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A HYDROPOWER DEVELOPMENT PERSPECTIVE IN ECUADOR: PAST, PRESENT, AND FUTURE

UNA PERSPECTIVA DEL DESARROLLO HIDROELÉCTRICO EN ECUADOR: PASADO, PRESENTE Y FUTURO

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Abstract

Ecuador is a small Andean country located in the western hemisphere of South America. The country has $361,747 hm^3$ annual superficial water resources; As a result, Ecuador, in the last fifteen years (2005 to 2020), has been rapidly developing hydropower projects to triple the production in this renewable source. There were eight new hydroelectric plants constructed in Ecuador among 2007 and 2015 invested close to USD 6 billion the projects. Increased the energy response with renewables; for example, in 1985, the country produced 4 TWh, in 2005-registered 7 TWh, and to 2020, 24 TWh. According to the Electricity Corporation of Ecuador in 2020 reported that generated around 80 % of all electricity through hydropower; thus, the article aims to critically analyze the development of hydropower in Ecuador in recent years and establish general energy projections to 2030 to expand the fields of knowledge and perspectives. The paper methodology is quantitative, according to scientific editorial sources, articles, investigative documents, and collects data from government agencies that regulate energy development in Ecuador. It is conclusive between a projection's calculation, Ecuador will need for the year 2030 around 43 TWh, 47 TWh, or 52 TWh to supply the energy grid, according to the scenarios proposed (low, medium, high). Although hydropower will be essential to contribute to this requirement, the country has a barrier because hydropower is very sensitive to external factors of diverse nature, generating an uncertainly future directly associated with climatic effects.

Keywords: Ecuador, renewable energies, hydropower development, perspective, projections.

Resumen

Ecuador es un pequeño país andino ubicado en el hemisferio occidental de América del Sur. El país cuenta con 361.747 hm^3 anuales de recursos hídricos superficiales. Como resultado, Ecuador, en los últimos quince años (2005 a 2020), ha estado desarrollando proyectos hidroeléctricos para triplicar la producción en esta fuente renovable. Hubo ocho nuevas centrales hidroeléctricas construidas en Ecuador entre 2007 y 2015, en donde se invirtieron cerca de USD 6 mil millones en los proyectos, lo que incrementó la respuesta energética con renovables; por ejemplo, en 1985 el país produjo 4 TWh, en 2005 registró 7 TWh y hasta 2020, 24 TWh. Según la Corporación de Electricidad del Ecuador en 2020 informó que generó alrededor del 80 % de toda la electricidad a través de hidroelectricidad. Así, el artículo tiene como objetivo analizar críticamente el desarrollo de la energía hidroeléctrica en Ecuador en los últimos años y establecer proyecciones energéticas generales al 2030 para ampliar los campos de conocimiento y perspectivas. La metodología del trabajo es cuantitativa, de acuerdo con fuentes editoriales científicas, artículos, documentos de investigación, y recolecta datos de agencias gubernamentales que regulan el desarrollo energético en Ecuador. Se concluye que, mediante un cálculo de proyecciones, Ecuador necesitará para el año 2030 alrededor de 43 TWh, 47 TWh o 52 TWh para abastecer la red energética, según los escenarios propuestos (bajo, medio, alto). Si bien la energía hidroeléctrica será fundamental para contribuir a este requerimiento, el país tiene una barrera porque la energía hidroeléctrica es muy sensible a factores externos de diversa índole, generando un futuro incierto directamente asociado a los efectos climáticos.

Palabras clave: Ecuador, energías renovables, desarrollo hidroeléctrico, perspectiva, proyecciones.

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1 Introduction

Ecuador is a small Andean country located in the western hemisphere, northwest of South America, composed of three main regions: Coast, Sierra, and Amazon (Ministerio de Medio Ambiente, Agua y Trancisión ecológica, 2019). The country characterizes by a unique topography, climatic zones diversity, and a prolific population of animal species. According to the Ecuadorian Ministry of the Environment and Water (MAATE, acronym named in Spanish), biological wealth is reflected in a wide array of organisms, and 10 % of species of vascular projects in the biosphere are found in a zone that barely represents 2 % of the global surface (Guilcatoma-Aimacaña, 2010; Mena-Vasconez, 2018). The country has 376.018 hm^3 of annual water resources, of which 361.747 hm^3 are superficial while the rest are underground (Hasan and Wyseure, 2018). In addition, the yearly average volume for the regions of the country, Coast, Sierra, and Amazon is 70.046 hm^3, 59.725 hm^3, and 246.246 hm^3, respectively (CISPDR and SENAGUA, 2016).

Moreover, with the availability of surface water resources, Ecuador has been rapidly developing hydropower projects to triple the production in the last fifteen years (2005 to 2020), as indicated in Figure 5. In 1985 the country produced 4 TWh, and in 2005 it registered 7 TWh, and in 2020 24 TWh of hydropower. The Electricity Corporation of Ecuador (CELEC, acronym named in Spanish) in 2020 reported that the country generated around 80 % of all energy through hydropower, so hydropower is a crucial source to meet the national demand (CELEC, 2020). On the other hand, there were eight new hydroelectric plants constructed in Ecuador among 2007 and 2015 invested close to USD 6 billion, doubling their capacity (Vaca-Jiménez et al., 2020). In 2017 it was inaugurated the Coca Codo Sinclair as the largest project with 1,500 MW capacity, which supplies 30 % of energy nowadays in the country with all the generating turbines (Álvarez-Chiriboga, 2020; Hidalgo et al., 2024).

