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Articles

Review of the state of the art between sustainability and hydropower generation: A vision from Asia

Revisión del estado del conocimiento entre sustentabilidad y generación hidroeléctrica: una visión desde Asia

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Abstract

Hydroelectric energy is a widely used technology in 180 countries benefiting in 2020, this source has 140 years of development, represents 16 % of the energy generated in the world and 63 % of renewables. The objective of this manuscript is to develop a state of knowledge that analyzes scientific theories, hypotheses and projects to propose this review as a robust theoretical framework to understand the effects and advantages of hydroelectric energy in Asia. For the review, the methodology collected scientific information from publishers such as Elsevier, Taylor & Francis and Springer. The Asian continent was selected due to the representative number of hydroelectric projects, and to represent more than 30 % of the world's hydroelectric generation, having the largest installed capacity. According to studies in 13 Asian countries —over future projections—, hydropower potential decreases over time in part due to the deep interaction between water and its location, variations in climate change and opposition from people near the sources and projects in often remote areas. The prominence of hydroelectricity will gradually change from a stable generation as a complementary source of other renewable energies. On the other hand, hydroelectricity, as the largest renewable source today, is competitive in generation price and responds to the growing demand of the population, therefore, to build sustainable energy systems, policymakers, engineers and builders must adopt procedures that organize projects based on sustainability criteria.

Keywords: Energy, hydropower, renewable, sustainable, water.

Resumen

En 2020, la energía hidroeléctrica es una tecnología ampliamente utilizada en 180 países. Esta fuente tiene 140 años de desarrollo; representa el 16 % de la energía generada en el mundo y 63 % de las renovables. El presente manuscrito tiene como objetivo desarrollar un estado del conocimiento que analice teorías científicas, hipótesis y proyectos para proponer esta revisión como un marco teórico robusto para conocer los efectos y las ventajas de la energía hidroeléctrica en Asia. Para la revisión, la metodología recolectó información científica de editoriales como Elsevier, Taylor & Francis y Springer. Se seleccionó al continente asiático por el número distintivo de proyectos hidroeléctricos y por representar más del 30 % de la generación hidroeléctrica mundial, al tener la mayor capacidad instalada. Según los estudios en 13 países asiáticos —a lo largo de las proyecciones futuras—, el potencial hidroeléctrico disminuye con el tiempo en parte debido a la profunda interacción entre el agua y su ubicación; las variaciones del cambio climático, y la oposición de las personas cercanas a los proyectos en áreas a menudo remotas. El protagonismo de la hidroelectricidad irá cambiando de modo paulatino de una generación estable a fuente complementaria de otras energías renovables. Por otro lado, la hidroelectricidad, como la mayor fuente renovable en la actualidad, es competitiva en el precio de generación y responde a la creciente demanda de la población, por lo tanto, para construir sistemas de energía sostenibles, los formuladores de políticas, ingenieros y constructores deben adoptar procedimientos que organicen proyectos basados en criterios de sostenibilidad.

Palabras clave: agua, energía, hidroelectricidad, renovable, sostenible.

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Introduction

The hydropower sector represents the largest source of renewable energy in the world, as well as one of the most widely used. It is estimated that more than 180 countries benefited from hydropower generation by the year 2020 (IEA, 2022). The International Commission on Large Dams mentions that by 2020, more than 9 000 hydropower dams will be registered globally, which supplies almost 70 % of all this renewable energy (ICOLD, 2021; Llamosas & Sovacool, 2021).

However, despite this, the technical potential for generating more hydropower on a larger scale is substantial enough in order to substantiate further deployment of this type of technology in the future. The amount of energy consumed by 2050 is estimated to be over 8 000 TWh (Pietrosemoli & Rodríguez-Monroy, 2019).

According to the International Hydropower Association (IHA) the energy production in 2020 was 4 370 TWh, putting a record high contribution from this renewable energy in the world history (IHA, 2021). From the large construction wave of the 1960s to the 1980s, hydropower capacity has increased linearly in many advanced economies. Over 40 % means 476 GW of the global projects is more than 40 decades old (Scherer & Pfister, 2016).

In addition, the International Renewable Energy Agency (IRENA) provides the ten countries with the biggest hydropower installed capacity in Megawatts (MW) in 2020, as Figure 1 (IRENA, 2020).

