas	Public	Enrique Garcia	Thermoelectric	Turbogas	Non-renewable	102	96	102
CELEC- Electroguayas	Public	Santa Elena II	Thermoelectric	Internal Combustion motor	Non-renewable	90.1	65.025	90.1
CELEC- Electroguayas	Public	Santa Elena III	Thermoelectric	Internal Combustion motor	Non-renewable	41.7	40.002	41.7
CELEC-Gensur	Public	Villonaco	Wind	Wind	Renewable	16.5	16.5	16.5
CELEC-Gensur	Public	Delsitanisagua	Hydro	Hydro	Renewable	180	180	180
CELEC_Hidroagoyán	Public	Pucará	Hydro	Hydro	Renewable	73	73	73
CELEC_Hidroagoyán	Public	Agoyán	Hydro	Hydro	Renewable	160	156	160
CELEC_Hidroagoyán	Public	San Francisco	Hydro	Hydro	Renewable	230	212	230
CELEC_Hidroazoguez	Public	Alazán	Hydro	Hydro	Renewable	6.23	6.23	6.23
CELEC-Hidronación	Public	Marcel Laniado	Hydro	Hydro	Renewable	213	213	213
CELEC-Hidronación	Public	Baba	Hydro	Hydro	Renewable	42.2	42	42.2
CELEC-Sur	Public	Molino	Hydro	Hydro	Renewable	1075	1,100	1,075
CELEC-Sur	Public	Mazar	Hydro	Hydro	Renewable	170	170	170
CELEC-Sur	Public	Sopladora	Hydro	Hydro	Renewable	486.99	486.9	486.99
CELEC-Sur	Public	Minas San Francisco	Hydro	Hydro	Renewable	270	270	270
CELEC-Termoesmeraldas	Public	Esmeraldas I	Thermoelectric	Turbovapour	Non-renewable	132.5	125	132.5
CELEC-Termoesmeraldas	Public	La Propicia	Thermoelectric	Internal Combustion motor	Non-renewable	10.5	8.5	10.5

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Table 5. Electricity Generation Projects under Construction [1]

Project/Power Plant	Company	Public or private	Type	Power [MW]	Average Energy [GWh/year]
Toachi - Pilatón	CELEC EP - Hidrotoapi	Public	Hydro	254.40	1,120
Machala Gas Ciclo Combinado	CELEC EP – Termogas Machala	Public	Thermoelectric	110	690
Machala Gas Tercera Unidad	CELEC EP – Termogas Machala	Public	Thermoelectric	77	510
Minas de Huascachara	Elecaustro S.A.	Public	Wind	50	119
Quijos	CELEC EP – Coca Codo Sinclair	Public	Hydro	50	355
Piatúa	San Francisco Genefran S.A.	Private	Hydro	30	210
Sabanilla	Hidrelgen S.A.	Private	Hydro	30	210.5
Rio Verde Chico	Hidrosierra S.A.	Private	Hydro	10	74.3
Chalpi Grande	EPMAPS EP	Public	Hydro	7.59	36
Mazar-Dudas: Dudas	CELEC EP - Hidroazogues	Public	Hydro	7.38	41.4
Mazar-Dudas: San Antonio	CELEC EP – Hidroazogues	Public	Hydro	7.19	44.9
San José de Minas	Hidroeléctrica San José de Minas S.A.	Private	Hydro	5.95	48
Chorrillos	Hidrozamora EP	Public	Hydro	4	23.2
Ulba	Hidroulba S.A.	Private	Hydro	1.02	8.4
TOTAL				**644.5**	**3,490.6**

Table 6. Power Generation projects with Enabling Titles [1]

Project/Power Plant	Company	Public or private	Type	Power [MW]	Average Energy [GWh/year]
Ibarra Fugúa	Hidro Ibarra Fugúa	Private	Hydro	30	208.4
El Salto	Hidroequinoccio EP	Public	Hydro	30	247
La Magdalena	Hidroequinoccio EP	Public	Hydro	20	167
Soldados Yanuncay, Central Yanuncay	Elecaustro S.A.	Public	Hydro	14.6	79.5
Pilaló 3	Qualitec Comercio e Industria Cía. Ltda.	Private	Hydro	9.3	68.7
Maravilla	Hidroequinoccio EP	Public	Hydro	9	61.6
Chalpi Grande	EPMAPS EP	Public	Hydro	7.59	36
Soldados Yanuncay, Central Soldados	Elecaustro S.A.	Public	Hydro	7.2	39.2
Pichacay II	EMAC-GBP	Mixed	Biogas	1	3.5
El Laurel	CBS Energy	Private	Hydro	0.97	6.8
TOTAL				**130**	**918**

