UNITED NATIONS
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EXECUTIVE REPORT

MARKET ASSESSMENT ON CLEAN HYDROGEN INNOVATION IN DEVELOPING COUNTRIES

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About UNIDO

UNIDO is a specialized agency of the United Nations with a unique mandate to promote, dynamize and accelerate industrial development. Our mandate is reflected in Sustainable Development Goal (SDG) 9: "Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation", but UNIDO's activities contribute to all the SDGs.

UNIDO's vision is a world without poverty and hunger, where industry drives low-emission economies, improves living standards, and preserves the livable environment for present and future generations, leaving no one behind.

Clean hydrogen technology innovation in developing countries faces unique challenges and opportunities that must be addressed within their specific contexts.

These nations can become key players in the global clean energy transition, but they require tailored approaches. The A2D Facility seeks to address this gap by driving the commercialization of clean hydrogen technologies and accelerating the adoption of innovative solutions.

INTRODUCTION

The global transition to clean hydrogen is widely recognised as a critical step towards achieving decarbonisation goals and addressing climate change. Clean hydrogen, produced either from renewable sources or through steam methane reforming (SMR) with carbon capture and storage (CCS), plays a pivotal role in this transformation. Developing countries present both unique opportunities and challenges in deploying clean hydrogen technologies.

This report provides a comprehensive overview of clean hydrogen technologies and projects in these countries, stakeholder engagement, ongoing initiatives, challenges, and opportunities shaping the sector. It also examines how clean hydrogen can contribute to the Sustainable Development Goals (SDGs) and presents the most promising developing countries in clean hydrogen innovation.

Several of them are developing or, more commonly, adopting technologies that are already at advanced Technology Readiness Levels[1] (TRLs) through projects of various scales. Figure 1 shows the 35 developing countries where such projects were found.

The report also examined countries where the private sector is involved and where the government has implemented policies and strategies to foster clean hydrogen innovation. 47 of the 141 developing countries met at least one of these criteria. Of these, 16 countries[2] were identified as pioneers in clean hydrogen innovation. The selection focused on the existence of a clean hydrogen ecosystem[3], the presence of stakeholders, initiatives, financing mechanisms, R&D activities and projects.

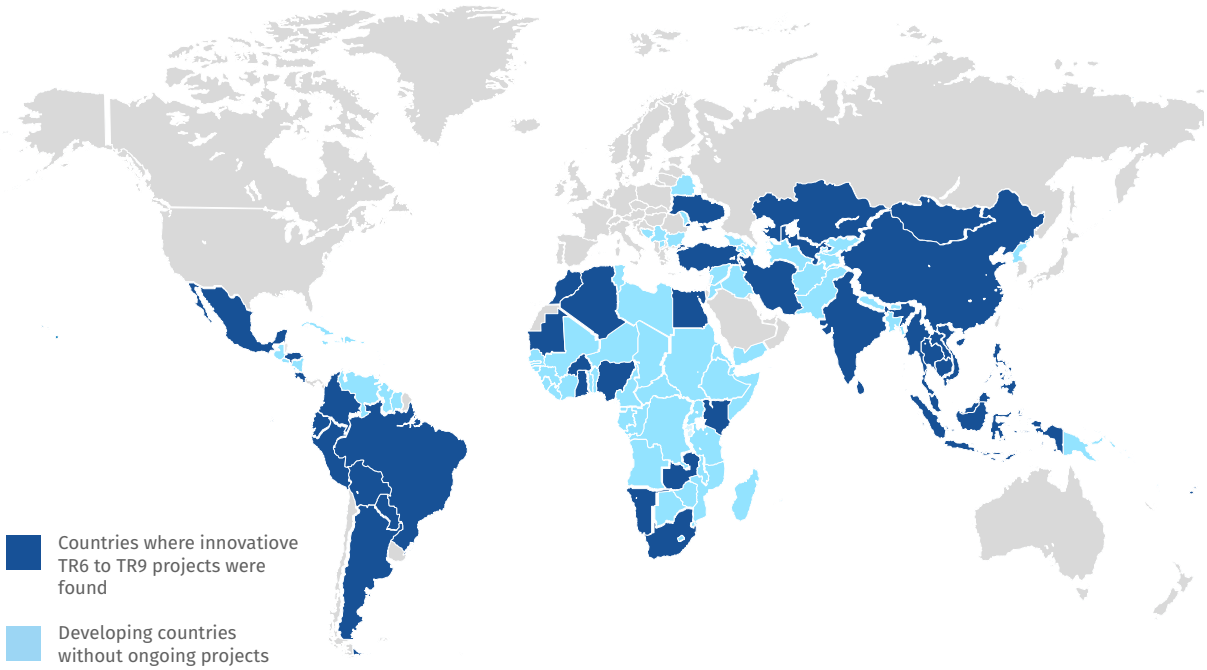

Figure 1. Map of developing countries that are developing innovative projects.

Source: Hinicio (2024), based on the Organisation for Economic Co-operation and Development's (OECD) Development Assistance Committee List of Official Development Assistance Recipients 2024-2025 (OECD, 2023) and information on projects.