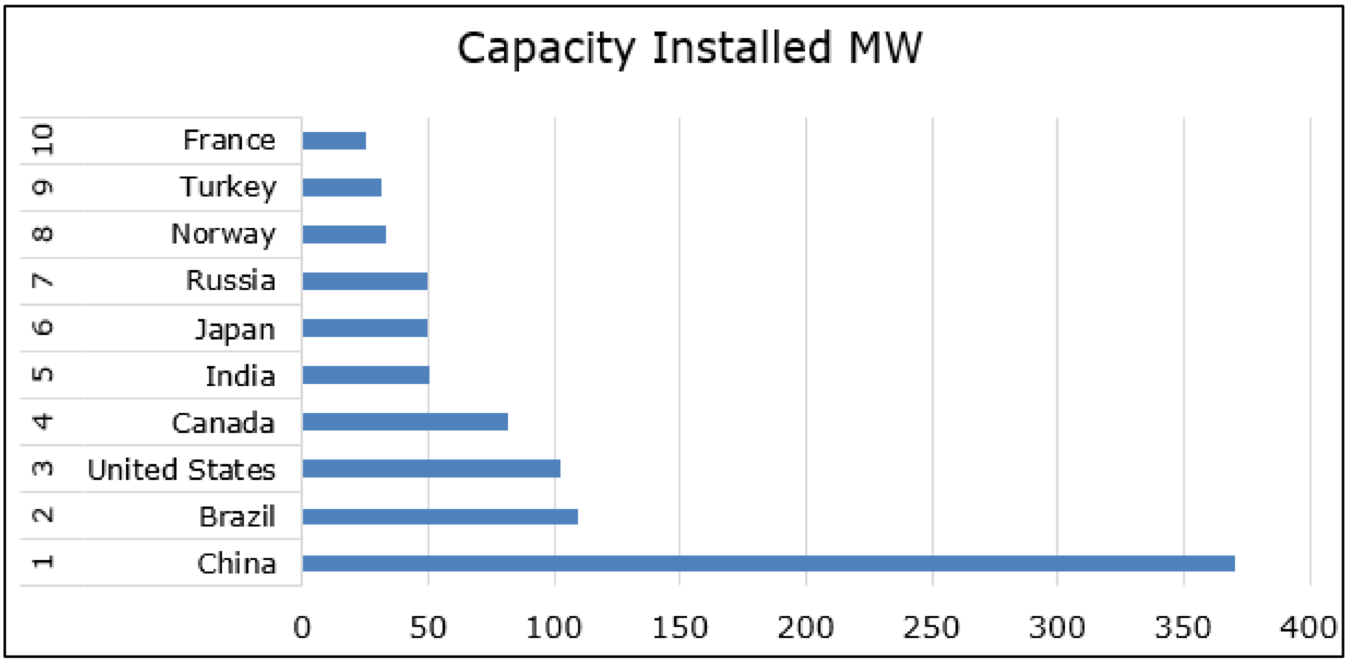

Figure 1. Ten countries with the most extensive hydropower capacity in 2020. Source: IRENA (2020).

Moreover, the hydropower status report of IHA in 2020 shows that the total global hydropower installed capacity reached 1 330 Gigawatts (GW), representing a rise of 1.2 percent, down on the five-year annual average of 2.1 percent, showing an annual slow in recent years (IHA, 2020). As a perception, comparing the grow of the hydropower in 1980 were 450 GW and 2020 were 1330 Gigawatts of global hydropower capacity, resulting in 40 years an expansion of 296 % in this source (IHA, 2022).

Data of IRENA to demonstrate this source scope, showing 2020 hydropower deployment in capacity in GW and determines that the globally accumulated by continent have the distribution: Asia (656 GW), Europe (254 GW), America (382 GW), and Africa (38 GW). Its distribution is represented in percentage in Figure 2. In addition, the data reported indicates that 35 countries in the same year, added hydropower capacity, and the fifth-highest individual increases in installed capacity were: China (13 760 MW), Turkey (2 480 MW), India (478 MW), Angola (401 MW), and Russia (380 MW) (Ritchie & Roser, 2022).

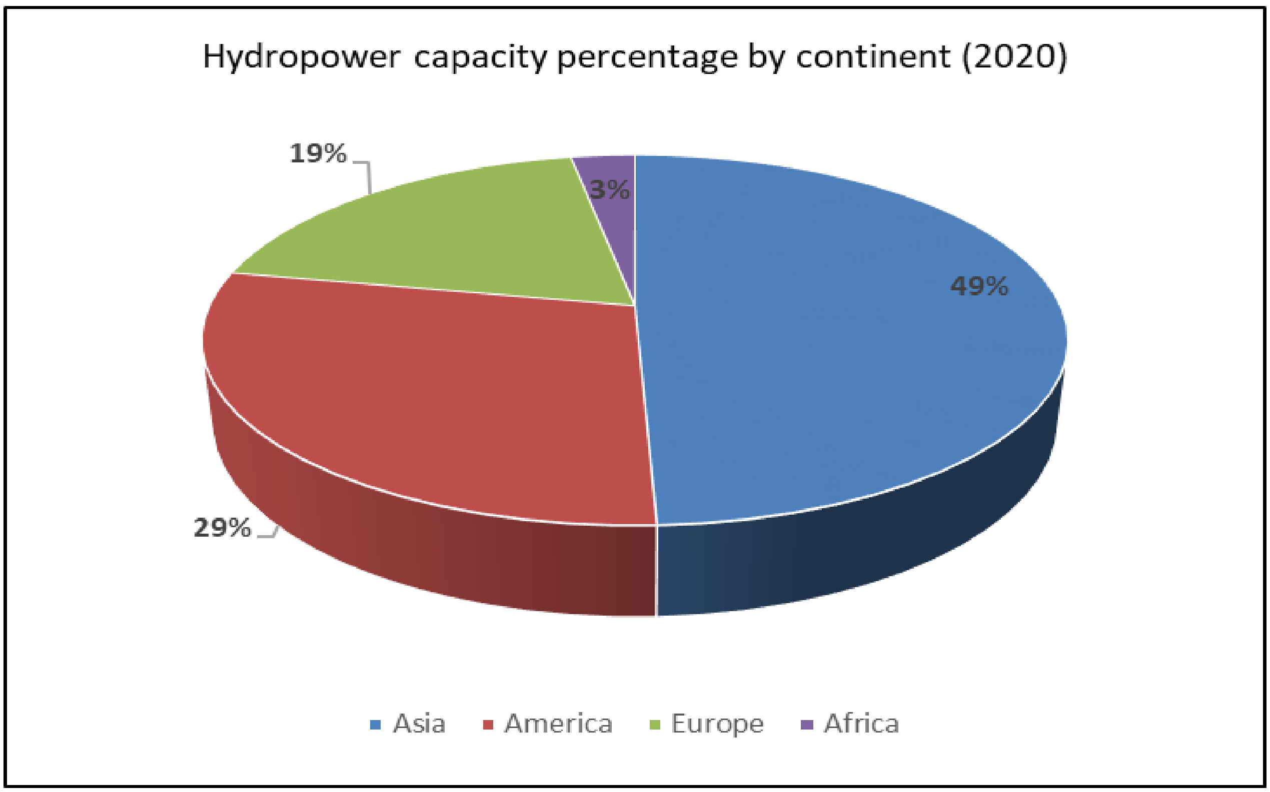

Figure 2. Continent distribution of installed hydropower capacity in 2020. Source: IRENA (2020).