However, Ecuador is very sensitive to external factors of diverse nature such as floods, tsunamis, earthquakes, and extreme rains due to atmospheric components, geographical location, rugged orography, and prevailing meteorological characteristics that can cause severe impacts on the economy (Naranjo Silva et al., 2021; Purcell and Martínez, 2018). Nevertheless, climate change intensifies natural meteorological variability, affecting the hydropower installations (Álvarez-Chiriboga, 2020). At the end of the 80s, the analytical development paradigm inserted concerns about the environment and extended the interest in growth policies based on the quality and management of renewable sources (Tang et al., 2018). But the effects of these renewable sources are not too quantified and verified, generating a new significant problem to analyze (Jin et al., 2016).

Under this background, this article aims to critically analyze the hydropower development in Ecuador in recent years and establish the general energy projections up to 2030 to expand the fields of knowledge and discern the perspective of this renewable source carried out quickly in a developing country.

2 Hydropower in the world

According to the International Hydropower Association (IHA), the worldwide hydropower capacity was 1,330 GW in 2020 (International Hydropower Association, 2021). In addition, this renewable source in 2020 reported around 14,000 active projects in 180 countries (ICOLD, 2019; Llamosas and Sovacool, 2021). Furthermore, the report of IHA mentions that there was an increase of 21 GW in the total hydropower installed capacity in 2020, increasing 1.6 % compared to 2019 (International Hydropower Association, 2021). Consistent with Killingtveit (2018), the hydropower development is expected to increase. Figure 1 establishes the average percentage growth tendency from 2007 to 2016 at around 3 %.

In addition, the International Renewable Energy Agency (IRENA) determines that the average evolution of installed capacity in the five years between 2016 and 2020 was 1.8 % (IRENA, 2020). However, globally, a 2017 calculation estimated that only 22 % of the hydropower potential and 4.2 % of the remaining renewable energies are currently used (Turner et al., 2017). In addition, the potential for amplified

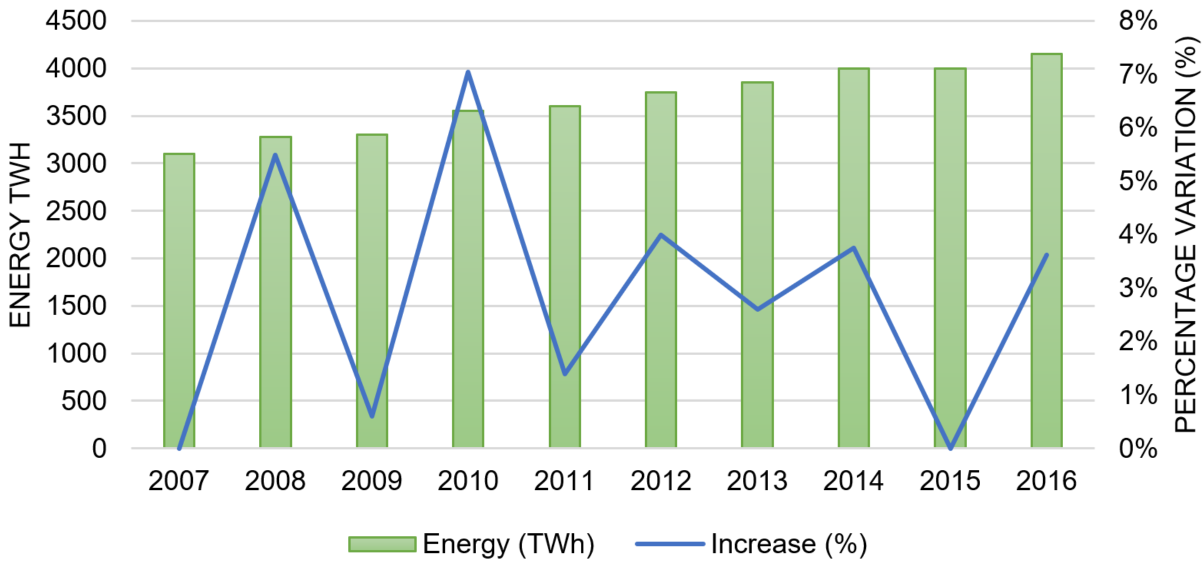

Figure 1. Global hydropower growth TWh period 2007- 2016.
Source: International Renewable Energy Agency (2020); Killingtveit (2018).

hydropower production is significant to meet an actual long-term deployment calculated at more than 8 000 TWh by 2050 (Schaefli, 2015).

With the global background, hydropower can be defined as a mature technology and the most widely used among renewables, although globally the share has slowly declined (Naranjo Silva and Álvarez, 2021). The global hydropower share fell from 72 % in 2010 (881 GW) to 41 % in 2020 (1,153 GW), excluding pumped-type hydropower despite the increase in installed capacity (IRENA, 2021). Currently, hydropower is substantial in most Latin American, Asian countries and Europe, but there are significant risks due to persistent inflows and water availability (Lu et al., 2020; Terävӓinen, 2019).

