THE POTENTIAL, OPPORTUNITIES AND CHALLENGES FOR PHOTOVOLTAIC GENERATION IN LATIN AMERICAN AND CARIBBEAN COUNTRIES

POTENCIAL, OPORTUNIDADES Y DESAFÍOS DE LA GENERACIÓN FOTOVOLTAICA EN LOS PAÍSES DE AMÉRICA LATINA Y EL CARIBE

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Resumen

La transición energética es un objetivo global para mitigar los efectos del cambio climático, derivado de las emisiones contaminantes, principalmente de la industria energética. Esta transformación implica un desafío económico y tecnológico, pero también genera oportunidades de desarrollo basadas en todo el entramado industrial-tecnológico que requiere la expansión de la generación de energías renovables. Ante este panorama de posibles beneficios económicos derivados de la descarbonización, este trabajo busca comprender el panorama del sector energético en América Latina (AL), la evolución del uso de fuentes renovables en la región y las políticas específicas para la generación solar fotovoltaica, en particular las de carácter industrial, con especial atención a Brasil, Chile y Argentina. Entre los resultados, la investigación demostró que no existen políticas industriales amplias y consolidadas enfocadas en el desarrollo de componentes para la generación solar fotovoltaica en la región. Las iniciativas encontradas se centran en el estímulo mediante incentivos fiscales y la importación de estos componentes. Por lo tanto, estas políticas para la adopción de fuentes fotovoltaicas y el financiamiento para la adquisición de equipos determinaron la configuración del sector en la región, que es principalmente importador de equipos. La excepción es Argentina, que tiene una política de creación de un polo tecnológico para la fabricación de componentes en el segmento de energías renovables, incluyendo módulos fotovoltaicos.

PALABRAS CLAVE: Estabilización de precios, Recursos combustibles, Recursos energéticos, Política energética, Economía energética, Abastecimiento de energía, Política fiscal

Abstract

The energy transition is a global objective to mitigate the effects of climate change, resulting from pollutant emissions, mainly by the energy industry. This transformation implies an economic and technological challenge, however, it also creates opportunities for development based on the entire industrial-technological apparatus that the expansion of renewable energy generation requires. Given this scenario of possible economic benefits arising from decarbonization, this work seeks to understand the panorama of the energy sector in Latin America (LA), the evolution of the use of renewable sources in the region and the specific policies for solar photovoltaic generation, notably, the of an industrial nature, focusing on Brazil, Chile and Argentina. Among the results, the research showed that there are no broad and consolidated industrial policies, focusing on the development of components for solar photovoltaic generation in the region. The initiatives found focus on stimulus via tax incentives and the import of these components. Thus, such policies for the adoption of photovoltaic sources and for financing the acquisition of equipment determined the configuration of the sector in the region, mostly importing equipment. The exception is Argentina, with a policy of creating a technological hub for the manufacture of components in the renewable segment, including photovoltaic modules.

KEYWORDS: energía solar fotovoltaica; América Latina; transición energética; política industrial; cadena de valor.

1. INTRODUCTION

Climate change due to global warming is a contemporary challenge, positioned at the heart of society's discussions. The goal of limiting global warming to 1.5º by 2050 is an objective agreed upon between several nations, consolidated in the Paris Agreement in 2015. This search for a new economic model that is environmentally sustainable has promoted changes in several economic sectors, particularly in segments that cut across the economy, such as the energy sector. In this context, the energy transition is one of the means of curbing climate change, through the decarbonization of the global energy matrix, replacing energy sources of fossil origin with renewable sources, such as photovoltaic, wind, hydroelectric and biomass.

The challenges for this transformation to be carried out involve the entire planet and require multifaceted policies. However, the different energy profile of each continent and each country gives particularities to this process. Therefore, the inclusion of renewable sources in the energy generation matrix is peculiar to each region and nation, given the varied opportunities arising from different types of energy sources to advance the reduction of emissions and geographic, political and regulatory barriers. present in each location. Thus, each region and each nation has a challenge for sustainable transition, with specificities regarding (i) their emissions, (ii) the current configuration of their energy matrices – which indicate the dimension of change –, (iii) possible transformation trajectories and (iv) opportunities to take advantage of this process in socioeconomic development strategies.

Given the complexity and diversity of contexts for the energy transition in each region of the world, as well as the urgency to focus on areas where decarbonization is promising, in this report the focus of the research is Brazil, Chile and Argentina. The objective is to build an overview of the development of renewable sources, focusing on photovoltaic solar generation, trying to demonstrate the evolution of this source, the scenario of the segment's production chain in the region and the policies aimed at expanding the use of this source and promoting economic development based on sustainable energy transition.

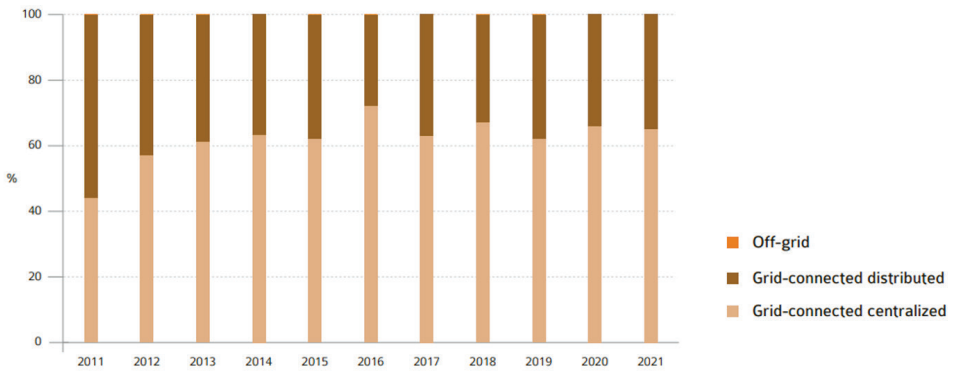
2. THE PHOTOVOLTAIC SOLAR ENERGY SEGMENT