1. Advanced TRLs represent the transition from technology demonstration to commercialization. This involves moving from prototype testing in relevant and operational environments (TRL 6-7), where many clean hydrogen technologies currently stand, to validating and proving fully developed systems in real-world commercial applications (TRL 8-9).
2. India, Indonesia, Malaysia, Viet Nam, Egypt, Kenya, Namibia, Morocco, South Africa, Brazil, Argentina, Colombia, Costa Rica, Mexico, Türkiye, and Ukraine.
3. A clean hydrogen ecosystem that fosters innovation in developing countries is a network that accelerates technology production and adoption through the interaction of innovators, off-takers, skilled talent, research collaboration and infrastructure, enabling policies, international partnerships, financing, and renewable energy infrastructure.

Landscape of Technologies

Developing countries are at the forefront of hydrogen technology innovation and early adoption of existing technologies. Most projects are in the initial stages of research and development (R&D). A total of 114 hydrogen projects in late-stage planning, focusing on TRLs 6 to 9, were mapped across 35 developing countries, excluding China[4].

Most projects concentrate on hydrogen production and end-use applications. Other value chain segments, such as hydrogen storage, transport, and alternative carriers, have made limited progress in developing countries.

Key findings across the clean hydrogen value chain in developing countries include:

- **Hydrogen Production:** 41% of the projects focus on producing clean hydrogen, with nearly all of them relying on well-established electrolysis technologies, largely due to their renewable energy sources and the high costs associated with CCS technologies. In some regions the absence of oil and gas infrastructure makes CCS a less viable option, which positions electrolysis as the more feasible technology for clean hydrogen production. Although CCS projects were identified in all regions, only Asia is developing CCS technologies for hydrogen production, particularly within SMR processes for low-carbon hydrogen and ammonia production. It was also found that hydrogen production projects are primarily funded by companies from high-income countries, seeking to capitalise on favourable geographic locations and boost the global clean hydrogen economy.
- **Hydrogen Storage:** Although some nations are exploring geological storage systems, such as natural gas fields and salt caverns, these projects remain at an early stage. Alternative hydrogen storage systems in liquid form, in solution as a carrier, or in metal hydrides have not yet been widely explored in developing countries.
- **Hydrogen Transport:** Only a few projects focus on transportation options. This is since most clean hydrogen production and end-use projects are located near ports, where transport is less of a challenge. As an alternative, existing solutions such as pipelines and tube trailers are utilised. Some regions, however, are exploring transport alternatives; in particular, several hydrogen pipeline projects in Europe include developing countries.

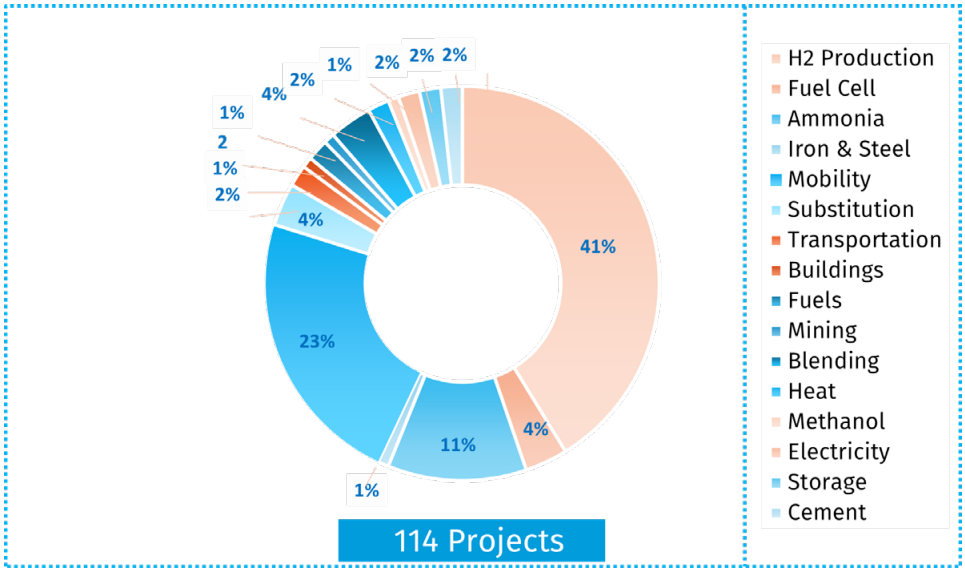

Figure 2. Share of focus categories for late-stage hydrogen-related projects in developing countries.
Source: Hinicio (2024).

[4] Many other projects were identified, but they are either in the early planning phases or have only been announced as memorandums of understanding.

- **Hydrogen Transformation:** Hydrogen transformation projects consider ammonia production as a key area of focus, particularly given the crucial role fertiliser production plays in enhancing food security in these regions, where many rely on fertiliser imports. Clean ammonia production accounts for 11% of all mapped projects, with most located in Latin America and the Caribbean (LAC).

