

## **Non-economic barriers to the penetration of Energy Transition Technologies in Latin America and the Caribbean**

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### **INTRODUCTION**

Technical barriers hinder the penetration of key technologies for clean energy supply in Latin America and the Caribbean.

The Region has great potential in natural resources for the generation of electricity with low carbon content, and thus reducing dependence on fossil fuels and greenhouse gas emissions. These differential characteristics of the region with respect to developed countries have implications for energy transition, which could impact the deployment of clean technologies.

Identifying the non-economic barriers that limit the adoption of clean technologies and thus promote the energy transition process is a positive contribution to the design of public policies aimed at accelerating the process of modernization of the energy sector and the incorporation of new sectoral planning models.

Non-conventional renewable energies, essentially wind and solar photovoltaic, began to penetrate the energy matrix of many countries in the region very recently, with accelerated growth that was slowed down by a series of technical and economic barriers. Other very important energy sources such as hydroelectricity, geothermal energy and biofuels, have a long tradition and are relevant, but they also encounter obstacles to continue their expansion.

New technologies such as hydrogen or electricity storage are still in an embryonic stage of research and development, subordinated to the results from the main scientific and technological centers in the world and to the cooperation that multilateral institutions promote to encourage research and implementation in the Region.

Only 3 countries in the region produce electricity using nuclear energy: Argentina, Brazil and Mexico. The adoption of modern technologies in this field, such as small modular reactors (SMRs), presents strong barriers. Liquefied Natural Gas (LNG) marketed in small volumes can also represent a solution in the transition, particularly in Caribbean countries

In the first section of this document, a general description of the main non-economic barriers considered is made, disaggregated into their specific characteristics: a) technological; b) existing assets that block other alternatives (lock-in effect); c) institutional, which have to do with regulatory aspects, planning or mechanisms for the development of public policies, and d) social, individual or collective behaviors.

A matrix of barriers was developed to be used in the analysis by technology, by subregion and in some cases by country.

The second section analyzes the evolution of these technologies in the seven-year period 2016-2023. The selection of the period is due to the fact that new technologies were non-existent or their penetration was very incipient previously, and have subsequently penetrated the markets facing technical barriers that make them difficult to maintain the same rate of growth. New projects of mature technologies such as hydroelectricity, geothermal or biofuels are growing slowly, and immature technologies are in the process of development and require international cooperation.

Some success stories are analyzed in order to identify how existing barriers were overcome, as in the case of photovoltaic solar energy in Brazil or wind energy in Uruguay, and what lessons could be learned for the rest of the Region from these experiences.

The document ends with some conclusions, highlighting the existence of common data that can be treated in a similar way in the different countries to overcome problems that arise in the energy transition process. This will contribute to the understanding of regional cooperation and energy integration that allows for the optimal use of existing resources to replace the use of fossil fuels.

### **Section One - Barriers: Overview**

The introduction of non-conventional renewable energies in the energy systems of Latin America and the Caribbean is limited by different types of non-economic barriers, classified in Table No. 1.

Different analyses have been taken as a reference on barriers to technologies for climate change mitigation and in particular on the carbon lock-in effect (IPCC AR6 2022, Ceto et al. 2016, FTDT 2020). Since barriers to non-conventional or low-carbon renewable energy sources impact energy systems as a restriction on the reduction of greenhouse gas emissions, they have a negative influence on the energy transition process.

**General classification of technical barriers**

<b>Technological</b>	<b>Assets</b>	<b>Institutional</b>	<b>Behavior</b>
<b>Standards</b>	<b>Infrastructure</b>	<b>Decision-making processes</b>	<b>Individual</b>
<b>Compatibility and integration</b>	<b>Capital goods</b>	<b>Regulations</b>	<b>Collective</b>
<b>Local capacities</b>		<b>Energy planning</b>	
<b>Scales</b>			
<b>Technology maturity</b>		<b>Policies and programmes</b>	
<b>Risks during construction and during operation</b>		<b>Stakeholders</b>	

Barriers are classified into: a) technological (related to the technology that is proposed to be incorporated), b) assets (related to the existing assets in the systems), c) institutional and d) behavioral.

The different types of barriers are detailed as follows:

## 1. Technological

**Standards.** It refers to the need to prepare and adopt standards for new technologies. The most relevant cases are those related with sustainability and safety, in both cases for the construction and operation of the new infrastructure and new equipment. Trained technical teams are required to prepare new standards and also for regulatory institutions to approve and enforce them. These processes can cause delays in the incorporation of new technologies.

**Compatibility and Integration.** It is the ability of new technologies to be incorporated into the existing systems. It requires compliance with specific parameters for its correct operation and for the stability of systems, particularly electrical systems. Intermittency, the maintenance of frequency and voltage in power grids in the face of load loss, harmonic production, and other aspects must be considered when making investment decisions in new generation and transmission infrastructure. To overcome the barriers, it may be required to develop new regulations and/or adjustments to the existing systems for the incorporation of new technologies.

**Local capacities.** Training of teams that can meet the needs of these technologies is required with respect to: a) systems planning, b) project preparation, c) feasibility studies, d) construction and installation, and e) operation and maintenance. On the other hand, investment in infrastructure will be required, and also logistics and development of local suppliers for the installation and operation of the new equipment.

**Scales.** In some cases, new technologies may have scales that require significant efforts to incorporate them into the existing systems.

**Maturity of the technology.** There are cases of technologies in stages of development or recently incorporated into the markets, and their lack of knowledge is a barrier to their incorporation. It requires dissemination, research and development efforts.

**Risks during construction and operation:** the complexity of the resources that feed new technologies results in risks during the construction stage and then during operation. The resulting uncertainties and higher costs also become barriers in the decision process. Reservoir management in the case of geothermal energy or geological hazards in large dams are often presented as emblematic cases in this category. The effects of uncertainty on the handling and final disposal of nuclear fuel in SMRs could be added.

## 2. Assets

**Infrastructure.** The most important barrier is access to existing electricity transmission and distribution networks. This barrier could have physical aspects (networks operating at their maximum capacities) or regulatory aspects.

**Capital Goods.** Existing assets in systems can act as a barrier to the introduction of new technologies, as they compete for the same demand (lock-in effect).

## 3. Institutional

**Decision-making processes.** The decision-making processes in energy systems have been adapted to the classic technologies currently available. The need to count on national and regional planning bodies is highlighted. In general, specific measurements of the renewable resources (e.g., winds, heliophany, hydrology) are required at the project location, as well as additional studies that depend on the technologies to be implemented, such as: geotechnics, soil studies, physical connection to existing networks, electrical studies, and environmental and social feasibility.

**Regulations.** The regulations of energy systems in Latin America and the Caribbean date back in most cases to the 1990s, and do not generally consider the introduction of new technologies and their particularities, thus requiring revision and adjustment.

**Energy planning:** The specific characteristics of the incorporation of new technologies in electricity systems require the existence of short, medium and long-term plans. The absence of planning or the lack of consideration of new technologies in existing planning are barriers to their orderly penetration. The decarbonization commitments and the carbon neutrality objectives (2050) require the use of new planning methods known as "*back casting*", for which the availability of adequate modelling is required, in parallel with the analysis of trajectories of the "*forecasting*" type<sup>1</sup>.

**Policies and programs.** New policies and programmes are generally required. Their absence or delay in the preparation and adoption results in a barrier for entry. Some examples of elements that should be included : a) explicit vision of the State on the role of new technologies to be incorporated into the market; b) specific legislation that translates this vision into concrete long-term policies with objectives and incentives; c) operational regulation of the operation of these technologies in existing systems; d) Architecture of the contracting processes.

