Hydrogen innovation in Latin American countries: a social network analysis

According to the Paris Agreement, governments are expected to compromise with the transition to a low carbon economy by 2050. Hydrogen is considered the future energy carrier because of its large capacity for generating a great variety of energy services without provoking environmental harm in its transformation. The hydrogen production occurs through the reforming or electrolysis that can be carried out through other energy sources. When these sources are renewable, such as biomass, solar photovoltaics, wind, and hydroelectricity, green hydrogen is obtained, that is, clean energy. Producing hydrogen from renewable sources is seen as a global alternative for decarbonizing energy production and economic activities by 2050.

Latin America has one of the highest shares of renewables in power generation among the world's regions. In the future, Latin American countries can achieve a comparative advantage in green hydrogen production projects based on the local availability of renewable sources for energy production, for example, wind and solar photovoltaics in Brazil and Chile. Besides the technical capacity, some advantages are the already low cost of capital, the national hydrogen strategies, and the growing number of bilateral export agreements. The windows of opportunity that hydrogen production offers can be explained in a few points. Hydrogen is an alternative for producing clean energy for use in sectors of difficult electrification such as refining, ammonia production, steel production. And also a product for exports through pipelines or shipping (ammonia). Since hydrogen production involves a broad value chain, with possibilities for industrial development in the stages of production, transformation, transport and end use, this is also an opportunity for industry diversification. The new renewable energy production sites (solar and wind) can attract new industries to their surroundings and stimulate the diversification of the location of industrial parks, that is, decentralization. Industry diversification across fossil fuel producing countries and regions can ensure a safer transition to a low-carbon economy.

Many countries have supported investments in green hydrogen technologies, targeting everything from power generation to passenger vehicles. Just as the development of fossil fuel production industries emerged decades ago from public-private initiatives, this new development trajectory requires an active role from governments. The roadmaps and national strategies developed in different countries for large-scale hydrogen production show that the

specific role that each country can play in the global hydrogen value chain depends on its domestic capacity for renewable energy production.

The potential of Latin American countries in developing green hydrogen production will vary according to the local availability of renewable sources and the cost advantages. However, other decisive factors will be the existing infrastructure, the energy matrix (hydrogen production depends on the installed capacity for wind and solar production), industry (ability to generate demand for hydrogen) and more institutional factors such as government support, business and political stability. Latin American countries have the challenge of creating local/regional conditions and forming an integrated value chain to support this clean industry development. Although they have abundant renewable resources, technological development is crucial for cost-efficient clean energy production. Even when significant parts of the development of industry-specific resources are external, there is a need to adapt and operate this new industry locally.

In the catching-up literature, the emergence of new sectors (industries) is explained through the gradual upgrade of the technological capabilities of firms. However, that does not explain the development of new sectors in contexts of late adoption, in which the previous capabilities of latecomers firms are not related to the new installed industry. Binz and Anadon (2018) bring the notion of the growing influence of "complex transnational linkages" on industry formation dynamics in cleantech. The successful case of the solar PV industry in China resulted from accessing a system of knowledge and industry-specific resources developed elsewhere and adding it to the local competences of the previous existing manufacturing industries through a process of unrelated diversification. The strategy of the latecomer firms consists of developing industry-specific capabilities elsewhere (through networks) and "anchoring" them locally through generic absorption capacity (local educational, scientific and industrial structure).

With this notion of the influence of complex transnational linkages on industry formation, we want to critically address the Latin American countries' potential for developing a hydrogen-based economy through a process of unrelated diversification. We aim to identify the technological competences and differences in the generic absorptive capacities and analyze their access to the (highly internationalized) industry-specific resources. We will look to their international collaborations to capture the transnational linkages from the region to elsewhere between companies, government and research institutes in constructing a local

knowledge base. This analysis aims to point out the strengths and weaknesses of these countries in catching up in the hydrogen economy.

The construction of the Hydrogen economy knowledge base considers the complete set of patents related to hydrogen production and commercial use as fuel, storage, fuel cells, and electric vehicles. We used the OECD, REGPAT database, version of July 2021 with patent applications ('international applications') filed under the Patent Cooperation Treaty (PCT) at the international phase. The search for patents related to hydrogen used CPC (Cooperative Patent Classification) class symbols was based on the methodology of EPO (2016) for the production, storage and use of hydrogen, fuel cells and electric vehicles, and for hydrogen fuel based on fossil sources of EPO and IEA (2021). The search for hydrogen and fuel cells patents using CPC class symbols resulted in 31,170 observations from priority date 1979 to 2018.

