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Comparative cost per kilowatt of the latest hydropower projects in Ecuador

(Costo comparativo por kilovatio de los últimos proyectos hidroeléctricos en Ecuador)

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Resumen: La hidroelectricidad es la mayor fuente renovable globalmente utilizada, para el 2020 ésta constituye el 77% de la matriz energética en Ecuador, pero los costos con los cuales se desarrollan estos proyectos generan el cuestionamiento entre el costo y beneficio de dichas inversiones debido a los impactos sociales, ambientales y culturales que se crean. Mediante una metodología cuantitativa en base a términos de inclusión y exclusión se encontró que las ultimas cinco centrales hidroeléctricas del Ecuador inauguradas en el período 2015 – 2019 contienen costos más altos del promedio global en comparación con el cálculo de la Agencia Internacional de las Energías Renovables, específicamente, para Coca Codo Sinclair se tiene un 79% de incremento, 34% para Sopladora, 21% para Minas San Francisco, 12% para Delsintagua y 119% para la central Manduriacu. Además, el costo promedio globalmente calculado por IRENA en el 2020 fue 1,472 USD/kWh, en el caso promedio de 499 MW del Ecuador se tiene un costo de 2,018 USD/kWh, valor 37% adicional a manera comparativa. Las decisiones de inversión en nuevos proyectos hidroeléctricos deben mejorarse con base en los datos de las plantas existentes, buscando mitigar los impactos, generando un análisis crítico y definiendo las metas del país con las poblaciones involucradas.

Palabras clave: Ecuador, costo, hidroeléctricas, energía, renovable, kilovatio.

Abstract: Hydropower is the largest renewable source globally used, and in Ecuador, by 2020, the energy grid was 77% hydroelectric, but the costs with which these projects are developed generate questioning between the cost and benefit of said investments due to the social, environmental and cultural impacts created. Through a quantitative methodology based on inclusion and exclusion terms that developed comparisons, it was found that the last five hydropower projects in Ecuador inaugurated in the period 2015 - 2019 contain higher costs than the global average in comparison by the calculation by the International Renewable Energy Agency, specifically, for Coca Codo Sinclair, there is a 79% increase, 34% for Sopladora, 21% for Minas San Francisco, 12% for Delsintagua and 119% for the Manduriacu plant. In addition, the global average cost calculated by IRENA in 2020 was 1,472 USD/kW in the average case of 499 MW in Ecuador, there is a cost of 2,018 USD/kW, an additional 37% value for comparison. Investment decisions in new hydropower projects should be improved based on data from existing plants, seeking to mitigate the impacts, doing critical analysis, and defining the country goals with the involved communities.

Keywords: Ecuador, cost, hydroelectric, energy, renewable, kilowatt.

1. INTRODUCTION

Hydroelectricity is the largest renewable source used; by 2020, around 14,000 projects operating activity as a widely used technology from a total of 180 countries in the world that reported benefiting [1], [2]. According to the International Hydropower Association (IHA), the

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global hydroelectric capacity in 2020 was 1,330 GW. In Figure 1, we see the countries that lead this type of energy source.