Since the beginning of the development of the photovoltaic market, around 945.4 GW of photovoltaic power plant capacity has been installed globally, of which approximately 70% has been deployed in the last five years. In the segment's development trajectory, a growing number of markets began to contribute to the expansion of installations globally, resulting in 2021 reaching a record for new countries installing a significant number of solar panels in their territories. The uses of solar energy at the beginning of this century focused on heating and cooling buildings, generating electricity (concentrated and distributed) and converting energy for industrial processes (HIDALGO, NODAL, BORGES, 2019).

The IEA PVPS (IEA Photovoltaic Power Systems Programme) group of countries represented 753 GW of this installed capacity globally (IEA, 2022b).

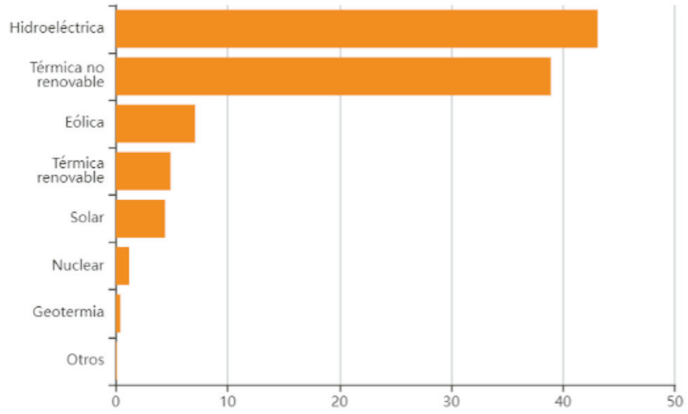
In the case of the Americas, considering the entire continent, in 2021, the amount of around 40 GW in photovoltaic solar panel installations was recorded and a total accumulated capacity of 164 GW (Graph 1). Although the largest portion of this capacity is installed in the United States, several countries have stood out in increasing panel installations in the center and south of the continent, with emphasis on Chile, Honduras, Mexico and Brazil (IEA, 2022b).

Graph 1 – Evolution of photovoltaic panel installations by segment | Americas 2011-2021



Source: IEA (2022b)

Graph 2 – Proportion of installed capacity to produce electrical energy by source | Latin America and the Caribbean 2020



Source: Cepal (2022)

Photovoltaic power generation is developing in the Americas mainly through tenders and in the centralized grid-connected model, except in the USA. It should be noted that instability has characterized the development of photovoltaic generation in most countries in recent years, with stop-and-go policies in Canada, Honduras and Mexico, for example. However, it is worth mentioning that the market was very dynamic in 2021 in Chile and Brazil, with prospects for development in several Central American countries, such as Costa Rica and Guatemala (IEA, 2022b).

In the particular case of Latin America and the Caribbean, photovoltaic solar energy generation is still in an expansion process, therefore, among the installed capacities of renewable sources most used on the continent to generate electricity, it is noted that hydroelectric power plants are still the majority, accounting for 43.1%, photovoltaics accounts for 4.4% (Graph 2). When analyzing the panorama of generation capacity in LAC, it is observed that, in 2021, the region's photovoltaic solar capacity grew 44%, with a total of 9.6 GW added in the year. Market expansion was much higher than that recorded in the previous two years. In 2019 and 2020, advances were 15% and 26%, respectively (SOLARPOWER EUROPE, 2021).

Still in terms of accumulated capacity, the continent had more than 30 GW of solar at the end of 2021. The number is almost four times greater than that

recorded at the end of 2018 and 40 times greater than the installed power in 2015. Therefore, such Data indicates that the trend is for great growth in photovoltaic generation capacity (SOLARPOWER EUROPE, 2021). Currently, four nations lead the solar market in Latin America: Brazil, Mexico, Chile and Argentina. Together, these countries account for around 90% of the region's photovoltaic capacity, with all having already surpassed the 1 GW capacity threshold. Furthermore, there is a projection of annual growth of 52% in 2022, with 14.6 GW added (SOLARPOWER EUROPE, 2021).

Highlight must be given to the case of Brazil, whose installation of new photovoltaic panels reached 5.7 GW, leading to an accumulated market of 13.7 GW in 2021. After years of limited development of the photovoltaic market, Brazil appears today as one of the main global players, demonstrating their potential much higher than the levels achieved until 2021 (IEA, 2022b). Specifically in the case of distributed generation, Brazil is among the 10 countries with the greatest capacity expansion in 2021, having added 4.16 GW in this segment (Table 1).

Table 1 – Top 10 countries with panel installations | Distributed generation 2021

COUNTRY	GW
CHINA	29,28
USA	6,62
BRAZIL	4,16
GERMANY	3,75
JAPAN	3,20
AUSTRALIA	2,90
INDIA	2,04
TAIWAN	1,59
SPAIN	1,40

Source: Cepal (2022)

Table 2 – Top 10 countries with accumulated capacity in panel installations | Distributed generation 2021

COUNTRY	GW
CHINA	108,22
GERMANY	48,56
JAPAN	48,11
USA	42,68
AUSTRALIA	16,68
ITALY	14,55
VIETNAM	10,46
TURKEY	9,73
BRAZIL	9,08
FRANCE	8,70

Source: Cepal (2022)

Chile is also a prominent case in LAC, being among the 10 countries with the most photovoltaic installations in the world, having installed 2.7 GW in 2021, which indicates great market development in the country. Furthermore, it is pointed out that Brazil and Chile must support the expansion of photovoltaic sources in LAC. For the region, it is projected that in 2026 annual installations could reach 30.8 GW (SOLARPOWER EUROPE, 2021).