3 Methodology

Numerous references were generated worldwide between protocols, manuals, and projections that leader or mitigate the hydropower impacts; therefore, in a world of technology and constant changes, there are reflections and approaches to each issue in a multi-diverse way. Therefore, the paper's proposed methodology is quantitative, evaluating the installed development of hydropower projects in Ecuador in recent years. In the quantitative part, simulations and projections are presented according to scientific editorial sources, articles, and investigative documents defined, looking for topics and aspects such as the hydropower development of Ecuador and energy policies. Thus, the valuable documents are listed based on issues that contribute to this paper; the databases analyzed are detailed in Table 1.

Table 1. Scientific editorial analyzed.

Period	Digital repositories	Selected articles
2016-2020	Science Direct	11
2016-2020	Springer	9
2016-2020	Taylor & Francis	8
	Total	28

Three digital repositories were selected (Science Direct, Springer and Taylor Francis) as they have more information associated to hydropower energy as the main topic of the present manuscript, and additionally the useful data was covering a specific period of time (2016-2020). After the first screening of scientific data, 76 publications, including journal articles, conference papers, books, and online reports were found. Due to the lack of quantitative contributions, many documents ended up being omitted from the first search. As a final criterion, articles future simulations, projections with relevant indicators and policies recommendations were selected. In addition, the search methodology uses key phrases such as "hydroelectric development in Ecuador"; "Hydropower projections in Ecuador"; and "Ecuadorian energy policies".

Throughout these documents, 28 selected papers are summarized, covering different application areas in the Ecuadorian hydropower development. Additional to know from direct sources data of the main hydropower projects in Ecuador, the following government agencies were consulted.

- Ministry of Energy and Non-Renewable Natural Resources of Ecuador (MERN, acronym named in Spanish)
- Electricity Corporation of Ecuador (CELEC, acronym named in Spanish)

The data were analyzed with scientific articles and information from government agencies that regulate energy development in Ecuador, generating indicators as annual energy consumption, per capita consumption ratio, and hydropower growth. On the one hand, for analyzing the energy projection of Ecuador, we took the base case of 2020, according to the historical record of the Ministry of Energy and Non-Renewable Resources, which grows at a percentage rate of 4.9%, and a quantitative percentage point that increased to the global trend of the hydropower expansion.

4 Results

To approach the topic, we divided the paper into two significant issues the Ecuadorian hydropower development of the recent years, and the country projections.

4.1 Ecuadorian hydropower development in recent years

Among 2007 and 2015, Ecuador invested USD 6 billion in eight hydroelectric plants, doubling their capacity (Vaca-Jiménez et al., 2020); one of them was Coca Codo Sinclair. Nowadays this project is the principal in Ecuador, with 1,500 MW capacity, which supplies 30% of the current energy in the country since 2017 (Álvarez-Chiriboga, 2020). To illustrate the hydropower development in Ecuador, Figure 2 shows the principal basins and projects.

As well, the IHA placed Ecuador third among the globally countries, adding new capacity in 2016 (International Hydropower Association, 2018b). Moreover, the Electricity Corporation of Ecuador reported in 2020 that 80% of all energy is through hydropower, as shown Figure 3 with the energy grid trend of the country since 2010 (CELEC, 2020).

Figure 3 shows that there was an increase of more than double in the hydropower production in the last ten years. For example, in 2010, Ecuador contributed to around 8,000 GWh, and 24,000 GWh was supplied by 2020, which represented an increase in the period of about 300%. In addition to this hydropower rise, thermoelectric production was reduced by more than triple production in 2010, 9,000 GWh versus 2020 with 2,000 GWh (CELEC, 2020; MERNNR, 2018).

Additionally, data from the annual statistics of the British Petroleum Company in a global comparison per capita energy consumption for the year 2019 establishes that worldwide around 20,884 kWh per capita is required. In contrast, 11,884 kWh per capita in Ecuador is necessary; perhaps about 67% represents hydropower with 7,904 kWh per capita, as indicated Figure 4 (BP p.l.c., 2020).

By way of comparison between renewable energies, the production since 1985 in Ecuador is detailed. According to Figure 5, a vast difference of the hydropower deployment is shown over time, verifying a slow and regular growth until the year 2000. The development began to increase, then in 2008, new projects were gradually incorporated, and finally, in 2017 there were around 20 TWh of hydropower production compared to 4 TWh in 1985 (MERNNR, 2018; Ritchie and Roser, 2020).

Figure 5 shows the hydropower in Ecuador supply increased from 4 TWh to 24 TWh in 35 years (1985 to 2020); it also indicates that other renewables such as wind and solar have reduced growth, with almost no relevance of contribution to the energy grid. Hence, in recent years, this representative hydropower development of Ecuador is pertinent to analyzing the effects and external parameters as the climate change. The country currently depends on many hydropower projects, and this source is sensitive to climatic variations (Zhong et al., 2019).