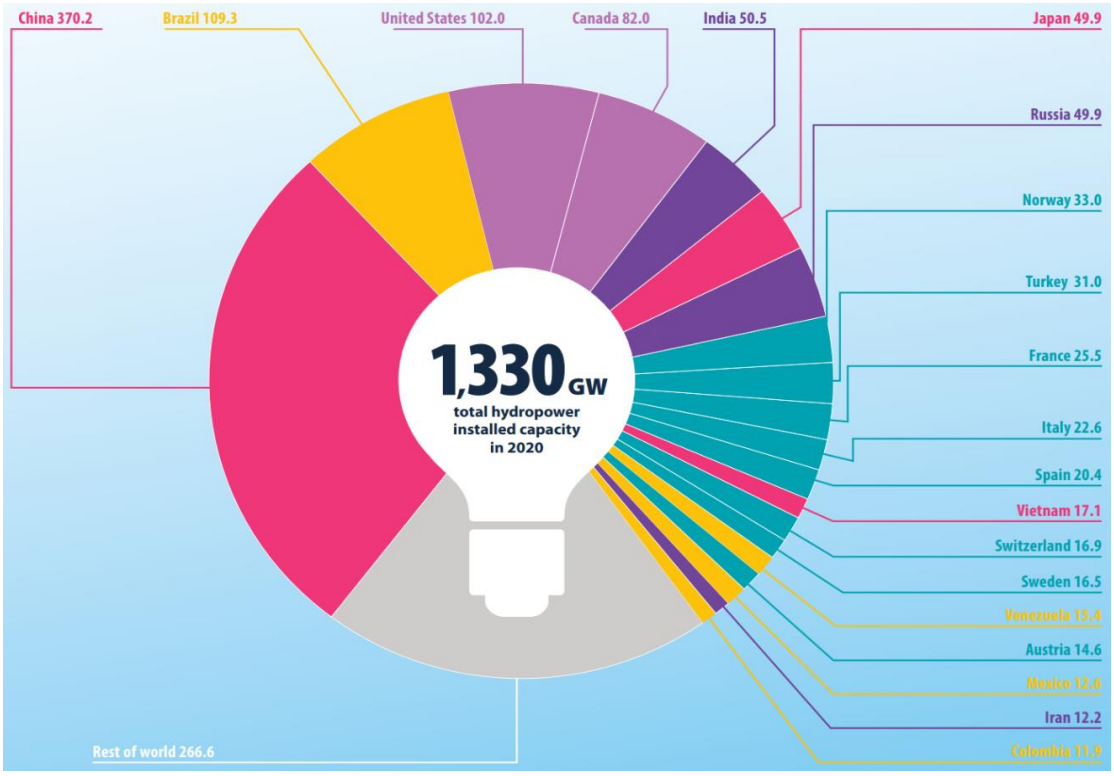

Figure 1. World hydropower capacity installed in 2020 [3].

But, despite its renewable nature, hydropower has environmental and social impacts that produce its use, as well as limitations of economic feasibility, making hydropower a subsector of special attention for its development in a sustainable way [4], [5].

The fact that hydropower is renewable should not suggest that adverse effects, the called "clean" energies are never clean when they are produced on a large scale or produce a drastic change, on the contrary, it has severe impacts on human lives and natural ecosystems, often irreversible [6].

Tuula Teravainen mentions technical, ecological, territorial, and cultural transformations at different levels and spaces of society where hydropower projects often involve conflicts, new knowledge regimes, other local practices, global mitigation frameworks, and water resources management [7].

Hydropower development requires built dams and large-scale infrastructure, as well as the opening of roads, water channels, pipelines, and other facilities that are not a novelty but that do find particularities, benefits, and disadvantages that characterize the process as that hydroelectric projects need extensive infrastructure that is often not based on territorial expansion plans or social and environmental compensation [8].

In addition, in developing countries that seek to increase their energy grid with massive hydropower expansion plans, abrupt changes are generated without analyzing the necessary support to produce sustainable electricity from the costs per project and per kWh that may be too high [9].

On the one hand, the infrastructure for hydropower production necessary in several countries is found in rural areas inhabited by peasant, indigenous or small farmer populations that are generally economically vulnerable, where the degree of social, environmental, and economic marginalization is marked, hydroelectric facilities imply a high degree of affectation from the movement of populations to the lifestyle change [10], [11]. Moreover, these hydroelectric projects are rarely promoted by people in those areas due to the changes they imply [12].

For this purpose, hydropower is the only renewable technology with a solid and binding interaction with the environment, particularly the need for a comprehensive cost-benefit assessment to build resilience and diversification in electricity grids [13], [14].

On the other hand, the value of the last five hydroelectric projects inaugurated in Ecuador in 2015-2019 shows wide divergences in the USD/kW percentage values of Ecuador were calculated compared to the global average [15]. For example, Coca Codo Sinclair has a 79% increase, 34% for Sopladora, 21% for Minas San Francisco, 12% for Delsintagua and 119% for the Manduriacu plant.

This document aims to compare the productive cost of each kilowatt of the last five hydropower projects in Ecuador (Coca Codo Sinclair, Sopladora, Minas San Francisco, Delsintagua, and Manduriacu) performing a critical analysis and evaluation of hydroelectricity to develop academic and professional contexts within a globalized society with little environmental awareness.

2. METHODOLOGY

The article's methodology is quantitative investigative, seeking to evaluate the cost of the kW of the last hydropower projects in Ecuador versus the benefit of the investments generated in recent years. About representative sources of scientific information are verified, evaluating specific publishers such as Elsevier and Taylor & Francis to select the best articles that serve as a reference using relevant criteria.