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<sup>1</sup> Pascal Charriau: Modelling energy systems: the new challenges, Enerdata, in Revue de l'Energie 658 September-October 2021

**Interest Groups.** There are groups with particular visions about systems and the incorporation of new technologies that can generate barriers to new technologies. Examples of these are the delays in the construction of the Belomonte hydroelectric project (11,000 MW) in Brazil, the suspension of the Windpeshi wind farm (205 MW) in La Guajira, Colombia, the indefinite postponement of the Portezuelo del Viento hydroelectric project (200 MW) in Argentina and the difficulties of the Ticul project (300 MW) of photovoltaic solar energy in Yucatán, Mexico.

#### 4. **Behaviour**

**Individual.** In some cases, the consumer directly incorporates the new technologies, which later requires a change in their behavior. Barriers can result from the need of information about the new technologies.

**Collective.** In other cases, incorporation is done at a collective level, for example, by a certain type of company, cooperatives or civil associations.

## **Section Two - Evolution of Decarbonization Technologies in the Electricity Sector in the period 2016=2023**

The analysis includes each of the technologies for the countries grouped according to the OLADE (Latin American Energy Organization) methodology:

1. Brazil;
2. Mexico;
3. Southern Cone: Argentina, Uruguay, Paraguay and Chile;
4. Andean Zone: Bolivia, Peru, Ecuador, Colombia and Venezuela;
5. Central America: Panama, Costa Rica, Nicaragua, Honduras, El Salvador, Guatemala and Belize and;
6. Caribbean: Barbados, Cuba, Grenada, Guyana, Haiti, Jamaica, Dominican Republic, Suriname and Trinidad and Tobago.

The technologies analyzed are the following:

1. Wind energy
2. Solar Energy: Photovoltaic, and Distributed Solar
3. Hydropower
4. Hydrogen
5. Nuclear modular: Small Modular Reactor
6. Storage (Battery, Pumping)
7. Cross-border interconnections
8. Geothermal
9. LNG. Small-scale regasification plants

The analysis matrices for each of the technologies mentioned above can be seen in the Annexes.

### ***1. Wind energy***

Wind energy is one of the oldest technologies used by man to obtain mechanical energy (e.g., pumping water, grinding). From this century onwards, accelerated development began with the aim of replacing fossil fuels in the production of electricity, being one of the main axes of decarbonization to meet the objectives of limiting greenhouse gas (GHG) emissions in the electricity production sector.

Technological evolution, with the increase in unit power modules of wind turbines and the decrease in unit production costs, facilitated a rapid penetration of wind energy into the world electricity matrix.

In the 1990s, wind turbines of around 300 kW were produced, the height of the tower did not exceed 40 meters and the rotor diameter was 13 meters; currently the largest onshore machines reach 200 meters in height, with rotors of 125 meters in diameter and powers of 5,000 kW, with some units exceeding 7,000 kW. This has enabled a growth model with the replacement of old equipment with higher power units, increasing the installed capacity in the same area.

A wind turbine is a system made up of the tower; an orientation system at its upper end; a main coupling cabinet attached to the base; a nacelle that houses the mechanical components of the mill and serves as the base for the rotor blades; a shaft and rotor control in front of the blades; and inside the nacelle, a brake, a multiplier, the generator and the electrical regulation system.

Wind projects require studies that include wind regimes at different heights at specific locations to determine the expected performance.

Wind turbines can operate in a variable wind range between 10 and 40 km/h. Below or above those speeds, these machines do not work due to lack of power or safety, respectively. The utilization factor can be less than 30%, with maximums in regions such as Patagonia in Argentina that can even exceed 60%. A barrier identified is visual impacts on the landscape, or prejudice to migratory birds that can see their natural routes interrupted and their survival affected. Another restriction to highlight is the feasibility of connection to transmission systems.

Wind farms can be located on land, but offshore installations are increasingly being analyzed, where the characteristics of the winds are usually more favorable, and the negative impacts on the landscape and the environment are also reduced, although these are more expensive and their development requires appreciable gains in competitiveness to reduce unit generation costs.

In off-shore installations, it is also necessary to differentiate between at least two technological types of wind turbines. On the one hand, those that are installed in shallow coastal areas and can be supported on the seafloor, with foundations specially designed for these conditions. In general, the average depths are in the order of 30 meters in the North Sea in Europe (Wind Europe; 2022) at an average distance from the coast of 33 kilometers.

In coastal areas with greater depths, such as in the Mediterranean Sea or on the Pacific coasts in America, off-shore wind farms require floating structures with semi-submersible platforms, or support platforms anchored to the seabed.

Wind energy began its penetration into the electricity systems of Latin America and the Caribbean in 2016, with a strong growth in the investment process in new onshore wind turbines, in almost all the subregions studied, with the exception of the Andean Zone and Central America. Offshore technology is not yet part of the Region's project portfolio.

In Brazil, installed wind power in 2023 (OLADE, 2024) was 13% of the country's total, and energy generated was 14%. The barriers were initially overcome, but there are still limitations that could slow down its growth, such as the weak interconnection of the Northeast system with the industrial areas of the center and south of the country, and the little development of local wind turbine production capacity. Brazil favors a strong local content in the equipment to be incorporated.

In the seven-year period analyzed, wind electricity production in Brazil grew at a cumulative annual rate of 15%. In 2023, installed capacity reached 29 GW (13% of the total).

Mexico had almost 7 GW of wind power installed in 2023, and although the growth of the wind farm has been significant, there are strong uncertainties regarding its continuity. Restrictions on the transmission network and regulatory changes have generated a "wait and see" effect on new investments.

In the Southern Cone, the development carried out by Uruguay stands out, with a participation of wind power plants in electricity generation close to 30%, driven by adequate legislation and the initiative of State institutions, particularly the Ministry of Mines and Energy and the state electricity company: State Administration of Power Plants and Electrical Transmissions (UTE). Uruguay's objective is to replace liquid fuels for electricity production (since it is a country that is a total importer of oil) and to export surplus electricity to Brazil and Argentina. The development of this technology was driven by the public sector, but implemented almost entirely by the private sector.

In Chile and Argentina, wind energy growth has been relatively moderate, reaching around 12% of total generation in each country in 2023. In both cases, the process of incorporating new wind power plants has encountered restrictions due to saturation in many sections of the transmission systems, which have become limiting barriers to the expansion of this technology. In Argentina, after the experience of auctions called Plan Renovar, which consisted of three rounds until 2019, and which allowed the incorporation of about 3000 MW in three years, the process was interrupted and not restarted.

Currently, in Argentina, the incorporation of new projects is being carried out within the so-called Renewable Energy Term Market, where private producers and industrial groups close long-term supply agreements.

In Central America, the Caribbean and the Andean Zone, the development of wind generation is of very low magnitude in absolute values, and the most important non-economic barriers to explain this behavior lie in the absence of policies and plans aimed at encouraging the development of studies of the resource and the potential of this technology for expansion.

## **2. *Photovoltaic Solar Energy***

Photovoltaic solar energy is obtained directly from solar radiation and allows electricity to be produced using semiconductor devices or thin metal-deposition films.

The efficiency of the panels, measured as the ratio between the electrical energy produced and the solar energy received, currently ranges between 15% and 23%, which, associated with the decrease in investment costs, has made this source very competitive compared to other electricity production alternatives. This huge leap in efficiency responds to the increase in the output power rating of standard-sized panels from 240-260W to 300-330W.

