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Development strategies for the green hydrogen economy in emerging economies[1]

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Abstract

Green hydrogen is widely recognized as a promising solution for reconciling economic growth with environmental sustainability. It holds significant potential for decarbonizing hard-to-abate sectors, such as steel and chemicals, and for fostering industrial development, job creation, and technological learning. However, the pathways through which emerging economies can effectively seize these opportunities remain underexplored. This paper addresses this gap by analyzing the green hydrogen strategies of Brazil, Chile, China, and South Africa. Drawing on extensive data, including stakeholder interviews, governmental documents, and academic sources, it uncovers marked contrasts in how these countries approach this window of opportunity. While Chile and South Africa prioritize green hydrogen, and Chile adopts an export-oriented agenda, Brazil and China adopt more technology-agnostic approaches that emphasize domestic markets. These variations reflect differences in natural resource endowments, energy infrastructure, and market dynamics. The analysis reveals that industrial policies across these countries focus predominantly on supply-side measures, with demand-side incentives lagging behind. Moreover, private sector responses often diverge from national strategies, illustrating the challenges of aligning policies with market realities. The findings emphasize the need for tailored, context-sensitive approaches to green hydrogen development, challenging the notion of a universal blueprint. For policymakers in the Global South, this study offers critical insights for leveraging green hydrogen for industrial transformation.

Key words: Green hydrogen, Industrial policy, Sustainable development, Emerging economies
JEL: E61, L52, O25, O38, O57, Q01

Content

1. Introduction

Green hydrogen[1] is a promising pathway for fostering economic growth while promoting environmental sustainability. It is the only type of hydrogen suitable for achieving a fully sustainable energy transition, serving as a pivotal pathway to decarbonise hard-to-abate sectors[2] such as steel and refinery industries (IRENA, 2021b). The implications of the green hydrogen economy might be extensive, offering prospects for generating economic co-benefits of the energy transition[3] such as value creation through technological capabilities enhancements across the production chain, exports, and its end uses (Altenburg et al., 2022; Hamukoshi et al., 2022; Müller et al., 2023; Pastore et al., 2022; Stamm et al., 2023).

Realising economic gains, however, is contingent upon overcoming barriers and securing a favourable position in the future international value chain. The sustainable transformation creates green windows of opportunity (GWO), temporary favourable conditions for latecomers to catch up in green sectors, typically emerging from institutional disruptions arising with the transformation towards sustainability. However, seizing these opportunities requires capabilities and undertaking robust efforts to timeously enter and develop these sectors (Lema et al., 2020; Lema and Rabellotti, 2023). Green technologies face market and coordination failures (Juhász et al., 2023; Rodrik, 2014), requiring steering and sustaining investments with the necessary scale and scope for systematically developing them (Andreoni et al., 2022). The scale-up of green hydrogen encounters additional barriers, including technological challenges, high cost, and deficiencies in infrastructure and regulatory frameworks.

Furthermore, economically powerful countries can affect windows of opportunity in developing countries. The capacity of one country to support green industries with subsidies might curtail some elements of value chain development in other jurisdictions, for instance, that do not have the fiscal space to implement corresponding measures. While a significant body of literature focuses on domestic actions to support GWOs (e.g. Lema and Rabellotti 2023; Pegel and Altenburg 2020), the international political economy of industrial policies and the impact of protectionist trade regimes on GWO in developing countries also need attention. In this sense, the agency of developing countries can be affected significantly by the policy choices of dominant global players. A push for energy security might also propel countries to encourage some value chain deployment beyond their borders. Such possibilities may increase the risk of supporting the green hydrogen sector given its cost and uncertainty level, but it can also create green windows of opportunity as first movers might be able to act to secure an advantageous position due to the open-ended disruptions that unfold whilst matters are still subject to ongoing decision-making.

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[1] Hydrogen obtained from water electrolysis using renewable energy.

[2] Hard-to-abate sectors are energy-intensive and generate carbon from non-combustion sources in their production process and as fuel combustion (Paltsev et al., 2021). They account for around one-third of global emissions and cannot rely on electricity for their energy transition (Azadnia et al., 2023).

[3] Potential economic gains, often referred to as economic co-benefits of the energy transition, include the localisation of value chains, the creation of jobs, and technological learning (Andreoni et al., 2022; Lema et al., 2021; Mathews, 2013; Pegels and Altenburg, 2020)

Therefore, the market and industrial development of green hydrogen hinge significantly on both the design and implementation of industrial policy and the response of the private sector to it, both nationally and internationally (Gurlit et al., 2021)[4].

Building a green hydrogen economy requires national and international efforts. On the domestic front, substantial investments are needed in renewable energy infrastructure and production. Additionally, infrastructure for transforming, transporting, and storing green hydrogen must be developed, alongside efforts to train the workforce, foster demand, implement certifications and standards aligned with the international market, and establish an enabling regulatory framework. International cooperation is crucial to creating a supportive infrastructure and international certification system for the development of the global value chain, as well as promoting access to green funds and supporting demand growth. The sector's immaturity poses risks due to the absence of dominant technologies throughout the value chain and a prevalent chicken-and-egg problem regarding the lack of production and demand. The high costs of green hydrogen hamper demand creation, which remains unclear – green hydrogen adoption in sectors like steel production still hinges on improving the cost competitiveness of green hydrogen and scaling up the adoption of new technologies, and it is far from demand projections to achieve the net zero scenario (IEA; Lee, 2023). Furthermore, government-mandate demand, which amounted to 25 Mtpa in hydrogen in 2030 is still far from the target, with only 3-7 Mtpa supported so far, significantly below the 50 Mtpa announced on the production side (Hydrogen Council, 2024). This adds uncertainties to large investment plans. The capital-intensive nature of green hydrogen production, coupled with the requirement for abundant natural resources, such as renewables, water, and land, also creates obstacles to its production.

Despite prevailing challenges, both developed and developing economies have joined the clean hydrogen race (Van de Graaf, 2021b), and countries like Brazil, Chile, China, and South Africa actively trying to position themselves in this market. However, there is limited evidence on the strategies followed by countries, what factors shape them, and the challenges to follow through. The experience of Brazil, Chile, China, and South Africa, four emerging countries with significant green hydrogen production potential offer an invaluable learning opportunity for other low- and middle-income countries (LMIC) that are entering this market.

Our study delves into the green hydrogen development strategies pursued by each of these four nations, scrutinising their motivations based on natural resources and market characteristics and potential interest group configurations. The central question revolves around understanding **to what extent, how, and why green hydrogen-led development strategies differ in Brazil, China, South Africa, and Chile**. To address it, the study formulates four operationalising questions:

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[4] The term 'industrial policy' here refers to State-led interventions in the market to promote economic restructuring towards a low-carbon economy (Karp and Stevenson, 2012; Schmitz et al., 2015).

1. What are the similarities and differences in these countries' strategies to develop the green hydrogen sector?
2. How do these differences in strategies reflect different preconditions and potentials for green hydrogen-led industrial development?
3. How are the responses taking shape and reflecting strategies?
4. What are the implications for future policy design for green hydrogen-led development in Global South countries?