A search protocol was generated in a structured way with Boolean operators using described routes analyzed as indicated in Figure 2 to synthesize and consolidate the results. 169 articles were found on the search, but inclusion terms give 59 documents were filtered for the period from 2015 to 2021 of hydropower cost reference in Ecuador; later, 38 duplicate sources or documents without quantitative data were excluded, leaving 21 sources referenced in this paper.

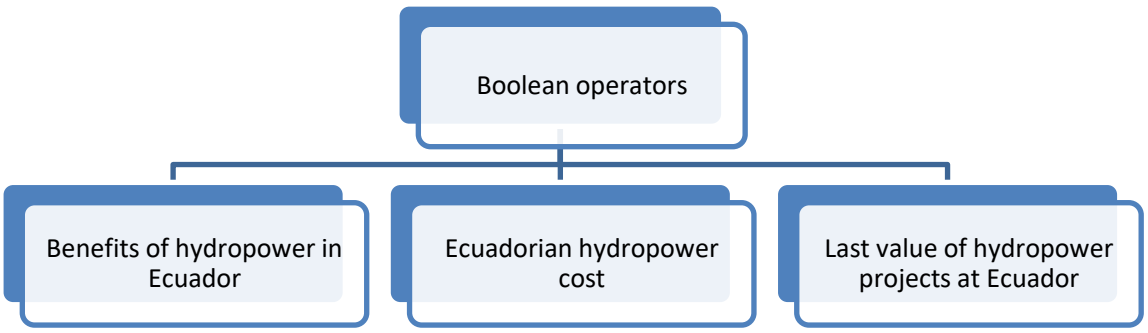

Figure 2. Used methodology

We selected the Elsevier and Taylor & Francis databases because they have more articles and journals related to renewable energies investigations. The 21 sources have the inclusion criteria and were examined further to assess the factors associated with the support for hydropower cost developments. The primary factors that influenced the paper were hydropower projects that

included terms as benefits of hydropower, cost, socio-economic impacts associated, and last value of hydropower projects in Ecuador.

This paper methodology will provide insight into future research that may guide the development of more effective communication strategies and hydropower policy development.

In addition to knowing local data from direct sources, the entities in charge of formulating energy control policies were consulted, such as the Ministry of Energy and Non-Renewable Natural Resources of Ecuador and its attached entity, the Electricity Corporation of Ecuador (CELEC in Spanish).

3. RESULTS

3.1. Hydropower

International Renewable Energy Agency (IRENA) established that in 2016 more than 1 billion people covered their demand with hydropower. It is the third-largest source of electricity generation and first of renewables [16].

The International Hydropower Association establishes that in 2020, 4,370 TWh of hydroelectricity were generated, having a growth of 1.1% more than in 2019. In addition, an additional 1.6% of 2019 was added [3]. On the other hand, to demonstrate the breadth of this source, IRENA produces renewable energy statistics, showing 2020 hydropower distribution in capacity in GW and percentage deployed by region in Figure 3 [17].