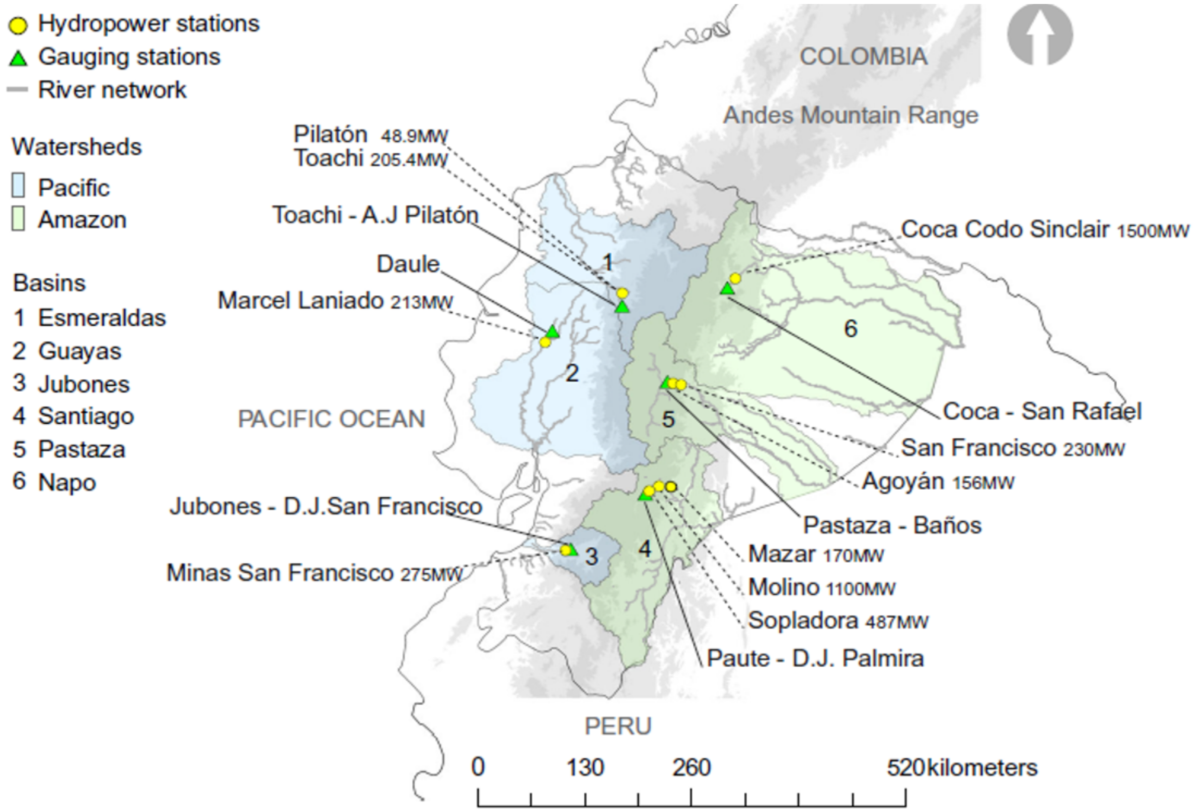

Figure 2. Main basins and hydropower projects in Ecuador.
Source: Carvajal et al. (2017).

According to the First Nationally Determined Contribution of Ecuador (NDC) of the Ministry of Environment and Water in 2019, an historical analysis of precipitation and average temperature for the 1960- 2015 period determined essential variations; the rains increased in the Coast 33%; Sierra 13%, and in the Amazon 1% of rainfall was reduced. In addition, there is an average temperature increase of 0,8° throughout (Ministerio de Medio Ambiente, Agua y Trancisión ecológica, 2019). Accordingly, the hydroelectricity depends on the availability of natural resources such as precipitation, which plays a fundamental role in the flow's runoff and the natural water cycle (Bakken et al., 2017; Van Vliet et al., 2016).

Additionally, it is necessary to mention that in Ecuador, being in the middle of the equatorial line, there are differences in precipitation between the north and south, where drought and hydropower sub-production are registered respectively due to its location, causing particularities to the time to analyze its trend and climate projection (Ponce-Jara et al., 2018).

Finally, before talking about the hydropower projections in Ecuador, it is important to mention that by 2021 there was 5,107 MW of hydropower installed, also according to the Regional Energy Integration Commission of South America, Ecuador has a feasible hydroelectric capacity of 23,120 MW, representing an installation of 22% so far of this renewable (Regional Energy Integration Commission of South America, 2021).