In terms of accumulated capacity in distributed photovoltaic generation, Brazil is the only Latin American country present in the ranking of nations with the largest capacities from this energy source segment. The country is in 9th place, accumulating 9.08 GW in photovoltaic installations. Even so, Brazil and the other countries in the ranking have a capacity far removed from that recorded by China, which in 2021 reached 108.22 GW of accumulated capacity in solar panels (Table 2).

In other countries, such as Argentina, progress has been seen in installed capacity as of 2021. It is also noted that several other countries in Latin America and the Caribbean have established support programs for the development of photovoltaic electricity, with an increase in the number of power plants that are connected to the grid, mainly in the Dominican Republic, Ecuador and El Salvador, followed by Uruguay and Panama (IEA, 2022b).

In the case of photovoltaic energy, the expansion of distributed generation (produced in small units) and large solar parks creates a potential industry, expanding and with technological complexity as efficiency improvements are an objective for the sector. Therefore, opportunities to internally develop niches in this segment need to be identified and taken advantage of by industries in each country that is committed to the energy transition, in addition to essential policies that somehow stimulate the local development of links in the production chain. The following section deals with the photovoltaic equipment industry in the world, in order to present an overview of the segment's production and its peculiarities.

3. THE GLOBAL PHOTOVOLTAIC EQUIPMENT CHAIN

The expansion of the solar PV supply chain has outpaced rapid demand growth over the past decade, with crystalline silicon technology dominating the market at more than 95% of installed capacity over the past five years. At the end of 2021, global capacity for manufacturing wafers, cells and assembling modules exceeded demand by at least 100% (IEA, 2022a).

In this trajectory of sectoral growth, economies of scale and continuous innovation throughout the supply chain have allowed sharp drops in manufacturing costs at all stages of the production process in the segment. As a result, module prices have fallen by more than 80% in the last decade and solar photovoltaics have become the most affordable electricity generation technology in many parts of the world. It should be noted that the costs of electricity generated from photovoltaic solar energy have fallen by 82% between the years 2010 and 2019 (HIDALGO; HERNÁNDEZ, 2021). In 2021, the average selling price of modules increased for the first time – by around 20% compared to 2020 – due to higher commodity and freight prices.

It should be noted that, in the last decade, a major geographic change has occurred in the manufacturing capacity of equipment for generating photovoltaic solar energy and its production. China further strengthened its leadership position as a manufacturer of wafers, cells and modules between 2010 and 2021, while its share of the global market capacity to produce polysilicon almost tripled. Thus, the country's participation in all links of the photovoltaic chain exceeds 80%, more than double its 36% participation in the implementation of this type of energy. Therefore, China currently significantly dominates all segments of the solar photovoltaic source chain (IEA, 2022a).

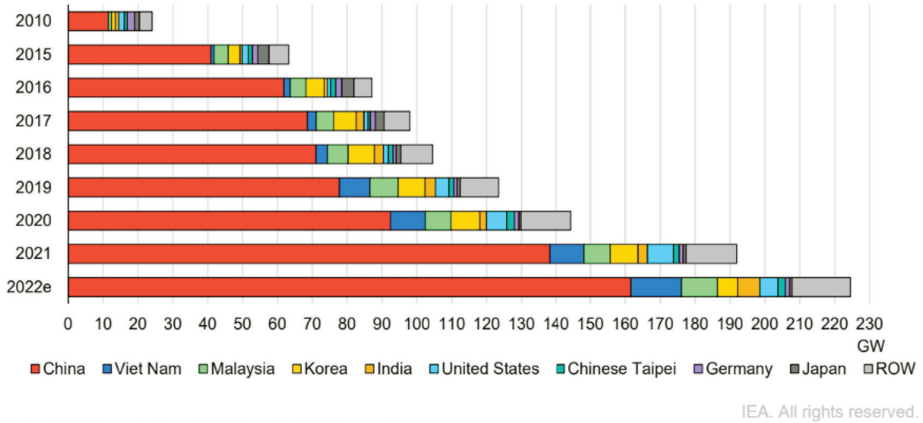
In all countries except China, demand for solar photovoltaics is above equipment manufacturing capacity, from polysilicon availability to module production. By the end of 2021, the annual manufacturing capacity of photovoltaic-grade polysilicon reached 750,000 tons, which should be enough to manufacture about 250 GW of crystalline silicon modules. In this scenario, China produced around 80% of the polysilicon used for solar PV modules in 2021, with the remaining

market share divided between Germany, Malaysia and the United States. Between 2010-2015, China expanded its panel production capacity twice as fast as the United States, Germany, Korea and Japan, triggering a global oversupply, causing polysilicon prices to fall by 70%, which led to many producers leaving the market.

In the case of generation modules, although the countries of North America and Europe have significant manufacturing capacity, the acquisition of solar cells occurs almost entirely from China and countries in Southeast Asia. It should be noted that China is also the main manufacturer of photovoltaic module components, including glass, EVA (ethylene-vinyl-acetate), back sheet and junction box.