The study adopts and expands the GWO framework by adding insights from the green industrial policy (GIP) literature and compiles a unique dataset by combining secondary data from interviews with key stakeholders, official governmental documents, and academic and grey literature. The study makes a comparative case study analysing the green hydrogen approaches of Brazil, Chile, China, and South Africa by triangulating the information and conducting a content analysis of governmental documents. The study is divided into five additional sections. Section 2 summarises the main opportunities and challenges of the green hydrogen economy, briefly reviewing the literature on economic gains expected from developing the green hydrogen sector, as well as the barriers to achieving them. Section three presents the green windows of opportunity (GWO) framework and the study's methodology, relying on content analysis and triangulation of the information gathered from the different sources. Section four focuses on the first question, presenting the findings of the content analysis on similarities and differences across the strategies. Section five focuses on the second research question, examining the influence of natural endowments and market structure on the strategies designed, while section 6 focuses on the third question, exploring the public and private responses to the GWO. Lastly, section 7 presents the conclusions, focusing on the implications of the findings to future policy design.

2. The opportunities and challenges of the green hydrogen economy

The 'green hydrogen economy' encompasses the concept of an energy infrastructure centred around green hydrogen. Its pivotal role lies in its potential to replace fossil fuels in sectors that are not easy to electrify, called 'hard-to-abate sectors'. Hydrogen's versatility extends to its application as a chemical feedstock, heating source, reagent for synthetic fuel production, and conversion to electricity through fuel cells. Additionally, it offers the capability for storage and cross-regional transportation (Oliveira et al., 2021).

Green hydrogen's market development can bring economic gains. Backward linkages involve expanding renewable energy, attracting investments, and enhancing techno-institutional capabilities (Altenburg et al., 2022). Green hydrogen production also entails investments in electrolysers to convert renewable energy into hydrogen. However, many of these activities tend to be capital-intensive, so foreign investments and foreign technologies tend to dominate the market in developing countries. Similarly, industrial processes are required to transform green hydrogen into derivatives like ammonia or methanol, but these are also capital-intensive activities (Altenburg et al., 2022; Stamm et al., 2023). Despite this, potential employment generation, particularly during renewable plant construction, remains (Stamm et al., 2023). Furthermore, developing renewable energies can localise industries if a country possesses the required production and technological capabilities and if there is strong policy effort, as demonstrated in experiences like the ethanol and the wind sector in Brazil (Hochstetler, 2020; Lema and Rabellotti, 2023; Veiga and Rios, 2017).

Besides industrial gains, other socio-economic benefits can be generated. Increased energy security and reduced import dependence result from green hydrogen deployment and storage, as it allows greater energy flexibility and resilience in the case of shocks. Exporting countries also benefit from exports and tax revenues (ESMAP, 2020; Hamukoshi et al., 2022; Müller et al., 2023) However, the transport mode choice affects spillover effects on the economy and the infrastructure investment requirements. Furthermore, a sole focus on exports may limit gains from value chain linkages and trigger the 'Dutch disease' (Stamm et al., 2023).

Finally, green hydrogen production might enhance the competitiveness of domestic companies, fostering industrialisation, creating value-added, and generating jobs (Hamukoshi et al., 2022; Pastore et al., 2022). External environmental regulations like the European Union’s Carbon Border Adjustment Mechanism (CBAM)[5] and corporate standards in global value chains as well as national environmental targets incentivise the adoption of cleaner technologies, potentially leading polluting industries to switch to green hydrogen to enhance competitiveness (Stamm et al., 2023). These measures may also pressure energy-intensive industries, leading to a ‘renewables pull’ effect where enterprises relocate production due to differences in the marginal cost of low-carbon energy (Samadi et al., 2021).

However, the scalability of its application faces challenges. Green hydrogen is in an early stage of development, marked by high costs and technical barriers across its value chain (Dong et al., 2023). For production, the primary cost components are the renewable energy sources used and the electrolyser.[6] Despite the decline in the cost of both, green hydrogen remains uncompetitive compared to hydrogen produced with natural gas or methane (Lee and Saygin, 2023). Similarly, challenges arise in the storage, transportation, and application of green hydrogen as well due to technological limitations, lack of safety and regulation standards, cost, and promoting hydrogen (Agaton et al., 2022; Fokeer et al., 2023).[7]

Furthermore, seizing economic co-benefits stemming from green hydrogen hinges on the country’s role in the international value chain. The foundation for green hydrogen production lies in a

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[5] The CBAM came into effect on October 1st 2023 and it applies a tax on imported carbon-intensive goods to account for their emission during the production process (European Commission, 2023).

[6] Green hydrogen projects entail other costs as well, like land, water, and among others. Such projects require a significant amount of capital expenditures not just due to their demands in terms of equipment (e.g., electrolyser), but also due to costs related to infrastructure and other demands like R&D and the size to achieve economies of scale. Thus, ensuring access to capital at a low cost is an important factor in decreasing the cost of green hydrogen (Africa Green Hydrogen Alliance and McKinsey & Company, 2022).

[7] For a more detailed explanation and literature review on this topic, please refer to the annexe.

nation's natural resource endowments, including wind and solar resources, water[8], and land availability. Additional factors like resource quality, technical potential for renewable electricity compared to its electricity demand, and the availability of relevant infrastructure further influence production, investments, and economic activities (Wetzel et al., 2023). Export projections introduce additional considerations, contrasting domestic demand and production potentials and import costs, while factors like capital costs, technology access, governmental support, investment climate, political stability, and transport logistics contribute to the competitiveness of green hydrogen (IRENA, 2022a).

It also depends on the implementation of effective green industrial policy. The specific characteristics of green hydrogen have further implications for the nature of the sectoral industrial policy. Green hydrogen's value chain includes many immature technologies, still lacking dominant designs (Carlson et al., 2023a; Ghaebi Panah et al., 2022; Lema and Rabellotti, 2023; Ma et al., 2022). Entering the development of these new technologies demands stronger R&D&I capabilities and investments as the capacity to acquire foreign technology to exploit the 'latecomer effect' is limited (Lema and Rabellotti, 2023; UNCTAD, 2023). These technologies are also capital intensive and subject to economies of scale, requiring the mobilisation and derisking of investments, which are surrounded by uncertainty given the technology risk, infrastructure limitations, and uncertainties regarding the regulatory and certification frameworks as well as the take-off of projects (Franzmann et al., 2023; Gabor and Sylla, 2023; Ma et al., 2022).

The green hydrogen race will produce winners and losers. There is uncertainty regarding market growth and technology dominance, and countries face risks, for instance, of investing in the "wrong" technology or market growth expectations not being met, especially considering the sizeable investments made in green hydrogen projects. This could lead to stranded assets or "white elephants", also regarding the infrastructure built in countries (Carlson et al., 2023b; Fokeer et al., 2023).

