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THE AMERICAN CONTINENT HYDROPOWER DEVELOPMENT AND THE SUSTAINABILITY: A REVIEW

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ABSTRACT

The present review compares and takes the main ideas around hydropower development in eight countries of the American continent, identifying its advantages and disadvantages, showing a vision concerning sustainability. It is conclusive that there are impacts for each megawatt produced with hydropower, and the generation structure that uses the water resource of natural currents is not highly clean. Moreover, there is the mistaken criterion for developing a renewable hydropower project related to sustainability, a wrong approach, as demonstrated with the review. The examination in the eight countries of America some analyzes and the most concludes that, before considering a construction with thousands of dollars of investment and water contained in dams, the social and environmental analysis must respond to the restrictions on building new hydropower projects, promoting other unconventional renewable energy sources development. It is recommended to determine an objective quantitative approach of hydropower combining hydrology, energy efficiency, and interaction scenarios of future climate change to know the best energy grids diversifying balanced renewable and no renewable sources for each country.

Keywords: Energy, Environment, Hydropower, Renewable, Sustainable, Water

1. INTRODUCTION

The International Energy Agency says that as of 2010, approximately 20% of the world's population does not have access to lighting, refrigeration, good education, or safe drinking water; nevertheless, electricity is essential for human life, welfare, and economic development International Energy Agency (2010). Light signifies socio-economic development, while darkness is a significant concern Berga (2016). As a result, in the last 100 years, the deployment of renewable energies has been accelerated to control fossil fuels burnings and give us electricity.

At present, the International Hydropower Association (IHA) reported in 2020; a database holds data for over 14000 hydropower stations, and, in 2018, there were 8998 individual stations above 1 MW capacity, representing 89% of total global ability International Hydropower Association (2020b). As shown in Figure 1, hydropower is the largest renewable energy source in the electricity sector. It comprises 62% of the renewable energy, more than combined renewable energy sources (38%) British Petroleum P.L.C. (2020), International Hydropower Association (2020a).

In 2016, hydropower energy reported economical benefiting in 159 countries globally; in 2020 is widely used technology around 180 countries Llamosas and Sovacool (2021). This renewable source is among the most efficient renewable energy technologies with a cost-competitive, and it is the only renewable source that produces electricity with a cost equal or less compared to the thermal energy sources like coal, oil, or gas in the USD 2 - 5 range per kilowatt-hour Killingtveit (2018).

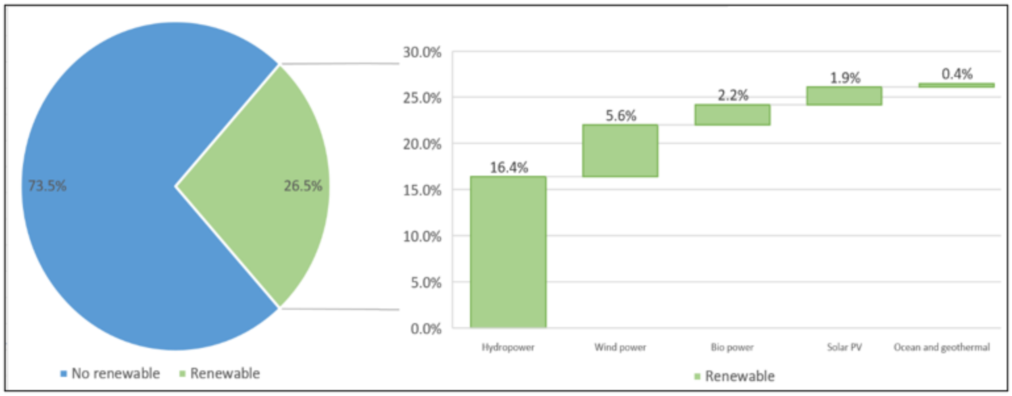

Figure 1 Type of energy source in the world in 2019

Source: British Petroleum P.L.C. (2020), International Hydropower Association (2020a)

Another way to look at hydropower potential across regions and the globe is from data from the International Journal of Hydropower and Dams (IJHD) that shows in Asia has 50% of all feasible potential, North and South America have about 30%, and Europe and Africa have about 20%. Taking into account that the average annual runoff across the globe amounts to 47000 km3, which includes 28000 km3 of surface runoff, this yields a theoretical potential for hydropower production Hamududu and Killingtveit (2012).