- **End- use Applications:** End-use applications account for 41%[5] of the 114 projects. Mobility projects including fuel cell electric vehicles, fuel cell trains, and fuel cell buses represent 23% of all projects mapped, with a focus on public transport solutions, in both large and small cities in developing countries. Some Asian, European, and African countries are developing fuel cell trains, while LAC countries such as Costa Rica and Colombia focus on private cars and public transport. Turkey, Costa Rica, and Colombia have also deployed prototype refuelling stations for both large and small vehicles.

Developing countries are strategically positioning themselves to address sector-specific challenges, particularly in 'hard-to-abate' industries where hydrogen can have a significant impact. These countries are aligning their hydrogen initiatives with regional strengths and industry needs. However, in many cases, they lack the necessary technological infrastructure to test technologies, which is why some end-use projects are being deployed in high-income countries with more advanced technology infrastructure.

Considering the different segments of the clean hydrogen value, the following trends were found across regions:

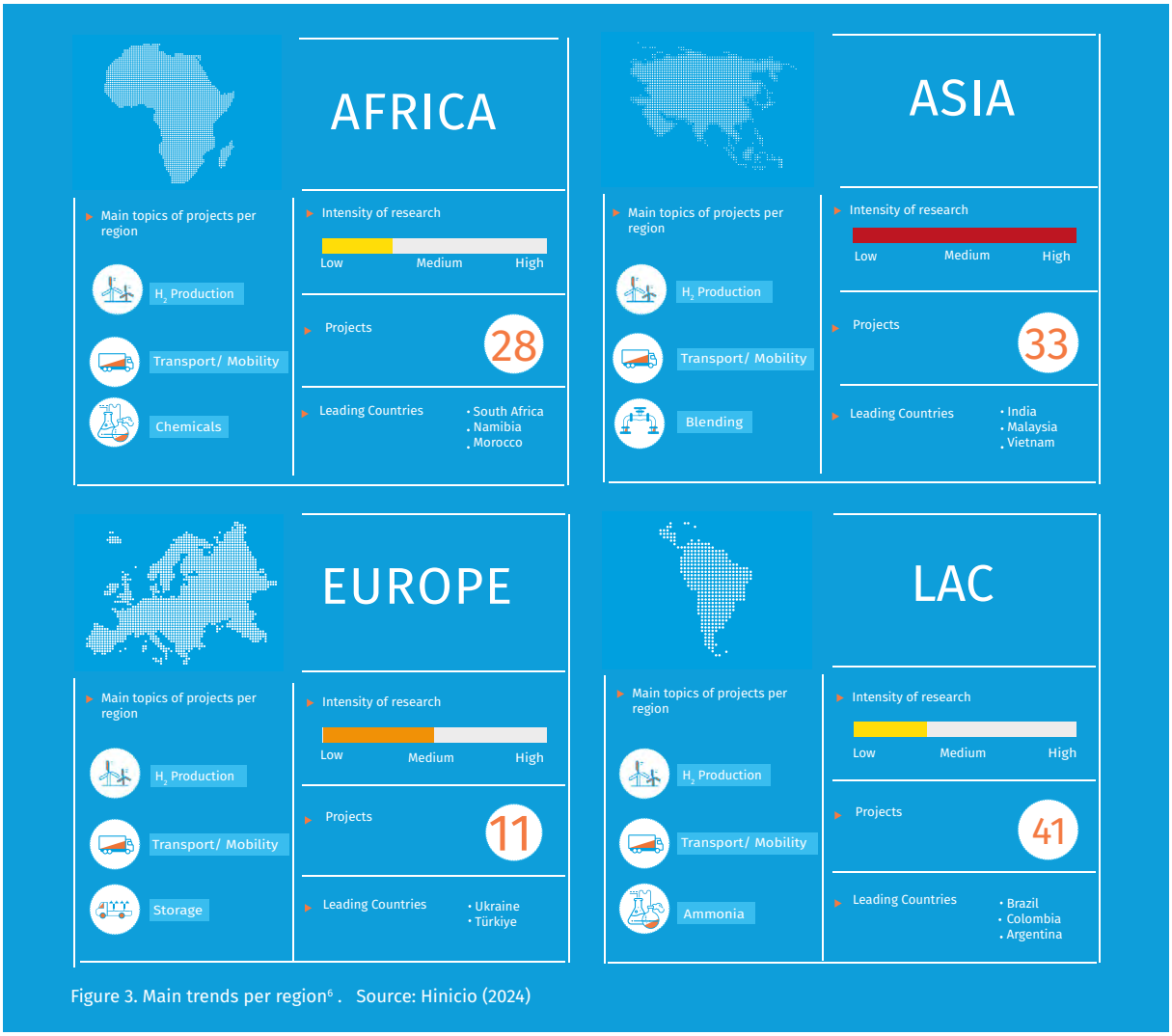

Figure 3. Main trends per region[6] . Source: Hinicio (2024)

[5] Category in which the following applications were considered: Fuel Cells, Iron & Steel, Mobility, Substitution, Buildings, Mining, Blending, Heat, and Electricity.