3. Conceptual framework for the analysis of green hydrogen-led development strategies

Lema et al (2020) proposed a framework that combines four elements: (a) green transformation, (b) associated emerging windows of opportunity, (c) responses in the sectoral system of producing and innovation in green sectors and (d) industrial development outcomes, ranging from success to failure. In essence, the green transformation induces technological, market, and institutional changes that create green windows of opportunity – temporary favourable conditions for latecomer catch-up in green sectors. Countries with adequate capabilities ('**preconditions**') and active efforts

[8] Green hydrogen production employing seawater is possible, but it requires a desalination process or advances in seawater electrolysis, which have additional costs and technical challenges (Kuang et al., 2019).

(‘**responses’**) may seize these windows, leading to different catching-up trajectories depending on how these factors combine and unfold.[9]

The GWO literature thus looks at the combination of preconditions and responses to understand sectoral outcomes. These analyses, as done in UNCTAD (2023) and Lema and Rabellotti (2023), take into consideration the capabilities and measures implemented rather than factors affecting the choice of measures. In this study, we incorporate elements from the green hydrogen and industrial policy literature to both tailor the framework to be employed to this sector and to allow us to consider the dynamics of the responses taking place to foster it.

Accordingly, green hydrogen presents unique characteristics that set it apart from the GWO in other sectors. In contrast to the endogeneity of most other GWOs, international factors strongly influence domestic dynamics in this industry. In contrast to other green technologies, the institutional changes that gave rise to such windows originated in foreign countries, especially the energy crises in European countries and their need to diversify their energy matrix and suppliers, and to environmental regulations like CBAM and the Paris Agreement. Such changes created the conditions for a new market to emerge for Global South countries by fostering demand expectations for clean hydrogen (Hancock and Wollersheim, 2021; Leonard et al., 2021). Furthermore, the expected tradability of green hydrogen prompts potential importers – especially Germany – to establish partnerships for its development in potential exporting countries (Franzmann et al., 2023).

Thus, the expected tradability of green hydrogen coupled with green hydrogen diplomacy fostered the development of ***strategies, programmes, roadmaps, and similar documents*** for the sector that compose **the national hydrogen strategy** (Galván et al., 2022; IEA, 2021). The national hydrogen strategy shows the aspirations, goals and targets related to green hydrogen development in the country, setting the direction for sectoral development.

However, these strategies should be both constrained by and affect the **preconditions** existent in the country, which represent the initial capabilities upon which it can build to seize the window of opportunity. Green hydrogen remains a nascent sector, creating obstacles to assessing the specific preconditions associated with success cases. However, the literature indicates factors favourable to its development. Foremost, the competitiveness for green hydrogen depends on the ***natural resource endowment***, demanding renewable energy resources[10], land, and water (Eicke and De Blasio, 2022; IRENA, 2022a; Kuang et al., 2019; Pflugmann and De Blasio, 2020). Other natural resources like critical minerals used in electrolyser production may also influence the development route, while the geographical location facilitates participation in international trade. In addition, green hydrogen production requires appropriate ***energy infrastructure***, and investments in

[9] Lema et al. (2020) emphasise that distinguishing these elements, while useful as an analytical tool, is not easy in practice.

[10] Given the current technology development stage, and following other studies, this analysis focuses on wind and solar energy generation.

renewable energy and infrastructure, as well as electrolysers, affect the investment needs of the sector (IRENA, 2021a; Wetzel et al., 2023). The presence of elements of the ***market structure***, including both the supply chain and demand for hydrogen already established and the potential for it, also facilitates the transition towards the development of green hydrogen, as well as economic diversification (Eicke and De Blasio, 2022; Fokeer et al., 2023).

The national hydrogen strategy should, on the other hand, be reflected to some degree in the **responses** that take place effectively developing the sector. The study focuses specifically on policy response by the public sector and private response in terms of project development, considering the main actors engaged in each of these dimensions as well. ***Policy response*** captures the active measures taken by the government to develop the sector such as public incentives for production, development of the knowledge base, demand, or dedicated infrastructure. ***Private responses*** refer to current projects in the value chain under development in the country (Lema et al., 2020; Lema and Rabellotti, 2023; UNCTAD, 2023). In later stages, such responses affect the factors encompassed in the precondition dimension – for example, green hydrogen projects with integrated renewable energy plants and their related infrastructure investments would alter the energy infrastructure once constructed and operational. Considering the initial stage of most of the current projects, this latter part is not included in the scope of this study.

These three dimensions studied in this paper and the factors used to analysed each of them are outlined in Table 1.

Table 1: Conceptual framework for the analytical analysis and main indicators

Dimension	**Factor**
Priority level	• Green hydrogen-focused documents • Mentions of green hydrogen compared to other types
Outwardness of development strategy	• Objectives (drivers) and focus on foreign or domestic markets
Concentration of hydrogen use and industrial linkages	• Market focus • Value chain priority
Preconditions	
Natural resources endowment	• Renewable energy potential and mineral wealth • Geographical location • Renewable freshwater endowment
Energy infrastructure	• Electricity matrix • Grid development
Market structure	• Existent and potential supply and demand market • Economic diversification
Responses	
Public responses	• Industrial policy instruments
Private responses	• Green hydrogen projects • Actors involved

Source: Elaborated by the authors.

This paper makes theoretical and policy contributions. Firstly, studies employing the GWO framework tend to either examine the existence of the window itself or the outcome of preconditions and responses (Dai et al., 2021; Hain et al., 2020; Hansen and Hansen, 2020; Lema et al., 2020; Lema and Rabellotti, 2023). Our study, on the other hand, focuses on the dynamics of how responses to green windows of opportunity come into being taking into consideration national strategies and preconditions in place. Further, the paper is also among the seminal studies that extend the framework to the green hydrogen sector[11], tailoring it to such analysis. Lastly, it contributes to the broader green hydrogen literature by offering comparative insights into Brazil, Chile, China, and South Africa, a gap existing in the current body of scholarly work, which tends to cover case studies of individual countries, see, for instance, Bairrão et al. (2023), Hamukoshi (2022), Kovalenko et al. (2021), and Wang et al. (2023), the geopolitics of green hydrogen – for example, Eicke and de Blasio (2022), Pflugmann and de Blasio (2020), Sadik-Zada (2021), Van de Graaf et al. (2020), and Van de Graaf (2021b, 2021a) – and its technical development – for instance, Hassan et al. (2023) and Zhou et al. (2022). This latter point is the basis for our contribution in terms of policy, as the study highlights the multitude of strategies and factors that shape it, emphasising the lack of a one-size-fits-all solution to develop the green hydrogen sector.

3.1 Methodology

The study aims at making a qualitative cross-country comparison. We selected Brazil, Chile, China, and South Africa as case studies foremost because these are countries with significant renewable energy potential, which is expected to translate into green hydrogen competitiveness. Furthermore, these emerging countries have implemented either programmes, roadmaps, or strategies to develop the sector and engage international initiatives to foster hydrogen development. An example is the Hydrogen Initiative, a voluntary multi-governmental institution that aims to advance policies, programmes and projects to expedite the commercialisation and deployment of hydrogen and fuel cell technologies (IEA, 2023a).