Table 7. Hydroelectric projects with more than 500 MW [1]

Project	Technology	Power [MW]	Average Energy [GWh/year]
Santiago	Hydro	2,400	14,613
Cardenillo	Hydro	596	3,409
TOTAL		**2,996**	**18,022**

Table 8. Summary of Electricity Generation projects [3]

Year of entry into operation	Project	State	Public or private investment	Type	Power [MW]	Average Energy [GWh/year]
2018	Normandía	In operation	Private	Hydro	49.6	350.3
2018	Delsitanisagua	In operation	Public	Hydro	180	1,411
2019	Minas – San Francisco	In operation	Public	Hydro	274.5	1,290.8
2019	Pusuno	In operation	Private	Hydr o	39.5	216.9
2019	Rio Verde – Chico	In operation	Private	Hydro	10	74.3
2020	San José de Minas	In construction	Private	Hydro	5.95	48
2020	Machala Gas Tercera unidad	In construction	Public	Thermoelectric	77	510

2020	Mazar – Dudas: San Antonio	Paralyzed	Public	Hydro	7.19	44.9
2020	Minas de Huascachaca	In construction	Public	Wind	50	119.0
2021	Machala Gas Ciclo Combinado	In construction	Public	Thermoelectric	110	680
2021	Piatúa	In construction	Private	Hydro	30	210
2021	Chalpi Grande	In construction	Public	Hydro	7,59	36
2021	Toachi – Pilatón (Sarapullo 39 MW, Alluriquín 205.4 MW)	In construction	Public	Hydro	254.4	1,120
2021	La Magdalena	Operation authorization	Public	Hydro	20	167
2021	Maravilla	Operation authorization	Public	Hydro	9	61.6
2021	Ibarra - Fugúa	Concession contract	Private	Hydro	30	208.4
2021	Mazar – Dudas: Dudas	Paralyzed	Public	Hydro	7.38	41.4
2021	Sabanilla	In construction	Private	Hydro	30	210.5
2022	El Salto	Operation authorization	Pubic	Hydro	30	247
2022	Chorrillos	Paralyzed	Public	Hydro	4	23.2
2022	Soldados Yanuncay, Central Soldados	Operation authorization	Public	Hydro	7.2	39.2
2022	PV Aromo and Wind: Villonaco II and III.	Structured public selection process	Private	Renewables	500	1,700
2023	Soldados Yanuncay, Central Yanuncay	Operation authorization	Public	Hydro	14.6	79.5
2023	Quijos	Paralyzed	Public	Hydro	50	355
2023	Bloque Ciclo Combinado I	Structured by public selection process	Public	ERNC	400	3,000
2023	Bloque ERCN II	In studies	Private and/or public	Thermoelectric	400	1,400
2023	Bloque Ciclo Combinado II	In studies	Private and/or public	Thermoelectric	600	4,500
2024	Santa Cruz	Minig self-generation in process	Private	Hydro	100	560
2025	Bloque de Proyectos Hidroelectricos I	In studies	Private and/or public	Hydro	150	850
2026	Bloque de Proyectos Hidroelectricos II	In studies	Private and/or public	Hydro	150	850
2026	Bloques de Proyectos Geotérmicos	In studies	Private and/or public	Geothermic	50	380
2026	Paute - Cardenillo	In public selection process	Private	Hydro	595.6	3,409
2026	Santiago (G8), Fase I	In public selection process	Private	Hydro	1,200	9,874
2027	Santiago (G8), Fase II	In public selection process	Private	Hydro	1,200	4,739
	Total				**6,644**	**38,816**

Table 9. Factors of maximum availability [2]

Type	Technology	AF_{ref}
Hydro	Reservoir	0.92
Hydro	Run-of-the river	0.90
Thermal	Vapour	0.80
Thermal	Gas	0.80
Thermal	Internal Combustion motor	0.80

2.5. Other considerations

Within this study, the following special aspects must be considered, referring to the generation projects that will enter in the following years:

- The Paute-Cardenillo Hydroelectric Project is the last project to be built for the development of the Paute River Complex and will work jointly with Sopladora, Mazar and Molino. It will have an installed capacity of

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596 MW. The referential investment of the project has a cost of USD 1.3 billion and will be awarded to the private company that will be responsible for the design, construction, implementation, administration, operation, and maintenance of the project.