In spite of these limitations, there is still considerable technical potential for increased hydropower generation in the medium (2030) and long term (2050) calculated scenario to over 8000 TWh by 2050 Killingtveit (2018).

According to the IHA, thirty-five countries added hydropower capacity in 2020 worldwide; in American Continent, there were: Brazil, Chile, Argentina, the United States, Colombia, and Peru, as shown in Figure 2. In addition, in 2020, the continent generation of hydropower was 724 TWh in North and Central America and 690 TWh in South America International Hydropower Association (2021).

In this scenario, America is strong in hydropower development; for example, in South America, there are five of the most important rivers in the world (the Amazon, Orinoco, Río Negro, Paraná, and Río Madera); three of the largest lakes in the world; and Brazil has a fifth of the planet's water resources and is the second-largest hydropower producer in the world, behind China Alarcon (2019), Jakob et al. (2019).

Figure 2 Capacity added in 2020 in American Countries
Source: International Hydropower Association (2021)

However, despite its renewable character, hydropower has social and environmental impacts caused by its use and economic feasibility limitations; hence, it must sustainably have exceptional attention to development Naranjo-Silva et al. (2022). Even though this type of energy does not require fossil fuels, it can have adverse effects on the environment. "Clean" energies cannot be considered as clean if produced in mass quantities or if they produce drastic changes, which often have severe consequences on human life and ecosystems Chiang et al. (2013), Scherer and Pfister (2016). The hydropower systems are a renewable technology with a strong interaction with the environment taking the hydric resource changing the natural flow, opening a particularly the need for a comprehensive sustainable evaluation Naranjo-Silva and Álvarez (2021).

With this background, the conflictive context between water resource sustainability and progress is mentioned, illustrating the true advantage of generating hydropower projects. The political decision and lack of technical support in the socio-environmental study with resources awareness Rivera-González et al. (2020). It is not achievable to guarantee the development of hydropower projects if not linked to sustainability due to various disadvantages. As IJHD mentions, in America, there is a continent with 30% of hydropower potential doing that, we can do an especial analysis.

The present paper aims to review the scientific theories, research, and hydropower projects studies in America to present this document as a robust-theoretical framework that contrasts hydropower sustainability to know the advantages, affections, and disadvantages of this renewable source.

2. MATERIALS AND METHODS

For the review, the experimental methodology used studies, concepts, and theories to progress new ones based on the data processing of hydropower development in the American continent; Overall, representative sources of scientific information were verified, searching editorials for the best articles that serve as orientation. It was found around 156 documents are divided into two extensive databases (Scopus and Google academic) by the facility of downloading the information; in the case of Scopus information, we collect from Elsevier and Springer databases.

Then, based on cross-references and keywords as negative hydropower impacts, hydropower influences, and hydropower relation sustainability have reduced a total of 87 papers for the 2015 - 2020 period, as Figure 3 illustrates.

Subsequently, a part of these articles and research documents were eliminated because they only had qualitative topics without great contribution or robust scientific data, with finally 39 publications remaining with title reference and abstract related to the present review, the criteria of the documents excluded was not meeting the inclusion parameters determined according to the specific research words.