Furthermore, among the advantages mentioned the hydropower being one of the most cost-effective, reliable, and efficient renewable. There are no other renewable energy sources that can produce electricity at a cost that is as low or lower than thermal energy sources such as coal, oil, and gas in the range of USD 2-5 for a kilowatt-hour (Killingtveit, 2019).

Nevertheless, hydropower production is a technology that depends on the availability of natural resources to play a critical role. Regardless of the development approach, the current rapid changes respond to the growing population demand for resources, energy, and food (Naranjo-Silva & Álvarez-del-Castillo, 2021a).

However, despite its renewable character, hydropower has social and environmental impacts caused by its use, and economic feasibility limitations; as a result, hydropower development must be treated with exceptional care to ensure its sustainability (Wang *et al*., 2019).

While, this highlights the real advantage of built hydropower plants by the conflict between sustainability, and growth. The socio-environmental study with resource awareness is dominated by political decisions and a lack of technical support. It is important to note that for the comparisons of each section, the scale of the hydroelectric plants is defined by size, according to the Latin American Energy Organization there is a classification by capacity of each hydroelectric project up to 1 MW, they are mini plants, up to 10 MW are small plants, up to 300 MW are characterized as medium, and 301 MW and above are large hydroelectric plants. Additionally, each country, according to its energy control structure, can define the scale of the projects that often address greater or lesser legal and environmental limitations, as well as the purpose (Daniel & Gaviria, 2018).

Also, due to various disadvantages, it is impossible to guarantee the hydro energy projects' development if not linked to sustainability. There is a turning point about which little is said between hydroelectric development as a renewable source, and the sustainability of water resources, it is worth mentioning that under own criteria, hydroelectric sustainability in any scale is defined as the adequate management and mitigation of environmental and social risks for improve the quality of life of communities and, simultaneously, protect the natural resources on which they depend. With this concept, this article will guide some studies and concepts that are important for everyone as energy consumers.

Meanwhile, the manuscript is proposed as a consolidated document for consultation of research carried out, unifying criteria where there are similarities and discussing gaps, from what has been investigated so far, the hydropower advantages, and migrating to renewable systems are detailed. In addition, projections of renewables to climate change were found, however, little is said about the effects of hydroelectricity and the sustainability criteria that this source should manage in its development. Therefore, these issues are detected as gaps to be discussed, and the present manuscript is a novel reflection of the hydropower systems in the Asian continent, because there is a significant opportunity to make recommendations to has a sustainable expansion of this source.

On the other hand, as the data shows in Figure 1 and Figure 2, hydropower is more representative in the countries of Asia, the continent occupying the first position in installed capacity in 2020 as the biggest country that deployment this source (China); therefore the following manuscript has the general aim to develop a state of art on recent research (2013 to 2022) that relate the sustainability with the hydropower development to propose this review as a robust-theoretical framework to know the effects, and advantages of the hydropower in Asia. In addition, as specific aims, it seeks to know the energy projections of this renewable source related to the climate change effects; and the social, and environmental aspects in the continent, using hydropower impacts of the existing projects as a basis.

Methodology

For the review using data processing, it used the non-experimental methodology developed new theories based on studies, and concepts; this methodology was used because take variables, events, and contexts that occur without the direct intervention. It is study is based on an organized review of hydropower technology; this systematic review is an iterative process where existing scientific studies are the data source to identify trends and projections in the current research in a specific place (Asia) (Cárdenas, Filonzi, & Delgadillo, 2021; Levenda, Behrsin, & Disano, 2021).

Orientation articles were selected from editorials from scientific information sources such as Elsevier, Taylor & Francis, and Springer. It was selected in these databases because, according to the initial search, these three editorials are the most technical studies related to the framework of renewable energies.

First-hand searching of the universe study for hydroelectric development in Asia found around 286 documents, the first search criteria did only peer-reviewed academic journals published in English were considered eligible. To select papers for supplementary investigation, it presented three additional filters structured a criteria search as it represented in Figure 3, it defined with key paragraphs, such as: "Negative hydropower impacts", "hydropower influences in Asia", and "hydropower development in Asia" and the documents were reduced to 139 papers giving a period for the 2013-2022.