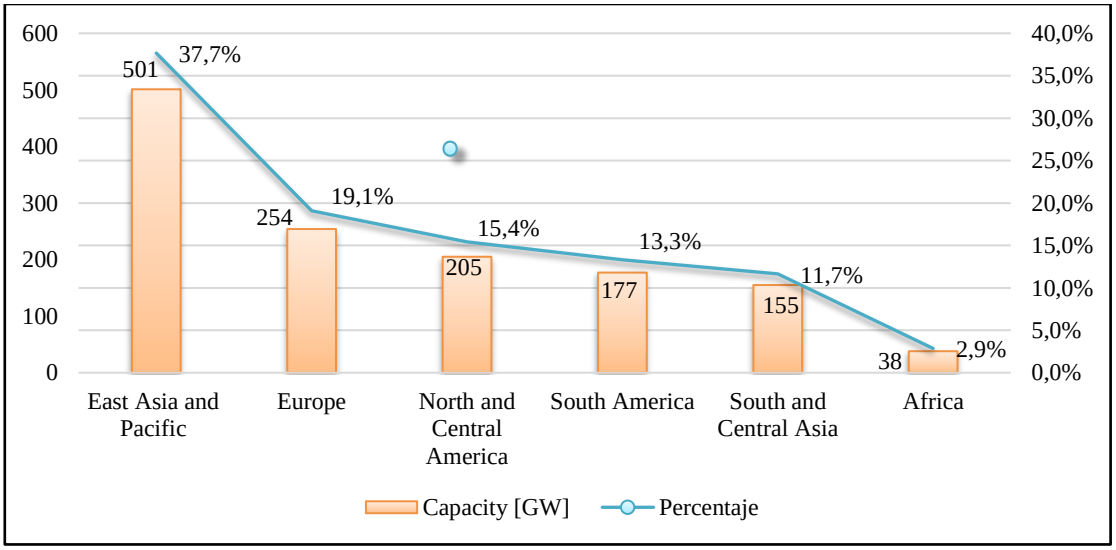

Figure 3. Distribution of hydropower capacity by 2020. [17].

As Figure 3, East Asia is the region with more implemented hydropower with 501 GW, besides Europe and North and Central America with 254 and 205 GW, respectively. Thus, in 2018 the global hydropower capacity was 1,292 GW; in 2019, 1308 GW increased at a compound annual rate of around 3.5% in the last five years (2015 - 2019), as indicated by Figure 4 [18].

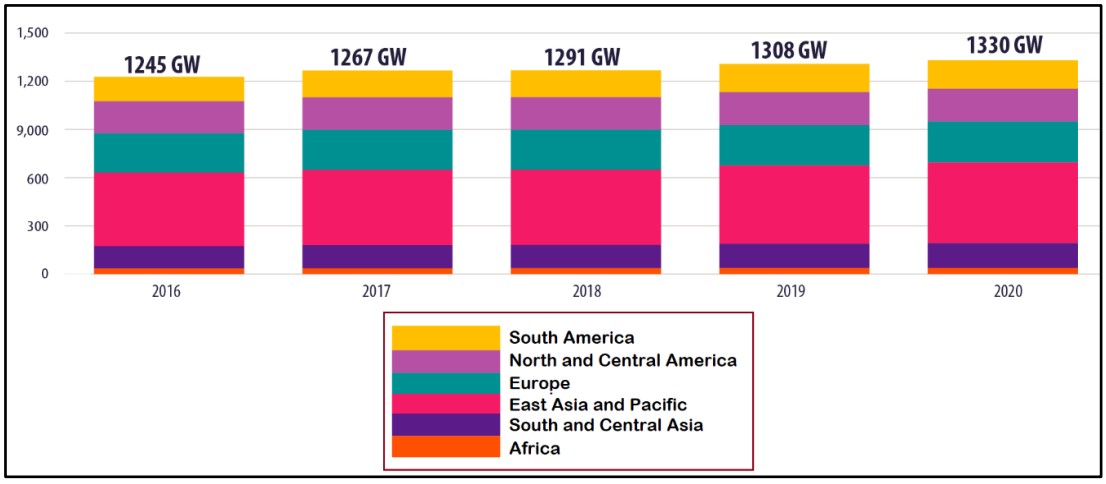

Figure 4. Global hydropower growth by region (2016-2020) [3]

In addition, with data from 2015, currently, around 160 GW of hydropower capacity are being built, and more than 1,000 MW are planned, with approximately 1,200 large dams under construction in 49 countries around the world, mainly in Asia. It 347 are important dams with a height of more than 60 meters. In Figure 5, the dam projects are under construction or globally planned [19], [20].