[6] China is not included in the number of projects for Asia because given its large number of projects its inclusion would distort the regional data.

Challenges to innovation

Technology innovation in developing countries faces challenges that are in addition to those encountered by all project developers across the globe, including limited access to advanced technologies, a lack of skilled professionals, and restricted financial resources for R&D across the hydrogen value chain. The project development process is further complicated by social and cultural resistance, particularly from indigenous and local communities concerned about environmental impacts, land use, and electricity and water scarcity. Additionally, the distance between renewable energy sources and industrial hubs presents logistical challenges in deploying clean hydrogen projects in these countries.

The ongoing subsidies for fossil fuels in many developing countries also distort the market, making it harder to promote clean hydrogen. Key risks identified to project development include the readiness of hydrogen technologies and high Levelized Cost of Hydrogen (LCOH). As a result, some innovators have chosen to keep their business plans private to avoid raising false expectations before projects reach final investment decisions. Despite these challenges, innovators have been identified across all regions, as detailed in the following section.

Landscape of Innovators

More than 200 innovators have been identified in developing countries, with the majority based in China (27.6%) and India (17.4%), driven by strong government support. These innovators include universities (33.9%), research institutions (13.4%), pure-play clean hydrogen[7] developers (8.9%), and energy companies (8.0%).

Innovators in developing countries are primarily focused on clean hydrogen production technologies. Although the manufacturing of electrolysers is also a priority, there is little development in this area outside of Asia. Likewise, innovation in high-emission industries such as cement, iron, and steel remain limited, with less than 5% of projects focusing on these sectors. Clean hydrogen for mobility is a common focus, particularly in road transport, with most innovators centred around hydrogen fuel cell vehicles, buses, and trucks.

To analyse the full landscape of innovators, those working on less advanced technologies or in early planning phases were also included. As shown in the figure below, many innovators are affiliated with research and education institutions. However, their projects often remain at lower TRLs and project

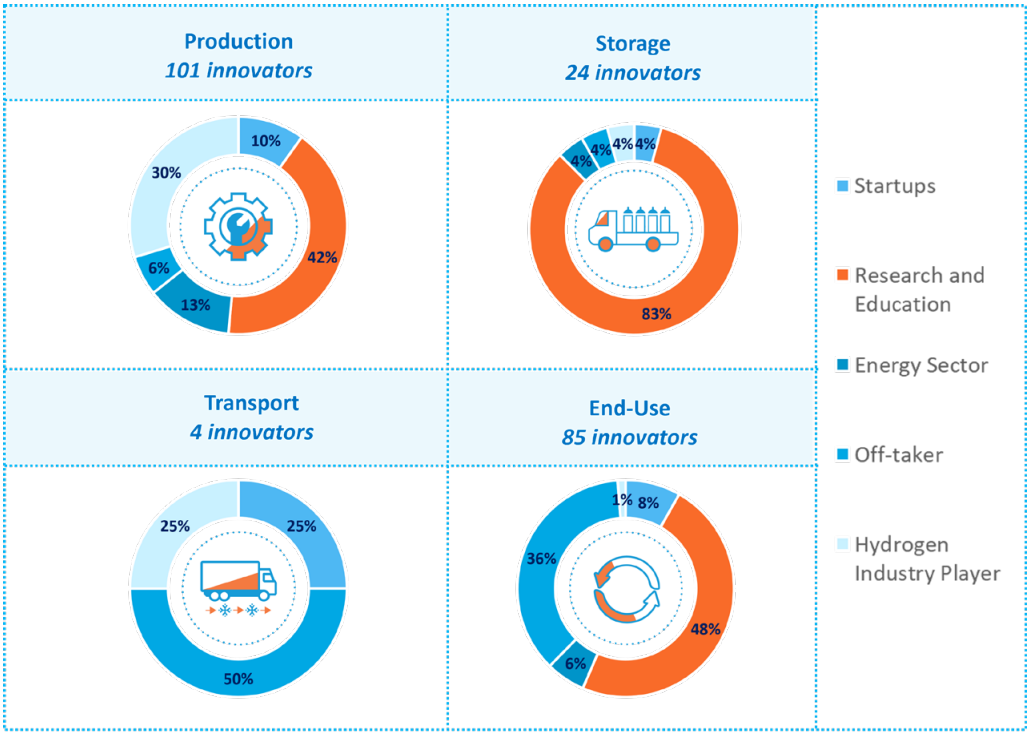

Figure 4. Number of innovators by segment of the clean hydrogen value chain.
Source: Hinicio (2024).

[7] "Pure-play" stands for companies created or related exclusively to clean hydrogen.

readiness levels. Industrial innovators, on the other hand, are adopting more mature technologies to produce and utilise clean hydrogen and its derivatives within a shorter timeframe.

Bridging the gap between academia and industry can increase innovation in the solutions needed by industry and attract funding for R&D projects in developing countries. The presence of off-takers as innovators in these projects is also crucial to ensure project success as they secure demand and can offer financing.