The following types of installations for the generation of electricity based on the photovoltaic solar source can be identified: a) installations in parks with high electrical power connected to the transmission network; b) individual residential, commercial or industrial photovoltaic installations that may or may not be connected to the distribution network. In both cases, they can also include battery storage systems.

The growth of this technology in Latin America and the Caribbean is remarkable. The growth experienced in Brazil, firstly, and then in Mexico is of note. With practically zero penetration in 2016, by the end of 2023 solar energy reached a penetration of more than 17% of the total installed capacity in Brazil and 8% in Mexico. The exception is the Andean Zone, where participation is near zero.

Recent regulatory changes in Brazil, with the opening of commercialization to all users without restrictions, has produced an exponential growth of photovoltaic solar energy powered by distributed generation, as we will see in the particular case of this country.

The promotion of electricity generation from the use of solar energy in Brazil is a clear case of success, becoming the second source of electricity in terms of installed capacity, after hydropower.

Brazil is one of the ten countries of the world with the highest installed photovoltaic capacity in the world. According to the Brazilian Solar Energy Association (ABSOLAR), it currently reaches 43 GW, that is, almost 19% of the installed capacity in the country, of which 70% (30 GW) corresponds to distributed generation and the rest to photovoltaic parks connected to the national interconnected system. Of the total installed capacity, 48% corresponds to the residential sector; 29% commercial and services; 14% rural; 7% industry and the rest to the public sector (ABSOLAR No. 68, June 2024).

This exponential growth does not seem to have reached a saturation point despite the fact that one of the great barriers to the continuity of the Distributed Generation impulse is the rates of financing in the retail residential segment, and the "shortcomings" in financial institutions to correctly evaluate distributed generation projects; although today there are more than 2.7 million systems connected to the grid. The new regulations of the law of micro and mini distributed generation have allowed this growth that has no parallel in the Region.

The distributed solar generation (DG) market in Brazil grew rapidly, fueled by the following factors that allow high profitability investments: i) sharp drop in the real price of photovoltaic generation systems in the last 5 years; ii) significant increase in electricity rates; and iii) implementation of the energy compensation system through Normative Resolution 482/2012 of ANEEL (net metering). ANEEL is the Brazilian National Agency of Electric Energy.

The expansion of this technology in Brazil could continue with greater availability of equipment and systems, making it essential to develop national suppliers so that projects can be implemented within the planned costs and deadlines.

Mexico has had a substantial development of its electricity production facilities with solar energy. However, the growth observed in the period 2016-2023 has encountered the following barriers<sup>2</sup>: 1) delays in obtaining permits for the construction of projects, which results in higher costs and reduces the competitiveness of the technology; 2) as in the case of wind energy, the availability of networks for the interconnection of new solar parks is reduced and produces restrictions on the transport and dispatch of production; 3) the fall in the prices of clean energy certificates due to regulatory modifications affects the profitability of projects and increases the unit price of solar energy; 4) electricity transmission tariff systems for connected plants make access more expensive and reduce competitiveness and; 5) system reliability policies, related to the intermittency of production.

The recent regulatory modifications, adopted by the CRE (Energy Regulatory Commission) in the Agreement of May 24, 2023 that allow combined cycle plants with natural gas to be considered as low carbon energy and therefore capable of receiving Clean Energy Certificates (CELs) while discouraging investments in wind or solar farms connected to the SIN, could lead to a prioritization of investments in smaller and less regulated Distributed Generation projects<sup>3</sup>, although results in this regard have not yet been detected.

Mexico's most recent electricity development plan, for the period 2022/2036, is seven years behind its commitment to generate 35% of its energy from renewable sources by 2024, postponing this goal to 2031, which could indicate a change in priorities in the country's energy strategy, at least in the short term.

Chile leads the Southern Cone in terms of photovoltaic solar energy, with a share of energy production in the country of 20%, in 2023. In Argentina and Uruguay, the share of solar energy is much lower: 2,7% and 3,8% respectively. Argentina has a large plant Cauchari in the province of Jujuy at an altitude of more than 4,000 meters, with the possibility of expanding its capacity of 300MW, but the distance from the consumption centers and the transmission restrictions pose barriers that so far have not been overcome.

The installed solar capacity in Chile at the end of 2023 (8971 MW; OLADE 2024) is second in Latin America, after Brazil and just above Mexico. Chile has been one of the pioneers in Latin America in encouraging its development. However, important barriers have been identified in a recent study that would be hindering its expansion (Chile Sustentable 2021). Listed below are those common in many cases to other countries in the region with similar market organization and also to other technologies such as wind power:

- 1) Difficulty of Free Competition and trends of market concentration
- 2) Distortion of the regulation on sufficiency: Energy Reserve State (Remuneration for availability of obsolete and inefficient thermal plants)
- 3) Transmission planning and pricing

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<sup>2</sup> Saldaña Méndez, Jaime Luis: "Five barriers that stop renewable energy investments in Mexico", Energy Cluster of Nueva León, Mexico, in Strategic Energy 8 June 2020

<sup>3</sup> It refers to the Agreement approved by the Energy Regulatory Commission on May 24, 2023. See statement from the Mexican Wind Energy Association (AMDEE) and the Mexican Solar Energy Association (ASOLMEX) of May 26, 2023.

- 4) Fixation, declaration and inspection of the actual operation of thermoelectric machines, with technical minimums
- 5) Limitation and lack of updating of Complementary Services
- 6) Limited conditions for distributed and residential generation (Net Billing)

In recent years, the production of photovoltaic solar energy in Chile has been restricted by various congestions in the transmission system and the delay in the construction of new lines. National and zonal transmission planning is carried out centrally by the National Energy Commission, with long materialization times.

In the case of Argentina, the saturation of transmission networks makes it difficult to execute new projects.

In Uruguay, the aim is to generate incentives by allowing a part of the installed power as a firm and remunerated power and thus foster incentives for greater investments.

In Central America, El Salvador stands out, where solar energy reaches the highest relative share in the Region, with 21% installed capacity and 16% in power generation, followed by Honduras with 19% and 9%, and Panama with a penetration of 13% and 6%, respectively. The installed capacity of solar photovoltaic plants in these countries in 2023 was close to 600 MW in each of them.

The rest of the countries of Central America, Guatemala, Nicaragua, Belize and Costa Rica do not register significant penetrations.

In the Andean region the penetration of photovoltaic solar energy does not exceed 1% and in the Caribbean Zone it is around 2,5%. However, Barbados in the Caribbean is an exceptional case since solar energy produced 10,4% of all electricity on this island in 2023, with an installed capacity close to 21% of the total. Although the absolute values are very low, the relative participation reveals efforts important to promote investments from solar sources, and their development could show a roadmap for the rest of the Caribbean countries, where solar photovoltaic participation is near zero.

### **3. *Hydropower***

This technology takes advantage of the potential energy of watercourses, which is proportional to the product of the flow and the jump in the use. There are different types of installations: a) a reservoir with weekly, monthly or annual regulation capacity; b) at the edge of water with little regulation capacity and c) pumping, which takes advantage of the difference in levels between reservoirs to store water in the upper reservoir and produce in periods of maximum demand.

Hydroelectricity provides auxiliary services to electricity systems such as power reserve, and frequency regulation, which other renewable technologies are not in a position to satisfy and therefore are an ideal complement to promote the penetration of all renewable technologies.

Hydroelectricity accounted for 14% of electricity generated globally (BP Statistical Review 2024) in 2023. In Latin America, with the exception of Mexico and the Caribbean, all subregions are well above the world average.

