Revista Iberoamericana Ambiente & Sustentabilidad Vol. 5, 2022

GESTIÓN SUSTENTABLE DE RECURSOS HÍDRICOS

DOI: https://doi.org/10.46380/rias.v5.e268

Investigation article

Hydropower and climate change concerning to the implementation of the First National Determined Contribution in Ecuador

La hidroelectricidad y cambio climático en torno a la implementación de la Primera Contribución Nacional Determinada en Ecuador

Energia hidrelétrica e mudanças climáticas na implementação da Primeira Contribuição Nacional Determinada no Equador

Sebastian Naranjo-Silva / Polytechnic University of Catalonia, Spain / hector.sebastian.naranjo@upc.edu

Omar Rolando Quimbita-Chiluisa / University of Armed Forces, Ecuador / quimbita.omar@gmail.com

Recibido: 14/04/2022 **Aceptado:** 12/08/2022 **Publicado:** 22/09/2022

ABSTRACT

Global warming threatens the world's water supplies, posing a significant threat to hydropower generation, however the continuing increase in energy demand due to world population growth and socio-economic development requires this renewable source. The manuscript aims to analyze the future tendency of climate change in hydropower development in five emblematic plants (Coca Codo Sinclair, Manduriacu, Minas San Francisco, Toachi Pilatón, and Delsintagua) concerning the implementation of National Determined Contribution. The article's methodology is exploratory with information on hydropower development in Ecuador since 20 projects are already working, and it presents two qualitative and quantitative approaches. To project the scenarios, we use data according to the Intergovernmental Panel on Climate Change related to three evolution lines A1, B1, and B2. The results show that climate change constitutes one of the most significant challenges in Ecuador faces in meeting the National Determined Contribution because hydropower energy has an inefficiency of 15.8% in the last 20 years. The scenarios show a reduction A1 up to 1909 MW to 2050, in the medium scenario B1 to 2041 MW, and in the conservative scenario B2 to 2132 MW from the total capacity for the emblematic hydropower projects thinker in 2275 MW initially.

Keywords: climate change, energy, environment, hydropower, renewable, sustainable

RESUMEN

El calentamiento global amenaza los suministros de agua del mundo, lo que representa una amenaza significativa para la generación de energía hidroeléctrica. Sin embargo, el continuo aumento de la demanda de energía debido al crecimiento de la población y al desarrollo socioeconómico requiere esta fuente renovable. El artículo tiene como objetivo analizar la tendencia futura del cambio climático en el desarrollo hidroeléctrico en cinco centrales (Coca Codo Sinclair, Manduriacu, Minas San Francisco, Toachi Pilatón y Delsintagua) en relación con la implementación de Contribución Nacional Determinada. La metodología es exploratoria y presenta dos enfoques: cualitativo y cuantitativo. Para proyectar los escenarios utilizamos datos del Panel Intergubernamental de Cambio Climático relacionados con tres líneas de evolución A1, B1 y B2. Los resultados muestran que el cambio climático constituye uno de los desafíos más importantes que enfrenta Ecuador para cumplir con la Contribución Nacional Determinada debido a que la energía hidroeléctrica presenta una ineficiencia del 15.8% en los últimos 20 años. Los escenarios muestran una reducción de la capacidad total para los proyectos hidroeléctricos hasta 2050 cercana a los 1909 MW para A1, de 2041 MW para B1 y 2132 MW en B2.

Palabras clave: cambio climático, energía, hidroelectricidad, medio ambiente, renovables, sostenibles

RESUMO

O aquecimento global ameaça o abastecimento de água do mundo, representando uma ameaça significativa para a geração de energia hidrelétrica. No entanto, o aumento contínuo da demanda de energia devido ao crescimento populacional e ao desenvolvimento socioeconômico exige essa fonte renovável. O artigo pretende analisar a tendência futura das mudanças climáticas no desenvolvimento hidrelétrico em cinco usinas (Coca Codo Sinclair, Manduriacu, Minas San Francisco, Toachi Pilatón e Delsintagua) em relação à implementação da Contribuição Nacional Determinada. A metodologia é exploratória e apresenta duas abordagens: qualitativa e quantitativa. Para projetar os cenários utilizamos dados do Painel Intergovernamental sobre Mudanças Climáticas referentes a três linhas de evolução A1, B1 e B2. Os resultados mostram que a mudança climática constitui um dos desafios mais importantes que o Equador enfrenta para cumprir a Contribuição Nacional Determinada porque a energia hidrelétrica apresenta uma ineficiência de 15,8% nos últimos 20 anos. Os cenários mostram uma redução na capacidade total dos projetos hidrelétricos até 2050 de aproximadamente 1.909 MW para A1, 2.041 MW para B1 e 2.132 MW para B2.