Despite the number of innovators found in developing countries, they are in only in 42 of the 141 developing countries (29.7%). The multiple problems that many developing countries face prevent their participation in the clean hydrogen ecosystem.

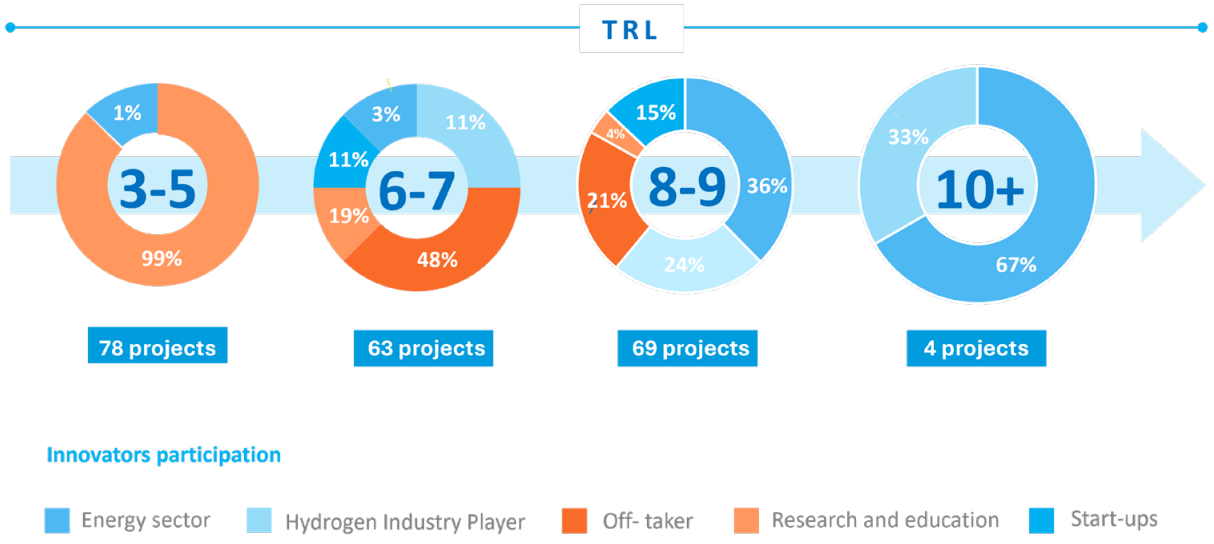

Figure 5. Distribution of the innovators according to the TRL of the projects.
Source: Hinicio (2024).

Landscape of Stakeholders

A favourable clean hydrogen innovation ecosystem requires coordinated efforts among governmental, industrial, academic, and international stakeholders. Governments play a key role in advancing clean hydrogen development by designing policies that attract both national and international investors, as well as programmes focused on R&D and technology innovation. Countries with the highest levels of hydrogen project activity are those where governments actively promote hydrogen market development, allocate resources, and attract financing.

Positioned at opposite ends of the innovation chain, as shown in the figure below, research institutions and universities provide the capacities and environments for testing technologies. Off-takers are crucial in securing demand, which ensures the long-term bankability of projects, enabling developers to raise the capital needed for deployment. However, their willingness to pay often hinges on binding regulations that mandate clean hydrogen use. For this reason, most off-takers from developing countries will come from developed countries with binding regulations.

International stakeholders, including development banks, international climate funds, think tanks, international organisations, donor governments, and development agencies provide funding, investment, and research for both pilot and large-scale projects. These stakeholders also offer technical assistance, regulatory support, and capacity building, but do not engage in a country unless there is government or industrial sector interest.