However, since the 1990s, the share of hydroelectricity in the energy generated has had a decreasing trend or is stagnant. In installed capacity, all subregions have maintained the values without variations or grown very slightly.

In 2023, the share of hydroelectricity in Brazil is 62% and the Andean Zone is 72% of the electricity produced. In Central America and the Southern Cone, this share is 37% and 39% of installed capacity, while Mexico and the Caribbean have a low proportion of hydroelectricity in their electricity matrix.

Latin America still has great potential to develop new hydroelectric projects that could be fully exploited, as indicated by various reports. The hydroelectric potential that could still be developed in Latin America is 275 GW in South America (IHA, 2021), 22 GW in Central America (SG-SICA, 2010) and 42 GW in Mexico (CFE, 2012) In addition, there may be an unidentified potential in pumping facilities and small hydroelectric developments (less than 50 MW). The International Energy Agency (IEA) shows in the Hydropower Special Market Report (2021) that there is an opportunity for this technology due to the auxiliary services that contributes to electrical systems.

Environmental aspects have acquired a very high relevance, and can generate barriers to the development of new hydroelectric projects. The lack of sustainability standards for construction, operation and maintenance can be an impediment to its implementation.

There are also specific risks that can result in barriers to investment. During the construction period, there may be lengthening of deadlines and increases in costs, due to circumstances that cannot always be identified in previous studies, such as inconsistencies in the geological conditions of the site. On the other hand, during the period of operation, there may be changes in prices and in the continuity of support policies. Another risk that can constitute a barrier is the hydrological one. Climate change can produce variations in hydraulic regimes due to modifications in snow and rainfall at the headwaters of rivers.

Projects, particularly large ones, require specific consideration in regulatory terms, as regards concession rights and water uses, long-term contract requirements to amortize significant capital investments, and agility in administrative processes to avoid extending deadlines that increase construction costs.

To strengthen the decision-making processes, pre-investment studies are necessary ranging from pre-feasibility to the execution of bidding documentation and technical preliminary projects, which generally have a cost that represents a non-negligible percentage of the total investment and are subject to risk if the project is not executed. However, the absence of these kinds of studies does not allow making the adequate decisions to consider all the variables of this type of large works. For example, studies of hydropower resource inventories are relevant, with those corresponding to pumping projects being very limited to date.

Related to the growing importance of social and environmental aspects, projects must address the particular visions of stakeholders so that they do not become a barrier to their acceptance.

#### **4. Hydrogen**

The successful implementation of Green Hydrogen (GH<sub>2</sub>) production will play a critical role in reducing greenhouse gas emissions, particularly in the transport and industrial sectors.

While the costs of solar and wind power have decreased significantly, this is still not enough to reduce electricity costs for the production of Green Hydrogen. The green hydrogen value chain is made up of the following processes:

1. Production and transformation: The production of GH<sub>2</sub> involves the process of electrolysis, whereby hydrogen is obtained in gaseous form.
2. Transportation and storage: Gaseous hydrogen can be transported through dedicated pipelines or existing pipelines. It can also be compressed and transported in trucks, trains or ships, or in the form of ammonia in liquid form at room temperature. It can be stored in various forms, including underground geological formations, in high-pressure tubes, or in steel and composite tanks.
3. End use: Hydrogen has multiple purposes as a feedstock, fuel, or energy storage medium. It can be used directly in industrial applications, for electric power generation, for heating uses, or as fuel for various modes of transportation, including road, sea, air, and rail. In addition, it can be blended with natural gas for certain applications or used in the production of green ammonia, green methanol, fertilizers, and synthetic fuels.

In Latin America and the Caribbean, several countries have published specific strategies in the last three years<sup>4</sup> (IADB, 2023).

Hydrogen demand in Latin America and the Caribbean (LAC) is expected to increase, driven by existing and new applications. In 2019, total hydrogen demand in the region was 4.1 million tonnes (MT), and is projected to increase to nearly 7 MT by 2030 (IEA, 2021).

The main concentration of demand is seen in countries such as Argentina, Brazil, Chile, Colombia, Mexico, Trinidad and Tobago, and Venezuela, mainly for the production of ammonia, methanol and refined products. These traditional uses will continue in most countries in the region, while new applications are expected to appear to replace fossil fuels in industries (such as cement, steel) and transport, and not only as hydrogen but through its derivatives, such as green ammonia and green methanol. In addition, it is being explored to transport hydrogen in small proportions through the natural gas infrastructure, for residential use.

For hydrogen production to grow, it is crucial to develop additional renewable energy capacity in the region. Another conditioning factor for the development of hydrogen is the capacity of port infrastructure, storage and logistics for international trade.

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<sup>4</sup> Chile, Colombia, Uruguay, Costa Rica, Trinidad and Tobago, and Panama. Paraguay and Argentina have established initial hydrogen roadmaps. Bolivia, Brazil, Ecuador and Peru are in the process of developing specific strategies

The estimated demand for GH2 in 2030 would reach 140 million tons/year, 10% of this demand would be subject to international trade of H2 from the European Union (12 Mt), Japan and South Korea (2 Mt), and the export potential from LATAM to these destinations could reach between 3 and 4 Mt/year<sup>5</sup>.

The certification of the product to demonstrate that it has been produced with energy from renewable sources plays a vital role in the international commercialization of hydrogen and its derivatives. Regional cooperation can play an important role in complementing national strategies and enhancing LAC's competitiveness in the global H2V market.

### **5. Nuclear Energy: Small Modular Reactors (SMRs)**

At the time of electrification of consumption, nuclear energy cannot be excluded from the set of options for electricity production: it is part of the low-carbon solutions of the future, especially for its firm power nature that is so necessary as the participation of photovoltaic and wind energy increases. Nuclear energy has the intrinsic advantage of being part of the dispatchable and controllable means of production, complementary to renewable, intermittent and non-storable production. While the production costs of renewable energies have been continuously reduced in recent decades, the costs of "historic" nuclear energy, i.e. large-scale projects (1000-1200 MW) have increased sharply, especially after the Fukushima accident (Japan, 2011).

In this context, small modular nuclear reactors, known under the generic name of Small Modular Reactor or SMR, appear as a solution. The United States, China, Russia and other countries are currently working on these mini nuclear reactors, also called AMR (Advanced Modular Reactor), MMR (Micro Modular Reactor) or XSMR (Extra Small Modular Reactor) and are developing micro generators of electrical power from 1 to 350 MW for large-scale production. They do so with the active support of their respective governments (Derdevet, Michel, Mazzucchi Nicolas, 2021).

Units of lower power, built in industrial series, grouped or isolated, appear as particularly relevant solutions. A significant evolution of the sector is observed, with the appearance of new projects, of different sizes, different production paradigms or different applications that can reach different uses.

The main barriers to this technology are: a) the existence of opposing views to nuclear energy in society; (b) the need for a scientific and technological community with relevant knowhow and practical experience in the management of nuclear energy for civilian uses; c) the need to have a clear political direction that leads to the creation of control and regulatory institutions that includes this technology in planning and decision-making processes, d) agreement with the international community on adherence to nuclear non-proliferation treaties as well as restrictions on the handling of fuels for transport and final deposition, under the supervision and safeguards established by the IAEA.

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<sup>5</sup> IADB: op. Cit.

The technology of small modular reactors for electricity generation is not yet mature, but it is in the research, development and demonstration phase.

The only countries with nuclear technology capabilities and development in Latin America and the Caribbean are Argentina, Brazil and Mexico, which have large-modulus reactors of different technologies. In the case of Argentina, a 28 MW prototype called CAREM is under development, with no certainty regarding its completion date. There are no expectations that other countries in the Region will develop sufficient capacities for the implementation of technologies of this type.