Although 38 countries have module assembly facilities, China still accounts for around 70% of production in 2021 – in 2010 it accounted for 50% of production. Other important manufacturers are Vietnam (5%), Malaysia (4%), Korea (4%) and Thailand (2%). However, it is important to highlight that most of the manufacturing capacity in these countries was developed by Chinese companies focused on exports to the United States. Furthermore, countries with considerable module assembly capacity, such as the United States (4%), Germany (1%) and India (1%), produce mainly for their domestic markets, that is, export to meet the Global market demand is dominated by China (Graph 6).

Graph 3. Global production of photovoltaic solar modules | 2010-2022

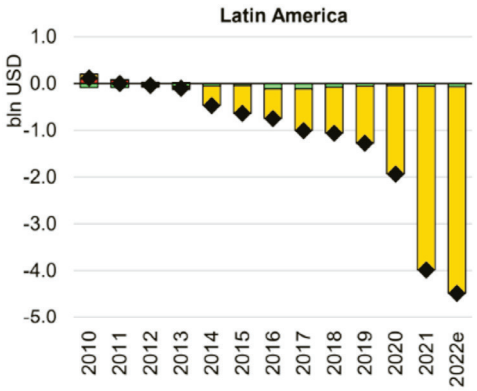


Notes: ROW = rest of world. Values for 2022 are estimates.

Source: IEA analysis based on BNEF (2022a), IEA PVPS, SPV Market Research, RTS Corporation and PV InfoLink.

Source: IEA (2022b).

Graph 4. Net import value of photovoltaic grade polysilicon, wafers, cells and modules | Latin America and the Caribbean 2010-2021



Source: IEA (2022b).

With the prospect of over 300 GW of new assembly plants in China, its market share is expected to remain high in the medium term, even if the trend towards productive expansion of equipment in India, Vietnam, Thailand, the United States and European Union. It is important to highlight that international trade volumes of photovoltaic solar energy depend heavily on domestic demand in China, as the country is the largest producer and consumer of polysilicon, wafers, cells and modules, dictating the pace of market evolution today.

It is worth mentioning that, between 2017-2021, Southeast Asian module manufacturers were responsible for 1/3 of global photovoltaic module exports, mainly to serve the United States and European Union markets, where Chinese modules were subject to several commercial restrictions. The rest of the market was dominated by China, with its shares in India and Brazil exceeding 90%. In Latin America, installations were records in 2022, with an increase in module imports across the region, which, together with high prices for this equipment in 2021, resulted in more than doubling its net import bill that year.

In this scenario, in 2021, China and countries in the Asia-Pacific region benefited significantly from higher rates of demand and prices, earning record revenues from sales of photovoltaic generation equipment. In view of the data presented, China's dominance throughout the production chain of equipment for the generation of photovoltaic solar energy is clear. The country has high technology, scale and production rate, which allows them to be the largest supplier of different components to the segment globally. Therefore, in regions such as Latin America and the Caribbean, where there is dependence on photovoltaic technology equipment, it is difficult for national companies belonging to this industry to emerge to meet local demand, given that the sector in China is consolidated and has advantages arising from the interconnection of the chain, with already dominated consumer markets.

In any case, certain market niches can become an alternative to taking advantage of the energy transition and expansion of photovoltaic generation for the industrial development of the LAC region. Among the alternatives, the recycling of panels and other photovoltaic equipment is a segment with potential growth in nations that import the technology. As the global photovoltaic market increases, so does the volume of decommissioned photovoltaic panels, so large amounts of annual waste are predicted for the early 2030s. The increasing waste of photovoltaic panels presents a new environmental challenge, but also opportunities to create value and seek new niches for economic development.

According to IRENA data, recycling or reusing solar photovoltaic panels at the end of their useful life of approximately 30 years could generate an estimated stock of 78 million tons of raw materials and other valuable components by 2050. If fully injected back into the economy, the value of the recovered material could exceed US$15 billion by 2050, which gives rise to the process of reverse logistics within a circular economy. It is noted that sectors such as photovoltaic recycling will be essential in the global transition to a future of expanding the use of sustainable and economically viable energy (IRENA, 2016).

In Brazil, the company Sun R is an example of a company that recycles generation modules. The process consists of dismantling, separating materials (aluminum, glass, connectors) and subsequent chemical treatment of the rest of the materials, so that the silver, copper and silicon can be extracted, ensuring the appropriate disposal of each element. Thus, with the reverse logistics and recycling process, around 90% of materials can be reused and reinserted into the module production cycle.

In addition to this specific market niche, it is possible to envisage the possibility of Chinese companies, dominant in the global market, expanding industrial plants to LAC. In this way, through the installation of industries in the segment in countries in the region, part of the continental demand could be met by local production. This movement could be a way for Latin America to increase local industry, based on the energy transition, gaining the benefits that the industrial sector is known to provide, such as generation of qualified jobs,

increased local income and possible intra-sectoral and inter-sectoral technological spillovers.

It should be noted that the attraction of companies that operate in links in the photovoltaic equipment chain depends on national policies for the development of solar generation and the installation of industrial plants in the sector. Therefore, it is important to check which policies have been developed in LAC. Such policies can be: (i) more general and transversal in terms of encouraging sustainable transformation, creating decarbonization targets and incentives for the adoption of renewable energy sources; (ii) or specific to the expansion of solar photovoltaic generation.