Palavras chave: energia, hidroeletricidade, meio ambiente, mudança climática, renovável, sustentável

INTRODUCCIÓN

Globally, there are still around 22% of households without access to electricity, according to the International Energy Agency this represented 1.5 billion people living in remote areas that were often difficult to connect to national or regional grids in 2008. In developing countries, it is estimated that 85% of the population lives in rural areas, mostly peri-urban and remote rural areas (Niez, 2010; Berga, 2016).

However, the scientists mentioned that the 2004 year is different, set against the backdrop of the crisis caused by the COVID-19 pandemic. A 2021 survey of more than 2500 energy leaders from 108 countries mentioned that the world needs an energy transition from renewables agenda, identifying the risks, opportunities, and action priorities for their sector (Lohrmann *et al.*, 2021; World Energy Council, 2004).

In recent years, renewable energy has played a bigger role in producing electricity than ever before. For example, hydropower accounted for 60% of clean energy production in 2018, followed by wind power (21%), solar photovoltaic power (9%), and bioenergy (8%). Overall, installed renewable energy capacity at the end of 2020 was sufficient to supply around 26.2% of global electricity production (International Hydropower Association, 2021).

Moreover, hydropower resource utilization nowadays holds a high position in the global electric power balance. After the Second World War, electric power production by hydropower projects was rapidly increasing: from 200 TWh in 1946 to 860 TWh in 1965, and from 975 TWh in 1978 to 4370 TWh in 2020 worldly (International Renewable Energy Agency, 2020; Naranjo-Silva & Álvarez, 2022). In the last 55 years, hydropower generation has been growing more 408%.

Nevertheless, the hydropower potential is still under used. With the project's production data, the International Hydropower Association determined that 74% of the potential in developing regions had not yet been built. Even with the continued advance over the last ten years (mainly in Asia and Latin America), most of the world's potential capacity has not been developed (International Hydropower Association, 2018). For example, in 2012, the global generation of hydropower was 3670 TWh, but the global technical potential is approximately four times that amount, around 14 680 TWh (International Hydropower Association, 2021).

Hydropower is a clean, renewable technology that can offer profits, such as water supply, flood control, economic development, and recreation (Hartmann, 2020). But the expected and continuous changes in hydrology are at the core of the relationship among hydropower and climate change (Naranjo-Silva & Álvarez, 2021b).

There is unfortunately another challenge that needs to be addressed together with trying to reintroduce renewable energies, and in particular hydropower. According to the Intergovernmental Panel on Climate Change (IPCC), climate change and greenhouse gases are trapping heat, accelerating the level of global warming in an aggressive and agile manner, and reducing the water required for the constant hydrological cycle needed for life (Jabbari & Nazemi, 2019; Uamusse *et al.*, 2020).

Climate change has been one of the core stimuli that brand societies change how they use natural resources sensitive to climate variations (Shove, 2010). Society adapts to changes when necessary to survive, and the consumption patterns of the most natural resources are no longer considered sustainable if new lifeways are not adopted (Antwi & Sedegah, 2018).

Thus, with the promotion of hydropower and taking precautions against the impacts of climate change, in 2019, the Ministry of Environment, Water and Ecological Transition of Ecuador presented the First National Determined Contribution (NDC) as a tool that has an objective to guide the application of the actions at the national, sectorial and local levels that encourage the reduction of greenhouse gases, as well as the increase in adaptive capacity and risk reduction in the adverse effects, the face of climate change in the prioritized sectors, including the energy sector (Ministry of the Environment, 2019; Llerena-Montoya *et al.*, 2021).

One of the impacts related to the National Plan for the Complementation of the Determined Contribution is that there are past extreme events related to rainfall that would cause that the 15.9% of the area is under flood risk of 15.9% of the national surface, in which 49.5% of the total population would settle of the country (Ministry of Environment and Water, 2021). To this end, said Ministry offers the following trend according to information on the initiatives of the energy sector:

Table 1. *First initiative and strategy of the National Determined Contribution, Ecuador in the energy sector.*

Initiative	Scenario	Description	GHG reduction potential in 2025 [Gg CO_2-eq/year]	Estate
Central Development	Unconditional	Hydroelectric unconditional use of water resources for electricity generation in 2275 MW of power	6000	Being implemented (operating)

Note: *GHG:* Green House Gasses.
Source: Ministry of Environment and Water (2021).