## **6. *Battery Electrical Energy Storage***

Battery storage of electrical energy has significant barriers due to technical and economic limitations to fulfill its function efficiently on a large scale. Currently, energy storage relies on technologies with constraints, such as limited capacity and lifetime, and environmental issues, such as sourcing and disposal of materials. In addition, energy storage can be expensive due to the need to retrofit energy and electrical systems, and to the high capital expenditure involved. This requires the introduction of different types of storage into the regulation of charging systems.

Energy storage will become an increasingly important part of power grids as generation based on intermittent non-conventional renewables increases. Energy storage systems, such as batteries or pumped storage hydroelectric plants (see Hydroelectricity), can support the integration of increasing shares of variable renewable electricity generation and effectively balance the growing electrified demand over different timescales, from milliseconds to seasonal periods.

The location of hydraulic pumping plants depends on the topography and requires a minimum altitude for the upper reservoir. In general, the best regions coincide with the major mountain ranges.

Battery systems are becoming more common thanks to technological advancements and lower costs. Global installed capacity reached 27 GW (108 gigawatt hours [GWh]) by the end of 2021 (IEA, Energy Technology Perspectives, 2023).

Because batteries are modular and scalable, they can be quickly deployed anywhere to balance variable renewable generation and provide diverse grid services in a short time, instantly responding to sudden imbalances between supply and demand and maintaining frequency and voltage stability. Battery systems equipped with virtual synchronous machine control algorithms can offer an inertial response similar to the mechanical inertia provided by rotating machines.

Battery costs are falling rapidly at the same time as technical parameters, such as degradation rate and energy density, are improving. This is expected to play a key role in increasing flexibility in the energy sector and enable a greater penetration of renewables in a context of reliability of supply. In the current situation, technology is in the process of maturing (IRENA 2020).

## 7. *Cross-border electricity interconnections (Regional Energy Integration)*

The benefits that can be assigned to international electricity interconnections have been widely studied<sup>6</sup>: expansion of markets, optimization and/or complementarity in the use of natural resources with a variety of non-CO2 emitting sources (hydroelectricity, biomass, solar and wind) that have significant potential in the energy transition process. The exploitation of shared resources and the improvement of security of supply levels, together with the local and global environmental benefits of reducing the emission of pollutants, are concrete examples of virtuous regional integration.

However, for these benefits at the "economic" or "social" level to work, they must produce identifiable economic benefits for all participants, which would compensate for the costs and/or losses that States (power and control), or private participants eventually have to assume in the process

The main barriers identified for cross-border electricity integration (CIER, 2013, 2019) are summarized below:

1. Changes in the regulatory guidelines of the interconnected countries; for example: Argentina had an electricity market in the 90s, with deregulated generation that has now led to a heavily regulated market. These changes change the rules of the game and constitute barriers to interconnections;
2. Differences between market designs among countries (countries with centralized state management and countries with a public/private market scheme);
3. Distrust between countries for historical reasons and due to contractual breaches (electricity and natural gas);
4. Price distortions (subsidies, taxes);
5. Reduction in the supply of financing for infrastructure development;
6. Need of feasibility studies that include identification of structural benefits: a) reduction of operating costs; (b) increased reliability of supply; c) reduction of GHG emissions;
7. Need of development of proposals to share the benefits obtained through integration among consumers in interconnected countries;
8. Absence of trade schemes preserving the autonomy and energy policy of the countries and their corresponding institutional support (treaties and agreements).
9. Lack of coordinated planning and governance with the exception of the SIEPAC model in Central America.
10. Technical requirements of the coordinating bodies for the administration and dispatch of national electricity systems.

In Latin America, three different models of integration or electricity exchanges can be identified (CIER, 2009):

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<sup>6</sup> Regional Energy Integration Commission (CIER): SIESUR Project, Energy Integration System of the Southern Cone",

1. In Central America, the construction of the 500 kV interconnection (Electrical Integration System for Central America: SIEPAC) led to the creation of an integrated system with common and dedicated regulatory and dispatch institutions. The Regional Electricity Market (MER) was created. The ownership of the infrastructure belongs to a Network Owner Company (EPR), whose shareholders are the national transmission companies of Guatemala, Honduras, El Salvador, Nicaragua, Costa Rica and Panama, ENEL of Italy and ISA of Colombia.

The instruments for the operation of the Regional Electricity Market (MER) created the following institutions: the Regulatory Commission (CRIE) and the Regional Operator Entity (EOR). The MER is a wholesale market with spot transactions and contracts between market agents and is independent from national markets, although it uses their networks for the purchase and sale of electricity between qualified agents.

2. In the Andean Community there are several border interconnections between Colombia and Venezuela; Colombia and Ecuador and Ecuador and Perú. There are actions by countries aimed at creating regulations for the creation of a regional market. In 2017, the Andean Regional Short-Term Electricity Market (MAERCP) was created, maintaining the validity of the transitional regime between Colombia and Ecuador; and between Ecuador and Perú, until the corresponding Operational, Commercial and Regional Coordinator Regulations are approved and published.

The technical body for discussion and analysis in the Andean Community is the Andean Committee of Regulatory Bodies and Regulatory Bodies for Electricity Services (CANREL), which has the participation of representatives of the Electricity Regulatory and Regulatory Bodies of each member country. Within the framework of CANREL, the Member Countries, with the support of the General Secretariat, formulate and analyze proposals conducive to advancing the process of harmonizing the necessary regulatory frameworks or for the full implementation of the Subregional Interconnection of Electricity Systems and Intra-Community Electricity Exchange.

3. In the Southern Cone, integration and electricity exchanges are developed through bilateral agreements; there is no regional body as in the two previous cases. The main interconnections are located in the Itaipú binational hydroelectric plants, between Brazil and Paraguay; Yacyretá, between Paraguay and Argentina, in both cases on the Paraná River; and between Argentina and Uruguay at the Salto Grande hydroelectric plant on the Uruguay River. There is also a link between Argentina and Brazil, with a 50/60 Hertz converter station Garabí, which allows exchanges of up to 2000 MW between the two countries.

All these operations are carried out through interconnection agreements, which contemplate compensated exchanges in emergency situations and commercial operations taking advantage of price arbitrages.

The development of the wind farms in Uruguay led to the construction of a 500 kV interconnection line between Uruguay and Brazil in 2019, linking the San Carlos Power Station, passing through the 50/60 Hz converter in Melo and reaching the Medici Power Plant in Candiota, Brazil, which is added to the existing 150 kV interconnection, linking the towns of Rivera (Uruguay) and Santa Ana do Livramento (Brazil) by which the first country can evacuate surplus wind generation. They are commercial operations managed by the dispatch institutions in both countries (Uruguay's national electric utility: UTE and Brazil's National System Operator, ONS).

There is a 330 kV interconnection between Argentina and Chile in the north of both countries, crossing the Andes Mountains. Also, a 132 kV line between Argentina and Bolivia has recently been put into service linking a thermoelectric plant in the department of Tarija (Bolivia) with the Argentine Interconnection System.

To date, no progress has been identified in the structuring of a regional market in the Southern Cone, despite the fact that strong interconnections have been operating since the 1980s and the integration of the markets of Argentina, Uruguay, Paraguay and Brazil could generate benefits by optimizing the exploitation of shared resources, promoting the use of renewable resources in the energy transition process. The interconnection between the Itaipú, Yacyretá and Salto Grande Hydroelectric Power Plants within the scope of MERCOSUR is a very interesting project that would make it possible to advance in the general process of electricity integration among the countries.