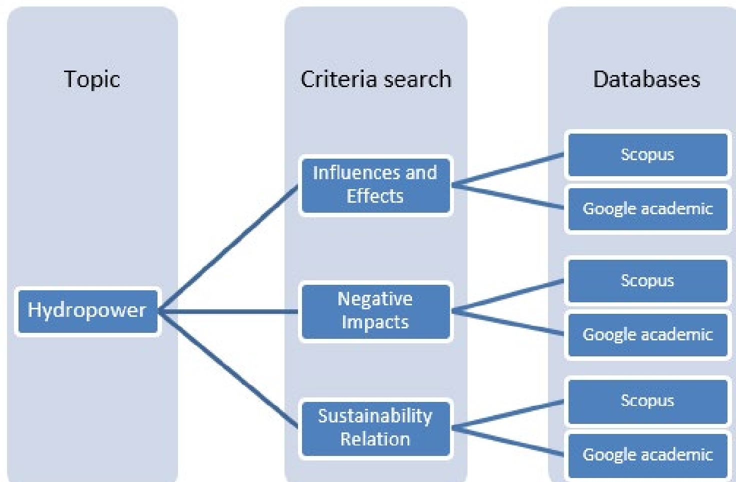

Figure 3 Methodology of research

With the documents collected based on keywords in research databases, the scientific scenarios executed by various researchers based on simulated data with information on temperature, flows, precipitation, among others, were studied. Finally, it is essential to mention an analysis of hydropower for the American continent. Still, there would be a lack of information from other continents with their respective countries; for example, many hydropower projects have various advantages and disadvantages in Asia or Europe.

Though just eight countries of the American continent were studied, due to the ease of this information, it is difficult to explore all the countries because not all of them have hydropower systems in their energy grid or development other sources.

3. RESULTS AND DISCUSSIONS

For learning and development, the America behaviour hydropower review, various documents generated among guides, and studies seek to focus hydropower on a sustainable path; next, the main ideas, observations, considerations, and research results conducted by country in Table 1.

Table 1 Hydropower analysis countries of American Continent

No.	Country	Conclusions, considerations, and observations
1	Brazil 	In the Brazilian Amazon, it is generated future energy modeling presenting an alternatives analysis in hydropower development. The foundation is the investment that the Brazilian government planned 26 large hydropower plants in the Amazon basin with an installed capacity of 44 GW, in a reservoir area of 9000 km^2 with a total investment of USD 50-70 billion De Queiroz et al. (2019). Brazil is a good case study given that its electricity sector depends mainly on hydropower as the main supply, an average, 75% of the country's electricity in the last ten years, entailing that currently by 2021, it will be the second country with the largest installed capacity of around 109 GW De Faria et al. (2017), International Hydropower Association (2020b). Therefore, alternative generation routes are evaluated to avoid hydropower reservoir's social effects and adverse environmental impacts. It concluded that investments for new hydropower projects are necessary. However, an essential precondition is an access to other renewable sources to diversify generation with alternative scenarios as wind, solar, and natural gas plants replace large hydropower that damages the surroundings De Faria et al. (2017). Despite the different analyses combined executed, the results projected show that the climate change impacts would lead to hydropower reduction and increased emissions pollutants in the mitigation policies and climate adaptation absence in Brazil Lucena et al. (2018).
2	Canada 	Canada is the fourths global country's with an installed of hydropower capacity of 82,053 MW in 2020 as 675 projects being a good study case, the country that generates in 2018 around 381,750 GWh of this renewable source IRENA (2020), give us an investigation of changes in hydroelectricity production potential due to historical trends in climate variables mentioned that the magnitude of this renewable source is determined by runoff, specifically defined determined by precipitation and temperature Jabbari and Nazemi (2019). Hydroelectricity production is essential to domestic and international needs and export, especially in places like Canada, where climate change has been significant. To estimate the expected monthly profit/loss of hydropower generation potential in the region, the study proposes using historical climate trends and causal relationships between climate variables and hydroelectricity generation. According to the findings, Canada's power generation potential varies considerably, although losses and profits are dependent on various areas. The results show a decline in hydroelectric power in the Western Territories, Canada's North and Nunavut, British Columbia, British Columbia, and Alberta Jabbari and Nazemi (2019). Moreover, another study in Canada indicates a critical result that the average annual hydropower will decrease by 1.8% between 2010-2039, and overall, the reliability of the reservoirs will decrease, and the vulnerability will increase as climate changes, as seen in recent years Minville et al. (2009).
3	Chile 	In the South American country, a 22-month ethnographic study verifies that there are impacts for each megawatt generated by certain small hydroelectric plants of 1 to 10 MW Kelly (2019). According to the Chilean Ministry of Energy, in 2020, the installed capacity of hydropower technology reached 6,823 MW, representing 25.9% of the local electrical system, in terms of generated energy, it is participation as 18.9% La Revista Energética de Chile (2020). In the foothills of the southern Chile chain mountains, new waterfall springs from mountainsides throughout the winter months are being produced because the significant rains accumulate; however, for comprehensively water management, tiny hydropower development should be a part of a coordinated river basin management approach Kelly-Richards et al. (2017).