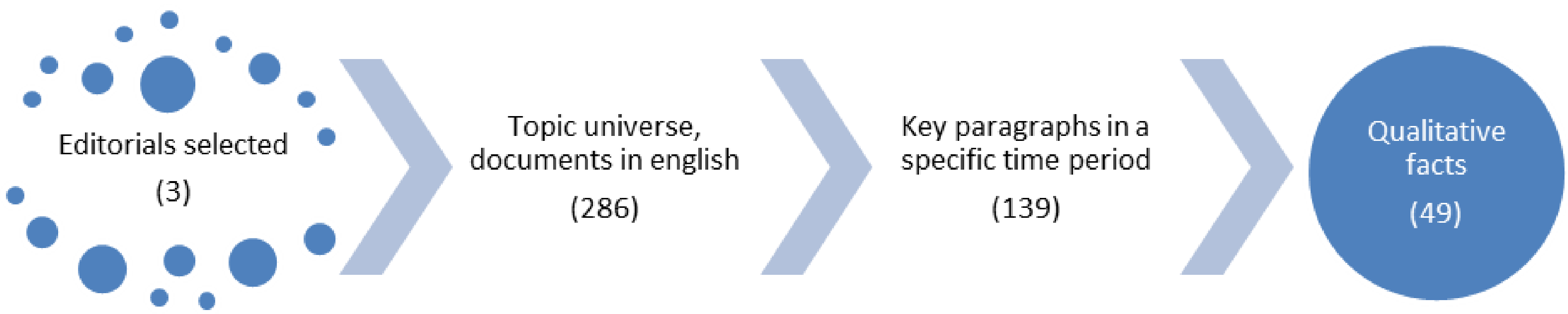

Figure 3. No experimental methodology.

In the end, a large number of documents were removed by the lacking in outstanding contributions, and robust scientific data showing just qualitative information, the final criteria were articles with quantitative facts with future simulations or projections giving indicators. As a result, 49 publications with title references and abstracts related to the current review remained for the Asian countries as show in Figure 3.

The 49 documents were reviewed in detail, consolidating concepts to form Table 1 with information from 13 specific countries, in addition, debate concepts were taken that served to develop the discussion area of this manuscript. In other words, with the relevant documents obtained,

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the research methodologies and results found in the various countries of the Asian continent were reviewed.

Table 1. The hydropower development in Asian continent.

Country	Principal considerations
Bhutan, and Nepal	Bhutan and Nepal are two countries with significant hydropower potential due to their hydrographic basins, even though they do not have access to the sea. Nepal has an energy deficit, whereas Bhutan has a surplus energy capacity to export (Ogino, Dash, & Nakayama, 2019). The hydropower potential for Bhutan is 26 760 MW, while the amount of hydropower for Nepal is 43 000 MW. Bhutan and Nepal have hydropower reserves of 50 000 MW and 84 000 MW, respectively. However, by 2019, Bhutan's installed capacity in a hydroelectric generation was 1 614 MW, while that of Nepal was 856 MW, that is, 6 and 2 % have been developed, respectively (Ritchie & Roser, 2022). Comparing Nepal's projects to Bhutan's, the results showed higher costs for civil works, financial charges, institutional management, and social and environmental safeguards in Nepal's projects. Consequently, the cost per kW of the project increases. Meanwhile, Bhutan's projects resulted in lower energy production than Nepal's (Ogino *et al*., 2019). In these two neighboring Asian countries, energy change and development are analyzed, it is shown that hydropower facilities are designed to retain large volumes of water in reservoirs, increasing environmental costs, and social risks. It is recommended to reduce the construction of large-scale infrastructure for efficient medium- or small-scale compact facilities with lower environmental and social risks and impacts, where financing resources are captured, including the issuance of climate funds related to carbon reduction by avoiding the use of fossil sources (Ogino *et al*., 2019).

Country	Principal considerations
China	In China, some simulated projections show that climate change modifies the entry water conditions dramatically with harmful consequences for hydropower, especially in southwest China, where hydropower projects dominate the energy systems (Jin, Andersson, & Zhang, 2016; Li, Zhang, & Xu, 2015; Zhang, Lei, Chen, & Song, 2019). Although solar and wind power are increasing in China and other countries, studies have suggested that studying climate change's impacts on renewable energy in coordination with hydropower could help complement regional energy grids. Integrating different renewable energy sources, such as solar, hydroelectric and wind, into a joint power generation system can be an effective strategy to make the most of available resources and ensure a more stable and reliable energy supply, e.g., solar energy is most intense during the day and usually peaks around noon, wind energy can be strongest at night or on cloudy days, and hydroelectric energy is constant when there is precipitation (Liu *et al*., 2020). On the other hand, while the largest hydropower project in the world is in a struggle to manage its water resources, the "Three Gorges" plant must take measures to use water in the face of inter-annual fluctuations to be located in the middle of the third largest river in the world (Qin *et al*., 2020). An ensemble of five General Circulation Models is used in this study to simulate the daily regulation and hydropower performance of the Three Gorges Reservoir (TGR). TGR will generate more hydropower and mean annual inflow as precipitation increases in the basin. Statistically significant increases are only observed for 2080-2099, and spring is the season of greatest concentration. As a result, the complexity of the management and production of hydroelectric energy in future climate change scenarios is shown, which promotes the need for detailed regulatory models of China's energy consumption. The country with the greatest installed capacity must know that the seasons are changing, and hydroelectric production is sensible (Qin *et al*., 2020). Moreover, in another Chinese region, on Tibetan Plateau, the hydric source of Lancang River base, upper Mekong is evaluated because its river provides fresh water for a large population, millions of people. The investigation and simulation indicate increases in the water inflow; it is recommended that this variability be considered for future hydropower planning sustainability (Li *et al*., 2015; Zhong, Zhao, He, & Chen, 2019). Thus, the results indicate that hydropower energy in China is sensitive to climate fluctuations, especially when it comes to temperature and rainfall. As a result, extreme weather events caused by global warmings, such as rain, heatwaves, floods, and drought, pose a significant threat to hydropower development in Asia (Fan *et al*., 2020)