Therefore, the following section seeks to present the most relevant public policies in LAC aimed at sustainability and the development of the photovoltaic solar energy sector, focusing on the cases of Brazil, Chile and Argentina.

4. POLICIES FOR THE DEVELOPMENT OF PHOTOVOLTAIC SOLAR GENERATION AND SUSTAINABILITY IN LATIN AMERICA AND THE CARIBBEAN

The energy transition represents a paradigmatic change in the contemporary production model, a challenge of transversal technological transformation. The dynamism generated by the implementation of this new model of energy generation based on renewable sources constitutes an opportunity to promote economic development in the face of technological growth in the area, production of new equipment and all the infrastructural and technological adaptations required in different segments. economic.

For the transition to occur, it is essential that a set of public policies be formulated by each country, in order to enable and accelerate change. In the case of photovoltaic solar energy, policies to encourage the adoption of this energy source are essential to finance its implementation, improve technology and reduce costs.

Therefore, in this section we seek to bring together the most relevant sectoral policies with a focus on expanding the photovoltaic solar generation segment in countries in Latin America and the Caribbean. The mechanisms that make up such policies are presented, as well as financial and fiscal incentives (financing programs, subsidies and commercial tariffs), and regulatory ones, such as concession rules, technical standards, commercial standards and incentives based on regulations. The focus is on the cases of Brazil, Chile, Argentina, Costa Rica and El Salvador. Table 3 at the end of the section brings together the most relevant policies aimed at sustainable transformation and stimulation of solar photovoltaic generation in the highlighted countries and in other LAC nations.

4.1. Brazil

Brazil is a country with a large stock of natural resources and a great potential for generating energy from renewable sources. As a signatory to the Paris Agreement, Brazil developed a set of policies focused on environmental preservation and energy transition. One of its first and main policies in the area of sustainability is the National Policy on Climate Change (PNMC), which establishes sectoral plans for mitigation and adaptation to climate change to consolidate a low-carbon economy, aiming to meet targets gradual reduction of quantifiable and verifiable anthropogenic emissions, considering various economic sectors, such as electricity (BRASIL,

2009). The PNMC served as the basis for the design of sectoral guidelines and normative instruments that seek to increase sustainability in various economic activities and diversify the Brazilian renewable energy matrix.

Another comprehensive and relevant policy proposed in 2021 was the National Green Growth Program, which aimed to offer financing and subsidies to encourage sustainable economic projects and activities, prioritize the granting of environmental licenses and generate so-called "green jobs". This policy was not implemented, which made it harmless in the short term (BRASIL, 2021).

Regarding the reduction of Brazilian greenhouse gas (GHG) emissions, actions to mitigate them in Brazil are based on sectoral plans, mainly in agriculture, energy and forest protection. To record and commercialize GHG emissions, the National System for Reducing Greenhouse Gas Emissions (SINARE) was created in 2022, which allows monitoring progress in sustainable transformation (OECD, 2022). The policy has a transversal bias, as it defines plans for segments of the economy, monitors pollution and, therefore, indicates the necessary measures for an environmentally sustainable economy.

Regarding policies to encourage renewable sources, specifically for photovoltaic solar generation, there is a set of devices that encourage the adoption of the source, finance the acquisition of equipment and installation and promote subsidies and tax exemptions, whether in the format of distributed generation or of large generation projects. In 2022, Bill No. 5,829/19 was sanctioned, which became Brazil's new Solar Legal Framework (Law No. 14,300/2022). The new regulations promoted improvements that facilitate the construction of solar plants, increase legal security for sectoral economic agents, granted permission for hybrid generation systems, in addition to allowing the rebate of credits between concessionaires and energy licensees (BRASIL, 2022).

The new law guarantees that operating own generation systems and new requests for access of up to 500 kW made within one year will still be regulated by current standards, until 2045. Requests made after a period of one year from the publication of the law will enter a staggered transition model. In this model, payment of the distribution system usage fee (Tusd) will be made gradually, with an annual increase in the percentage to be paid by generating companies. The transition model also has two distinct rules: one for requests made between the 13th and 18th months after the publication of the law; and another for orders made after the 18th month. In the first case, the transition period until Tusd is paid is eight years. In the second, the time is shorter, six years.

Within these transition models, for each unit of energy injected into the electrical grid, the equivalent of 4.1% of the average low voltage electricity tariff in 2023 will be discounted. In the following years, the discount will gradually increase by 4.1% per year, until reaching 24.3% in 2028. These discounts are made with the aim of remunerating the use of the electrical distribution infrastructure, only when the electrical energy generated by the consumer (figure of the self-producer) is injected into the network.

In the case of consumers with new systems above 500 kW in the remote self-consumption modality – in which case the generating system is installed in a location different from that where the energy will be consumed –, the payment for the energy injected into the electrical grid will be 29 .3% of the average low voltage electricity tariff, from 2023 to 2028. The law also creates the Social Renewable Energy Program (PERS), designed to finance the installation of photovoltaic generation and other renewable sources for low-income consumers. The resources must originate from the Energy Efficiency Program (PEE) (BRASIL, 2023).

Another way to expand the adoption of solar sources, making its technology cheaper, was the inclusion of the photovoltaic panel segment in the Semiconductor Industry Technological Development Support Program (Padis). In this way, the panels now have a zero rate of Import Tax, Tax on Industrialized Products (IPI) and the Social Integration Program/Contribution for Social

Security Financing (PIS/Cofins), until 2026 – valid for all solar panels manufactured by companies authorized by Padis (BRASIL, 2023).