The potential for reducing *greenhouse gasses* emissions due to the displacement of diesel used in electricity generation is considered. The plants are assumed to correspond to that power installed from 2010 to November 2018 (Emblematic Projects) and will operate between 2020 and 2025, and the specific projects are listed in *table 2*. According to the

Table 2. *Emblematic hydropower projects determined by National Determined Contribution.*

No.	Project	Capacity (MW)	Ubication States	State
1	Coca Codo Sinclair	1500	Napo and Sucumbíos	In operations, November 2016
2	Minas San Francisco	275	Azuay and El Oro	In operations, January 2019
3	Toachi Pilatón	255	Santo Domingo	In construction
4	Delsitanisagua	180	Zamora Chinchipe	In operations, December 2018
5	Manduriacu	65	Pichincha and Imbabura	In operations, March 2015
	Total [MW]	2275	-	-

Note: *GHG:* Green House Gasses.

Source: Ministry of the Environment (2017).

Implementation Plan of the First National Determined Contribution of Ecuador for 2020-2025, the country is susceptible to the effects of climate change and is threatened due to its social, economic, and environmental conditions due to the increasingly frequent and intense rainfall and extreme temperatures (Ministry of Environment and Water, 2021; Rivera-González *et al.*, 2020).

Hence, this paper presents historical energy hydropower data of Ecuador and aims to analyze the future tendency of climate change in hydropower development in five emblematic plants (Coca Codo Sinclair, Manduriacu, Minas San Francisco, Toachi Pilatón, and Delsintagua) concerning to the implementation the National Determined Contribution of this Latin American country in the energy sector as the first strategy.

METHODOLOGY

The article's methodology is exploratory, collecting information and processing it on the specific topic of hydropower development in Ecuador, and it is presented with two qualitative and quantitative approaches. For example, the qualitative part gives notions and definitions of the hydropower development of Ecuador and the future perspectives.

In the quantitative part, the energy production data of the last twenty years are recovered from 20 hydropower plants determined indicators of difference in energy production to final project this percentage at the five emblematic plants contemplated in the National Determined Contribution of Ecuador to operate until 2025.

To calculate the future, we do a percentual difference of the last 20 years, knowing the energy production of the actual hydropower plants working, dividing the energy data into periods of 10 years, have a variance (increase/decrease) of 2000-2010 and 2010-2020, calculating the discrepancies between these two periods. The average of each of the last decades is executed to look for a trend and thus be able to project future analyses.

Moreover, to project the upcoming difference conservatively to the emblematic plants, the data according to the Intergovernmental Panel on Climate Change (IPCC) scenarios that mention climate change can have fluctuations related to evolution lines divided into four groups (A1, A2, B1, and B2). The A-line presents a pessimistic scenario where emissions are maintained or increase in the future. The evolution line B represents an optimistic scenario in which greenhouse gasses emissions are reduced worldwide (Alley *et al.*, 2007; Arango-Aramburo *et al.*, 2019). In this context, besides explaining the IPCC scenarios in groups to emulate our future analyses.

Table 3. *Climate change scenarios according to the IPCC.*

Line	Description	Indicator
A1.	According to this evolutionary family, the world will experience rapid economic growth, and the population of the world will peak around the mid-century and decline after the rapid introduction of new and more efficient technologies. As a result, there are several distinguishing features that seem to have emerged. These include convergence between regions, capacity building, cultural and social interaction, and a significant reduction in the differences in per capita income between regions.	It is the most aggressive future evolutionary line of world changes, where any projection and trend are accepted at 80% of changes.
A2.	Scenario A2 describes a very assorted world, the most distinguishing characteristics being self-sufficiency and preservation of local entities. Despite the fact that patterns across regions converge very slowly, there has been a continuous rise in the world population. The focus of economic development is on regions and not on countries, and it is per capita that matters most.	Economic growth and technological change are fragmented and slower than in other evolutionary lines.
B1.	The B1 family of storylines describes a converging world with the same global population peaking around mid-century and falling after that, as in the A1 storyline, but with rapid changes in economic structures oriented toward the service economy and information, accompanied by less intensive use of materials and the introduction of clean technologies, with efficient use of resources. Global solutions aimed at economic, social, and environmental sustainability and greater equality are dominant, but in the absence of additional climate initiatives.	The average evolutionary line is based on ecological aspects; any projection and trend are accepted at 50% of changes.
B2.	A world where local solutions dominate economic, social, and environmental sustainability is described by the B2 scenarios. Compared to B1 and A1, its population is growing at a slower pace, its economic development is on an intermediate level, and its technological development is slower and more diverse. There is an emphasis on environmental preservation and social equality in this scenario, but it focuses mainly on local and regional levels in order to achieve environmental protection and social equality.	This evolutionary line is the most conservative based on ecological aspects and the use of resources in a sustainable way, the projections of change are acknowledged at 30% of deviations.