The comparison centres around the dimensions summarised in Table 1. The study draws on different sources of information to examine these dimensions. The national strategy approach is studied mainly through a content analysis of governmental documents to gather how the strategies differ. For that, we selected documents by including the ones focused solely on the development of the hydrogen sector published by the national government of the countries here included in recent years (between 2020 and mid-2024), leading to the inclusion of seven documents. These documents were selected because they are elaborated by the national governments and express targets, priorities, and goals regarding the hydrogen sector.

Table 2: Documents included in the analysis

Country	Document
Brazil	National Hydrogen Programme (PNH2) and Triennial Workplan for the PNH2

[11] The two only other publications, to the best of our knowledge, are UNCTAD (2023) and Lema and Rabellotti (2023), which do not solely focus on green hydrogen, limiting the depth of their sectoral investigation.

Chile	National Green Hydrogen Strategy (NGHS) and Green Hydrogen Action Plan
China	Medium and Long-term Plan for the Development of the Hydrogen Energy Industry (2021-2035)
South Africa	Hydrogen Society Roadmap (HSRM) and Green Hydrogen Commercialisation Strategy (GHCS)

Source: Elaborated by the authors

The study implements content analysis to systematically examine governmental documents to identify patterns relevant to green hydrogen development strategies. We used a deductive approach based on the literature, relying especially on the work by Fokeer et al. (2023). Each text was coded with Atlas.ti, guided by a codebook to ensure consistency. Following coding, we reviewed recurring patterns, which were then synthesized in relation to our research questions. We also triangulated the information obtained with the content analysis with the information gathered through other sources, including form interviews and a revision of academic and grey literature.

The analysis of preconditions and responses relies mostly on secondary information from interviews and a review of academic and grey literature. Details in Sections 4 and 5 derive from interviews, unless stated otherwise. Furthermore, it also used the IEA hydrogen production projects database to have a list of the projects taking place in each country and their technical information, besides using it as a basis to search the companies engaging in each case. It is important to highlight, however, that this database has shortcomings, not always fully reflecting the projects in place. We comprehensively reviewed official governmental and policy domestics, news pieces, company websites and the existing literature to map the industrial policies targeting green hydrogen in the case studies and the actors involved in the sector, with a focus on production projects included in the 2023 International Energy Agency Hydrogen Production Projects database.

This study has shortcomings related to analysing an emerging and dynamic sector, meaning that policies and projects are still taking place. The factors listed in Table 1 represent an initial effort to find indicators to examine them, but the analysis remains exploratory. The detailed information across all the factors mentioned in Table 1 is in the Annex.

4. The similarities and differences across green hydrogen strategies

The identification of the main similarities and differences in the strategies of these countries to develop the green hydrogen sector focuses on three dimensions. First, the *priority level* of green hydrogen in the hydrogen strategies, which considers the overall importance of green hydrogen in national energy and industrial policy documents. Secondly, the study examines the *outwardness of development strategy*, analysing the extent of export orientation versus domestic use in the national strategy (export orientation). Lastly, it considers the *concentration of hydrogen use and industrial linkages*, examining the degree to which green hydrogen is used for one key application versus diversified uses, which also highlights the emphasis on forward and backward linkages for industrial development. Table 3 summarises the findings, which are further developed in this section. It is important to highlight that this refers to the strategy as per official documents, which is not necessarily reflected by policies and projects in place, which in this study is encompassed as "responses".

Table 3: Summary of main similarities and differences in Green Hydrogen Strategies in governmental documents

	Brazil	Chile	China	South Africa
Technology focus	Technology agnostic	Greater focus on green hydrogen	Technology agnostic	Greater focus on green hydrogen
Priority as agenda topic	Strategic but not priority	Priority	Strategic but not priority	Priority
Outwardness of official development strategy	Domestic	Foreign	Domestic	Domestic
Concentration of hydrogen use	Transport and industry	Transport and e-fuels	Transport and industry	Transport and industry
Attention to industrial linkages	Yes, with a focus on end uses	Yes	Yes, focusing on both electrolysers and end uses	Yes, focusing on end uses

Source: Elaborated by the authors

4.1 The priority of green hydrogen in Brazil, Chile, China, and South Africa

We consider how much focus governmental documents place on green hydrogen when compared to other hydrogen production pathways to analyse the priority level of the green hydrogen agenda. The study performed a content analysis to contrast the mentions of green hydrogen (or renewable or electrolytic hydrogen and other synonyms) and other technology routes for hydrogen production, encompassing blue, grey, black, and others. Low-carbon or clean alternatives, unless specified as referring to green hydrogen, were considered in the latter group. Table 4 summarises the findings, showing the share of mentions in the documents that were not green hydrogen-specific.

Table 4: Absolute number of mentions of green and other types of hydrogen in the national documents

Document	Green hydrogen	Other
Brazil: NHP2	5.5%	94.5%
Brazil: Triennial Workplan for NHP2	6.1%	93.9%
Chile: NGHS	Green hydrogen specific	
Chile: Action Plan	Green hydrogen specific	
China	1%	99%
South Africa: HSRM	Green hydrogen specific	
South Africa: GHCS	Green hydrogen specific	

Source: Elaborated by the authors.

A national strategy serves the purpose of stating a clear policy direction and targets across the sectoral value chain that may steer investments and projects into a desired path (Fokeer et al., 2023). Across the four case studies, Chile and South Africa have green hydrogen-focused policy documents that establish targets and priorities. The Chilean Ministry of Energy published the NGHS to guide the development of the green hydrogen sector specifically, as indicated by the title. Meanwhile, South Africa's HSRM emphasises the development of hydrogen from renewable sources. The country also established the GHCS in 2023, showing its commitment to green hydrogen. Brazil and China, on the other hand, adopted a technology-neutral approach. In the case of Brazil, the Work Plan justifies this choice due to the national richness in terms of natural resources and the technology and market immaturity of green hydrogen. China has a similar approach. Hydrogen is a key part of the decarbonisation strategy besides being considered a priority, but there is a commitment to low-carbon hydrogen without necessarily focusing on a specific production route. The central government does not prioritise the development of green over blue hydrogen either as a decarbonisation route or as a balancing strategy to stabilise energy provision from renewables (Gong and Quitzow, 2024).