## **8. *Geothermal energy***

Geothermal energy is obtained by harnessing the Earth's internal heat. When the temperature in the reservoir is above 150°C, enough heat can be extracted to produce electrical energy from water vapor. A drilling system to the reservoir is required, to extract the existing heat in the form of steam, conducting it to the surface where it must generally be treated to be in a position to enter the turbogenerator system, driving it and producing electricity. The condensate is reinjected into the reservoir through other independent boreholes, to maintain the level and pressure of the reservoir.

This type of energy is used in Mexico, which has an installed capacity of 976 MW (1% of installed capacity in 2023), and in Central América. In Costa Rica, the installed capacity is 263 MW and represents 8% of the total, El Salvador has 209 MW installed and 7% of the total capacity, Nicaragua with 165 MW and 10% penetration in the electricity matrix, and to a lesser extent Honduras (50 MW) and Guatemala (39 MW). In South America, only Chile has a geothermal capacity of 78 MW. The location of the projects responds to the characteristic geology of the Pacific volcanic belt.

The main barrier to the development of this technology is related to the risks of exploration for resource identification and the long deadlines for the development of projects. Initial development (exploration) is extremely risky and costly, constituting a significant barrier to investment.

## 9. *Liquefied Natural Gas – Small-Scale Plants*

This technology is included as it is considered as part of a strategy in the energy transition towards decarbonization, particularly suitable for small and island countries in Central America and the Caribbean: however, in some cases, it is considered as an alternative in Ecuador and other countries in South America.

The International Gas Union (IGU) defines small-scale liquefaction and regasification plants as those with capacities of 0.05 million tonnes per year (MTPA) to 1 MTPA, equivalent to an interval between 200 thousand and 4 million m<sup>3</sup>/day.

The main barriers are: a) development of port infrastructure in regasification plants and, in the event that there is no natural gas consumption in the destination considered, transport and distribution networks to final consumers; (b) local technical capacities for planning, project preparation, operation and maintenance of systems, coordination of operation; c) LNG purchasing capacity in the different markets. Distribution to end consumers has different complexities depending on the type of consumer: residential, small industries, large industrial users or electricity generators.

Decision processes require the development of comprehensive feasibility studies, and the small scale of demands suggests regional coordination for the optimization of purchasing processes.

## CONCLUSIONS

Two aspects stand out in the identification of non-economic barriers to non-greenhouse gas emitting technologies.

First, the decision processes, regulations, existing infrastructure, and technological frameworks of existing systems are designed and adapted to conventional technologies. The competitiveness achieved by wind and solar sources together with significant cost reductions bring these renewable sources to a level called grid parity taking into account the levelized costs of energy produced (LCOE).

Environmental considerations impact energy projects in two dimensions. From a global perspective, the commitment to reduce greenhouse gas emissions results in the need to increase the share of low- or zero-carbon energy sources. From the local level, the social perception of the negative environmental impacts of energy projects has grown.

These new circumstances generate common barriers to almost all technologies: regulatory, infrastructure and technological, since all systems and processes are adapted to the already existing classic technologies.

In Latin America and the Caribbean, these trends became significantly evident from the second decade of this century, with the advantage of the learning achieved in developed countries. The technological evolution of facilities for the production of electricity from non-CO<sub>2</sub> emitting sources accelerated its penetration in some subregions based on the commitments assumed within the Paris Agreement framework.

The new technologies evolve differently, depending on the specific policies implemented in each country. Hydroelectricity has historically played an important role in the electricity matrix of almost all countries in the Region, except Mexico and the Caribbean. On the other hand, geothermal energy has a relevant participation in the volcanic belt that runs from Mexico to Central America whereas only three countries have nuclear technology. Biofuels are relevant in Latin America countries.

In this context, the penetration of new electricity generation technologies such as wind and solar has occurred in different ways and at different speeds.

In some cases, participation has grown rapidly and continues this trend, indicating that non-economic barriers were identified and lifted.

In others, after an initial period of accelerated growth, this participation stopped as a result of barriers not initially identified, such as the saturation and lack of adaptation of electricity transmission systems and the need to have adequate reserves for the operation of intermittency in the electricity production generated by wind and solar sources.

Cases have also been identified where these new technologies have not yet managed to be introduced into the electricity markets of some countries, which would indicate that there has been no political intention to deepen these processes.

In short, where non-economic barriers could be overcome, there was a rapid growth of new technologies in the first stage. Then, in a second phase, new barriers, such as the saturation of long-distance transmission systems, delay growth and in a third stage, growth is resumed under new characteristics (distributed generation in Brazil, as an example), or there is a momentary stoppage due to the lack of adequate solutions.

The solution for bottlenecks in the transport and distribution infrastructure, and the competitiveness of new technologies, requires long-term policies and specific expansion plans that encourage the development of new technologies, as well as the economic and social feasibility of the projects that consolidate the solutions adopted, in a continuous and dynamic process.

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## ANNEX 1: Power and energy data in Latina América and Caribe

INSTALLED CAPACITY RENEWABLES 2023 (MW)														
Country	Installed Capacity (MW)										% ERNC	Wind	FV Solar	Geothermal
	Total	Nuclear	Hydro	Solar	Wind	Geothermal	Biogas	Thermal Renewables	%					
Argentina	44424	1755	11359	1366	3705	0	0	151	37%	12%	8%	3.1%	0%	
Barbados	319	0	0	67	0	0	0	0	21%	21%	0%	21.0%	0%	
Belice	135	0	55	5	0	0	0	22	61%	20%	0%	3.7%	0%	
Bolivia	4154	0	759	172	135	0	0	224	31%	13%	3%	4.1%	0%	
Brasil	222636	1990	109922	37843	28682	0	0	13655	85%	36%	13%	17.0%	0%	
Chile	34503	0	7591	8971	4830	86	0	605	64%	42%	14%	26.0%	0%	
Colombia	19994	0	13206	522	18	0	0	210	70%	4%	0%	2.6%	0%	
Costa Rica	3500	0	2372	5	408	263	0	71	89%	14%	12%	0.1%	8%	
Cuba	5369	0	65	255	12	0	0	440	14%	13%	0%	4.7%	0%	
Ecuador	8900	0	5192	29	71	0	0	153	61%	3%	1%	0.3%	0%	
El Salvador	2998	0	638	633	54	209	0	304	61%	33%	2%	21.1%	7%	
Grenada	59	0	0	4	0	0	0	0	7%	7%	0%	6.8%	0%	
Guatemala	3435	0	1514	100	107	38	0	576	68%	23%	3%	2.9%	1%	
Guyana	345	0	0	15	0	0	0	12	8%	8%	0%	4.3%	0%	
Haiti	482	0	78	4	0	0	0	0	17%	1%	0%	0.8%	0%	
Honduras	3219	0	917	600	241	50	0	220	63%	33%	7%	18.6%	2%	
Jamaica	1061	0	29	82	102	0	0	0	20%	17%	10%	7.7%	0%	
Mexico	89008	1608	12612	7469	7055	976	0	2729	35%	19%	8%	8.4%	1%	
Nicaragua	1627	0	158	16	186	165	0	218	46%	26%	11%	1.0%	10%	
Panama	4130	0	1845	543	336	0	0	75	68%	23%	8%	13.1%	0%	
Paraguay	8842	0	8760	1	0	0	0	80	100%	1%	0%	0.0%	0%	
Peru	16362	0	5544	401	1016	0	0	205	44%	10%	6%	2.5%	0%	
Republica Dominicana	5675	0	623	675	417	0	0	30	31%	20%	7%	11.9%	0%	
Suriname	586	0	189	9	0	0	0	2	34%	2%	0%	1.5%	0%	
Trinidad y Tobago	2032	0	0	0	0	0	0	0	0%	0%	0%	0.0%	0%	
Uruguay	5263	0	1538	301	1517	0	0	731	78%	48%	23%	5.7%	0%	
Venezuela	30979	0	18246	5	23	0	0	50	59%	0%	0%	0.0%	0%	
<b>TOTAL</b>	<b>520037</b>	<b>5353</b>	<b>203212</b>	<b>60093</b>	<b>48915</b>	<b>1787</b>	<b>0</b>	<b>20763</b>						
Regional Groups	Total	Nuclear	Hydro	Solar	Wind	Geothermal	Biogas	Thermal Renewables	%	% ERNC	Wind	FV Solar	Geothermal	
Brasil	222636	1990	109922	37843	28682	0	0	13655	85%	36%	13%	17.0%	49%	
Mexico	89008	1608	12612	7469	7055	976	0	2729	35%	19%	8%	8.4%	14%	
South Cone	93032	1755	29248	10639	10052	86	0	1567	55%	24%	11%	11.4%	31%	
Andean Region	80389	0	42947	1129	1263	0	0	842	57%	4%	2%	1.4%	53%	
Central America	19044	0	7499	1902	1332	725	0	1486	68%	25%	7%	10.0%	39%	
Caribeann	15928	0	984	1111	531	0	0	484	20%	13%	3%	7.0%	6%	