		Notwithstanding, it is necessary to emphasize the ecological principle of these constructions considering ethnographic or collaborative perspectives with the affected people. It is recommended that dams be regulated more suitably findings suggest change, and the environmental laws do evaluations hydropower integrally Kelly (2019).
4	Colombia 	This South American country generates a multimodal analysis on climate change and hydropower; it detected that water availability is affected in some regions, therefore, varies hydropower production. The research uses four independently developed energy models, two partial equilibrium models (GCAM and TIAM-ECN) and two general equilibria (MEG4C and Phoenix), identifies the four apply projections deterioration hydro for the next three decades Arango-Aramburo et al. (2019). The models found that the losses caused by the climate in hydropower must compensate with other technologies expansion, showing the need to explore energy synergies Arango-Aramburo et al. (2019). In addition, another study found that during the 2015 to 2029 period, climate change will reduce hydropower generation capacity by 5.5–17.1% in Colombia Guerra et al. (2019). Finally, new non-hydropower power plants recommended sustaining a growing population. Colombian electrical technology change will depend on the economy, financial sectors, and regulatory constraints that are uncertain or complex for global energy models Calderón et al. (2014).
5	Ecuador 	In Ecuador, the long-term power system hydropower is evaluated, and the contribution towards fulfilling the Nationally Determined Contributions (NDC) Carvajal et al. (2019). Between 2007 and 2015, the country invested nearly 6 billion American dollars in eight hydropower projects, more than doubling its capacity MERNNR (2018). According to the International Hydropower Association, Ecuador is ranked third after China and Brazil for countries that added new capacity in 2016 International Hydropower Association (2020a). In addition, in 2020-year, Ecuador generated 77% of the energy grid through hydropower CELEC (2020). The study shows that hydropower increases stress on water resources using environmental conditions, relating impacts with water accumulation and hydrological changes caused by dams and flooding construction of upstream lands Carvajal et al. (2019). Concluding is evident that the hydropower deployment faces regulatory, financial, and social acceptance issues, underscoring the critical importance of undertaking an energy system analysis Escribano (2013). Ecuador shows uncertainty about hydropower; the results explain that the total electricity supplied by hydropower will vary significantly from 53% to 81% by 2050, which generates the NDC goal of Ecuador will achieve without the deployment of a sizeable hydropower infrastructure, but through a more diversified portfolio with not necessarily renewable energy Carvajal et al. (2019).
6	Mexico 	In addition, another study of evaluation of the hydropower dam "El Infiernillo" in the Balsas River course at Michoacan and Guerrero states. Using stochastic dynamic programming, the results mention that the hydropower produces significant changes in their action place. It requires after operation programs to mitigate mainly social and environmental influences Arganis et al. (2015).
7	United States 	Several studies are generated in the North American country for being the third country with the most significant global hydropower capacity with 103 GW by 2020 International Hydropower Association (2020a). A study established that the future impact of the climate on the availability of water indicates a seasonal variability between the climate models, air currents, and water inlets in a hydropower generation; the results mention that a changing climate represents a significant threat to future civilizations due to differences in precipitation and temperature patterns that alter hydrology, the natural water cycle, and hydropower Chilkoti et al. (2017). Therefore, according to the compensate models for deficiencies hydropower, it would need to activate more thermo-electric plants