4.2 The outwardness level of the green hydrogen development strategy

As Fokeer et al. (2023) state, countries may decide to invest in the development of the green hydrogen market for a myriad of reasons ("drivers"). First, they may want to participate in the international trade of green hydrogen and its derivatives. As the countries analysed in this study are considered potential self-sufficient or exporting countries in the literature, this has been simply related to **export** opportunities in our analysis, as any mention of the import of hydrogen is, indeed, missing from the governmental documents examined. Secondly, countries may be interested in **decarbonising their economies**. It is important to mention that this is not necessarily driven by environmental sustainability concerns per se – many local industries might lose their competitiveness due to international trade regulations like CBAM and national decarbonisation goals or corporate standards applied by leading firms in their supply chains (p. 30). However, our analysis cannot reach this level of detail, so we focus on mentions of the decarbonisation of the national market. Thirdly, countries may invest in green hydrogen development to promote energy security or diversify their energy supplies. In our study, we have grouped both under **energy security**, which refers to increasing the energy supply, stabilising the supply from renewable electricity through storage, and diversifying the energy matrix. Fourth, countries may be interested in **innovation and industrial development gains**, which we refer to as the development of new capabilities and industries. Lastly, there might be **other socioeconomic gains** at play, such as the generation of jobs or the promotion of local development in specific regions. The content analysis focused on identifying these drivers, adding a sixth: **domestic market application** for cases missing a specification of the exact nature of the opportunity in the domestic market.

Building on the previous categories, it is possible to contrast the domestic market and foreign market focus of the strategy. Socioeconomic benefits may arise regardless of the end use of the hydrogen produced. Due to upward linkages, energy security may also relate to hydrogen and derivatives produced for export or domestic markets. Thus, this comparison builds on contrasting exports and domestic focus by aggregating decarbonisation of the national economy, innovation and industrial development gains, and domestic market application, albeit the caveats remain that decarbonisation could refer to the increase in renewables generation and that innovation and industrial development gains could be related to upstream linkages or R&D focused on hydrogen production instead of applications. Table 5 summarises the findings, showing the relative number of mentions across the dimensions in each document.

Table 5: Share of mentions of drivers of clean hydrogen development in the national documents by category.

Document	Domestic	Foreign
Brazil: NHP2	83.3%	16.7%
Brazil: Triennial Workplan	64.1%	35.9%
Chile: NGHS	57.1%	42.9%
Chile: Action Plan	92.5%	7.5%
China	100%	0%
South Africa: HSRM	81.3%	18.7%
South Africa: GHCS	75%	25%

Source: Elaborated by the authors.

The documents of all countries highlight more the domestic than the foreign market, but the focus varies considerably. In the Brazilian case, the decarbonization of the national economy is more often mentioned, with the documents highlighting that hydrogen development must be aligned with the decarbonisation goals of Brazil, which established the target of becoming net zero by 2050. Achieving innovation and industrial gains appears in second.

The Chilean NGHS reveals a balanced focus considering the number of references to domestic or foreign markets**.** However, exports are arguably the main driver and opportunity for green hydrogen development in the country. First, the strategy indicates that domestic applications may be a pathway to achieve competitiveness and successfully enter global markets while also enabling a greater value capture by local enterprises. Furthermore, the volumes of green hydrogen for domestic consumption and foreign trade are considerably different. Markets will primarily be abroad, accounting for about 60% of the earnings by 2030 and a bit more than 70% by 2050. Chile released the Green Hydrogen Action Plan, laying out public policies to construct the sector and the next steps necessary to achieve the objectives of the NGHS. Thus, the document focuses more on the domestic market.

China is the only case in this study where hydrogen development was not connected to exports. Across the drivers connected to the domestic market, domestic applications and innovation and industrialisation are the most emphasised. Lastly, South Africa highlights domestic market applications, followed by decarbonization of the national economy and innovation and industrial gains. In terms of volumes, however, the GHCS projects 3.8 Mtpa of green hydrogen production by 2040, with half of it going to domestic markets while the other half is directed towards foreign markets.

4.3 Concentration of hydrogen use and industrial linkages in the green hydrogen development strategies

Clean hydrogen production has different potential applications. The document analysis focused on identifying the sectors and end uses mentioned in governmental documents to highlight whether there are differences across the strategies in terms of applications. It is important to highlight, however, that it does not differentiate whether it refers to domestic or foreign markets, except for cases that explicitly referred to the exports of specific products. Table 6 summarises the mentions across the dimensions in each document.

Table 6: Mentions of sectors/end use in the documents as percentage of total mentions in the documents per country by category.

Sector/end use	Brazil	Chile	China	South Africa
Industry	29.8%	15%	24.4%	22.4%
Capital goods	1.1%	0%	1.7%	0.6%
Refining	3.2%	3.1%	3.4%	1.8%
Transport	22.3%	29.9%	40.7%	35.2%
E-fuels/methanol and other derivatives	11.7%	18.1%	8.5%	16.7%
Mining	2.1%	4.7%	8.5%	6.5%
Blend with natural gas	4.3%	5.5%	0%	0.8%
Energy/heating	7.4%	6.3%	11.9%	4.1%
Exports of decarbonised goods	2.1%	5.5%	0%	2.4%
Exports of hydrogen/ammonia	16%	11.8%	0%	9.6%

Source: Elaborated by the authors.

Brazil, Chile, and South Africa have a similar pattern. In the three cases, industry, transport, and e-fuels/methanol and derivatives applications are the most often mentioned for hydrogen use, although the order between them varies. In the Brazilian case, industrial applications are most frequently cited, especially those related to ammonia-based fertilisers. Applications in the transport sector appear in second place. In Chile, the transport sector and e-fuel production are, respectively, the two most cited end uses for clean hydrogen. The GHNS mostly mentions exports of green hydrogen and derivatives (e.g., ammonia), but also covers the exports of green products, especially green copper. Regarding domestic usage, it focuses on the replacement of fossil fuel-based hydrogen in ammonia production (for explosives and fertilisers) and oil refining. The mining sector is expected to switch to e-fuels and replace heavy oil with green hydrogen in copper processing. Applications in the transport sector and for heating might follow later. South Africa highlights applications in the transportation and industrial sectors. The HSRM, for example, highlights that most of the domestic demand should come from applications like transportation, steel, chemicals and refining, with green hydrogen also playing a role in the stabilisation of energy supply through renewables. The GHCS, however, highlights that domestic applications will be driven by price competitiveness. Thus, applications in sectors like mining, where infrastructure costs can be mitigated, should come before applications in transportation and steel, for instance. In Brazilian and South African documents, industry, transport, and e-fuels/methanol account for around 65% and 70%, respectively, of the mentions of clean hydrogen applications, while in Chile this stays around half. China stands out because it covers a lower range of end uses. However, among the three, it presents the highest focus on the transportation sector, which is followed by the industrial sector.

5. Preconditions for Green Hydrogen development in Brazil, Chile, China, and South Africa

The second subsidiary research question explores how differences in public policies reflect varying preconditions and potentials for green hydrogen-led industrial development. This involves examining how the differences described in section 4.1 reflect initial conditions. To examine this issue, we review and synthesise the country-level information described in section 3. We focus here on the following three preconditions and how they have helped to shape national strategies:

- ***Natural resource endowments****:* The influence of natural resource availability on strategy development.
- ***Energy infrastructure****:* The impact of existing energy infrastructures on strategy development.
- ***Market structures****:* The influence of current market structures, including supply chain and demand for hydrogen.