Source. Latino American Energy Organization (OLADE). Energy Outlook for Latin America and the Caribbean (2024)

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Trinidad y Tobago	2032	0	0	0	0	0	0	0	0%	0%	0%	0.0%	0%
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Source. Latino American Energy Organization (OLADE). Energy Outlook for Latin America and the Caribbean (2024)

## Participation and growth of technologies: Wind, Solar and Hydropower. 2016- 2023

<b>Hydropower</b>						
	<b>Share (%)</b>				<b>Growth CAGR (%)</b>	
	<b>Power Capacity</b>		<b>Energy Generation</b>		<b>Power Capacity</b>	<b>Energy Generation</b>
	2023	2016	2023	2016		
Brazil	49.4%	65.2%	61.5%	66.0%	2%	2%
Mexico	14.2%	21.0%	5.9%	9.5%	1%	-5%
Southern Cone	31.4%	40.5%	38.8%	40.5%	0%	-2%
Andean Region	53.4%	50.6%	69.8%	52%	2%	4%
Central America	39.4%	42.2%	36.8%	42.7%	1%	3%
Caribbean	6.2%	5.8%	4.3%	4.7%	0%	0%
<b>Wind</b>						
	<b>Share (%)</b>				<b>Growth CAGR (%)</b>	
	<b>Power Capacity</b>		<b>Energy Generation</b>		<b>Power Capacity</b>	<b>Energy Generation</b>
	2023	2016	2023	2016		
Brazil	12.9%	6.8%	13.8%	5.8%	16%	16%
Mexico	7.9%	1.2%	6.0%	0.8%	39%	36%
Southern Cone	10.8%	3.5%	10.4%	1.9%	22%	26%
Andean Region	1.6%	0.5%	1.2%	0%	20%	14%
Central America	7.0%	6.4%	6.4%	6.1%	4%	5%
Caribbean	3.3%	1.5%	2.2%	0.9%	12%	15%
<b>Solar PV</b>						
	<b>Share (%)</b>				<b>Growth CAGR (%)</b>	
	<b>Power Capacity</b>		<b>Energy Generation</b>		<b>Power Capacity</b>	<b>Energy Generation</b>
	2023	2016	2023	2016		
Brazil	17.0%	0.1%	7.3%	0.01%	149%	149%
Mexico	8.4%	0.3%	5.3%	0.1%	89%	55%
Southern Cone	11.4%	1.8%	7.4%	0.9%	50%	34%
Andean Region	1.4%	3.6%	0.9%	2%	24%	12%
Central America	10.0%	0.2%	5.1%	0.1%	62%	45%
Caribbean	7.0%	0.9%	2.4%	0.2%	40%	47%

Source. Latino American Energy Organization (OLADE). Energy Outlook for Latin America and the Caribbean (2024)

## Annex 2: Barriers per technology

### Wind

Technological	Assets	Institutional	Behavior
<p><b>Standards.</b> No identified barriers</p>	<p><b>Infrastructure.</b> Existence of and access to electrical transmission capacity Need to adapt the electrical transmission infrastructure (e.g., protections).</p>	<p><b>Decision-making processes.</b> Need for general and specific basic studies on the location of the projects (evaluation of the resource) and feasibility.</p>	<p><b>Individual.</b> No identified barriers</p>
<p><b>Compatibility and Integration.</b> Integration requires solutions for services that wind energy cannot bring to the system, such as power reserve and frequency regulation.</p>	<p><b>Capital goods.</b> No identified barriers</p>	<p><b>Regulations.</b> Unprovided service costs charged to this technology.</p>	<p><b>Collective:</b> No identified barriers</p>
<p><b>Local capacities.</b> Local capacities should be developed for planning, project preparation, installation, operation and maintenance. Infrastructure (e.g., cranes), Human Resources.</p>		<p><b>Energy planning.</b> Necessary condition</p>	
		<p><b>Policies and programs.</b> Necessary condition.</p>	
		<p><b>Stakeholders.</b> Other generators. Fuel suppliers. Environmental</p>	

## Solar photovoltaic

Technological	Assets	Institutional	Behavior
<p><b>Standards.</b> No identified barriers</p>	<p><b>Infrastructure.</b> Infrastructure. Existence of and access to electricity transmission capacity. Need to adapt the electricity transmission infrastructure (e.g., protections).</p>	<p><b>Decision-making processes.</b> Need for general and specific basic studies in the location of the project (evaluation of the resource) and feasibility.</p>	<p><b>Individual.</b> For the case of distributed generation, the lack of knowledge of the technology</p>
<p><b>Compatibility and Integration.</b> Integration requires solutions for services that PV cannot bring to the system, such as power reserve and frequency regulation. Integration of distributed generation into urban grids</p>	<p><b>Capital goods.</b> No identified barriers</p>	<p><b>Regulations.</b> Connection and exchanges with the distribution network (distributed generation)</p>	<p><b>Collective.</b> For the case of distributed generation, the lack of knowledge of technology</p>
<p><b>Local capacities.</b> Local capacities should be developed for planning, project preparation, installation, operation and maintenance. Infrastructure, Human Resources.</p>		<p><b>Energy planning.</b> Necessary condition</p>	
		<p><b>Policies and programs.</b> Necessary condition.</p>	
		<p><b>Stakeholders.</b> Other generators, distribution companies, fuel suppliers, environmental.</p>	

## Cross-border electricity interconnections (Regional Energy Integration)

Technological	Assets	Institutional	Behavior
<b>Standards:</b> Common Electrical Safety and System Operation Regulations	<b>Infrastructure.</b> Access to transport capacity in interconnected systems. Need for adjustment in transmission systems	<b>Decision-making processes.</b> Need for complete feasibility studies (technical, economic and environmental), for new projects	<b>Individual.</b> No barriers identified
<b>Compatibility and Integration.</b> Installations that reconcile frequency differences and voltage regulation	<b>Capital goods.</b> No barriers were identified	<b>Regulations.</b> Interconnection Agreements, and Coordinating Bodies	<b>Collective.</b> Social acceptance in interconnected countries (importer and exporter)
<b>Local capacities.</b> Local capacities should be developed for planning, project preparation, installation, operation and maintenance. Infrastructure, Human Resources.		<b>Regional energy planning.</b> Necessary condition	
		<b>Policies and programs.</b> A necessary condition.	
		<b>Stakeholders.</b> Electricity market players, industries in general, consumer groups	