Source: Alley *et al.* (2007); Arango-Aramburo *et al.* (2019) y United Nations (s.f.)

In our methodology, at the researcher's criterion, we just take lines A1, B1, and B2 because we believe that these are the evolution aspects more realistic for the future scenarios when the projections depending on the region evolution with gradual changes, accelerated in some sectors and slow in others, in addition to criteria of divided economic growth marked by developed countries and partially by developing countries.

Moreover, the reduction percentage and variation are from the researcher's assumptions with the consulting data of IPCC. On the other hand, a reflection of the qualitative issues is generated on scientific bases. The ideas and conclusions of various studies on climate change and hydroelectricity were obtained and collected to integrate into the discussion of the manuscript.

In both approaches, the National Determined Contribution of Ecuador determines the five analyzed projects, contributing to the interconnected national system of 2275 MW and a projection of the future capacity to 2050 (Corporación Eléctrica de Ecuador, 2021).

RESULTS

As mentioned in the methodology, the historical behavior of the plants over the last 20 years is first understood to analyze future hydroelectric production. To do energy examination, we use data from the Ministry of Energy to 20 hydropower projects in Ecuador, doing the specification of energy generated in MWh to 2000, 2010, and 2020 in *table 4.*

Table 4. *Energy production, in MWh, of hydropower in Ecuador.*

No.	Hydropower project	2000	2010	2020
1	Agoyán	1,022,213	914,900	946,800
2	Alao	78,328	80,300	80,688
3	Ambi	25,323	26,400	34,283
4	Carlos Mora	15850	15,600	15,000
5	Chillos	15,268	12,510	13,894
6	Cumbaya	180,626	140,570	117,393
7	El Estado	8,541	7,230	9,479
8	Guangopolo	92,596	65,330	57,093
9	Illuchi 1	20,598	17,930	21,771
10	Illuchi 2	26,414	20,840	26,104
11	Marcel Lanido	547,409	773,790	878,780
12	Nayón	164,948	115,460	104,726
13	Pasochoa	32,897	23,900	22,839
14	Paute	4,865,426	4,048,760	3,842,160
15	Península	15791	10,020	12,405
16	Pucara	224,653	141,940	234,720
17	Río Blanco	17,493	20,860	8,892
18	San Miguel de Car	20,395	17,740	3,728
19	Saucay	118,108	101,670	115,530
20	Sayamin	94,941	71,560	90,650

Source: *Prepared by the author.*

As shown in *table 4*, we have the data of 20 hydropower projects in Ecuador over the last 20 years and the energy tendency divided into ten-year periods to calculate the percentual difference (increase/decrease). Finally, we make an average between 2000-2010 and 2010-2020 in *table 5*. The key is finding the energy production's tendency (amplified or reduced) around these 20 years.

Table 5. *Energy production tendency in MWh of hydropower in Ecuador.*

No.	Hydropower project	Tendency 1 2000-2010	Tendency 2 2010-2020	Average difference Tendency (1-2)
1	Agoyan	-11.7%	3.4%	-4.2%
2	Alao	2.5%	0.5%	1.5%
3	Ambi	4.1%	23.0%	13.5%
4	Carlos Mora	-1.6%	-4.0%	-2.8%
5	Chillos	-22.0%	10.0%	-6.0%
6	Cumbaya	-28.5%	-19.7%	-24.1%
7	El Estado	-18.1%	23.7%	2.8%
8	Guangopolo	-41.7%	-14.4%	-28.1%
9	Illuchi 1	-14.9%	17.6%	1.4%
10	Illuchi 2	-26.7%	20.2%	-3.3%
11	Marcel Lanido	29.3%	11.9%	20.6%
12	Nayon	-42.9%	-10.2%	-26.6%
13	Pasochoa	-37.6%	-4.6%	-21.1%
14	Paute	-20.2%	-5.4%	-12.8%
15	Península	-57.6%	19.2%	-19.2%
16	Pucara	-58.3%	39.5%	-9.4%
17	Rio Blanco	16.1%	-134.6%	-59.2%
18	San Miguel de Car	-15.0%	-375.9%	-195.4%
19	Saucay	-16.2%	12.0%	-2.1%
20	Sayamin	-32.7%	21.1%	-5.8%
	Total average			-19.0%