- The Santiago hydroelectric project is in the southeaster region of Ecuador, it is located on the river of the same name within the Amazon hydrographic region, in the Tiwintza, Limón Indanza and Santiago de Méndez cantons, in the province of Morona Santiago, it will have an installed capacity of 3,600 MW. Due to its size, it will be executed in phases. This project will also be concessioned to a private company.
- The renewable blocks corresponding to technologies such as hydroelectric, wind, solar and biomass are projects that will be in different sectors of the country, and that will be concessioned to private companies according to the structured legal framework.
- The Chespi, Chontal, Tortugo and Tigre Hydroelectric Generation projects with a total capacity of 943 MW have the following investment time: Chespi (48 months, USD 793 million), Chontal (60 months, USD 435 million), Tortugo (50 months, USD 471 million) and Tigre (54 months, USD 215 million) are considered in our modelling.

Additionally, for the analysis of the demand, it is necessary to consider the hypotheses raised in the Master Plan, where the industrial city of Posorja is considered and from 2030 it will be a normal scenario of demand growth, the needs are projected for 12,000 GWh energy and 3,000 MW power.

Within the operational planning of the electrical system, there must be a rolling reserve that can act in the event of possible dynamic scenarios or sudden increases in demand, according to what is established by the Master Plan, this reserve is around 20% in the Ecuadorian Electrical System. Which considers the technical reserve, the primary frequency regulation, and the secondary frequency regulation.

Additionally, the cold reserve must be considered, unlike the rolling reserve, this is not available immediately. The cold reserve is the part of the non-rolling reserve (hydraulic or thermal) that can come into service and reach its available power in a time of no more than 15 minutes, which are within a merit list, to cover the deficit of generation reserve caused by various contingencies that occur in the system.

The cold reserve amount will be determined based on a reliability study, while in the case of the NTG it has been technically determined. The maximum value of the cold reserve according to the dispatch and operation procedures (of CENACE) must be equal to the generation unit with the highest power dispatched, thus preventing way the probable loss of the largest generation of the system.

3. Results

This section details the results to carry out the modelling of our Ecuadorian Electric System, for which we use the LEAP program [4], obtaining an analysis of the planning of electric power generation systems. The planning of electrical power systems represents a great economic development, for this reason it is necessary to define strategies for its expansion in the medium and long term, within this scenario the forecasted load plays an important role, for this reason we will follow the approaches determined in the Master Plan. The analysis carried out exclusively involves the expansion of generation and its attention to the scheduled demand, the expansion of the Transmission and Distribution Systems that require additional investments is not being considered, although the power losses did were considered.

The Hypotheses that we will present below are those found in the Master Plan where three study hypotheses are proposed that generated seven projection scenarios in LEAP, of which six were inherited from a trend scenario of energy demand. The study hypotheses will allow the construction of scenarios that will manage to articulate the policy of productive development, energy efficiency and basic industries (Master Plan). To make a projection from 2020 to 2035, the possible trends in the short, medium, and long term were entered with the aim of being able to determine the energy needs in the stages of generation and transmission of Electric Power. From 2030 to 2035, a normal increase in demand growth has been considered; needs of 12,000 GWh and 3,000 MW are projected. To enter the data of the demand 2030 to 2035 in the LEAP program in the base scenario we must create a folder in the Demands branch that we will call 2030 loads where an ‘energy-intensive technologies" will be created, when selecting the reference case, we locate the variable ‘Final Energy Intensity’. In this scenario, it contemplates what is the upward growth trend of users of industrial, commercial, and residential consumption. An average annual growth of 5.44% is estimated from 2018 to 2027, reaching 33,840 GWh in 2027 (Master Plan chapter 3 Electricity Demand, page 84) considering the average annual growth of 2.43% in users, reaching 6.48 million of users in 2027.