Country	Principal considerations
India	As a growing country, India studies hydropower production and meteorological relation. During the observation period between 1951 and 2007, seven large hydropower projects experienced significant global warming values, precipitation decreases, and streamflow decreases since RCP 8.5 since the study was conducted (Ali, Aadhar, Shah, & Mishra, 2018). Under a global warming scenario, the projected increase in precipitation will be reflected in the simulated streamflow in hydropower reservoirs. A future climate increase change streamflow by up to 45 % and hydropower production by 25 %. Streamflow for hydropower projects such as those at Nathpa Jhakri and Bhakra Nangal will be affected by an increase in warming of 6.25 ± 1.62 °C, which modify hydropower production in May and June (Ali *et al*., 2018). In summary, precipitation and air temperature significantly fluctuate hydropower generation in the hydrological basins. According to the analysis, future climates will be wetter and warmer (Choudhury & Dey-Choudhury, 2020; Negi & Punetha, 2017). In addition, the average annual precipitation temperature is estimated to increase between 18 ± 14.6 % in India (Ali *et al*., 2018)
Iran	Two hydropower plants in this Asian country are studying the impact of climate change based on their discharges (Bakhtiari and Dez), using six global climate models and three scenarios from the Special Report on Emission Scenarios. The precipitation projections are anomalous, demonstrating an increase and decrease in rainfall (Mousavi, Ahmadizadeh, & Marofi, 2018). In response to climate change, the investigation shows that the hydropower production percentages range from -1.7 % (B1-2050) to -26.8 % (A1B-2080) for the Bakhtiari reservoir inflow. Further, for the Dez reservoir's inflow decreased by 21.8 % (A1B-2080) and increased by 3.6 % (B1-2080), respectively. In the study, climate change was evaluated with regard to multiple variables, including the impact on hydrology and hydropower; projections of all scenarios show a substantial increase in temperatures of up to 4.9 °C as well as changes in precipitation of up to 18 % during the middle and end of the century (Mousavi *et al*., 2018). The hydrological model confirms a hydropower projected annual in average reduction of 33 % under climate change conditions, and the results demonstrate the renewable source vulnerability around the uncertain climatic (Mousavi *et al*., 2018)

Country	Principal considerations
Laos	Using a survey at 40 households obtain 160 households downstream and upstream of four hydropower projects in Laos were collected. In the survey, two thirds of the respondents were farmers, 75 % were males, the average age of the participants was 48 years old (ranged from 24 to 84 years old), and the average academic level was six years (Sivongxay, Greiner, & Garnett, 2017; Souksavath & Nakayama, 2013). It was found that the impact of the hydropower power plants in the communities exhibited positive and negative results. For example, hydropower can be a significant employer in the construction and operation phase with financial benefits that community members relate to direct employment (Sivongxay *et al*., 2017). In the eyes of the communities, hydropower degrades natural capital by changing rivers, reducing fishing productivity, and creating more negative than positive influences. In order to shed lighter on the importance of economic development and the people's livelihoods, it is recommended that similar studies be carried out, analyzing how hydropower affects the people living in the local area (Sivongxay *et al*., 2017; Souksavath & Maekawa, 2013)
Malaysia, Indonesia, Thailand, and Myanmar	The economy of four Southeast Asian countries is examined, concluding that both energy and water resources are vital to economic development, and the two needs have increased. As a result of the deprived energy policies, and poor supply of hydropower stations in the cited countries, the hydropower future is fraught with obstacles as climate variations by the climate change, efficient designs by the future projects, and financial policies (Tang *et al*., 2019). Malaysia is a prosperous state in hydropower resources due to its unique geographic location, the country has 189 rivers with a dimension of 57 300 km, which means that it can generate 414 000 GWh/year. Of this, 329 000 GWh/year comes from its eastern region (Ahmad & Tahar, 2014; Chow, Bakhrojin, Haris, & Dinesh, 2018). In terms of hydroelectric capacity, Indonesia theoretically ranks fourth in Asia with an estimated 75 000 MW, of which 500 MW is small-scale hydropower. In addition, Indonesia's hydropower potential is distributed over more than 1 300 potential locations due to the country's unique geography (Purwanto & Afifah, 2016). Thailand has a surface extent of 310 000 km^2 also an annual rainfall of 1 560 mm, and its developed hydropower resources amount to about 18 000 million kilowatt-hours. Though theoretically, there are 190 billion kWh of hydropower available, only 100 billion kWh can be utilized (Aroonrat & Wongwises, 2015).

Country	Principal considerations
	Myanmar is a tropical country with a technical hydropower potential of 39 720 MW, and the large-scale potential occupies more than 25 000 MW. But like other countries, Myanmar only uses a small part of the considerable hydropower, less than 1 %, around 350 MW (Kattelus, Rahaman, & Varis, 2015). This study indicates that hydropower in the four South Asian countries has a wide application due to geographical conditions, and it is rousing to notice that Southeast Asia is becoming a new economic growth point in the world. In Malaysia, Indonesia, Thailand and Myanmar, energy supply lags behind the demand for economic growth. Hydropower generation is essential when considering global resources since it is a renewable resource. However, the lack of energy policies, disputes within national governments, and insufficient international cooperation for developing sustainable hydropower projects in these countries (Tang *et al*., 2019)
Nepal, and Pakistan	Around South Asia, in Nepal and Pakistan, hydropower is covered by their energy potential of 2 and 12 %, respectively; therefore, a recommendation to generate strategies and energy policies emphasizes the priority of water resources. The study illustrates the technical, political and economic challenges that arise as environmental and ecological problems when developing and operating hydroelectric plants that are built to avoid traditional thermal systems with fuel burning (Hussain *et al*., 2019). As the region faces electricity shortages and growing demand, trade-in energy between countries has potential, resulting in benefits from connecting power transmission stations transnationally and conducting business between countries. The energy trade will strengthen the energy security of countries; therefore, adequate strategic planning and efficient coordination are key to maximizing the benefits of this renewable energy that can often be shared by two or more countries due to the specific hydric flows where it can be exploited (Ali, Li, Congbin, & Khan, 2015). The annual average precipitation in Nepal is increasing at a slight rate of 0.284 mm/year, while in Pakistan, the average temperature is decreasing, due to the erratic yearly changes in rainfall areas, resulting in a decrease in rainfall (Sahukhal & Bajracharya, 2019). The study recommends an intelligent energy exchange approach as well as regional collaboration for the development and collective energy between the two nations, to reduce impacts on downstream populations, aquatic life, and terrestrial ecosystems (Pakhtigian, Jeuland, Bharati, & Pandey, 2019)