Source*: Prepared by the author.*

The energy results are part of the variations that reduce the energy efficiency of each project, as the analysis of the Ministry of Environment, Water and Ecological Transition of Ecuador did in the National Determined Contribution plan that mentions climate change is a big threat to energy systems (Ministry of Environment and Water, 2021). The tabulation results between the two periods of 10 years give us a global hydropower generation reduction of 19%, a percentage that in 20 years can be projected to the capacity of the emblematic hydropower projects.

Moreover, the total average means each year of a 0.95% energy reduction in hydropower production. For the projects to be in operation until 2025 from the National Determined Contribution, we can throw a future decrease with the tendency calculated in Table 5. Thus, we need the temperature and precipitation information, the official trends establish that climate change is a worldwide problem, and Ecuador is not unaware. To the reference period 1960 – 2015, the rains increased on the Coast by 33%; Sierra by 13%, and only in the Amazon was a 1% reduction in rainfall where rains were previously common (Ministry of the Environment, 2019; Naranjo-Silva, Punina, Álvarez, 2022).

As a result, making a lineal reduction with the different scenarios as illustrated in *table 3*, we project a capacity to 2050 around the besides calculus for the emblematic projects, called emblematic by the capacity that changed in a notable way the renewables increase in energy grid of Ecuador.

Table 6. *Capacity projection in MW to 2050 of emblematic hydropower plants – A1 scenery.*

Period	Coca Codo Sinclair	Minas San Francisco	Toachi Pilatón	Delsintagua	Manduriacu	Total capacity [MW]
2023-2030	1,420	260	241	170	62	2,154
2030-2040	1,312	241	223	157	57	1,990
2040-2050	1,213	222	206	146	53	1,839

Source: Prepared by the author.

In addition, doing a scenario of just the reduction of the 50% percent that is 0.48%, and 30% represents 0.29% of each year's reduction presents the following series:

Table 7. *Capacity projection in MW to 2050 of emblematic hydropower plants – B1 scenery.*

Period	Coca Codo Sinclair	Minas San Francisco	Toachi Pilatón	Delsintagua	Manduriacu	Total Capacity [MW]
2023-2030	1,450	266	247	174	63	2,199
2030-2040	1,381	253	235	166	60	2,095
2040-2050	1,316	241	224	158	57	1,995

Source: Prepared by the author.

Table 8. *Capacity projection in MW to 2050 of emblematic hydropower plants – B2 scenery.*

Period	Coca Codo Sinclair	Minas San Francisco	Toachi Pilatón	Delsintagua	Manduriacu	Total Capacity [MW]
2023-2030	1,470	270	250	176	64	2,230
2030-2040	1,428	262	243	171	62	2,166
2040-2050	1,387	254	236	166	60	2,104

Source: Prepared by the author.

On the other hand, the conception of the emblematic projects means that these hydropower plants will drastically change Ecuador's energy grid by their capacity to integrate clean energy into national consumption. They are also presented as the largest constructions and investments in infrastructure over the last years (Vaca-Jiménez *et al.*, 2019). With the background of the hydropower development in the unconditional energy scenario and the first strategy, next analyzing each project's state, benefits, and problems related to complying with the first initiative of the National Determined Contribution of Ecuador with compliance of 2019 goals sets.

DISCUSSION

As the results show, in the five projects established as emblematic by Ecuador in the First National Determined Contribution, the biggest problem is the delay in work execution; some operate but are not at 100% capacity. Moreover, the results of the 20 hydropower projects show a future reduction, due to the climate change, in the generation parameter that will not allow the real capacity of the emblematic plants (Coca Codo Sinclair, Manduriacu, Minas San Francisco, Toachi Pilatón, and Delsintagua). The variable aspects due to the changing climate, it is pertinent to clarify that hydropower energy depends on the availability of natural resources and their interaction with precipitation to play an essential protagonist in the runoff of flows; all these aspects represent an obstacle to achieve the National Determined Contribution goal with the emblematic hydropower projects in Ecuador (Naranjo-Silva & Álvarez, 2021a; Villamar et al., 2021).