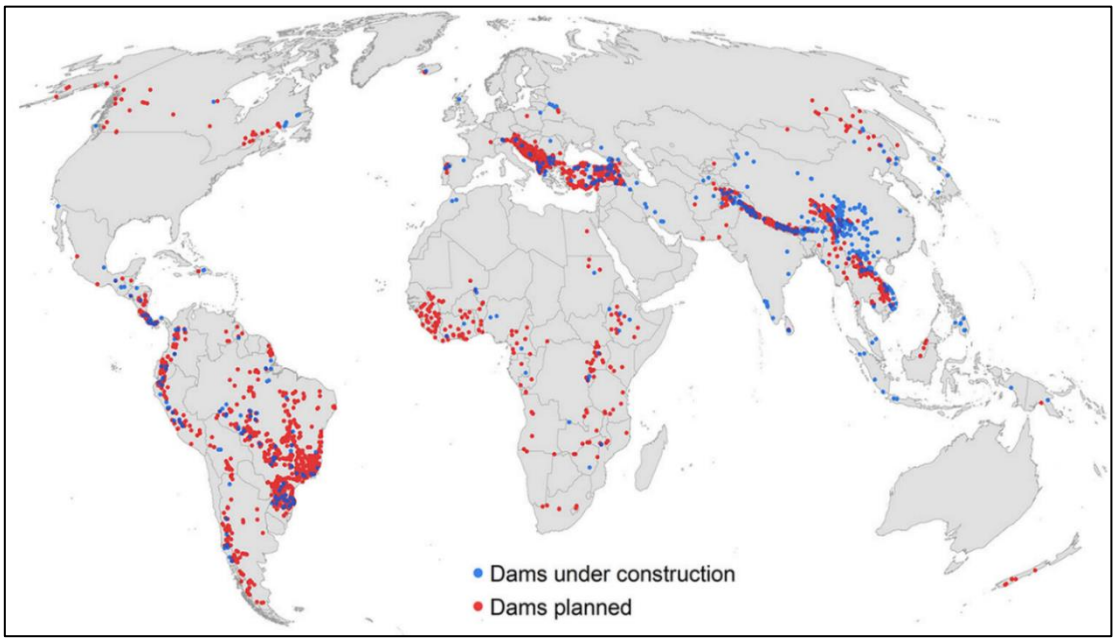

Figure 5. Hydropower dams are under construction and planned until 2030 [20].

Hydropower is widely deployed in developed countries, which take advantage of more than 50% of its viable technical potential, and emerging economies have invested between 20% and 30% of its potential. Africa is an extreme case, where only 7% of the hydroelectric potential is executed [21].

On the other hand, to define the relationship of hydropower and impacts from different areas of knowledge, perspectives are compared and emerge with the technical research support; for example, the World Bank developed the Hydropower Sustainability Assessment Protocol (HSAP).

The HSAP is a tool to guide and supports hydropower development seeking to mitigate effects in the partner countries of the World Bank [22]. The last update of the protocol is from 2018, where awareness is created through commitment at the sector level with a document that assesses sustainability using an approach and consideration of the Life Cycle Assessment (LCA) and from the perspective of the complete hydroelectric system. i.e., analyze reservoir, dam, power plant, transmission, project location, and surroundings [23].

3.2. Cost of hydropower projects in Ecuador

Between 2007 and 2017, the country invested close to USD 6 billion in eight hydropower projects to double its capacity (Manduriacu, Sopladora, Delsitanisagua, Mazar Dudas, Minas San Francisco, Quijos, Toachi Pilatón, and Coca Codo Sinclair), [24]. According to the International Hydropower Association, Ecuador ranked third after China and Brazil for countries that added new capacity in 2016 [25]. In addition, data from the Electricity Corporation of Ecuador mentions in 2020, Ecuador generated around 77% of all energy through hydroelectricity [26].

In Ecuador, these large hydropower infrastructures are due to tropical conditions with strong water currents. Then the Figure 6 of projects according to the main basins of the country to reference the hydropower potential and locations.