5.1 Natural resource endowments and energy infrastructure

Natural resource endowments provide part of the explanation of the strategies for green hydrogen development as they determine the cost advantage of hydrogen production and its potential for domestic consumption and exports. Chile is seen as one of the global leaders in green hydrogen potential due to its unique natural resource advantages. It combines high solar energy potential, especially in the Atacama Desert, which has one of the highest solar irradiance levels in the world. Moreover, wind resources are strong in Patagonia, complementing the renewable mix and enabling it to potentially produce green hydrogen at one of the lowest costs globally. Across the case studies, it has the highest average irradiation and wind speed.

Similar to Chile, Brazil's location facilitates exports to other markets, and it has abundant renewable resources, although less strong than Chile. Furthermore, Brazil's renewable energy infrastructure is well developed, with electricity being mostly based on hydropower. Green hydrogen can benefit both from the stable renewable provision as well as the nationally interconnected grid, facilitating projects without captive energy and the transfer from producing to consuming sites. However, while Brazilian documents link clean hydrogen development to the country's decarbonisation agenda, there could be competition with other alternatives in specific end uses. Moreover, land use linked to agricultural production represents a significant share of

Brazilian emissions, and deforestation stands as one of the main challenges for the country's environmental targets, which cannot be addressed by green hydrogen in the absence of a better-developed carbon market (Garofalo et al., 2022; Kruid et al., 2021). Such factors may partially explain the lower priority given to green hydrogen in the national agenda when compared to other countries – the richness in terms of resources leads to both competition when it comes to production and decarbonisation routes. Additionally, the environmental challenge is different from other case studies. On the other hand, mineral richness in iron ore reserves, which Brazil is among the top producers in the world, incentivises the development of downward linkages focusing on green hydrogen application in green steel production.

South Africa is also rich in terms of both wind and solar resources. Furthermore, South Africa has abundant mineral resources, detaining over 70% of platinum group metals, an essential input for some hydrogen technologies like electrolysers and fuel cells, which is a significant motivation to push the development of the sector. Such mineral abundance represents a possibility of further exploiting these resources and developing activities to capture greater value. Geographically, South Africa is well-positioned to provide exports to Europe. However, water scarcity and drought conditions in some regions may hamper green hydrogen as it increases the pressure on natural resources, including the demand in terms of land availability and energy (Dagnachew and Solf, 2024; Sparks et al., 2014; Varras and Chalaris, 2024). Furthermore, South Africa faces a significant bottleneck in terms of energy infrastructure, facing constraints both in terms of availability and stability of grid and renewables provision. Investments in renewables have been increasing, but energy in the country remains strongly based on coal, with long-term purchase agreements contributing to a technology lock-in predicted until around 2040 (Mirzania et al., 2023).

Considering the renewable resources endowment, China faces greater constraints than the other case studies, especially in terms of land for onshore wind power generation and water availability. China already surpassed the sustainable level of domestic water use. Furthermore, depending on the renewable generation technology employed to produce green hydrogen – specifically, if it entails onshore generation – China may also face land availability restrictions (Tonelli et al., 2023). It does, however, still present favourable conditions for green hydrogen production as the country has significant wind and solar energy resources. Furthermore, China is a key producer of green technologies for the energy transition, being a technology leader in the wind and solar industries (Binz et al., 2020; Zhang and Gallagher, 2016). At the same time, the country is a leader in grey hydrogen production, which could be turned into blue with CCSU technology, which represents an alternative in terms of the clean hydrogen technology route.

5.2 Market structures

Economic diversification opens opportunities for green hydrogen application in the domestic market. Brazil already has some hydrogen production, but it is based on fossil fuels, comprising mostly grey hydrogen (87%). It is mainly consumed in the domestic market for oil refining and ammonia for fertilizer production (EPE, 2022). Such grey hydrogen consumption could be displaced by its green counterpart. Potential demand markets in the country include the chemical industry, particularly for fertilizer production, mining, steel, and transport. Green ammonia represents another pathway for creating demand for green hydrogen in Brazil. The country is one of the largest exporters of agricultural goods in the world, but it relies on fertiliser imports for its production. In 2022 alone, the nation imported fertilisers valued at USD 22.5 billion, making it the largest importer globally (OEA, n.d.). The domestic production of green ammonia could spur a fertiliser industry that replaces the imports of nitrogen fertilisers. Thus, leveraging green hydrogen production to develop the fertilising industry in the country offers an attractive alternative both as an industrialisation opportunity and as well as decreasing balance of payments pressures. However, the first industry to sign a green hydrogen offtake agreement in the Brazilian domestic market was cement – the government of the Rio Grande do Norte state, CPFL Energy, State Grid and Mizu Cimentos have signed a contract to construct a hydrogen plant with 1 MW electrolyser capacity to provide green hydrogen to the production of cement (Rodrigues, 2024).

Chile, on the other hand, has limited domestic consumption potential compared to its production capacity. The current domestic market for hydrogen is limited as domestic demand represented less than 0.1 % of the global demand in 2018, reaching circa 59,000 tonnes, mostly from refineries. However, decarbonisation targets open pathways to expand green hydrogen demand. The Long-Term Strategy on Climate Change specifies that by 2040, 20 % of the fuels used for transport are to be based on green hydrogen. Accordingly, all newly registered buses for intra-urban services, taxis and personal vehicles must be emission-free by 2035, using either green hydrogen or lithium-based electric mobility. The same objective applies to long-distance buses and vehicles that transport cargo by 2045 (Government of Chile, 2021). Moreover, the Chilean government projects that mining will play a key role in green hydrogen development. Big mining companies – Anglo American, Antofagasta Minerals, BHP Billiton and Codelco – are signalling significant interest in green hydrogen (La Tercera, 2021a, 2021b), and mining haul trucks should represent 30% of local hydrogen demand (Boese Cortés and Soto, 2023), increasing the attractiveness of green hydrogen production in the Antofagasta region as it is one of the world leading copper mining locations Furthermore, the presence of large-scale mining also impacts the availability of suitable infrastructure for green hydrogen development in the North of Chile since the infrastructure and capabilities can be leveraged to green hydrogen as well. The regional power grid is also developed enough to transmit the electricity needed for the first projects of green hydrogen production. Local suppliers to transnational mining corporations may also benefit from their experience when entering the green hydrogen sector. However, despite the opportunities opened by mining and, at a later stage, the transport sector, the Chilean production potential remains higher than the domestic demand, justifying the focus on exports