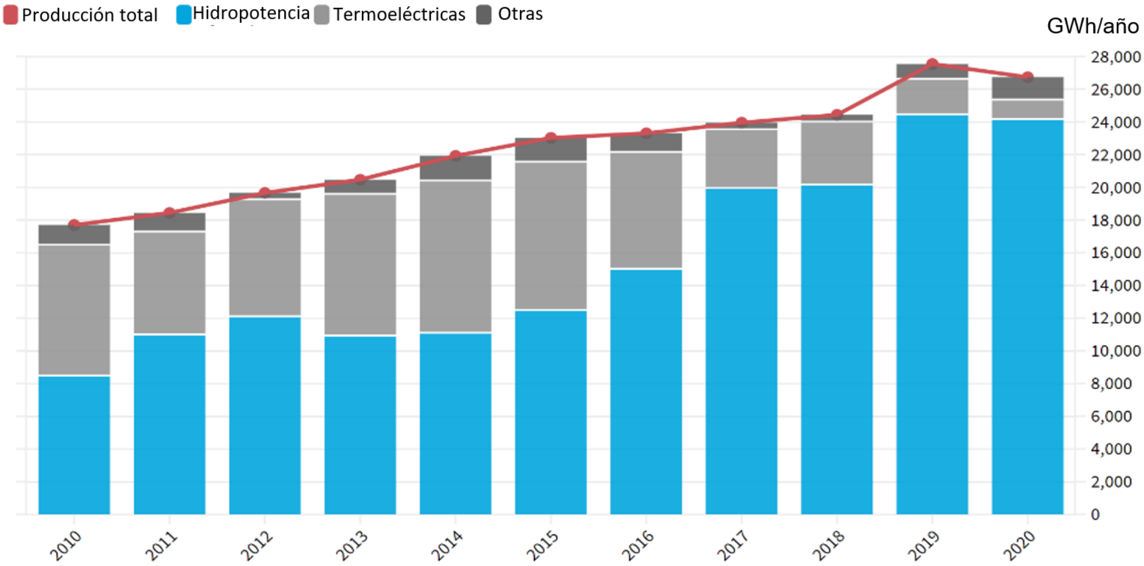

Figure 3. Ecuador energy production GWh / year.
Source: CELEC (2020).

4.2 Hydropower projections in Ecuador

According to the MERN of Ecuador in the Electricity Master Plan projected until 2027, 645 MW would be incorporated with 14 projects that will provide average annual energy of 3,491 GWh. Out of the 14 projects under construction, 11 correspond to hydropower projects with 407.5 MW, i.e., 63% of the planning, two thermoelectric projects with a capacity of 187 MW, and one wind power project with a power of 50 MW, as indicated in Table 2.

Table 2 shows that hydropower development will continue to be essential in Ecuador. In addition to the small and medium hydropower projects exposed, the data shows public and private investment at 88% and 12%, respectively. Nevertheless, two large hydropower projects seek to continue the hydro expansion strategy due to their capacity; these are Santiago and Cardenillo, as shown in Table 3.

However, this two hydropower have no interest due to the representative amounts of invest necessary and their degree of progress only in studies; they do not constitute plants with the certainty of execution to include them in the current energy expansion. However, with short-term projections, the MERN of Ecuador must define these projects as priorities and the State should put out tenders to attract international funds, which can be partly constituted by carbon credits, since they are renewable sources projects, which generally have 50 years of life.

Nevertheless, the projections, the population growth, and consumption constantly require additional electricity generation despite the current hydropower facilities; the Ministry of Energy and Non-Renewable Natural Resources data establishes the trend of growing historical annual energy consumption of Ecuador in 4.89%. Therefore, it is necessary to think in the short and medium term about continuing to implement renewable projects, not only hydroelectric.

Under this background, at the researcher discretion, three growth trends are projected until 2030 based on the real consumption of Ecuador in 2020 and taking the historical annual increase of 4.9% of the MERN. In addition, the researcher increased one percentage point for the following two trends, in the medium case 5.9%, and high scenario 6.9% as a conservative trend of energy needs for the country. As shown in Table 4, Ecuador will need in 2030 around 43 TWh, 47 TWh, or 52 TWh of energy, according to the scenarios proposed (low, medium, high) respectively, which will require a wide renewable and non-renewable development. As a reference, if more hydropower projects are implemented, they should use instruments such as the Hydropower Sustainability Assessment Protocol (HSAP) that contains concepts and suggestions for the countries that build these projects at a global level to manage sustainability criteria (International Hydropower Association, 2018a).

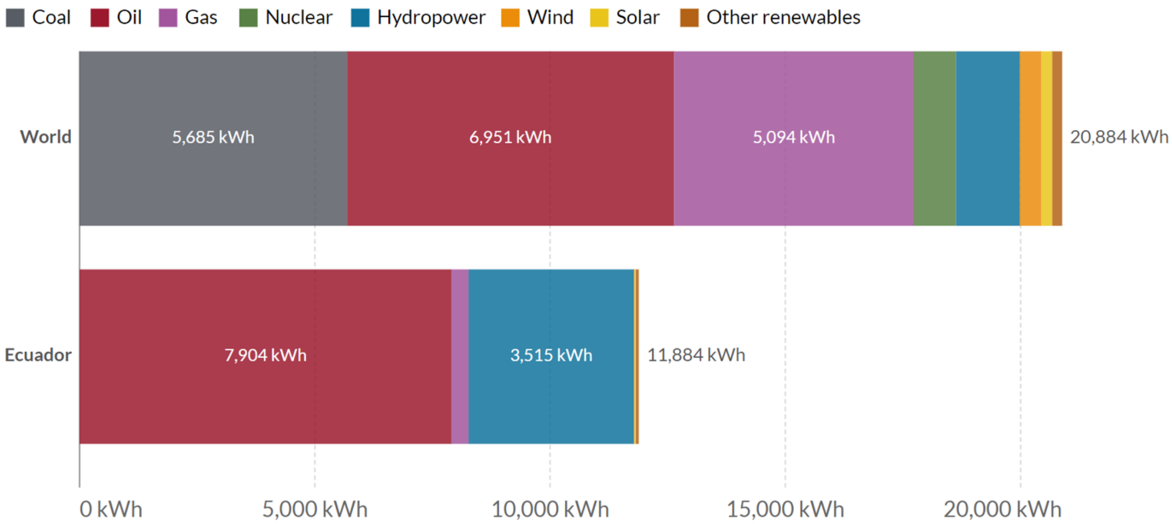

Figure 4. Consumption per capita primary energy by source 2019.
Source: (BP p.l.c., 2020).
Note: On the figure the term "oil" represents fossil fuels destined to produce thermoelectricity.