Hypothesis 1 corresponds to the projection baseline, which considers the trend growth of electricity demand; it incorporates econometric models, analysis of previous periods and analytical schemes. Hypothesis 2 results from incorporating into the projection baseline Hypothesis No. 1, the singular loads of the industrial group, which are linked to mining, cement, steel, oil, transportation, among others; energy efficiency projects, the load of the agricultural and agro-industrial community of Ecuador and to the Connection of the NTG with the Interconnected Petroleum Electric System (SEIP), with the purpose of optimizing the use of energy resources in an integral way (Master Plan, Chapter 3 page 92). The singular loads correspond to the electrical demand of industries that are expected to grow or expand. The singular loads were classified as:

singular loads in operation and projected. The data for each classification can be found in the Electricity Master Plan in Chapter 3, page 94. Due to its importance, in the projection of electricity demand, the incorporation of new technologies that are commercialized in the future were considered, the incorporation of which foresees significant electricity requirements. These projects are the Quito (capital city) Metro, the Cuenca (third city) Tram, electromobility (mass transportation) and the entry of electric vehicles. (Master Plan Chapter 3 page 95). For the hypothesis No. 3, in addition to all mentioned in hypothesis 2, the incorporation of the demand corresponding to Basic Industries, thereby obtaining the power and energy requirements of the electrical system in all functional stages, this scenario is what is called the Productive Matrix Case for the elaboration of the expansion studies of generation and transmission. (PME Chapter 3 page 96).

The Master Plan proposes the construction of two emblematic hydroelectric projects Cardellino and Santiago with an installed capacity of 596 MW and 3,600 MW, respectively. The decision of how to include the Central Santiago to the NTG is complex because within the planning there are many important variables that are currently not clearly defined regarding the concession, adjudication, construction timeline, operating stages and in how many years would be the most beneficial for its commissioning and operation, for this reason five additional scenarios inherited from hypothesis 3 are proposed.

Scenario 1 where the Renewable Blocks and the Hydroelectric Plants made up of Chespi, Chontal, Tortugo and Tigre are included to the NTG, but the contribution of Santiago and Cardenillo is not considered. Scenario 2 corresponds to the inclusion of Cardenillo (2026), does not consider the contribution of Santiago. Scenario 3 which includes Santiago with a power of 3,600MW in the following possible phases of operation: (i) phase 1: 1,800 MW (2026) and phase 2: 1,800 MW (2030); (ii) phase 1: 2,400 MW (2026) and phase 2: 1,200 MW (2030); and phase 1: 1,200 MW (2026), phase 2: 1,200 MW (2028) and Phase 3: 1,200 MW (2030).

This section shows the results of the LEAP simulations regarding the demand and energy generated by the power plants modelled in each of the scenarios proposed with their respective hypotheses. This Section is organized as follows: Section 3.2 corresponds to the demand results for each of the hypotheses of the proposed scenarios. In Section 3.3 is the energy planning of the system for each of the proposed scenarios.

3.1 Demand

The demand for electricity is presented with a growth of 5.44% for the period from 2020 to 2035, confirming an entry of singular loads projected in operation from 2020 to 2035, the entry of the transportation load corresponding to transportation in year 2020, the export of energy is maintained in the same current terms, the development of the industrial city of Posorja from 2023 and from 2030 the demand increases by 12,000 GWh. The demand results for hypothesis (number 3) are shown in Figures 5 (graph) and 6 (tabular), respectively.

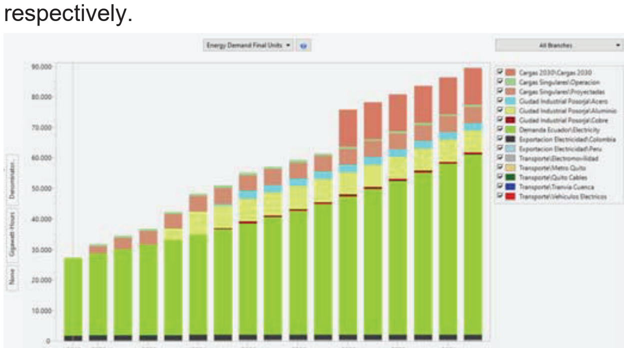

Figure 5. Graph - demand results for Hypothesis 3

Energy Demand Final Units
Scenario: Hipotesis 3, All Fuels
Branch: Demand
Units: Thousand Gigawatt-Hours