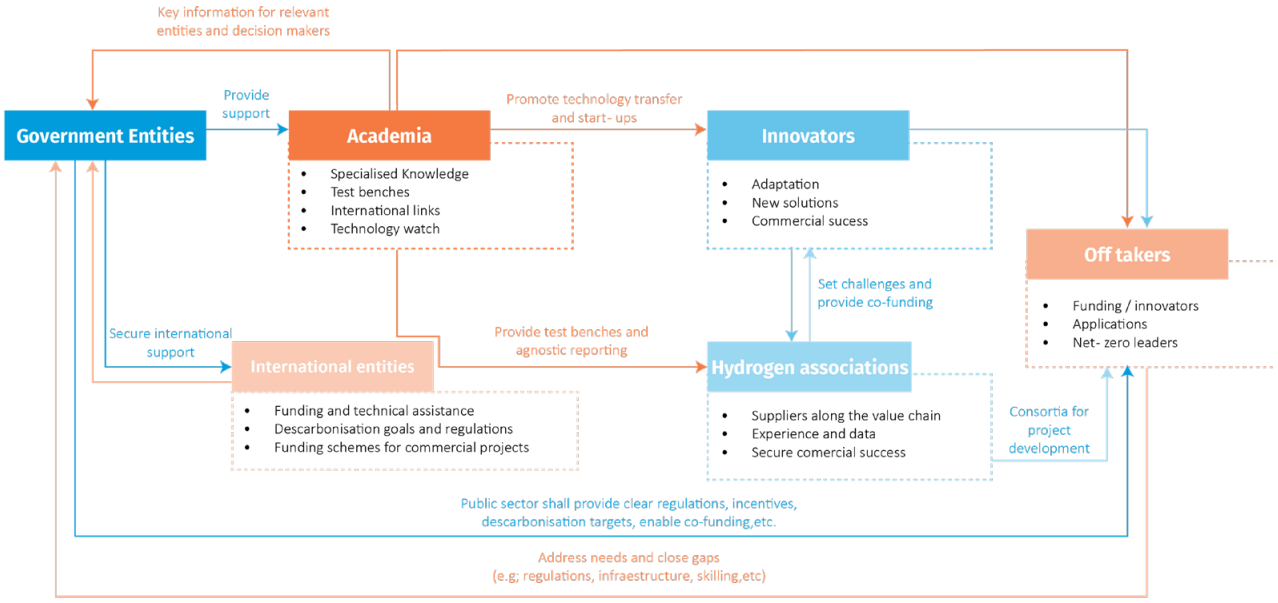

Figure 6. Role of key stakeholders involved at different stages of innovation.
Source: Hinicio (2024).

Landscape of Initiatives

Several developing countries are involved in various national, regional, and international initiatives aimed at advancing clean hydrogen. National initiatives focus on policy and regulatory development, while regional ones foster collaboration and knowledge sharing. International efforts largely provide technical assistance and funding. Most existing initiatives operate at either the national or international level, with only a few regional initiatives.

National Initiatives: Of the 141 developing countries, 27 (19.1%) have published a national hydrogen strategy or roadmap. A smaller percentage (14.2%) mention support for innovation and technological development, and 12.7% have plans to establish R&D programmes focusing on technology and innovation.

Figure 7. Number of countries by region which have already published a National Green Strategy or Roadmap.
Source: Hinicio (2024).

Many roadmaps have yet to be translated into effective policies and laws that establish programmes supporting innovation. In most developing countries, binding regulations for clean hydrogen use and R&D are still lacking.

Several developing countries are well-positioned to develop hydrogen hubs[8] due to their renewable energy potential, extensive land areas, and, in some cases, port infrastructure. National hydrogen hubs are planned in more than 15 developing countries, though only China currently has a fully operational hub.

Regional Initiatives: Regional initiatives provide platforms for knowledge sharing and best practices, and networking opportunities between industry stakeholders. They can be further enhanced by pooling financial resources, reducing costs through shared investments, and accelerating technology transfer among participating countries.

Shared infrastructure initiatives can also enhance the different regions´ potential. Several potential regional hubs were identified to serve as connections between hydrogen consumers, producers, and exporters, leveraging shared infrastructure and renewable energy sources to reduce costs, but they require extensive planning.

[8] Hydrogen hubs are geographical areas with the potential to integrate clean energy sources, hydrogen producers, demand, and supporting infrastructure.

International Initiatives: International initiatives are crucial for developing a clean hydrogen ecosystem that fosters innovation, especially since many developing countries lack the necessary resources and capabilities.

Many initiatives and international cooperation efforts aimed at developing countries focus on similar objectives, such as supporting prefeasibility studies, developing regulatory frameworks, and providing technical and financial assistance. However, several of the international partnerships analysed do not address local challenges, such as lack of laboratories and materials, educational resources, and hydrogen security protocols—remain unaddressed.

Additionally, only 26.2% of developing countries are involved in the international initiatives mapped, highlighting the need for more inclusive efforts to address these challenges.

The support tends to be concentrated in a select group of countries, leaving many emerging markets without the necessary backing to develop their clean hydrogen ecosystems.

On the other hand, coordination between countries remains unclear, and cross-country technological exchanges are limited. Expanding collaborative efforts among developing nations, especially within the Global South, could minimise duplicative efforts and enhance knowledge-sharing.