China is in a particularly good position in terms of the domestic market. It is the world's largest producer and consumer of hydrogen, besides also being one of the leaders in the production of outputs in sectors that represent (potential) demand markets such as steel. The country achieved a production level of various types of hydrogen of about 40 million tons in 2022, with a 32% year-on-year growth. Under the vision of carbon peaking by 2030, the production of hydrogen will exceed 50 million tons per year. However, most of this production comes from fossil sources and as an industrial by-product, with green hydrogen accounting for less than 1% of total production (TrendBank, 2023). China is, however, building on its experience with fuel-cell electric vehicles to develop a domestic market for hydrogen, with many demonstration projects and investments targeting this sector. In terms of technology for green hydrogen, the country also positions itself well. It is one of the global leaders in alkaline electrolysers, achieving significant cost competitiveness when compared to other players. In addition, the electrolyser capacity in China – both operational and under construction –surpasses that of the EU and the US (Gong and Quitzow, 2024). From 2019 to 2022, the installed capacity of hydrogen electrolysers in China has grown rapidly. It is projected that by 2025, the demand for green renewable hydrogen in China will reach over 1.3 million tons, and the cumulative shipments of electrolytic hydrogen production equipment from 2023 to 2025 are estimated to exceed 17 GW (TrendBank, 2023)

The decarbonisation agenda opens new opportunities for hydrogen. Under the dual carbon strategy, with the goal of achieving carbon neutrality by 2060, the total demand for hydrogen energy in various industries in China will increase to about 100-130 million tons, with renewable hydrogen accounting for about 75%-80%, or 75-100 million tons per year (Li et al., 2022). From the perspective of energy consumption, the demand for hydrogen is growing rapidly in sectors such as chemical raw materials and road transportation. Hydrogen demand is significant and expanding, especially in sectors like chemicals and transportation. Following its emphasis on fuel cell electric vehicle (FCEV) development, the transportation sector appears as one of the main focuses of hydrogen development plans, besides the efforts in terms of technological capabilities throughout the hydrogen production chain. In a zero-carbon context, the proportion of hydrogen in the final energy consumption of these industries is expected to reach 40-80%, making it the primary power source. However, due to the deep reliance of other sectors on fossil energy, this should not be the case for the industrial sector as a whole (Li et al., 2022).

Albeit more limited when compared to China, South Africa has a well-developed industrial structure, but the country has been subject to deindustrialization. In a slow-growing economy, the share of manufacturing in GDP has declined sharply from 19.3% of GDP in 1994 to 11.8% in 2019 (Black, 2021). It has large heavy industry and mining sectors; consequently, the economy is highly energy-intensive, and, considering the reliance on coal-based energy, also emission intensive (Winkler and Black, 2024) – South African carbon emissions per capita (7.5 tons) surpass that of richer regions like the EU (6.4 tons) (Stamm et al., 2023).

This hampers competitiveness in global markets and that could be exacerbated as carbon taxes are being imposed by trade partners like the EU (Bell et al., 2022). However, it also creates a potential market for green hydrogen to decarbonise sectors like mining, refining, and transportation. Furthermore, the capabilities of the private sector, which is the world leader in the Fischer-Tropsch process may facilitate the the development of some end uses of green hydrogen in the national market. Localising activities related to the green hydrogen value chain is also an alternative to promote industrialisation and local economic gains. Such points push for the strategy to highlight domestic applications and the industrial gains that could come from green hydrogen.

5.3 Summary

Table 7 provides a comparative overview of how these preconditions influence each country's strategy. Brazil's abundant natural resources and robust infrastructure support a diversified approach with a focus on domestic industrial use. Chile leverages its renewable energy potential for export-oriented hydrogen production, especially considering the size limitation of the domestic market. In this sense, the country is the best positioned among the four to become a supplier in the global markets. China uses its industrial scale to promote domestic hydrogen applications, focusing on catching up in the technologies to produce, transport, and store hydrogen. In terms of end uses, the transport sector remains central, following the previous strategy of the country in FCEV exports. For domestic usage, Brazil and China have inherent advantages due to their already well-established infrastructure and renewables industry. South Africa seeks to address energy security and decarbonisation challenges while building industrial demand that counterbalances the deindustrialization process faced by the country. The limitations in terms of water endowment in certain regions promote the development of projects along the coast, while the energy infrastructure poses a challenge as it is necessary to upgrade the grid and renewable energy capacity to scale hydrogen production effectively.

Table 7: Summary of the role of preconditions in influencing national strategies

Precondition	Brazil	Chile	China	South Africa
Natural resource endowments	Rich but less competitive	Strong in solar and wind, competitive	Constrained in land and water	Strong in wind and solar, constrained in water
Energy infrastructure	Well-developed	Well-developed	Well-developed	Limited
Market structure	Diversified	Diversified but limited in size	Diversified	Diversified

Source: Elaborated by the authors.

6. Public and private responses

The third subsidiary research question investigates how the responses are being implemented. Responses can be divided into two categories. The first comprises the action from the public sector in the form of incentive measures targeting the development of the green hydrogen sector. Contrary to the strategies examined previously, such policies are in the form of production, technology, or demand incentives, being, on the other hand, more limited in scope. The second group of response encompasses green hydrogen production projects, which may involve a myriad of actors, including domestic and foreign public and private enterprises as well as research institutes and universities, among others. We analyse responses focusing on two dimensions:

- ***Industrial policies:*** The most relevant incentive policies and how they reflect national strategies.
- ***Local and foreign actors:*** The most relevant local and foreign enterprises and agencies in the sector according to production projects.

6.1 Industrial policies

In 2024, Brazil established the legal framework for hydrogen, which implements rules and incentives for this industry. It includes the Special Incentives Regime to the Production of Low Carbon Hydrogen (Rehidro), which offers tax benefits for companies involved in low-carbon production, transport, distribution, conditioning, storage, and commercialisation, as well as in the production of biogas and renewable electricity to hydrogen production. Eligibility is, however, conditioned on companies meeting a minimum level of national purchase of inputs to the production process – except when there is no national equivalent or national production is insufficient to meet the demand – and of investments in national R&D&I, but such conditionalities are yet to be specified (Lei 14948/2024, 2024; MF, 2024). Such conditionalities reinforce that interest in low-carbon hydrogen in the national agenda hinges on the industrialisation or domestic market capabilities enhancement that it can bring. However, the rules of Rehidro do not limit export possibilities, as it does not include conditionalities in terms of domestic usage. Furthermore, the country still lacks demand-side incentives and a well-developed carbon market that could fasten the transition towards green hydrogen.

In Chile, the state takes the role of a facilitator that brings foreign lead firms and local suppliers together, taking additional support measures to overcome market uncertainties. On this line, the Economic Development Agency (CORFO) launched a call in 2021 to select proposals to receive USD 50 million as co-finance for green hydrogen development. In 2024, the country established a subsidy scheme to grant up to USD 10 million per plant targeting companies interested in building new electrolysers manufacturing or assembling factories (Collins, 2024). Furthermore, the government announced the USD 1 billion Green Hydrogen Development Fund to derisk hydrogen projects by catalysing private investments in production and demand projects as well as related infrastructure and the institutional framework. This initiative is supported by organisations like the Inter-American Development Bank (IDB), the World Bank, the German Development Bank (KfW), and the European Union, with additional funding coming from private sources. (Ministerio de Energia, 2023; Ministerio de Hacienda, 2023). Chile is also incentivising domestic demand through CORFO's Use and Adoption of Green Hydrogen in the Chilean Industry"[12] programme. Together with a call for a programme targeting the manufacturing of components of the hydrogen industry, they entail USD 15 million in subsidies offered over 5 years, with an additional USD 12 million coming from private resources (Ministerio de Economía, Fomento y Turismo, 2024).