This fiscal policy with a focus on technological development indicates the effort to develop links in the solar photovoltaic chain in Brazil. However, the effect of the program is to reduce the costs of importing parts and equipment for solar panels, without promoting the national production of components. Within the scope of financial policies for the segment in Brazil, the financing programs for photovoltaic solar generation offered by the National Bank for Economic and Social Development (BNDES) stand out, which provides special credit conditions for the import of photovoltaic equipment, with the aim of encouraging the expansion of distributed generation in the country.

One of its programs is BNDES Finem – Geração de Energia, aimed at financing the expansion and modernization of energy generation infrastructure from renewable sources and natural gas thermoelectric plants. The projects to be financed have a minimum value of R$40 million, with a period of up to 40 months to pay off the credit (BNDES, 2023a). In this scope, another program designed to implement the policy of diversifying the use of renewable energy sources is BNDES Finem – Baixo Carbono, created in 2018. The program is aimed at financing the acquisition and commercialization of solar and wind energy generation systems , solar heaters, electric, hybrid and biofuel-powered buses and trucks and other machines and equipment with higher energy efficiency rates or that contribute to reducing greenhouse gas emissions (BNDES, 2023b).

This Brazilian public financing policy is essential for the photovoltaic segment, as it allows companies to be able to acquire the technology and start generating, selling and consuming renewable energy from solar plants. Through both programs, access to photovoltaic technology is expanded, given the lower costs of financial resources for the construction of solar plants.

In view of the above, it is noted that Brazil has a set of policies to encourage photovoltaic solar generation. The existing instruments are of a regulatory nature, establishing a normative reference for investments in energy sources, which includes tax incentives for the expansion of the national solar park. Furthermore, given the current scenario in which China is the largest producer of solar panel components, a policy was formulated to make the import of this equipment cheaper.

It should also be noted that financing instruments for solar parks are essential, enabling long-term amortization, with lower costs. Access to financial resources is essential in cases where a new technology is still considered more expensive when compared to others that are already consolidated.

In the Brazilian case, it is clear that there is no policy equipped with mechanisms that enable the development of a photovoltaic equipment industry in the country. However, it is necessary to consider that, as production in the segment is dominated by China, with companies producing on a large scale and at lower costs, a strategy to create the sector in Brazil would possibly not be viable in this context. In this sense, policy proposals that deal with attracting links in the chain to the country, focusing on the development of assembly, repair and component recycling activities, are more appropriate.

In any case, Brazil is the country in the region that presents a considerable set of policies with different biases to increase the participation of solar photovoltaic generation in its energy matrix. However, there is no program that aims to increase industrial development based on the energy transition, notably the photovoltaic generation value chain.

4.2. Chile

Chile stands out as a country with a relevant set of policies aimed at sustainability and energy transition, having developed programs in different segments of this area, based on achieving the goals established in 2021 in its Long-Term Climate Strategy, defining the basis for actions environmental issues in the coming years. It is worth mentioning that, in the search for new energy sources to mitigate GHG emissions, Chile is at the forefront of research for new fuels. In this sense, the National Green Hydrogen Strategy (OECD, 2022) was created, aiming to:

- Develop 5 GW of electrolysis capacity by 2025;
- Produce the cheapest green hydrogen in the world;
- Position the country among the three main fuel exporters by 2040.

As green hydrogen is a fuel of renewable origin and its potential use in mobility is envisaged, the development of a policy focused on enabling its large-scale production, as well as making it cheaper, can guarantee participation in global trade of the product in the future. . It should be noted that for a new technology to be adopted, a range of instruments is needed to enable its development, technological mastery and economic-commercial viability of the product generated.

Regarding the generation of photovoltaic solar energy, through Law No. 20,571/2012, the framework for the distributed generation of photovoltaic energy in Chile was established. Thus, the possibility for homes with solar systems to generate their own energy began to be foreseen and regulated, with the surplus being able to be sold on the national energy market. This policy encourages the adoption of this source and ensures that consumers/generators benefit from the sale of their surplus and also strengthens the participation of photovoltaics in the Chilean energy matrix (CHILE, 2012).

This policy is similar to the new regulatory framework for distributed photovoltaic generation in Brazil, stimulating the production and commercialization of renewable energy. Furthermore, as part of the policy to increase photovoltaic generation, the Chilean Ministry of Housing provides subsidies to vulnerable families to implement renewable energy systems. In this way, the policy encompasses the aspect of just transition, by enabling lower-income classes to acquire technology and benefit from clean and autonomous energy generation.

Within this set of policies is the Invest Chile Program, a cooperation plan of the Ministry of Energy (represented by the National Energy Commission (CNE) before 2010) with the Chilean Economic Development Agency (CORFO), to support renewable energy projects and finance the generation of renewable energy across the country. program includes two subprograms (IEA, 2022).

The first initiative is a subprogram to enable grid-connected non-conventional renewable energy (NCRE) projects, through financial incentives in the pre-investment phase. In the period 2005-2009, the program subsidized 50% of the total cost of several projects, with a ceiling of US$60,000 in pre-feasibility studies and 50% of the total cost of pre-investment studies, with a maximum ceiling of US$160,000. In total, 217 wind, biomass, biogas, geothermal and small-scale hydroelectric projects were developed based on the benefits of the program. Between 2008-2010, the CNE and the Ministry of Energy transferred US$2 million to CORFO, aiming to continue the program.