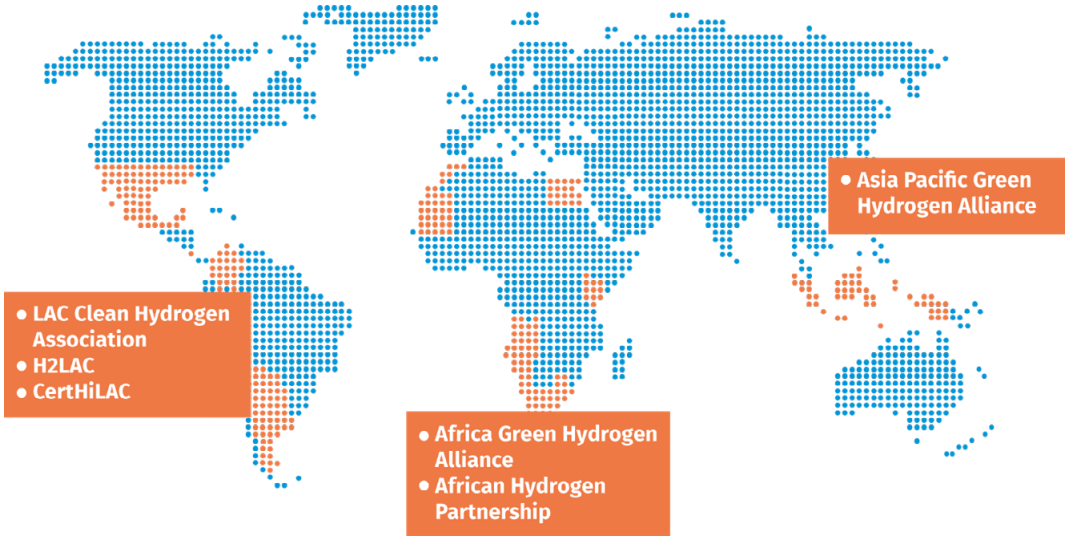

Figure 8. Map of Regional hydrogen associations and their respective members from developing countries (in orange).
Source: Hinicio (2024).

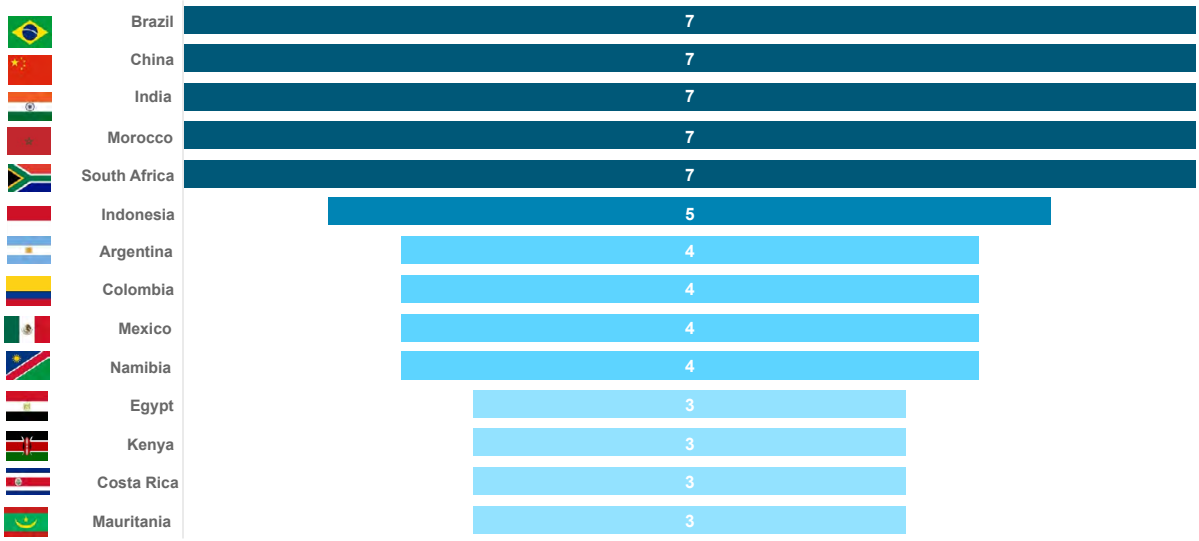

Figure 9. Number of international clean hydrogen initiatives identified of which each developing country is a member.
Source: Hinicio (2024).

Delivery Mechanisms

Governments and development organizations have actively stepped in with various mechanisms as shown in Figure 10, including concessional financing, grants, and technical assistance, to support the first-movers in the industry.

National hydrogen roadmaps have been established in several regions, introducing formal delivery mechanisms and incentive schemes to extend fiscal incentives to derisk investment in the clean hydrogen industry. Private sector involvement is on the rise, particularly through expanding public-private partnerships, though its overall participation remains relatively limited at this stage.

At present, funding initiatives and partnerships for R&D projects in developing countries are primarily focused on improving the cost and technical efficiency of clean hydrogen production technologies, particularly electrolysis.

Impacts on Sustainable Development Goals

Developing countries, characterised by low adaptive capacities, are disproportionately affected by the adverse impacts of climate change. The integration of clean hydrogen technology offers significant opportunities to advance progress towards the SDGs, particularly in these regions. The development of a clean hydrogen industry has strong linkages with SDG 1 (No Poverty), SDG 9 (Industry, Innovation, and Infrastructure), and SDG 13 (Climate Action).

However, without appropriate policy interventions to ensure that projects align with environmental and sustainability mandates, clean hydrogen initiatives face several risks, including job displacement in traditional fossil fuel sectors, conflicts over land and water usage, and potential environmental harm to fragile ecosystems. Without safeguards, these risks could deepen social inequalities and exacerbate environmental degradation.

Figure 10. Notable delivery mechanisms and funding initiatives across developing countries.
Source: Hinicio, puREsource (2024).