On the other hand, comparing the tendencies, according to an investigation of long-term role of hydroelectric systems towards compliance with the Nationally Determined Contribution of Ecuador, hydropower generates impacts by using environmental conditions, relating effects due to the water accumulation as water quality change, deforestation, and sub climate variations. Under this analysis Ecuador demonstrates uncertainty. The investigation shows that the energy provided by hydroelectricity would vary significantly between 53% to 81% by the year 2050, hence the Ecuadorian NDC goal would be deprived of the distribution of sizeable hydroelectricity structure. In addition, the study projections show that if there is a 25% decrease in hydropower availability, then accumulated CO_2 emissions by the use of fossil fuels will double (Carvajal et al., 2019; Guallpa et al., 2022). Also, for long term, the simulations determine that the impacts quantified for 2071-2100 has a wide range of annual difference; hydropower production in Ecuador varies between - 55% and + 39% of the historical average (Carvajal et al., 2017).

Furthermore, the Nationally Determined Contributions based on hydropower are highly vulnerable to the appearance of a dry climate scenario due to climatic variations in the Amazon area. Moreover, given the pattern of seasonal rains in Ecuador independent of the amount of hydropower installed, the NDC goal requires a diversified portfolio and not essentially from renewable sources (Carvajal et al., 2019). For Ecuador, a more robust energy grid in the long term should make emphasis on an adequate diversification of generation technologies with the sustenance of policies to rise non-conventional renewables (solar, wind, tidal, and geothermal) (Carvajal et al., 2017). The Inter-American Development Bank determines that in the future hydroelectricity is projected as a source of support, enabling other renewables (Alarcon, 2019).

Table 2. Energy projects in construction or planned in Ecuador.
Source: (Ministerio de Energía y Recursos No Renovables, 2019).

Project	Type of investment	Type	Capacity [MW]	Average power [GWh/year]	State
Toachi Pilaton	Public	Hydropower	254.4	1120	Santo Domingo
Machala Gas	Public	Thermoelectric	110	690	El Oro
Machala Gas Tercera	Public	Thermoelectric	77	510	El Oro
Minas de Huascachaca	Public	Wind	50	119	Loja
Quijos	Public	Hydropower	50	355	Napo
Piatua	Private	Hydropower	30	210.5	Pastaza
Sabanilla	Private	Hydropower	30	210.5	Zamora Chinchipe
Río Verde Chico	Private	Hydropower	10	74.3	Tungurahua
Chalpi Grande	Public	Hydropower	7.59	36	Napo
Mazar - Dunas	Public	Hydropower	7.38	41.4	Cañar
Mazar San Antonio	Public	Hydropower	7.19	44.9	Cañar
San José de Minas	Private	Hydropower	5.95	48	Pichincha
Chorrillos	Public	Hydropower	4	23.2	Zamora Chinchipe
Ulba	Private	Hydropower	1.02	8.4	Tungurahua
	Total		**644.5**	**3 490.6**	**-**

Note: IRENA defines. Small projects $\leq$ 300 MW of capacity, medium to 11 MW $\leq$ 300 MW, and large up to 301 MW.

In addition, in an ecosystem assessment carried out in Ecuador, Briones-Hidrovo et al. (2020) in a study of five installed hydropower projects: Baba, Marcel Laniado, Alazán, Mazar - Dudas, and San Antonio determined that faced the climatic and ecological collapse the world has an objective to develop renewable energies. However, there are environmental problems due to the deep interaction with the immediate areas moving people from the original communities and lifestyle change (Briones-Hidrovo et al., 2020; Hasan and Wyseure, 2018).

Parra (2020) explains that hydropower in Ecuador is susceptible to climate variations. The studies exposed that hydroelectric capacity could display substantial sensitivities to differences in rainfall patterns. In Ecuador, this can change precipitation patterns, especially in high Tropical Andean regions. In the last years, the promotion of hydropower plants produced a reduction in fossil fuel burning. In spite of this, considering the possible impacts of climate change on this renewable, as occurred in 2009, the hydroelectric energy was affected by dry weather conditions (Cabrera et al., 2021; Parra, 2020).