Latin American countries together have a small share of all hydrogen technologies patents for the entire period of 1979 to 2018. We use the Revealed Technological Advantage index (RTA) to address Latin American countries' technological development in hydrogen technologies as previous capabilities and local competences for industry diversification. The RTA index measures the relative specialization of each country by weighting the relevance of hydrogen technologies in each country's portfolio by the relevance of the said country to the global patent stock.

The Latin American countries that developed capabilities in hydrogen-related technologies were Argentina, Brazil, Chile, Colombia and Mexico. Mexico increased its share and specialization in hydrogen technologies from non-carbon containing sources during the two decades of the 2000s. Chile and Colombia developed a comparative specialization in hydrogen technology in the 2009-2018 period. Argentina and Colombia have specialized in hydrogen fuel (fossil fuel production) from the 2000s onwards. Brazil specialized in hydrogen fuel patents during the 1980s, but then the country’s participation decreased in this field. During the 2009-2018 period, Brazil’s hydrogen fuel patents’ share increased and recovered the specialization. None of the Latin American countries specialized in fuel cells. The results demonstrated that competence building of Latin American countries in hydrogen-related technologies was more significant in hydrogen fuel production (fossil fuel supply).

The development of the hydrogen economy is part of a global energy transformation that is shaping the relations between countries. International collaborations are an essential dimension for the strategic construction of technological capabilities in the hydrogen economy since they represent opportunities for knowledge transfers from countries with the most remarkable technological development and the major players in this market.

We use co-patenting data as an index on collaboration in technology research. The indicator of international collaboration in technology development (bilateral) is based on the number of co-invention by country of residence of the inventor(s). In the collaboration networks, the nodes are linked if countries have co-inventions in hydrogen technologies. We use the VOS clustering technique, a community detection method, to find groups in the networks with a high density of connections within and a low density of links between groups. We generate a network of international collaboration between countries from the adjacency matrix, including all hydrogen technologies - hydrogen technology (non-carbon containing sources), fuel cells, and hydrogen fuel.

Due to the small number of patents Latin American countries possess for hydrogen technologies, they are analyzed as the same group of technology. We constructed collaboration networks for two periods, 1999-2008 and 2009-2018, considering they were the most relevant to the development of hydrogen technologies in the world.

The network analysis demonstrates the unequal development of "complex transnational linkages" and the increasing gap between countries. The structure of collaboration networks in hydrogen technologies is made up of peripheral and central countries. The central countries have more links and a more complex subnetwork. Latin American countries occupy a peripheric position in the global hydrogen technologies networks because they have few connections, but they are paired with the developed countries that are core to the network in both periods. Chile is not represented in the networks for no co-inventions.

In the 2009-2018 period, Latin American countries did not connect directly and were also connected to wholly separated clusters. All Latin American countries reduced the number of co-invention partners from 1999-2008 to 2009-2018. Also, Brazil no longer connects to China, and there is no direct collaboration with other Asian countries in the subnetwork for 2009-2018. While Latin American countries gained little participation in patent fillings in 2009-2018, their subnetworks had fewer participants and links, becoming less complex. Diminishing complexity in the collaboration networks indicates fewer opportunities for

accessing a system of knowledge and industry-specific resources developed elsewhere and adding it to the local competences.

The differences between Latin American countries positioning in the inventor's collaboration networks can be partially explained by their patent's ownership (applicants). For all cases, the hydrogen patents that have inventors from outside the region are owned or co-owned by foreign firms, universities or technological and scientific institutions. That explains, for example, why Chile has no participation in the collaboration network since it has patents in hydrogen technologies, but they are all owned by Chilean firms or institutions and have no participation of inventors from abroad.

Assessing this present context of specialization and existing technological capabilities in hydrogen in Latin American countries can benefit industrial policy formulation. New applications and solutions on hydrogen technologies from non-carbon containing sources offer future opportunities for industry diversification, including countries that produce fossil fuels. Industrial policy will be essential to establish partnerships, collaborations, cooperations through which countries can have access to technology, knowledge and capital to develop the hydrogen sector. To take the most from the windows of opportunity that hydrogen production offers to generate high-quality jobs and income, it is crucial to look beyond the production of the final commodity, the energy to be exported or used in large multinational industries. Importing hydrogen technologies for production, storage, and many applications may be a possible path, but one that has limited positive internal impacts. Identifying the technological potential and national bottlenecks can contribute to more targeted policies at this stage of developing national plans for the hydrogen economy.