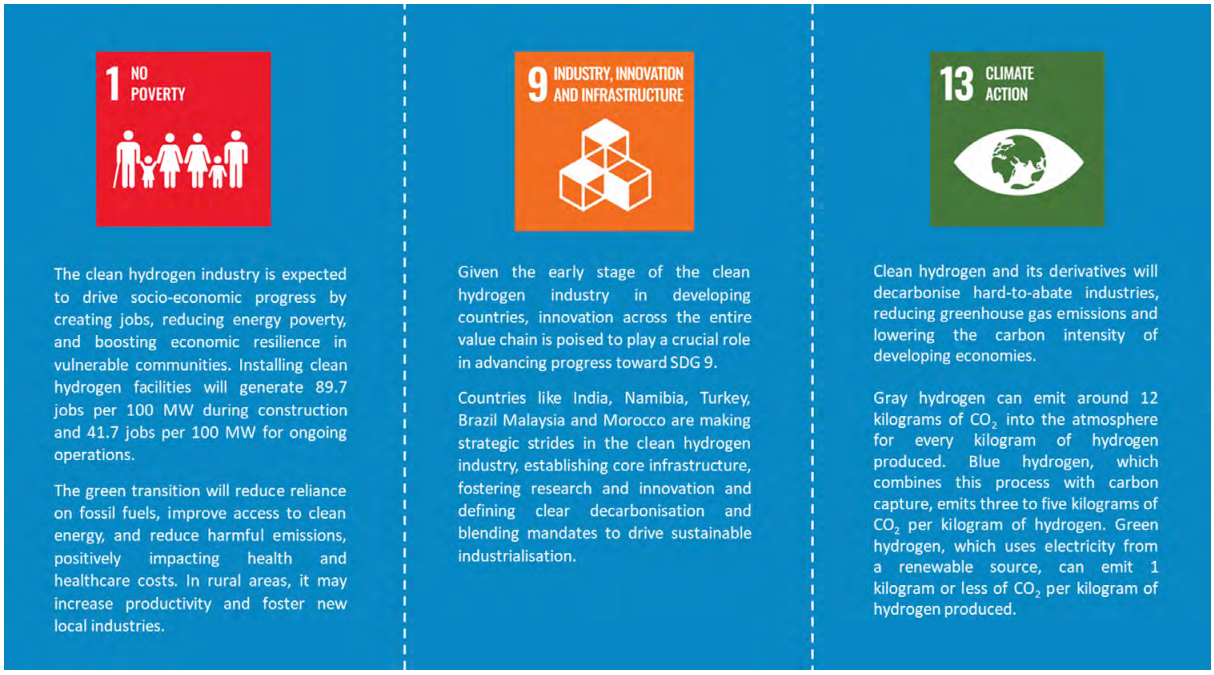

Figure 11. Direct contribution of clean hydrogen industry on SDGs.
Source: Hinicio, puREsource (2024).

Conclusions and recommendations

The present study has demonstrated that the implementation of catalytic conditions has the potential to enhance the capacity of developing countries to advance clean hydrogen projects. These conditions constitute the foundation of a robust and thriving innovation ecosystem. They encompass the following key elements:

- Given the nascent nature of the clean hydrogen industry and its derivatives, investment i n clean hydrogen projects in developing countries needs to focus on the adoption of commercial technologies to advance to the commercial stage. Adaptation and implementation of these technologies in different environments and their integration to renewable energy sources are crucial to lower the costs of clean hydrogen and its derivatives and build a sustainable industry.

- Project developers can foster investor confidence by addressing the value chain from production to end-use. This approach ensures that the techno-economic analysis accurately reflects the business case.

- Involvement of off-takers will not only strengthen the commercial viability of clean hydrogen projects for investors but also stimulate local demand and drive wider adoption of clean hydrogen technologies across industries. This growth will facilitate sustainable industrialisation, contributing directly to SDG 9 (Industry, Innovation, and Infrastructure) and SDG 13 (Climate Action).

- It is crucial for public entities to be equipped with the necessary technical knowledge; and legal and administrative tools to ensure long-term success in the clean hydrogen industry.

- Government incentives, enhanced access to public and private financing, and the presence of strong regulatory bodies will be critical in ensuring that projects are designed in alignment with the local needs, technologies are adapted as per the local context, and the projects are being implemented in conformity to the international best practices to drive progress in sustainable development.

- Optimising existing technologies rather than innovating from low TRLs, has an advantage in progressing to commercial stages more quickly, aligning with market demand in those premium countries.

- It is advisable that, during the design phase of a project, measures be put in place to mitigate the risk of potential issues arising. Some examples of such measures are:

  - Reduce costs related to infrastructure investment wherever possible.
  - To aim at premium markets and address their demand.
  - To evaluate and incorporate elements pertinent to the specific local conditions, such as environmental hazards and community participation.
  - Involve off-takers in the project's design
  - Build local capacities at all levels: technicians, professionals, local government agencies and companies.

Therefore, projects with a catalytic effect shall focus not only on the technological aspects of innovative clean hydrogen projects, but also on the other factors that may facilitate their transition to a commercial stage, ensuring their sustainability and value-add to the local economy.

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