Finally other study determines the capacity to 2030 of the five important hydroelectric projects of Ecuador (Coca Codo Sinclair, Manduriacu, Minas San Francisco, Toachi Pilaton, and Delsintagua). These plants were projected to have an initially capacity of 2 275 MW, however the investigation concludes that from the Intergovernmental Panel on Climate Change three scenarios (A1, B1, and B2) there are important capacity decreases, for example in the line called A1 there is a reduction of 1 839 MW to 2050, in B1 scenario is projected to 1 995 MW, and in the conservative scenario B2 up to 2 104 MW. Concluding in the A1, B1, and B2 scenarios, the capacity of these plants will decline by 19 %, 12 %, and 8 %, respectively (Naranjo-Silva and Quimbita, 2022).

Summarizing the projections, the value of ecosystem services declined with the hydroelectric projects structure; renewable source exploitation implies degradation and suppression of ecological services. Therefore, it reduces the ecosystem's capacity to provide all its functions quantitatively and qualitatively, proposing a worrying issue, given that hydropower should not be sponsored as a sustainable energy source (Briones-Hidrovo et al., 2017, 2019). In addition, studies mention that hydropower depends on a strategic ubication and capacity but has some social, environmental and cultural issues as unbalances in the aquatic life before and after the reservoir, fragmentation and transformation of rivers, destroying ecosystems, reducing fishery resources and sometimes using territories from far communities, thus forcing those people to relocate (Voegeli et al., 2019; Zarfl et al., 2019).

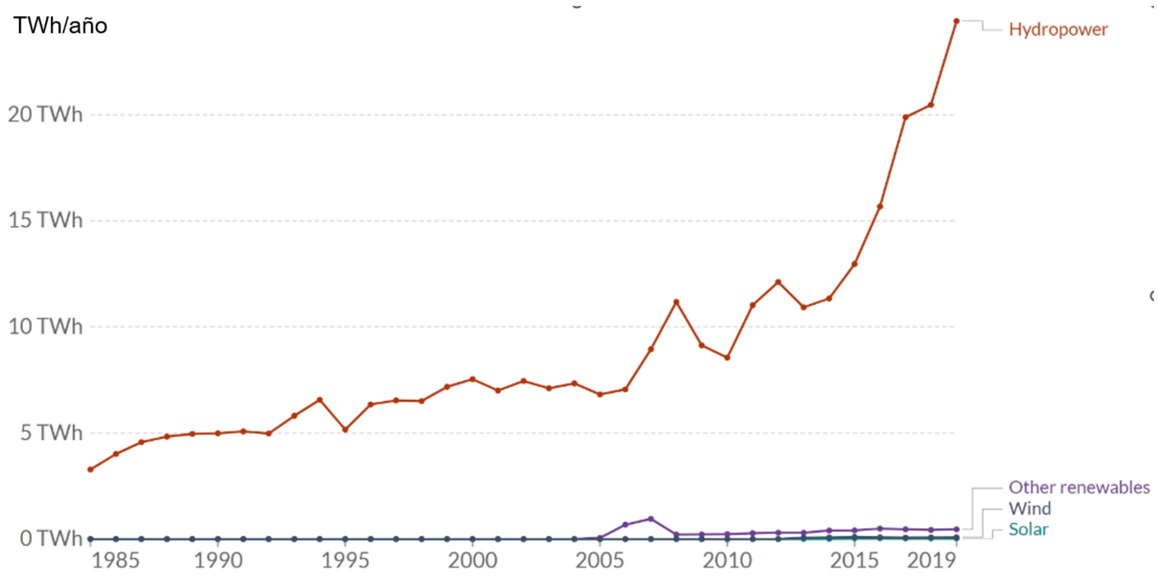

Figure 5. Renewable energy production by source in Ecuador in 2019.
Source: (Ritchie and Roser, 2020).

5 Discussion

In order to achieve global energy sustainability, renewable energy must replace fossil fuel burning (Camayo et al., 2021; García-Parra et al., 2022). However, at a global level, the hydropower production presents a broad vision of the advantages, and little is explained about the disadvantages and problems; hence, scientific studies show that hydropower generation has several implications, generating impacts on ecosystems due to the large infrastructure's development (Naranjo-Silva and J., 2021).

In Ecuador, large hydropower infrastructures have quickly developed for 15 years due to conditions with great availability of water, but to what extent is this water overuse sustainable? According to the IHA, Ecuador ranked third for globally nations that added new hydroelectricity projects last years (International Hydropower Association, 2018b).

On the other hand, global studies were carried out on climate impacts and aggressive hydropower development; for example, Lehner (2005) estimates that the gross hydropower potential will decrease by approximately 6 % to 12 % by Europe 2070s (Lehner et al., 2005). Estimates in vulnerable or modified regions establish that globally, a trillion dollars are cumulatively required to offset the deterioration of the last 18 years of hydropower generation associated with climate change (Turner et al., 2017).

According to Hofstra et al. (2019), climate change poses a global threat to hydropower and thermoelectric production. Through coupled hydrological modeling, options for sustainable adaptation of water and energy are evaluated. For the time scenario 2040-2069, the study estimates a reduction of 61 %-74 % in the usable capacity of hydropower and thermoelectric projects.

Table 3. Hydropower projects of more than 500 MW in Ecuador.