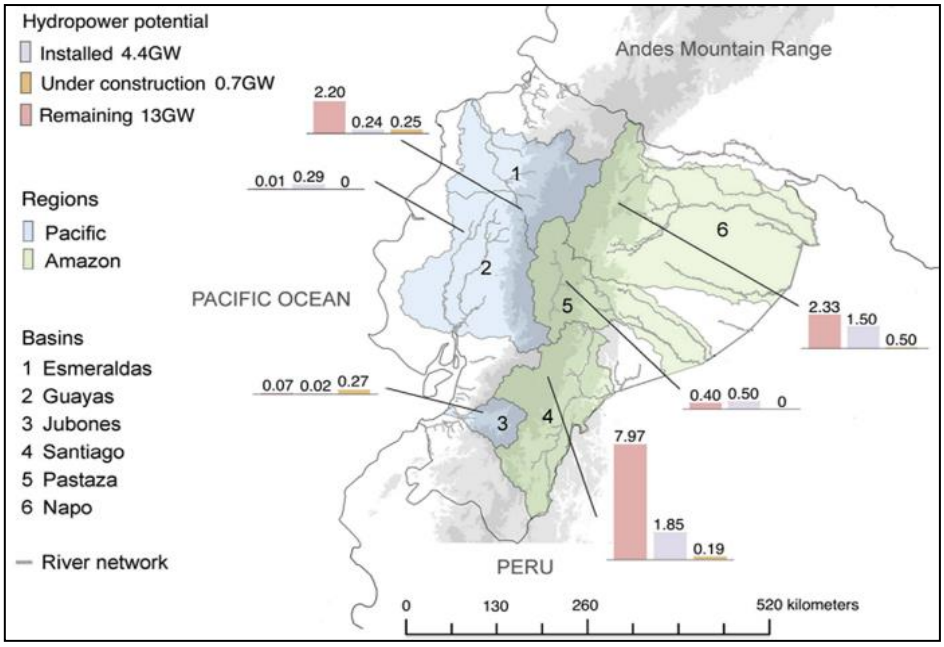

Figure 6. Ecuador's main basins and their hydroelectric potential in GW [27], [28].

According to the Electricity Corporation of Ecuador, the value of the last five hydropower projects in Ecuador inaugurated between 2015 and 2019 is determined in Table 1 when the energy grid increased the percentage of renewable energy [15], [27].

The average information of the last five (5) hydroelectric projects of the Electricity Corporation of Ecuador establishes that, for four generating units with an average power of 499 MW, the cost is extremely expensive of more than one billion dollars, which does not consider the high environmental, social and cultural impacts intangibly developed. Then, a cost-benefit relationship is generated.

Table 1. Cost and investment of hydropower projects in Ecuador [15], [27].

Item	Hydropower projects	Power [MW]	Power [kW]	Units number [U]	Investment [USD]	Cost per kilowatt [USD/kW]	Cost per generating unit [USD/U]
1	Coca Codo Sinclair	1,500	1,500,000	8	2,850,966,262	1,901	356,370,783
2	Sopladora	487	487,000	3	962,846,620	1,977	320,948,873
3	Minas San Francisco	270	270,000	3	662,480,054	2,454	220,826,685
4	Delsintagua	180	180,000	3	334,843,245	1,860	111,614,415
5	Manduriacu	60	60,000	2	227,389,966	3,790	113,694,983
	Average	**499**	**499,400**	**4**	**1,007,705,229**	**2,396**	**224,691,148**

$$\textbf{Relation} = \frac{\textbf{Average cost}}{\textbf{Energy benefit}} \qquad \textbf{1}$$

$$Average\ relation = \frac{1{,}007{,}705{,}229\ \text{USD}}{499.4\ \text{MW}}$$

$$Average\ relation = 2{,}017{,}831\,\frac{\text{USD}}{\text{MW}}$$

$$Average\ relation = 2{,}018\,\frac{\text{USD}}{\text{kW}}$$

In other words, each kilowatt of average hydropower installed in Ecuador costs around 2,000 US dollars, an extreme value, if the aggressive changes in the ecosystems mentioned above are taken into account.

According to International Renewable Energy Agency in the 2020 renewable energy cost analysis, the cost-benefit of hydroelectricity depends on several factors such as the size of each project, type of plant. Still, in 2020, the global average installation cost of hydropower projects increased to 1,870 USD/kW, 9% more than in 2019. In addition, the international average installation cost in 2020 was the highest value recorded since 2010 [29], as the Figure 7.

The increase in the cost of hydropower is explained by the higher proportion of installed capacity deployment in other countries or regions with higher average installation costs. In Turkey, for example, 2.5 GW was added in 2020, while there was also a higher share of deployment in Eurasia and Asia in 2020 compared to 2019 [29]. Followed in Figure 7, the median prices illustration from 2010 to 2020 for hydropower, presents at the global level.

In Figure 7, the total installation costs for most hydro projects commissioned between 2010 and 2020 range from a minimum of around 600 USD/kW to a maximum of about 4,500 USD/kW. However, we can find projects outside of this range. For example, adding hydroelectric capacity to an existing dam built for other purposes can cost significantly less at 450 USD/kW. In contrast, remote sites with poor infrastructure far from existing transmission networks can cost considerably more [17]. Furthermore, in Table 2, the specific detail by the capacity of each hydropower project is calculated by IRENA [29].