Overall, the results of *table 6, 7* and *8* of each projection show a reduction in the projected capacity. However, it depends on the Ecuadorian Government's need to apply to mitigate actions on the hydropower developments to corroborate these results. We can compare with Van Vliet's study that presents a vulnerability assessment of the world's current hydropower generation system to climate change affecting water resources, testing water and energy adaptation options during the 21st century. Using hydrological-electric modeling coupled with data on 24,515 hydroelectric plants globally, it showed reductions in usable capacity between 61–74% for hydropower plants worldwide for the scenario of time 2040–2069 by the climate change (van Vliet, van Beek *et al.*, 2016; van Vliet, Wiberg *et al.*, 2016).

In addition, comparing our results from *tables 6* to *8*, we have the research of Carvajal in 2019 year, whose show that hydropower energy generates impacts by using environmental conditions, and it is evident that the deployment of hydroelectricity indicates uncertainty in the global climate model shows that for Ecuador the hydropower energy would vary significantly between 53% and 81% by 2050, which means that Ecuador's National Determined Contribution goal would be achieved without the distribution of a large hydroelectric infrastructure, but rather through a more diversified energy group (Carvajal *et al.*, 2019; Carvajal & Li, 2019).

In 2005, the World Bank conducted a study that examined the multiplier effects of large hydropower projects in several countries. This report indicates that hydropower multipliers range from 1.4 to 2.0, which means that for every dollar invested in dam-related activities, 40 to 100 cents can be generated indirectly in the region for every dollar invested (Edenhofer *et al.*, 2011; Schaeffer *et al.*, 2013). Hence, it is estimated that this type of renewable energy would require a billion dollars to compensate for the deterioration caused by climate change in the last 18 years of hydropower generation (Turner *et al.*, 2017).

According to the scenarios projected by the Inter-American Development Bank in many countries, hydropower will be susceptible to the climatic variations. It will lose efficiency due to climate change, reduction of water causes, and it will conclude to be the main source of supply, for which it will become a facilitator of other renewable energies, which will benefit both environmentally and in the reduction of other impacts (Banco Interamericano de Desarrollo, s.f.). It means that the role of hydropower will gradually shift from a firm source of production that covers a growing demand to a flexible source that complements other renewable energy sources, such as wind, geothermal, solar, and tidal.

Across the world, with millions of people, there are high vulnerabilities to the current and expected effects of climate change that often affect the poorest. Climate change will affect precipitation, increase the melting of snow and glaciers, change evaporation fluxes, and disrupt the natural water cycle, creating a complex uncertainty for water resource management and hydroelectric development (Zhang *et al.*, 2018; Naranjo-Silva *et al.*, 2022).

Climate change influences all existing hydropower plants and possible future projects; therefore, new projects have greater freedom to generate design choices. Future lines can determine the climate simulations and related effectiveness to a changing environment that needs adaptation parameters.

CONCLUSIONS

The presented scenarios show a lineal reduction denominated A1 that can accumulate up to 1839 MW to 2050, in the medium scenario denominated B1 the capacity can show up to 1995 MW, and in the conservative scenario B2 up to 2104 MW. The total capacity for the five emblematic hydropower projects (Coca Codo Sinclair, Manduriacu, Minas San Francisco, Toachi Pilatón, and Delsintagua) that were thought of at 2275 MW initially. Therefore, the projection has a percentual reduction to 2050 of 19%, 12 and 8% of their capacities to the scenarios A1, B1, and B2 respectively.

As a climatically sensitive technology, hydropower contributes significantly to reducing global climate change. However, it is becoming increasingly inefficient due to climatic variations, which are becoming more prominent, as seen in Ecuador's power generation trend during the last two decades.

Climate change constitutes one of Ecuador's most significant challenges to meet the goals of the National Determined Contribution projected in the energy sector by hydropower production to the inefficiency calculated in 19% accentuated in the last 20 years in 20 projects presented in *table 5*.

The National Determined Contribution implementation plan can be actualized every two years to control the hydropower energy production to know the real carbon reduction capacity and the projected efficiency. With our calculations, the five projects are affected by the climate change impacts with the historical data.