The second incentive subprogram was started in 2008, supported by the transfer of resources from the Kreditanstalt für Wiederaufbau (KfW) development bank. The institution granted a loan of €85 million to finance projects classified as NCRE, providing credit facilities and low interest rates. The contribution allowed the financing of 19 energy generation projects from renewable sources. It is worth mentioning that, as of 2012, the Renewable Energy Center (CER), which is part of CORFO, developed two new programs

to subsidize pre-investment studies for NCRE projects. The grant awarded is up to 40% of the total costs of initial phase studies. To date, 31 projects (5 biogas plants, 1 biomass plant, 13 wind farms, 4 photovoltaic parks and 7 mini-hydro plants) and 78 studies have benefited for a total value of CLP 542 million.

Regarding international partnerships to develop the energy transition and sustainability in the country, as a member of the Pacific Alliance, Chile participates in the Finance and Sustainable Development Working Group, which organizes regional cooperation for the adoption of environmental, social and environmental criteria. governance in the supply of financing. Furthermore, between 2019 and 2022, Chile presented its milestones for green finance, social and sustainable bonds (GSS), which are linked to key performance indicators (OECD, 2022).

Since 2020, a fiscal framework has been developed by the Ministry of Finance, with the help of Nationally Determined Contributions (NDC) and the United Nations Development Program (UNDP) Support Program, to measure the effectiveness of public and private green investments . Thus, in 2019, Chile was the first country in the region to issue green bonds and, in 2022, it was the first nation in the world to issue bonds linked to sustainability, currently constituting 28.7% of public debt. To qualify and sustain these actions, the Mesa Public-Private de Finanzas Verdes initiative coordinates the public and private sectors for training in relation to climate change (OECD, 2022).

In the Chilean case, it is clear that there is a public policy framework focused on the energy transition and sustainable development of the economy. The country's initiative to expand photovoltaic generation is relevant, providing the sector with a regulatory framework to organize activities and also stimulate the growth of the energy market based on this source. As it is still an expensive technology, whose investments need to be amortized over the long term, low-cost financing facilitates and accelerates its insertion into the country's matrix.

As in the Brazilian case, in the case of Chile, a program was not identified with the objective of making the local industry take advantage of the insertion of photovoltaic energy in the matrices. Therefore, there are no incentive mechanisms for the solar panel components industry. Faced with this gap, which can be justified by the great effort to be made in the face of a dominant China in the global production of photovoltaic equipment, the alternative arises of developing activities related to this industry. Therefore, an alternative for the country is to formulate new policies focused on market niches linked to the maintenance and operation of photovoltaic equipment and parks.

4.3. Argentina

Argentina is one of the Latin American countries that has developed policies focused on energy transition and sustainable transformation. In 2019, the country promoted the Law on Minimum Requirements for Adaptation and Mitigation of Global Climate Change and created the National Climate Change Office, responsible for formulating the National Response Plan to problems arising from environmental degradation.

In terms of mitigating climate effects, the National Energy and Climate Change Action Plan promotes the development of biofuel production, renewable energy and increased energy efficiency, aiming to reduce GHG emissions from the energy sector. Another initiative belonging to this scope is co-financed with the Green Climate Fund (GCF), whose objective is to increase investments by small and medium-sized companies in renewable energy and promoting energy efficiency. Furthermore, Argentina is working with EUROCLIMA+ on studies and projects on forest management, electric mobility and energy efficiency, therefore covering strategic segments to increase sustainability in economic activities (OECD, 2022).

The country has also developed initiatives to boost the hydrogen market, considered an alternative to fossil fuels. Since 2021, Argentina has been part of the international PtX Pathways initiative, led by the German government, to promote sustainable hydrogen markets. As part of the International PtX Hub, PtX Pathways supports the development of sustainable markets for the energy transition in Morocco, South Africa and Argentina. The project assists ministries responsible for the energy or economic sector in developing allocation scenarios for PtX, including value chain analysis, identification of business development opportunities and recommendations to improve the PtX regulatory framework (INTERNATIONAL CLIMATE INITIATIVE, 2022). Furthermore, Argentina is also working with 13 Ibero-American countries in the "H2Transel" project to develop hydrogen production.

In the case of photovoltaic solar energy, the country created regulations to regulate and encourage its expansion. Through Law No. 27,424/2017, which addresses distributed generation, the rules for the use of this type of energy were defined, as well as the target for this source in the country. Thus, through the law that underlies the policy for the photovoltaic segment, the objective is to reach a distributed renewable energy capacity of 1,000 MW by 2030. Furthermore, the Argentine government created the Cluster Renable Nacional, a cluster focused on renewable energy sources, with the aim of increasing the supply of clean energy generation and promoting the local manufacturing of components such as wind turbines, wind blades and photovoltaic modules.

The policy aims to promote 750 MW of renewable generation in the next two years and 300 MW annually from 2024. The project has an estimated investment for the development and construction of plants of approximately US$1 billion. To access the resource, companies must meet the requirement of 50% participation of national components. In other words, this is a case of local content policy for the renewable sources sector, something not observed in other countries. However, it is important to highlight that the policy needs to be calibrated to be linked to a scenario in which global competition with China is very strong. Developing links in the photovoltaic chain currently requires investments in improving technology, given the production scale already achieved by China.

Another initiative by the Argentine government needs to be highlighted. In early 2016, the country launched the "RenovAr" initiative, an auction-based renewable energy program designed to expand private renewable energy generation capacity in the country. The objective of the program is to increase the share of renewable energy production to 8% in 2017 and 20% in 2025. The RenovAr project seeks to help resolve the main problems and barriers to the development of renewable energy in Argentina. These include limited access to long-term financing sources and perceptions of high country and sector risks (WB, 2018).