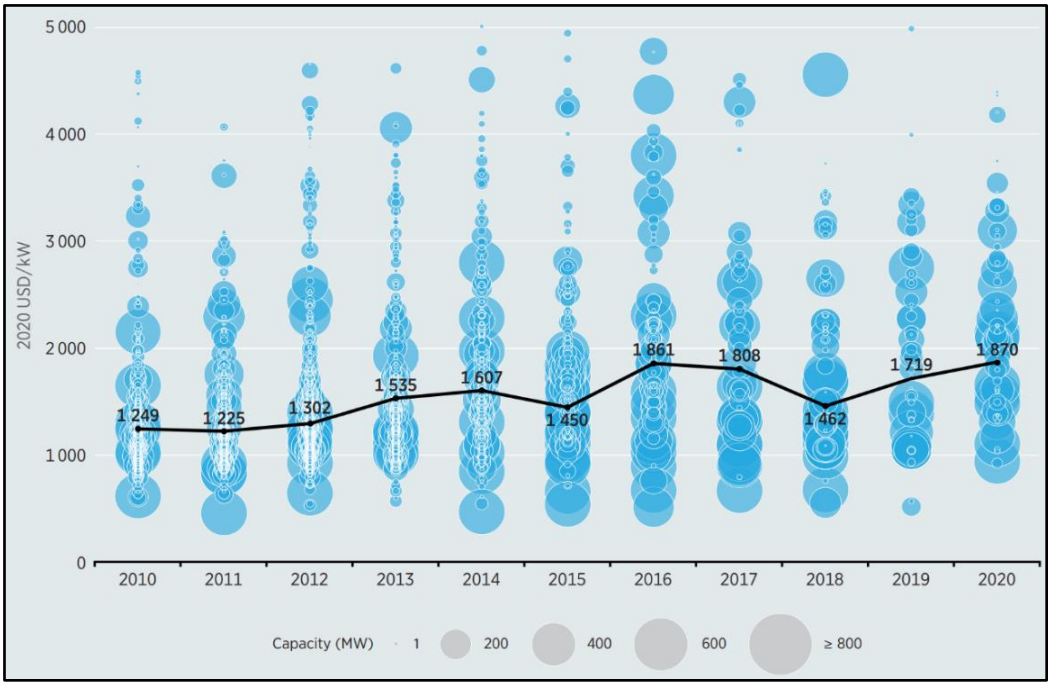

Figure 7. Hydropower installation costs per kW at the global level [29]

Table 2. Average investment and by percentile about hydropower capacity [29]

No.	Capacity [MW]	5th percentile [2020 USD / kW]	Weighted average [2020 USD / kW]
1	0-50	807	1,518
2	**51-100**	836	**1,728**
3	101-150	890	1,685
4	**151-200**	805	**1,656**
5	201-250	886	1,730
6	**251-300**	789	**2,022**
7	301-350	896	1,927
8	351-400	652	1,632
9	401-450	1,155	1,925
10	**451-500**	918	**1,472**
11	501-550	1,074	1,467
12	551-600	1,296	1,817
13	601-650	1,034	1,401
14	651-700	743	1,928
15	701-750	933	1,392
16	751-800	1,034	1,519
17	801-850	1,137	1,769
18	851-900	8,261	1,368
19	**901 onwards**	635	**1,063**

Such as set out in the Ecuador costs and global average, hydropower is a capital-intensive technology, often requiring long lead times, especially for large-capacity projects. The delivery time includes permitting, site development, construction, and commissioning. Hydropower projects are large and complex, with high civil engineering development and extensive site surveys, inflow data collection (if not available), environmental assessments, and permits all take time [29], [30].

4. DISCUSSION

According to the projected scenarios, hydropower will be susceptible, between 2010 and 2020, the global weighted average total cost of installing new projects increased from 1,249 USD/kW to 1,870 USD/kW, the year-over-year increase is driven by implementation in different regions and changes in specific [29]. Table 3 exposes the comparison by the capacity to supply of each project in Ecuador versus the global average from Table 2 data in bold.

Table 3. Hydropower costs comparison in Ecuador. [15], [27].