BIBLIOGRAPHIC REFERENCES

Alley, R. B., Berntsen, T., Bindoff, N. L., Chen, Z., Chidthaisong, A., Friedlingstein, P., Gregory, J. M., Hegerl, G. C., Heimann, M., Hewitson, B., Hoskins, B. J., Joos, F., Jouzel, J., Kattsov, V., Lohmann, U., Manning, M., Matsuno, T., Molina, M., … Zwiers, F. (2007). *Resumen para Políticas Responsables de los Expertos sobre Cambio Climático.* Grupo Intergubernamental de Expertos sobre Cambio Climático https://bit.ly/3QGKGpN

Antwi, M., & Sedegah, D. D. (2018). Climate change and societal change—impact on hydropower energy generation. In A. Kabo-Bah and Ch. J. Diji (Ed.), *Sustainable hydropower in West Africa: planning, operation, and challenges* (pp. 63–73). Elsevier. https://doi.org/h76q

Arango-Aramburo, S., Turner, S. W. D., Daenzer, K., Ríos-Ocampo, J. P., Hejazi, M. I., Kober, T., Álvarez-Espinosa, A. C., Romero-Otalora, G. D., & van der Zwaan, B. (2019). Climate impacts on hydropower in Colombia: A multi-model assessment of power sector adaptation pathways. *Energy Policy*, *128*, 179–188. https://doi.org/ggvnfz

Banco Interamericano de Desarrollo. (s.f.). *Energía sostenible, confiable y diversificada para América Latina y el Caribe*. Recuperado el 6 de julio de 2022 de https://bit.ly/3w3F7Km

Berga, L. (2016). The role of hydropower in climate change mitigation and adaptation: A review. *Engineering*, *2*(3), 313–318. https://doi.org/ghk54p

Carvajal, P. E., & Li, F. G. N. (2019). Challenges for hydropower-based national determined contributions: a case study for Ecuador. *Climate Policy*, *19*(8), 974–987. https://doi.org/h76s

Carvajal, P. E., Li, F. G. N., Soria, R., Cronin, J., Anandarajah, G., & Mulugetta, Y. (2019). Large hydropower, decarbonisation and climate change uncertainty: Modelling power sector pathways for Ecuador. *Energy Strategy Reviews*, *23*, 86–99. https://doi.org/ggjv9j

Corporación Eléctrica del Ecuador. (14 de enero de 2021). *CELEC EP genera y transmite más del 90 por ciento de la energía eléctrica limpia que consume el país y exporta a los países vecinos*. https://bit.ly/3dpDNLb

Edenhofer, O., Pichs-Madruga, R., Sokona, Y., Seyboth, K., Kadner, S., Zwickel, T., Eickemeier, P., Hansen, G., Schlömer, S., von Stechow, C., & Matschoss, P. (2011). *Renewable energy sources and climate change mitigation: Special report of the intergovernmental panel on climate change*. Cambridge University Press. https://doi.org/cdkjg8

Hartmann, J. (2020). *Manual de Entrenamiento sobre Cambio Climático e Hidroenergía. Proyecto AICCA.* Ministerio del Ambiente y Agua de Ecuador/Consorcio para el Desarrollo Sostenible de la Ecorregión Andina (CONDESAN) (p. 1012). https://bit.ly/3K1yXA8

International Hydropower Association. (2018). *Hydropower Sustainability Guidelines on Good International Industry Practice.* https://bit.ly/2PXZdh5

International Hydropower Association. (2021). *2021 Hydropower Status Report. Sector trends and insights*. https://bit.ly/3pk8h3P

International Renewable Energy Agency. (2020). *Renewable Energy Statistics 2020.* https://bit.ly/3phP1E7

Jabbari, A. A., & Nazemi, A. (2019). Alterations in Canadian hydropower production potential due to continuation of historical trends in climate variables. *Resources*, *8*(4), 163. https://doi.org/h77b

Llerena-Montoya, S., Velastegui-Montoya, A., Zhirzhan-Azanza, B., Herrera-Matamoros, V., Adami, M., de Lima, A., Moscoso-Silva, F., & Encalada, L. (2021). Multitemporal analysis of land use and land cover within an oil block in the Ecuadorian Amazon. *International Journal of Geo-Information*, *10*(3). https://doi.org/h77c

Lohrmann, A., Child, M., & Breyer, Ch. (2021). Assessment of the water footprint for the European power sector during the transition towards a 100% renewable energy system. *Energy*, *233*(15), 121098. https://doi.org/gkbvms

Ministry of the Environment. (2017). *Estrategia nacional para el cambio climático de Ecuador 2012-2025.* https://bit.ly/3REgo88

Ministry of the Environment. (2019). Contribution Nationally Determined: Ecuador. https://bit.ly/3B9jyK1

Ministry of Environment and Water. (2021). Plan de Implementación de la Primera Contribución Determinada a Nivel Nacional del Ecuador 2020-2025 (PI-NDC). https://bit.ly/3QKcFEt