Country	Principal considerations
Taiwan	A study of the climate change influence on hydropower generation based on the Kaoping river discharge is being conducted in Southern Taiwan, using scenarios based on data from rain and temperature from a Global Climate Model. The projection shows how the watershed uses hydrological model loading functions to simulate the river's discharge in the A2 and B2 scenarios from the Intergovernmental Panel on Climate Change (Chiang, Yang, Chen, & Lee, 2013). Each scenario represents a development of the divergent level in demographic, social, economic, and technological questions, presenting a pessimistic or an optimistic evolutionary line, respectively (IPCC, 2009). During the study period, the south had more variable rainfall, while the north had a wider range of temperatures. In the south of the country, the average annual temperature is about 24° C. Considering Taiwan's average annual rainfall of more than 2 500 mm and the steep slopes of its rivers (average: 0.655), thus the hydropower is a feasible possibility here Taiwan's south is examined for its hydropower potential under climate change. It predicts that the Kaoping river flow will fluctuate between -26 and -15 percent in the dry period and -10 to -82 percent in the rainy season (Chiang *et al*., 2013). Climate change can alter Taiwan's hydropower production capacity with high variance, and most results require climate mitigation and adaptation plans (Chiang *et al*., 2013).

In addition, the decision to use hydropower technologies is because, nowadays, it is the most significant renewable energy, moreover it's a source involved in shaping policy decisions, mainly in Asia, where it emerged as the large continent that implemented compared to others world places (Zhong *et al*., 2019). Thus, this methodology can achieve the goal of develop a state of art that relate the sustainability with the hydropower development, as a robust-theoretical framework.

Results and discussion

As part of the review, various documents have been created to focus hydropower on sustainability; toward the end of the article, Table 1 present the databases results, and repository scientists over the last seven years, organized by country. It is important to mention that in this section of results, it is important to divide by country because each of them requires data, relationships, projections and analysis of different ecosystems where hydropower plants are built and operate. Although they are located on a similar continent, there are differences in the type of energy use, energy grid of each country, and forms of consumption, which is why studying each one shows a breadth of criteria that strengthen the discussion.

As it shown in Table 1, hydropower has a complex interaction of impacts, commonly treated as independent, but hydropower consequences are not purely social, climatic, ecological, technical, or economic, although related (Naranjo-Silva & Álvarez-del-Castillo, 2021b). These effects poorly quantified in vulnerable or modified regions are cumulatively estimated at approximately one trillion dollars to offset the last 18 years' deterioration of hydropower and climate alterations (Turner, Hejazi, Kim, Clarke, & Edmonds, 2017). In Figure 4, a hydropower impacts summary based on the collected data between positive and negative aspects.