Item	Hydropower project	Capacity [MW]	Investment [USD]	Cost per kilowatt at Ecuador [USD/kW]	Cost per size according to IRENA [USD/kW]	Increase (Ecuador/Average) IRENA
1	Coca Codo Sinclair	1,500	2,850,966,262	1,901	1,063	79%
2	Sopladora	487	962,846,620	1,977	1,472	34%
3	Minas San Francisco	270	662,480,054	2,454	2,022	21%
4	Delsintagua	180	334,843,245	1,860	1,656	12%
5	Manduriacu	60	227,389,966	3,790	1,728	119%

As Table 3 compares in Ecuador, there are costs with a reasonably representative increase compared to the average that IRENA determines globally for 2020. Moreover, we take the middling of cost per kilowatt in Table 1; the calculations were made based on the developed project's size, averaging the cost and capacity of the five projects in the country, having the second comparison at Table 4.

Table 4. Average cost and power comparison of five hydroelectric plants in Ecuador. [15], [27].

Average capacity [MW]	Average investment [USD]	Cost per kilowatt at Ecuador [USD/kW]	Cost per size according to IRENA [USD/kW]	Increase (Ecuador/Average)
499	1,007,705,229	2,018	1,472	37%

Ecuador's cost variations versus the global average have considerable divergences. Moreover, in comparison, the hydropower with other renewable sources such as solar photovoltaic and wind cost, following data from the IRENA in Table 5 shows the relation of the investment on period 2010 – 2020 [29].

Table 5. The average cost of renewable sources. [29]

Source	2010 [USD/kW]	2020 [USD/kW]	Percent change
Hydropower	1,269	1,870	47%
Solar PV	4,731	883	-81%
Onshore wind	1,971	1,355	-31%

Table 5 reflects that the cost of hydroelectricity has risen substantially, and onshore wind and photovoltaic alone have significantly reduced. The role of hydropower will gradually change, from a firm generation that covers a demand to a flexible generation complementary to non-conventional renewable production such as wind, geothermal, tidal, and solar [31].

In addition, the real benefit caused by hydropower projects generates a comprehensive discussion for the uncertain future, such as besides authors.

- Michelle Van Vliet projects decreases in global average hydropower usable capacity from 0.4% to 6.1% in the Representative Concentration Scenarios (RCP), RCP 2.6 to RCP 8.5 for 2080 relative to 1971- 2000 due to water reductions in the United States, Europe, East Asia, South America, South Africa and Australia where substantial temperature increases are scheduled combined with drops in the average annual water flow [32].
- Matteo Mattmann generates a meta-analysis of hydropower externalities with the help of a database consisting of 81 observations derived from 29 studies that assess the impacts of hydropower. The study creates evidence of public aberration towards hydropower projects due to landscape changes, vegetation damage, and wildlife death. In addition, there is resistance to hydropower in areas where the external negative potential is significant; for example, in conservation areas, hydroelectric plants should be planned where they have the least possible impact on the environment and populations [33].

As studies show, hydropower and its complex impacts are commonly treated as independent, but consequences are not purely social, ecological, technical, or economic but related [34]. Policymakers, engineers, and builders must adopt methodologies or protocols to prioritize hydroelectric plants sustainably in different parts of the world, avoiding high construction costs [35].

The future of hydropower presents a challenging path for projects underway around the world through external variations [36]. Hence, hydropower will continue to be controversial renewable energy in the coming years, needing to evaluate risks, advantages, and viability, including the size and impacts of this source that actually in Ecuador has a significant cost of investment [37].

5. CONCLUSIONS

According to investment data from the last five hydropower projects in Ecuador inaugurated in the period 2015 - 2019, the calculated costs are higher than the global average for Coca Codo Sinclair there is a 79% increase, 34% for Sopladora, 21% for Minas San Francisco, 12% for Delsintagua and 119% for Manduriacu.

The global average cost for hydropower projects calculated by International Renewable Energy Agency in 2020 was 1870 USD/kW, in the average capacity case of 499 MW, Ecuador has a calculated cost of 2018 USD/kW, IRENA defined in 1472 USD/kW, it indicates a high value in 37% by comparison.

Investment decisions in new hydropower projects should be improved based on data from existing plants, seeking to mitigate the impacts on the environment and society, critical with knowledge of the effects and country goals.

The hydropower investment costs analyzed in Ecuador establish high amounts and criteria that do not determine the water overuse effects, basins deterioration, and natural conditions on the planet.

Before thinking about a mega hydropower construction with dams, it is necessary to analyze this future large-scale development with more accurate decisions about the actual efficiency of the projects and promote in the coming years the advancement of other unconventional energy sources such as wind, geothermal, and solar photovoltaic to mitigate social and environmental impacts.

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