Naranjo-Silva, S., & Álvarez, J. (2021a). An approach of the hydropower: Advantages and impacts. A review. *Journal of Energy Research and Reviews*, *8*(1), 10–20. https://doi.org/h77f

Naranjo-Silva, S., & Álvarez, J. (2021b). Hydropower: Projections in a changing climate and impacts by this "clean" source. *CienciAmérica*, *10*(2), 32. https://doi.org/h77g

Naranjo-Silva, S., & Álvarez, J. (2022). The American continent hydropower development and the sustainability: A Review. *International Journal of Engineering Science Technologies*, *6*(2), 66–79. https://doi.org/h77j

Naranjo-Silva, S., Punina, D. J., & Álvarez, J. (2022). Comparative cost per kilowatt of the latest hydropower projects in Ecuador. *InGenio Journal*, *5*(1), 1–14. https://doi.org/h77q

Naranjo-Silva, S., Rivera-Gonzalez, L., Escobar-Segovia, K., Quimbita-Chiluisa, O., & Álvarez, J. (2022). Analysis of water characteristics by the hydropower use (up-stream and downstream): A case of study at Ecuador, Argentina, and Uruguay. *Journal of Sustainable Development*, *15*(4), 71. https://doi.org/h77r

Niez, A. (2010). *Comparative study on rural electrification policies in emerging economies: Keys to successful policies*. International Energy Agency. https://bit.ly/3SQeEJN

Rivera-González, L., Bolonio, D., Mazadiego, L. F., Naranjo-Silva, S., & Escobar-Segovia, K. (2020). Long-term forecast of energy and fuels demand towards a sustainable road transport sector in Ecuador (2016-2035): A LEAP model application. *Sustainability*, *12*(2), 472. https://doi.org/h77s

Schaeffer, R., Szklo, A., Lucena, A., Soria, R., & Chávez-Rodríguez, M. (2013). The vulnerable Amazon: The impact of climate change on the untapped potential of hydropower system. *IEEE Power & Energy Magazine*, *11*(3), 10. https://doi.org/h77t

Shove, E. (2010). Beyond the ABC: Climate change policy and theories of social change. *Environment and Planning A: Economy and Space*, *42*(6), 1273-1285.https://doi.org/cj9fjq

Turner, S. W. D., Hejazi, M., Kim, S. H., Clarke, L., & Edmonds, J. (2017). Climate impacts on hydropower and consequences for global electricity supply investment needs. *Energy*, *141*(15), 2081–2090. https://doi.org/gcxkhq

Uamusse, M. M., Tussupova, K., & Persson, K. M. (2020). Climate change effects on hydropower in Mozambique. *Applied Sciences*, *10*(14), 4842. https://doi.org/gjdndj

United Nations. (s.f.). *Climate Change*. https://bit.ly/3DjZiI6

Vaca-Jiménez, S., Gerbens-Leenes, P. W., & Nonhebel, S. (2019). The water footprint of electricity in Ecuador: Technology and fuel variation indicate pathways towards water-efficient electricity mixes. *Water Resources and Industry*, *22*, 100112. https://doi.org/ggjv9n

van Vliet, M. T. H., van Beek, L. P. H., Eisner, S., Flörke, M., Wada, Y., & Bierkens, M. F. P. (2016). Multi-model assessment of global hydropower and cooling water discharge potential under climate change. *Global Environmental Change*, *40*, 156–170. https://doi.org/f84jww

van Vliet, M. T. H., Wiberg, D., Leduc, S., & Riahi, K. (2016). Power-generation system vulnerability and adaptation to changes in climate and water resources. *Nature Climate Change*, *6*, 375–380. https://doi.org/bbsp

Villamar, D., Soria, R., Rochedo, P., Szklo, A., Imperio, M., Carvajal, P., & Schaeffer, R. (2021). Long-term deep decarbonization pathways for Ecuador: Insights from an integrated assessment model. *Energy Strategy Reviews*, *35*, 100637. https://doi.org/h77x

World Energy Council. (2004). *Comparison of energy systems using life cycle assessment. A special report of the World Energy Council*. https://bit.ly/3DilbaL

Zhang, X., Li, H. Y., Deng, Z. D., Ringler, C., Gao, Y., Hejazi, M. I., & Leung, L. R. (2018). Impacts of climate change, policy and water-energy-food nexus on hydropower development. *Renewable Energy*, *116*(A), 827–834. https://doi.org/gf4tbj