Branch	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demanda Ecuador	25,3	26,7	28,1	29,7	31,3	33,0	34,8	36,7	38,7	40,8	43,0	45,3	47,8	50,4	53,1	56,0	59,1
Ciudad Industrial Posorja	-	-	-	-	3,5	7,4	8,2	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3	10,3
Transporte	-	0,1	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Cargas Singulares	-	3,0	4,4	5,1	5,4	5,6	5,8	5,9	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0
Cargas 2030	-	-	-	-	-	-	-	-	-	-	-	12,0	12,0	12,0	12,0	12,0	12,0
Exportacion Electricidad	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8
Total	27,1	31,6	34,5	36,7	42,2	48,0	50,8	54,9	57,0	59,1	61,3	75,6	78,1	80,7	83,4	86,3	89,4

Figure 6. Tabular - demand results for Hypothesis 3

For Hypothesis 2, the demand presents a growth of 5.44% for the period between 2020 and 2035, transport charges and singular charges are considered from the year 2020, we maintain electricity exports and energy requirements from of 2030. The results obtained are shown below in Figures 7 and 8. For Hypothesis 1, demand presents a growth of 5.44% for the period from 2020 to 2035, we maintain electricity exports and energy requirements from 2030. The results obtained are shown below in Figures 9 and 10.

3.2. Generation

3.2.1. Hypothesis 1

For Hypothesis 1, in the final year of the analysis, 2035, there is a generated energy of 75,058 GWh and an estimated demand of 72,896 GWh. The maximum installed generation capacity is given in the year 2028 with 11,605 MW. In Figure 11 we observe the energy supplied by the generation plants.

3.2.2. Hypothesis 2

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For Hypothesis 2 in the year 2035 there is an energy of 81,442 GWh and an estimated demand of 79,096 GWh. The maximum installed generation capacity occurs in the year 2028 with 11,605 MW. In Figure 12 we observed the energy supplied by the generation plants.

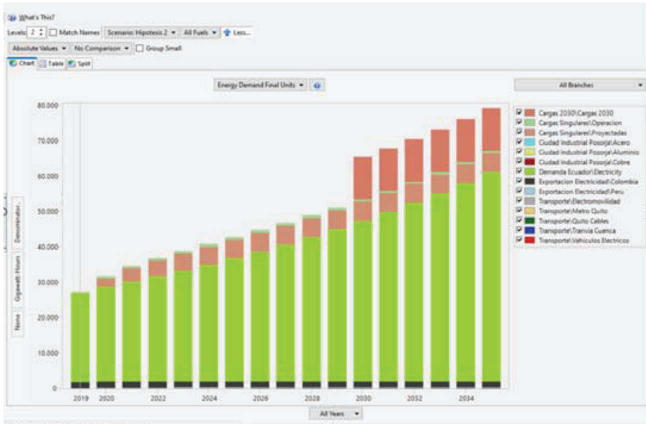

Figure 7. Graph - demand results for Hypothesis 2

Energy Demand Final Units Scenario: Hipotesis 2, All Fuels Branch: Demand Units: Thousand Gigawatt-Hours																	
Branch	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demanda Ecuador	25,3	26,7	28,1	29,7	31,3	33,0	34,8	36,7	38,7	40,8	43,0	45,3	47,8	50,4	53,1	56,0	59,1
Ciudad Industrial Posorja	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Transporte	-	0,1	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2	0,2
Cargas Singulares	-	3,0	4,4	5,1	5,4	5,6	5,8	5,9	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0	6,0
Cargas 2030	-	-	-	-	-	-	-	-	-	-	-	12,0	12,0	12,0	12,0	12,0	12,0
Exportacion Electricidad	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8
Total	27,1	31,6	34,5	36,7	38,7	40,6	42,6	44,6	46,7	48,8	51,0	65,4	67,8	70,4	73,2	76,0	79,1