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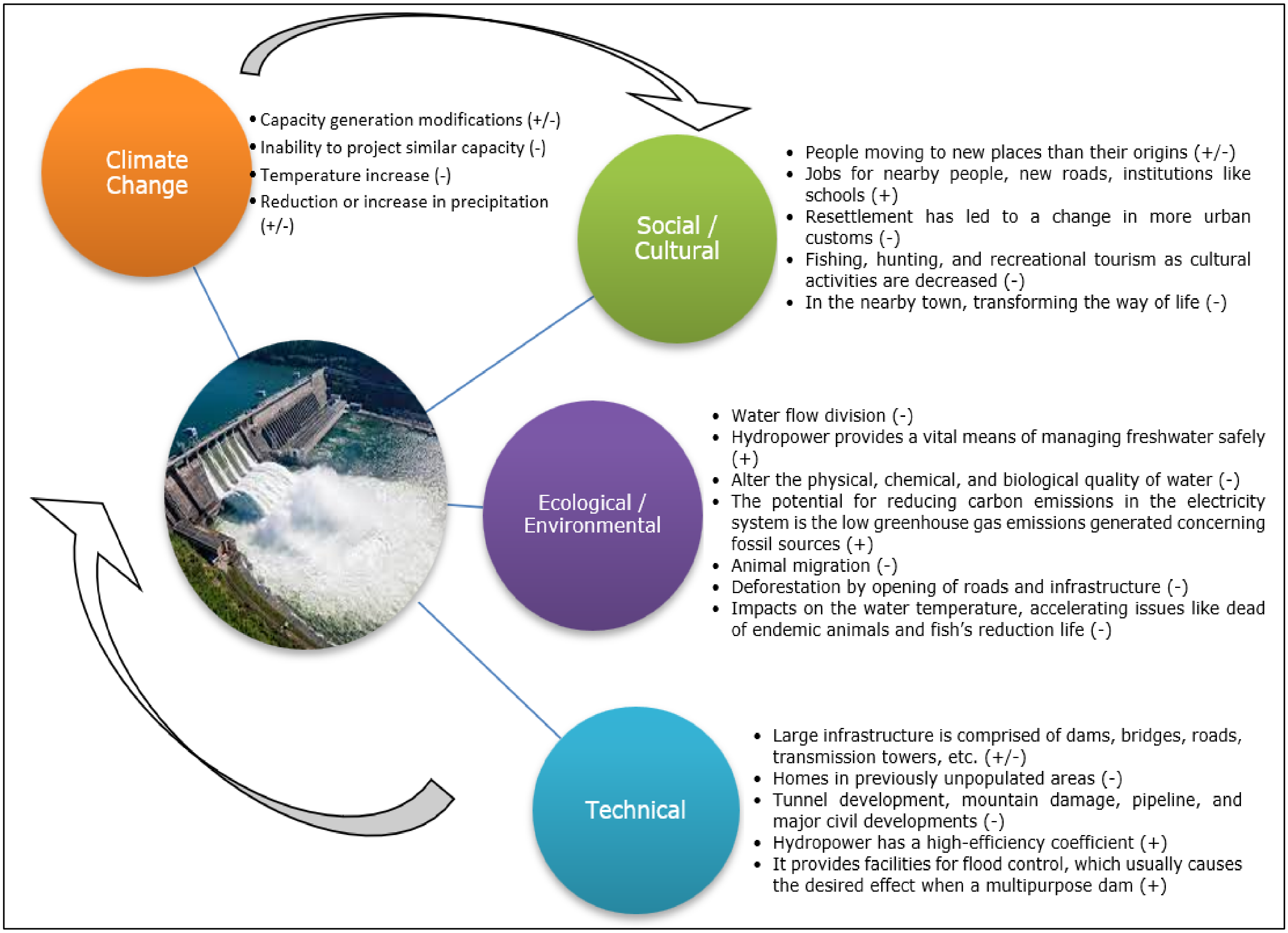

Figure 4. Effects of hydropower production.

Sustainability and hydropower generation

In Asia (Table 1), traditional hydropower (reservoir, pass or channel) has an impact directly on ecosystems and water resources. In contrast, sustainability is considered to address existing problems such as managing resources that require studies to adapt to natural changes as dams' construction, river diversion, deforestation among other activities. Consequently, it is required to produce valuable data on water balance, energy planning scenarios, and station allocation for sustainable hydropower production to make the best decisions.

However, currently, as the largest renewable source, hydroelectricity serves as energy for the development of several countries, but there are support tools to make sustainable selections in the plants (Tang, Li, & Tu, 2018). One tool around hydropower sustainable construction from knowledge from different ranges and perspectives arises with the technical tool called: Hydropower Sustainability Assessment Protocol (HSAP). In 2014, the World Bank approved the Protocol as a guide to hydroelectric development in the Bank's partner countries.

A significant proportion of the world's hydropower is already being generated through hydropower, so the adoption of this protocol is not as fast as it should be because it is a document that uses the life cycle assessment as part of the assessment of sustainability, as well as considering the reservoir, dam, power plant, transmission, project location, impacts, and surroundings of the project (IHA, 2018b; IHA, 2018a). The sustainability evaluation protocol is a robust document, however there is very little information on its implementation. IHA was consulted but no response was obtained from the projects that have implemented it.

Therefore, the International Hydropower Association has developed the HSAP protocol for measuring and streamlining hydropower approaches. Despite the shortness of this protocol, it gives an overview of the parameters involved in sustainable hydropower development; the HSAP provides recommendations for the construction of sustainable hydropower plants and it is important to highlight the endorsements to make the projects viable. The HSAP main recommends on environmental aspects determines water test, sediments treatment, opening roads control, and native flora precaution and care. On the other hand, in social aspects, the education and communication with local residents are all essential elements of supporting the construction phases, thus, the socializations did by the government with the communities around the human rights to companies can establish policies and processes governing their business are essential.

At India, for example, evaluated the implementation of this protocol (HSAP) in some hydropower projects in the Uttarakhand area; it saw that companies always seek the positive impact, but significant consequences are leading to the forced relocation of local communities, loss of employment opportunities, loss of access to water, and fear of natural calamities as floods. In Uttarakhand, most projects fall under different levels of sustainability, so mitigation measures specific to each project are recommended based on the protocol guidelines (Chhabra-Roy & Roy, 2022).

Though, there is an incorrect criterion about hydropower associated to sustainability, it is a wrong approach, as shown by the review findings nonetheless, if there are voluntary instruments to adopt criteria and recommendations in a social, economic, and cultural way that support the built of the plants (Bondarenko, Kortunov, Semenova, & Khetsuriani, 2019).

On the other hand, there are some conclusions, and studies that impact the sustainability source are brought up and serve to compare our finds, for example, the climate change affect globally, but an investigation is projected to result in an overall decrease of 6 % in hydropower potential of Europe by 2070. However, for Western and Central Europe, a stable hydropower pattern is predicted, and for the Mediterranean, a decrease of 20 to 50% is forecast (Bakken, Killingtveit, & Alfredsen, 2017).