Project	Project phase	Capacity [MW]	Average power [GWh/year]	State	Specific location
Santiago	Feasibility and definitive design	2400	14 613	Morona Santiago	Twinza
Cardenillo	Feasibility and definitive design	596	3409	Morona Santiago	Méndez
Total		2996	18 022	-	-

An analysis in China indicates that hydropower is sensitive and vulnerable to climatic fluctuations, temperature and rain are the most important factors; therefore, extreme meteorological phenomena such as rain, heatwaves, floods, and drought, impose challenges for the hydroelectric development of the country with the highest global installed capacity with 356 GW (2020 year) (Fan et al., 2020).

Studies in India conclude that all hydrological basins experience substantial changes in precipitation and temperature that affect the water availability for hydropower production, and a warmer and more humid climate is observed in the future; therefore, it is calculated that the average annual temperature will increase between $18 \pm 14{,}6\,\%$ until the end of the century (Ali et al., 2018).

With the global comparations, the Ecuador results showed a rapid hydropower expansion last years. Nowadays is the principal energy source, and the middle conservative scenario by 2030 determines a 47 TWh needed to the country. Nevertheless, Escribano (2013) in an Ecuadorian energy policies analysis, mentions it is apparent that the hydroelectricity expansion faces regulatory, financial, and social problems, underlining the serious importance of undertaking an exhaustive examination of the energy grid relating to the country development versus the environmental conservation.

In addition, as mentioned in the section of hydropower projections in Ecuador, there is a 22 % feasible installed capacity with data from 2021, but due to the differences in precipitation between the north and south of Ecuador, where drought and under-production are registered hydroelectric respectively, it is technically complicate to materialize additional projects that require robust analysis in addition to the constant climatic variations. Therefore, achieving the total feasible hydropower capacity would depend on resources, which means investment that the country does not have, because at the moment (December 2022 cutoff), the public debt is around 73,114 million dollars (Llerena-Montoya et al., 2021). In addition to the economic costs as an obstacle to new investments in hydroelectric systems, technical and administrative areas due to the lack of advance of final feasibility and engineering studies do not allow the specific development of this type of structures that finally also have environmental repercussions on virgin ecosystems that are in places far from the main cities.

In an energy scenarios study in Ecuador, Villamar2019, Villamar2021 show that the climate change influences would hinder the hydroelectric capacity to contribute to the fulfillment objectives as a country to lower the greenhouse gases that cause global warming. Although hydropower is presented in a renewable way, it shows environmental impacts, making a subsector of special consideration for its development (Chiang et al., 2013). Overall, the global trend is to develop more hydropower projects to mitigate the pollution of greenhouse gases from fossil generation sources. However, nowadays, in Ecuador, there are some impacts from this renewable source. It is essential to consider that growth and energy supply requires a specific analysis of the hydropower infrastructure. Substantial changes in precipitation and temperature are globally expected to affect water availability for hydroelectric generation making Ecuador a vulnerable country (Ali et al., 2015; Mousavi et al., 2018).

Table 4. Scenarios of energy demand in Ecuador Country.
Source: (Ministerio de Energía y Recursos No Renovables, 2019).

Year	Low [GWh]	Medium [GWh]	High [GWh]
2020 (Base)	26 727	26 727	26 727
2021	28 037	28 304	28 571
2022	29 410	29 974	30 543
2023	30 852	31 742	32 650
2024	32 363	33 615	34 903
2025	33 949	35 598	37 311
2026	35 613	37 699	39 886
2027	37 358	39 923	42 638
2028	39 188	42 278	45 580
2029	41 108	44 773	48 725
2030	43 123	47 414	52 087
Percentage of variation 2020-2027	4.90 %	5.90 %	6.90 %

Finally, this manuscript has a general brief of hydropower in Ecuador with data analysis, however, it is still only an example of a small country in Latin America with a substantial water ability. In order to know in depth, the repercussions of hydroelectricity, especially in large scale, more information should be obtained from countries such as Brazil, China, and the United States, where hydroelectric expansion is greater in installed capacity.

6 Conclusions

Hydropower in Ecuador has overgrown in the last years; in 1985, the country generated 4 000 GWh; in 2010, Ecuador contributed around 8 000 GWh. By 2020, it supplied 24 000 GWh, which represented a relative increase for 2010- 2020, around + 300 %.

Based on the Ministry of Environment and Water's estimate of temperature and precipitation changes, the projections performed by the energy grid and hydropower plants of Ecuador are subject to uncertainty. Moreover, by 2030, the country will require the low, medium, and high energy scenario at around 43 123 GWh, 47 414 GWh, and 52 087 GWh, respectively, and hydroelectricity will remain to be an essential renewable source for the country.

By the projections for Ecuador to 2030, a medium conservative average growth of 5.9 % annual energy consumption was established as the principal scenario. But, regardless of the percentage of installed hydropower capacity, an expansion not necessarily renewable will be required for the future, which could cause a noticeable environmental imbalance.

Ecuador is a global example of managing an energy grid with more than 80 % hydropower by 2020. Therefore, this renewable development relates the fragility finding to the ecosystems surrounding hydropower projects, generating a new issue plus climatic change effect.

Future research could analyze the strong interaction of hydropower to the installed ecosystems with availability modeling of water and environmental change. Also, it is recommended to develop and apply sustainability criteria through a methodology climate assessment, economic, environmental, and social to offset the effects produced by the hydropower projects.

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