Figure 8. Tabular - demand results for Hypothesis 2

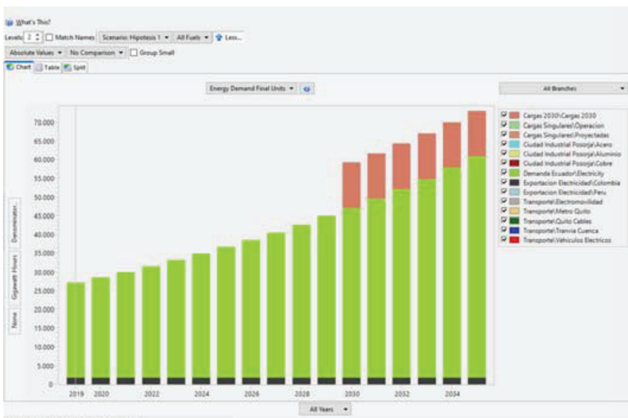

Figure 9. Graph - demand results for Hypothesis 1

Energy Demand Final Units Scenario: Hipotesis 1, All Fuels Branch: Demand Units: Thousand Gigawatt-Hours																	
Branch	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035
Demanda Ecuador	25,3	26,7	28,1	29,7	31,3	33,0	34,8	36,7	38,7	40,8	43,0	45,3	47,8	50,4	53,1	56,0	59,1
Ciudad Industrial Posorja	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Transporte	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cargas Singulares	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Cargas 2030	-	-	-	-	-	-	-	-	-	-	-	12,0	12,0	12,0	12,0	12,0	12,0
Exportacion Electricidad	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8	1,8
Total	27,1	28,5	30,0	31,5	33,1	34,8	36,6	38,5	40,5	42,6	44,8	59,2	61,6	64,2	67,0	69,8	72,9

Figure 10. Tabular - demand results for Hypothesis 1

3.2.3. Hypothesis 3

For Hypothesis 3 in the year 2035 there is a generated energy of 89,320 GWh and an estimated demand of 89,380 GWh. The maximum installed generation capacity is given in the year 2028 with 11,605 MW. In Figure 13 we observed the energy supplied by the generation plants.

3.2.4. Hypothesis 3 – Cardenillo

For Hypothesis 3 and entry of the Cardenillo Power Plant in 2026, in 2035 there is a generated energy of 91,690.4 GWh, an estimated demand of 89,380 GWh and an installed capacity of 11,261 MW. The maximum installed generation capacity occurs in the year 2028 with 12,201 MW. In Figure 14 we observed the energy supplied by the generation plants.

3.2.5. Hypothesis 3 – Santiago A

For Hypothesis 3 and the entry of the Santiago Power Plant in 2026 with 1,800 MW, there is an installed capacity in the system of 13,601 MW. When the second phase of 1,800 MW enters in 2030, there is the capacity maximum installed in the system of 15,801 MW., and in the year 2035 we have a generated energy of 92,031 GWh and an estimated demand of 89,380 GWh. In Figure 15 we observed the energy supplied by the generation plants.

3.2.6. Hypothesis 3 – Santiago B

For Hypothesis 3 and entry of the Santiago Power Plant in the year 2026 with 2,400 MW., there is an installed capacity in the system of 13,661 MW., when entering the second phase of 1,200 MW in the year 2030, there is the maximum capacity in the system of 15,801 MW., and in the year 2035 we have a generated energy of 92,031 GWh and an estimated demand of 89,380 GWh. In Figure 16 we observed the energy supplied by the generation plants.