A study of watersheds show that are affected by stress and food shortages in six hydropower producing countries of South Asia, such as Afghanistan, Bangladesh, Bhutan, India, Nepal, and Pakistan. A rapidly growing population and economic deficit are likely to exacerbate these problems. South Asia's needs for water, energy, and food are growing, and resources are being depleted globally, threatening water sustainability. Each degree of temperature rise is expected to increase water demand for crop production by 6-10 %. Although the six south Asian countries have a total hydropower capacity of around 388 GW, only 16 % of it is being utilized. In contrast, 80 % of it is being utilized in industrialized countries. The assessment of the water resources potential indicates that coordination and management need to be improved, and synergies are underutilized on the hydropower plants (Rasul, Neupane, Hussain, & Pasakhala, 2019).

Comparing, in the Middle East, at Kurdistan region, integrated by Iran, Turkey, Iraq, and Syria, has impacted many people for the last decade's unstable water situation. Since ancient times, Tigris and Euphrates rivers have been used for the Mesopotamian lowland's irrigation (Ahmad-Rashid, 2017). On Tigris and Euphrates rivers, there are 32 important dams, eight added are under construction, and more than 13 will be planned with total hydropower installed capacity of 11.35 GW (Kibaroglu & Gürsoy, 2015). Unfortunately, the water crisis in Kurdistan requires the existing expertise, proper use, and the decision-makers determination to do a framework for a further logical hydric resources development that can solve the population water supply and electricity generation as multipurpose projects for water supply and power generation, seeking to optimize the use of water resources, offering a variety of economic, social and environmental advantages (Ahmad-Rashid, 2017).

In addition, a study of global hydropower projects simulates the ensemble projections of stream flow and mentions that in Eastern Asia, United States, and Australia, water reductions are projected to 2080, where sharp increases in combined temperature reductions of these regions are expected to affect 11-14 % of annual hydropower generation for RCP 2.6, and 41-51 % for RCP 8.5 of the world population by the 2080s (Van Vliet *et al*., 2016).

Nonetheless, all these studies and approaches are implemented due to the attention in hydropower, in response to the increasing need to advance an economy with low carbon emissions, but which ensures strategies accompany the water resources management where the sustainability criteria are far from being reconsideration (Uamusse, Aljaradin, Nilsson, & Persson, 2017).

Limitations and future directions

Across the globe, the number of hydropower plants is continuously increasing, and plays an increasingly important role in electricity production. Hydropower dams are one of the most significant infrastructure energies in the world, and there is a huge need to build more dams, but through a political ecology framework with social concerns, energy, social justice, environmental protection, ecosystems rehabilitation, transparency constructive, and social responsibility (Hartmann, 2020; Sánchez, Morales, Vélez, & Castillo, 2022).

Every new installation of such a system carries a wide range of effects that should be evaluated in depth and thoroughly. Nevertheless, the effects are poorly quantified, the studies presented dispute hydropower's primary protagonist and apparent benefits since settlements differ in terms of energy access, economic development, flood prevention, and carbon dioxide reduction, for example, these effects do not occur in most urban zones, and generally are rarely accepted by the populace (Naranjo-Silva & Quimbita, 2022; Zhuo, Feng, & Wu, 2020).

Therefore, hydropower will continue to be a controversial energy option in the coming years; hence, it is necessary to evaluate risks, advantages, and viability, including size, costs, and impacts. Moreover, a problem defined as a limitation is that the hydropower generated has public aberration towards the project's construction, landscapes change, vegetation damage, wildlife, and aquatic death (Mattmann, Logar, & Brouwer, 2016).

Concerns about hydropower development's environmental and social influences have made sustainability a critical and unavoidable issue. Industry and government are paying close attention to it. Therefore, for the long-term sustainable hydropower expansion, an objective and comprehensive assessment of these impacts is crucial (Naranjo-Silva & Alvarez-del-Castillo, 2022).

Using negative hydropower impacts of the existing projects as a basis, future directions can define parameters and data for resilient hydropower projects in areas with the least potential for damage to ecosystems.

In light of knowledge, other future discussions can be the investigations of the climatic scenarios for the new hydropower projects using sustainable parameters, an awareness background, and incentives applied to the stakeholders.

Conclusions

Hydropower is the biggest renewable source nowadays, it is competitive in generation price, and respond to the growing population demand. Nevertheless, the different studies show that the overall hydropower potential of the thirteen Asian countries decreases over time in part due to the deep interaction between water and it is location, meaning adverse effects on the environment.

The development of hydropower systems must be prioritized based on all the advantages and disadvantages arising from the use of this renewable. In order to build sustainable energy structures, policymakers, engineers and builders must adopt procedures that can arrange projects based on their sustainability.

With the review of the state of art between sustainability and hydropower generation in Asia, as a novelty a consolidated discussion document is generated, unifying insights where there are similarities in 13 countries and discussing gaps such as the effects of hydroelectricity on water resources, environmental impacts and criteria that this the source should communicate in its development to mitigate the social effects of the surrounding communities.

In the future, the hydropower protagonist will gradually change from a stable generation as a complementary source of others renewable energies; this will mean a move away from promoting hydropower energy as a sustainable source, because confronts the temperature variations by the climate change, the deficient global financial policies, and opposition from people close to projects in often rural and remote areas, particularly dam projects with more significant ecological and environmental impacts.

The limitation of this study is that it just takes thirteen countries of Asia to do a small global sample. Moreover, some data from particular hydropower projects can be observed, and there is a significant opportunity to discover tools, and make recommendations to has a sustainable hydropower expansion.

To obtain a realistic quantitative to hydropower, it is recommended to utilize a combined approach of climatology, hydrology, and energy efficiency, which can simulate future climate change and diverse world modifies to be developed energy studies on planning scenarios with balanced renewable sources.

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