## Hydropower

Technological	Assets	Institutional	Behavior
<p><b>Standards.</b> Need to incorporate sustainability standards for construction and operation</p>	<p><b>Infrastructure.</b> Existence of and access to transmission networks for the evacuation of the energy generated</p>	<p><b>Decision-making processes.</b> Need for complete feasibility studies (technical, economic and environmental). Need for hydrological resource assessment studies</p>	<p><b>Individual.</b> No barriers were identified</p>
<p><b>Compatibilidad e Integración.</b> No se identificaron barreras</p>	<p><b>Goods for use.</b> No barriers were identified</p>	<p><b>Regulations.</b> Need for specific regulation for this type of technology (water uses, long-term contracts, administrative processes)</p>	<p><b>Collective.</b> Barriers are considered in Stakeholders</p>
<p><b>Local capacities.</b> Local capacities should be developed for project preparation, installation, operation and maintenance. Infrastructure, Human Resources. In some cases, these capacities existed, but they may have been lost for long periods without the construction of exploitation</p>		<p><b>Energy planning.</b> Necessary condition</p>	
<p><b>Scales:</b> Need to attend to the acceptance of large-scale projects</p>		<p><b>Policies and programs.</b> A necessary condition.</p>	
<p><b>Risks during construction.</b> Lengthening construction timelines, cost increases  <b>Risks during the operation.</b> Uncertainties about prices and continuity of support policies, hydrological</p>		<p><b>Stakeholders.</b> Other generators, fuel suppliers, environmental</p>	

## Geothermal energy

Technological	Assets	Institutional	Behavior
<b>Standards.</b> Need for environmental regulations for construction and operation	<b>Infrastructure.</b> Access to transport capacity.	<b>Decision-making processes.</b> Need for complete feasibility studies (technical, economic and environmental). Need for reservoir studies.	<b>Individual.</b> No barriers were identified
<b>Compatibility and integration.</b> No barriers were identified	<b>Capital goods.</b> No barriers were identified	<b>Regulations.</b> No barriers were identified	<b>Collective.</b> No barriers were identified
<b>Local capacities.</b> Local capacities should be developed for planning, project preparation, installation, operation and maintenance. Infrastructure, Human Resources.		<b>Energy planning.</b> Necessary condition	
<b>Maturity of the technology.</b> No barriers were identified		<b>Policies and programs.</b> A necessary condition.	
<b>Risks during exploration and construction.</b> High exploration costs and lengthening development periods.		<b>Stakeholders.</b> Environmental	

## Battery Electrical Energy Storage

Technological	Assets	Institutional	Behavior
<p><b>Standards.</b> Need for Safety Regulations for its operation and for final disposal.</p>	<p><b>Infrastructure.</b> Access to transmission and distribution capacity. Need for adjustment in transmission and distribution systems</p>	<p><b>Decision-making processes.</b> Need for complete feasibility studies (technical, economic and environmental).</p>	<p><b>Individual.</b> Investments in own generation equipment, training for basic knowledge of operation and equipment</p>
<p><b>Compatibility and integration.</b> No barriers have been identified</p>	<p><b>Capital goods.</b> No barriers have been identified</p>	<p><b>Regulations.</b> Storage Service Pricing</p>	<p><b>Collective.</b> Dissemination of experiences on social networks. Actions in chambers and business associations</p>
<p><b>Local capacities.</b> Local capacities should be developed for planning, project preparation, installation, operation and maintenance. Infrastructure, Human Resources.</p>		<p><b>Energy planning.</b> Necessary condition</p>	
<p><b>Maturity of the technology.</b> Need to develop R+D and Pilots</p>		<p><b>Policies and programs.</b> A necessary condition.</p>	
		<p><b>Stakeholders:</b> no barriers identified</p>	

## Development of the hydrogen industry

Technological	Assets	Institutional	Behavior
<p><b>Standards.</b> Certification of the H2 produced. Storage and transportation safety specifications to control volatility, leakage, and other product-related risks</p>	<p><b>Infrastructure.</b> Analysis of H2 transport logistics. Particular case of natural gas networks</p>	<p><b>Decision-making processes.</b> Need for complete feasibility studies (technical, economic and environmental).</p>	<p><b>Individual.</b> No barriers were identified</p>
<p><b>Compatibility and Integration.</b> No barriers were identified</p>	<p><b>Capital goods.</b> No barriers were identified</p>	<p><b>Regulations.</b> Minimum cut-off requirements of the H2/NG mixture in natural gas transportation infrastructure. Regulations for retrofitting equipment that currently burns fossil fuels.</p>	<p><b>Collective.</b> No barriers were identified</p>
<p><b>Local capacities.</b> Local capacities should be developed for planning, project preparation, installation, operation and maintenance. Infrastructure, Human Resources.</p>		<p><b>Energy planning.</b> Necessary condition</p>	
<p><b>Maturity of the technology.</b> Need to develop R+D and Pilots</p>		<p><b>Policies and programs.</b> A necessary condition.</p>	

## Development of small modular nuclear reactors (SMRs)

Technological	Assets	Institutional	Behavior
<b>Standards.</b> Safeguards regime. Fuel management and waste disposal	<b>Infrastructure.</b> Access to transport capacity taking into account the modularity of the reactors and future expansions. The location has to take into account access to water for cooling	<b>Decision-making processes.</b> Need for complete feasibility studies (technical, economic and environmental).	<b>Individual.</b> No barriers were detected
<b>Compatibility and Integration.</b> No barriers were detected	<b>Capital goods.</b> No barriers were detected	<b>Regulations.</b> Nuclear Activity Control and Regulation Institutions with IAEA-supervised safeguards	<b>Collective.</b> No barriers were detected
<b>Local capacities.</b> Local capacities should be developed for planning, project preparation, installation, operation and maintenance. Infrastructure, Human Resources. International cooperation		<b>Energy planning.</b> Necessary condition	
<b>Maturity of the technology.</b> Need to develop R+D and Pilots		<b>Policies and programs.</b> A necessary condition.	
		<b>Stakeholders.</b> Other generators, fuel suppliers, environmental	

## Development of small Liquefied Natural Gas (LNG) plants

Technological	Assets	Institutional	Behavior
<p><b>Standards.</b> Safety regulations for regasification plants and gas consumption facilities in economic sectors</p>	<p><b>Infrastructure.</b> Regasification plant and transmission and distribution networks</p>	<p><b>Decision-making processes.</b> Need for complete feasibility studies (technical, economic and environmental). Need for regional coordination for purchasing processes.</p>	<p><b>Individual.</b> No barriers were detected</p>
<p><b>Compatibility and integration.</b> No barriers were detected</p>	<p><b>Capital goods.</b> No barriers were detected</p>	<p><b>Regulations.</b> Regulatory framework and institutions for the activity</p>	<p><b>Collective.</b> No barriers were detected</p>
<p><b>Local capacities.</b> Local capacities should be developed for planning, project preparation, installation, operation and maintenance. Infrastructure, Human Resources. LNG purchasing capabilities</p>		<p><b>Regional energy planning.</b> Necessary condition</p>	
		<p><b>Policies and programs.</b> A necessary condition.</p>	
		<p><b>Stakeholders.</b> Residential, commercial and industrial consumers. Environmental</p>	