		producing pollutant emissions Boehlert et al. (2016). In addition, it is verified, there are several implications for energy resource planning, for example, water infrastructure is managed by a municipal and regional large number of institutions; each one of them with their plans, thus, the jurisdiction of water and hydropower facilities rarely align themselves involving challenges for American decision-making Tarroja et al. (2019). Moreover, other American investigations mentioned using a water watch runoff and annual hydropower generation on federal projects. They concluded that the median change in annual age at national plants is projected to be -2 TWh, with an estimated ensemble uncertainty of ±9 TWh Kao et al. (2015).
8	Venezuela 	Venezuela in South America, near of Atlantic Sea, is a country that has an installed capacity of 154,393 MW in 2020 that produces 72,000 GWh in some particularities International Hydropower Association (2021). Specifically, this study focused on sustainability aspects (environmental, technical, socioeconomic, and institutional) for six micro-hydro projects in southern Venezuela's rural indigenous communities. For sustainability, the institutional dimension between participating institutions has been crucial. Institutional alignment is indeed key to strengthening the impacts on environmental size, minimizing emissions and effects on local ecosystems; the socialization was that using electricity can improve education, health, and productivity López-González et al. (2019). Another study of energies in the transition towards sustainability in Venezuela faces a contradictory energy performance. A country with an energy crisis today, unthinkable in a nation that was an indisputable world leader in energy two decades ago; the authors consider the impact of hydropower on society and the environment and say that it can help to reduce the use of fossil fuels Pietrosemoli and Rodríguez-Monroy (2019).

4. DISCUSSION OF RESULTS

As shown in the different studies in some American countries, hydropower directly impacts ecosystems and water resources. Still, sustainability is a concept used to find and solve troubles, for example, the management of natural resources as the water that is used in hydropower projects that change the natural water basins, making infrastructures, roads, and moving people.

However, there is the incorrect criterion that, because it is a hydropower project of renewable energy-related to sustainability, it is a wrong approach, as shown by the review findings nonetheless, there are voluntary instruments to adopt criteria and recommendations in a social, economic, and cultural that support the construction of the hydropower projects Ardizzon et al. (2014), Li et al. (2015).

Moreover, there are support tools to make sustainable choices at hydropower projects; one tool to guide the construction from different areas of knowledge and perspectives emerges is The Hydropower Sustainability Assessment Protocol (HSAP); in 2014, the World Bank approved the Protocol as a tool to guide hydropower development in the Bank's partner countries International Hydropower Association (2018a). At present, the protocol adoption is relatively slow in countries where a large part of the hydropower energy is already working because it is a document that assesses sustainability by using a bottom-line approach, with the consideration of the life cycle assessment and from the reservoir, dam, power plant, transmission, project location, impacts, and surroundings perspective International Hydropower Association (2018b).

Hence, the International Hydropower Association generates the HSAP protocol that evaluates sustainability criteria to measure and streamline hydropower approaches in a multiple-level convergence search. The Protocol measures parameters to analyse based on four perspectives (4): environmental, social, technical, and economical. It provides a scoring system in the range of a broad topic, but there is no recognition, nor additional profit for operators, plus builders must pay the Bank's advisers, specifically for research; the Protocol serves as a reference with sustainability criteria that evaluate projects International Hydropower Association (2018a).

Despite this Protocol, it shows parameters around the sustainable hydropower development; currently, there are protocols, guides, manuals, among other documents, such as the HSAP or Blue Planet Award, that generates recommendations for the sustainable power plants construction by supporting the building phases with education criteria, communication to residents, worker's health, among other items.