To further increase the confidence of investors and financiers, the World Bank supported the preparation of the first RenovAr bids and provided a guarantee of US$480 million to back certain government obligations under the program. In this way, support from the World Bank helped Argentina unlock its renewable energy potential by creating a structured market, mobilizing around US$3.2 billion in investments.

In Round 1, 15 of the 29 selected projects, with a total installed capacity of 590 MW, requested a guarantee from IRBD (International Bank for Reconstruction and Development, belonging to the World Bank group) in the total amount of US$295 million. For Round 1.5, 12 of the 30 selected projects, with a total installed capacity of 443 MW, requested the IBRD guarantee for a total value of US$185 million. The total IBRD guarantee was US$480 million for 1,033 MW covering 27 different projects (12 wind projects for 721 MW, 10 solar photovoltaic projects for 306 MW, four small hydroelectric projects for 4 MW and one biogas for 1 MW). The average guarantee period for project financing is 16 years (WB, 2018).

Through the RenovAR program, Argentina seeks to expand energy generation plants from renewable sources. It is noted that photovoltaic solar generation benefited from this policy, with financial resources for project financing in its favor. However,

the objective of creating a photovoltaic industry in the country based on this policy is not observed. The program that seeks to develop links in the chain of this source and other sustainable sources is the National Renable Cluster, mentioned previously. In terms of sustainable finance, the Ministry of Economy is developing a roadmap for issuing green sovereign debt, social and sustainability bonds (GSS). In this sense, in 2019, the National Securities Commission presented guidelines for the issuance of GSS Marketable Securities and created a Sustainable Finance Program. In 2020, the Argentine Ministry of Economy created the Mesa Técnica de Finanzas Sostenibles (MTFS) as a permanent forum to develop a national financial strategy and strengthen the financing of sustainable projects in the country. Within the MTFS framework, a joint statement was signed by banking, insurance and capital markets regulators to promote, finance and advance the analysis of climate-related financial risks (OECD, 2022).

5. CONCLUSIONS

In several countries in Latin America and the Caribbean, public policies aimed at increasing sustainability in the economy and the energy transition are observed. Such policies differ in terms of the specificity of the energy sources whose adoption is encouraged, in terms of their scope, duration and scope. The countries that have the most recent policies and programs aimed at sustainability and encouraging the generation of photovoltaic solar energy are Brazil, Chile, Peru, Colombia and Argentina. In the other countries surveyed, there are older laws and provisions encouraging renewable sources. In certain countries there are policies embodied in medium-term plans, such as in El Salvador, with its Master Plan for Renewable Energy Development (2012-2026) (2012), a plan for the development of renewable energy that extends over 14 years. Another example is the case of Guatemala, with its National Energy Policy 2013-2027 (Politica Energetica 2013-2027) and Costa Rica, with the Electricity Generation Expansion Plan 2016-2035 (Plan de Expansion de la Generacion Electrica).

When it comes to photovoltaic solar energy, incentive programs for its expansion are found in Brazil, Peru, Paraguay, Uruguay, Dominican Republic, El Salvador, Argentina and Chile. It is important to highlight that such policies are mostly aimed at expanding solar sources in the countries' energy matrix, and are not focused on the development of the industrial chain of their equipment. In the case of hydrogen, there are public policies focused on the development of technology and national production in Brazil, Argentina, Colombia, Costa Rica and Chile. These policies are particular because the technology is still in the development process, seeking greater efficiency in its production, storage, transportation and application. Thus, hydrogen programs are characterized by their focus on innovation and the initial stage of research, financing and economic-financial incentives.

According to the policies observed for renewable sources projects in the countries analyzed, they were convergent with Sustainable Development Goal 7 (SDG-7). This objective is to ensure reliable, sustainable, modern and affordable access to energy for all. The focus of this access is to substantially increase the share of renewable energy in the global energy matrix by 2030, in addition to improving energy efficiency.

The achievement of these objectives is observed in view of the set of incentives and mechanisms created, resulting in the expansion of the participation of photovoltaic energy in the matrices of Latin American countries. Despite incentives for photovoltaic energy projects, it is clear that there is no effort to achieve SDG 9, focused on building resilient infrastructure, promoting sustainable industrialization and fostering innovation. For example, no devices were found that aimed to develop links in the photovoltaic chain in LAC (with the recent exception of the case of Argentina).

In this way, such policies show that they contributed to the expansion of the photovoltaic solar energy sector in the countries analyzed, in terms of the adoption of this energy source. It is worth noting that, as the policies reported for the segment did not focus on creating links in the industrial chain in the countries, there was, consequently, no emergence of a photovoltaic equipment industry in Latin America. This characteristic of the policies, aimed at the adoption of photovoltaic sources and financing the acquisition of equipment, determined the configuration of the sector in the region, mostly importing equipment.

Added to this policy bias, China's dominance over the production of photovoltaic source equipment produced a scenario with reduced space for the national development of links in this industry. China's advantage in terms of cost, investments in technology and production scale has meant that opportunities to develop segments of photovoltaic technology in other regions have become restricted. Regarding this profile of policies for the sector in LAC, as previously stated, the exception found is the case of Argentina, with its policy to create a hub for the development of renewable energy sources. The country seeks to create its own technological production nucleus, with the aim of boosting the solar, wind and hydrogen energy equipment industry. It should be noted that this strategy is very recent, being in the formulation and implementation stage by the government. Therefore, different results are possible for this public policy in the country.

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