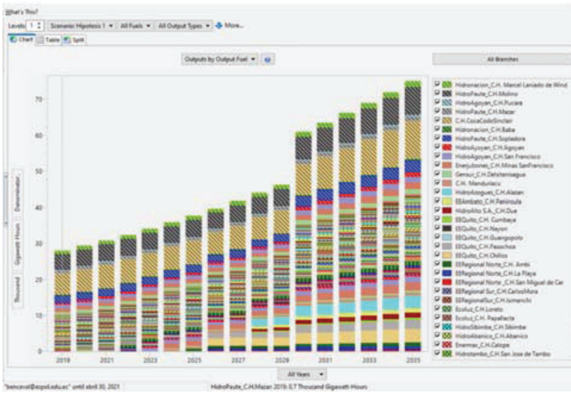

Figure 11. Energy supplied by the Generation Plants - Hypothesis 1

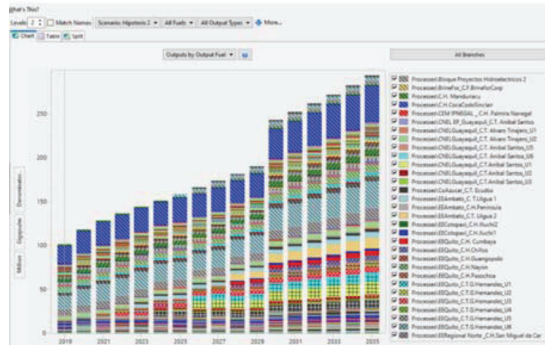

Figure 12. Energy supplied by the Generation Plants - Hypothesis 2

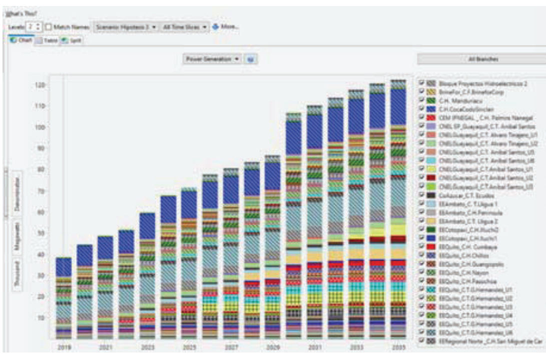

Figure 13. Energy supplied by the Generation Plants - Hypothesis 3

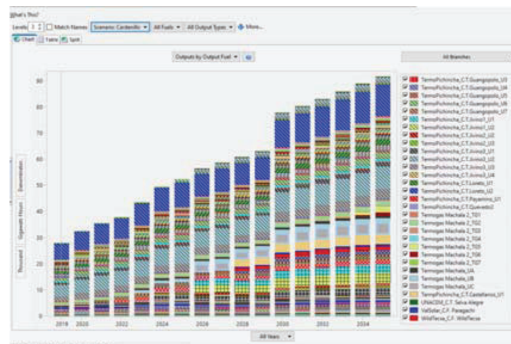

Figure 14. Energy supplied by the Generation Plants – Cardenillo

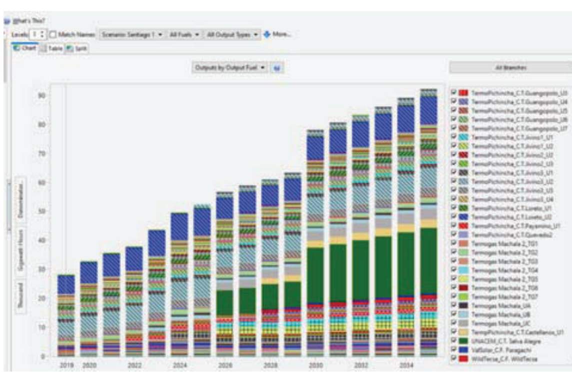

Figure 15. Energy supplied by the Generation Plants - Santiago A

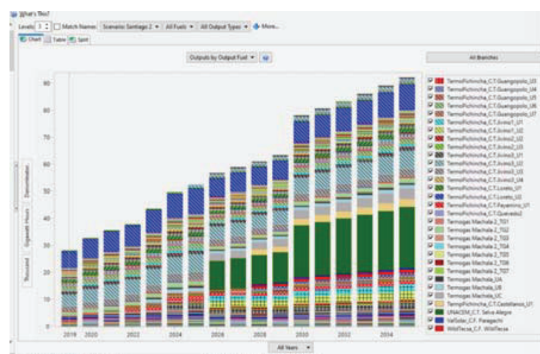

Figure 16. Energy supplied by the Generation Plants - Santiago B

3.2.7. Hypothesis 3 – Santiago C

For Hypothesis 3 and the entry of the Santiago Power Plant in 2026 with 1,200 MW, there is an installed capacity in the system of 12,461 MW. When the second phase of 1,200 MW enters in 2028, we have an installed capacity of 14,601 MW., and when entering the final phase of 1,200 MW in the year 2030, we have the maximum capacity in the system of 15,801 MW., in the year 2035 we have a generated energy of 92,031 GWh and an estimated demand of 89,380 GWh. In Figure 17 we observed the energy supplied by the generation plants. Regarding renewables, we can see the importance of this group, Figures 18 shows where we see its growth from the projects awarded recently, which would be the beginning of a group of projects that will be fundamentally for the energy development of the country contributing additionally to minimizing CO_2 emissions.