On the other hand, interdisciplinary studies question the perceived advantages of hydropower production in very remote urban areas Sovacool and Walter (2019). The hydropower production reduction comes from different parameters and variables locally and regionally and is found around some components. Next, some studies of other continents that mention the hydropower and the sustainability relation source to compare.

- Lernerd in a global study of impact and change on the hydropower potential since water models mentions that the hydropower potential for the whole of Europe is estimated to decrease by 6% by 2070, and in the same way a reduction from 20% to 50% is expected throughout the Mediterranean Lehner et al. (2005).
- Rasul creating an integrated solution for water, energy, and food security in Asia. He observes that in places such as Afghanistan, Bangladesh, Bhutan, India, Nepal, and Pakistan, stress exists in watersheds and food is in short supply. These problems are expected to intensify with the rapidly growing population and economic deficit; besides, South Asia demands water, energy, and food have a shortage and globally decreases resources, presenting a threat to the hydric sustainability. The analysis demonstrates that the potential of water resources is underdeveloped Rasul et al. (2019).
- Antwi and Sedegah study Africa about climate change creating social change, impacting hydropower generation; the study shows a reduction of up to 3% of the hydropower for the 2050 year. In the course of time, many threats can be generated on the continent such as frequent droughts, poverty, disease, famine, social conflicts, and others that can make adaptation more difficult Antwi and Sedegah (2018).
- Van Vliet has studied the impact of drought and heat years on the world's water and electricity supply; Higher water reductions are projected in the United States, Europe, East Asia, South America, South Africa, and Australia, where a large, combined temperature increase is expected to reduce average annual hydroelectricity production Van Vliet et al. (2016).

From the investigations, the relation of hydropower and sustainability presents difficult future scenarios; comparing the studies with the eight countries of America, there are a lot of hydropower projects that have negative impacts, and sustainable development does not have a necessary relation with this renewable source that changes the natural flow of rivers, reduces the fish, damages the environment, and moves people from hometowns Cavazzini et al. (2016), Wang et al. (2019).

Nonetheless, this approach is executed due to the interest in hydropower, in response to the increasing need to develop an economy with low carbon emissions, but which ensures the water resources management, and the growing interest is accompanied by strategies for evaluating hydropower projects new and existing at the local, regional, and global levels Carvajal et al. (2017), Tobin et al. (2018).

Finally, new discussions and analyses can be done based on negative hydropower impacts that need scientific information on the development of climatic scenarios for the specific location of new projects, the awareness framework, and the incentives that can be attractive to the builders and investors by applying sustainable parameters.

5. CONCLUSIONS AND RECOMMENDATIONS

According to the different models, simulations, and hypotheses on the eight American countries analysed, the general hydropower potential decreases throughout the future projections because this renewable energy has a deep interaction with the environment.

Investing in new hydropower projects is necessary, but hydropower generation presents a highly uncertain and sensitive factor to climate change, in America, the electricity should focus on adequate diversification generation technologies with a support planning policy to increase non-conventional renewable energies.

Projecting hydropower development and considering problems and disadvantages, comprehensive planning of future energy systems should be thought holistically. Policymakers, engineers, and builders must adopt methodologies for sustainably prioritizing hydropower project's locations in different parts of the world.

The hydropower role needs gradually change, from a stable generation that covers a demand to a flexible generation complementary to another renewable, and the hydropower energy systems should not be promoted as a very sustainable source because varies the availability of water resources and require careful attention by the environmental and social influences.

It is recommended that previously invest in a new hydropower project, it determines a quantitative approach of hydropower combining hydrology, energy-efficiency and interacts scenarios of future climate change to know the best energy grids diversifying sources for each country.

AUTHOR CONTRIBUTION STATEMENT

Sebastian Naranjo-Silva conceived the idea, collected the data, performed the analysis, and wrote the first draft of the manuscript. Both authors critically revised the work and read and approved the final manuscript.

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