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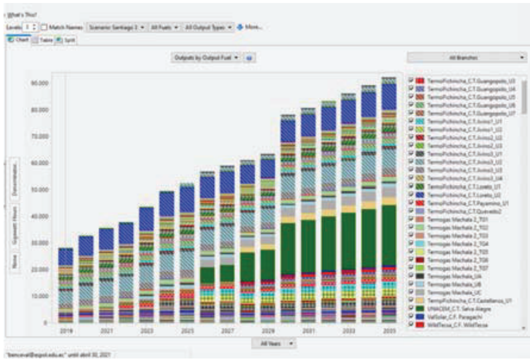

Figure 17. Energy supplied by the Generation Plants - Santiago C

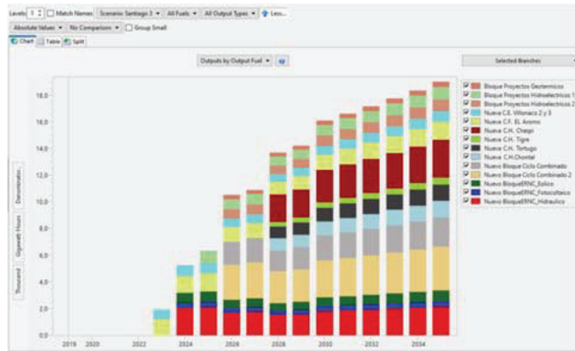

Figure 18. Graph - Energy supplied by the Renewables Hypothesis 3 - Santiago C

4. Discussion

Although in this paper the authors has carried out a systematic and brief review of what corresponds to the Ecuadorian Electric Sector reviewing its regulations and energy planning for the period 2020-2035, we have to indicate that the results of the simulations for each scenario indicate how the generation will be distributed over time, although we guarantee that the different loads are attended in all the periods analysed, there will always be maintenance, contingencies and other internal and external eventualities to which one must be prepared, as the success of continuing to have generation that meets our demand, as well as possible energy exports to neighbouring countries depends exclusively on the continuation of the energy policies carried out by the current National Government.

There will be many criteria that differ specifically with the inputs of specific generation, with the way in which the expansion of the system is proposed, energy policies, cost of energy, etc., but there is a point in which all the technicians and officials of the In the electricity sector we converge, attention to demand and avoid energy rationing in the near future, we must maintain this perspective, for years we have seen how the electricity sector has not had the continuity that is required and the results are in history and as in a previous era, there was a severe impact on the electricity supply. Additionally, we could optimize the income of new projects by applying non-traditional methods for their study where costs have their own decision scenario. The updating of the data as well as the useful life of the equipment proposes a vision of reengineering and replacement of generators that due to useful life must be replaced in the future.

5. Conclusion

The analysis of the demand and the energy planning of the generation was carried out in different scenarios, for this reason the values proposed in the available technical information were used, it is necessary over time to be able to guarantee that the hypotheses proposed for the demand can be met or adjustments must be made that lead to a rescheduling in relation to long-term energy projects. The Santiago hydroelectric project becomes essential for the country's energy development. It has been shown that the National Electric Power System would not be able to supply the demand for electricity when the industrial city of Posorja is under development.

If we want to maintain Ecuador's electricity trade balance as an Electricity exporting country, we must continue with the energy investment plans currently issued by the MERNNR, otherwise we will once again need imports from the existing binational electrical interconnections with Colombia and Peru.

The production of renewables in the Ecuadorian Electric System will have a substantial increase from 2023 with the concession of the EL Aromo and Villonaco projects (II and III).

Once the analysis of the different scenarios of the phases in which the Santiago hydroelectric project could be put into operation, it can be concluded that the best option is to divide it into three phases of 1,200 MW each and that revenues should be in 2026, 2028 and 2030 respectively. In this way, it could be supplied without the projection of the most critical demand raised by the MEM.

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