[12] *Uso y Adopción de Hidrógeno Verde en la Industria Chilena*

In China, hydrogen fits the Chinese project of developing fuel cells electric vehicles and related technologies. The transport sector figures among the priorities of multiple governmental documents, including the National Hydrogen Development Plan, which designs a phased approach to the adoption of hydrogen fuel cell vehicles, setting the goal of 50,0000 FCEVs by 2025. However, the primary focus of China's current hydrogen policy is not on the demand side, but mostly on improving supply-side capacity. In particular, most policies mention the need to accelerate the construction of the hydrogen production chain, and one of the main priorities of the central government is developing relevant technological knowledge (Gong and Quitzow, 2024). China's focus lies on the production, transportation and storage of liquid hydrogen, the localisation of fuel cells, and the construction of hydrogen power networks. To that end, initiatives to promote innovation were proposed, including the provision of policy guarantees and organisational facilitation for the construction of innovation systems (Wang et al., 2022).

South Africa relies mostly on previously existing support measures. One example is the legislation stating that the deployment of renewable energy projects related to green hydrogen production is exempted from electricity policy planning and regulatory requirements (licensing) if it is isolated from the grid. Further support measures include initiatives such as the Department of Trade, Industry, and Competition (DTIC) Energy One Stop Shop and the Energy Resilience Fund. High-level government support was offered to a range of proposed green hydrogen projects such as the Hive Energy project in the Eastern Cape, which included commitments around infrastructure development, regulatory approval, and financing. Furthermore, there have been several publicly funded research initiatives, some undertaken jointly with big firms like Sasol. Lastly, South Africa announced the launch of the SA-H2 Fund in 2023. It is a blended finance fund that aims at supporting large-scale renewable energy infrastructure projects. It is currently raising resources, aiming at achieving USD 1 billion in a collaborative effort involving public and private as well as foreign and domestic institutions. It counts on the support of Invest International B.V., Climate Fund Managers, Sanlam Limited of South Africa, the Development Bank of South Africa, and the Industrial Corporation of South Africa, among other strategic partners (Alabi, 2024). Thus, similar to other countries, industrial policies focus on the supply side. Furthermore, projects with export components can take advantage of special economic zones in the country like Freeport Saldanha and the Coega Special Economic Zone.

6.2 Enterprise responses

In Brazil, the domestic private sector's involvement in green hydrogen is influenced by renewable energy firms. These companies see green hydrogen as a potential solution to surplus renewable energy, as green hydrogen represents an offtaker for their output. Their interest overlaps with that of subnational governments like Ceará, who have been more proactive than the national government in the green hydrogen agenda, establishing MoU and developing strategies to attract investments dating longer than the recent development of the hydrogen framework by the national government. Production projects in Brazil encompass a mix of national and foreign companies.

In Chile, mining and renewable energy companies are key players, with green hydrogen seen as vital for reducing emissions and maintaining export competitiveness. Many production projects involve exporting goals, with recent initiatives focusing on markets in Europe and Japan. They involve groups from Chile, encompassing research institutions, mining, oil and natural gas, and renewable energy companies, as well as multinationals. The Chilean state is involved both through CORFO and state-owned enterprises like Enap. The Chilean Hydrogen Association (H2 Chile) represents a channel for the government to collaborate with industries.

In China, national energy firms (e.g. Sinopec) and automotive firms (e.g. SAIC) are key in driving green hydrogen development, focusing on scaling technologies for domestic decarbonization goals, and aligning with the broader industrial strategy of China. The China Hydrogen Alliance brings together private firms, SOEs, and R&D institutions in the sector. Similarly to Brazil, subnational governments have acted more strongly than the national government, as subnational (local and provincial) governments have established their plans and targets for hydrogen. National policies focus on technology development, not yet targeting offtake. In terms of production projects, most of them targeted mobility, with Central and state-owned energy companies being the main force in green hydrogen construction (TrendBank, 2023). Currently, there are over 300 large industrial companies across the industrial chain in China, mainly distributed in the Yangtze River Delta, Guangdong-Hong Kong-Macao Greater Bay Area, Beijing-Tianjin-Hebei region and other areas (Li, 2022).

In South Africa, firms in mining and heavy industries, such as Sasol, are relevant actors in the development of green hydrogen to meet international decarbonisation regulations. Indeed, a number of production projects include domestic partners, with Sasol being an important actor. Further, large emission-intensive sectors and firms have issued a series of statements and plans to reduce emissions, encompassing the of development green hydrogen capacity in a number of cases. Three key sectors in this regard are chemicals, steel and cement (Andreoni et al., 2023)

Foreign public agencies have played distinct roles across these countries with significant activity, especially by German and Dutch agencies. The Brazil-Germany alliance (H2Brasil) sought to promote studies, training, and technology and project development (GIZ, 2022a). Chile has been building on significant support from international organizations, including the World Bank, which approved a USD 150 million loan to green hydrogen projects in the country (World Bank Group, 2023). Similar to Chile, South Africa builds on partnerships to promote the development of the green hydrogen sector and access financing. For example, the European Union provided grants to develop the green hydrogen value chain in South Africa (The European Union et al., 2024). In China, UNIDO is involved in the development of green hydrogen through both the GEF Project (GEF; UNIDO, n.d.) and the International Hydrogen Energy Centre. There are also exchanges among the case studies – for example, Brazil and China established agreements to promote knowledge exchange (China Dialogue, 2021).

6.3 Summary

Table 8 provides a comparative overview of how industrial policies in each case reflect the country's strategy as well as the actors that are emerging. The experience of the case study countries highlights the role of enterprises but also the key role played by specific actors such as BNDES, in Brazil and CORFO, in Chile. It also highlights the importance of subnational governments, that have been pushing this agenda further – sometimes, more actively than the national government – as showcased in Brazil, China, and Chile. In terms of foreign enterprise involvement, multinationals such as Siemens Energy, Shell, and Engie and Linde play important roles in investments in green hydrogen. Chinese companies and SOEs stand out in terms of involvement in green hydrogen projects, with the country also leading the number of production initiatives across the case studies, followed by Chile. Furthermore, the support from foreign agencies has been playing a significant role.

Table 8: Summary of the role of preconditions in influencing national strategies

	Brazil	**Chile**	**China**	**South Africa**
Public policies	Recent initiatives focus on supply-side and encompass localisation efforts and local R&D conditionalities, reflecting the industrialisation effort.	Focus on co-financing and de-risking projects, also encompassing R&D and demand-side incentives.	Focus on technology incentives, reflecting its goal of establishing as a technology leaders.	Builds mostly on pre-existing measures, focusing on supply-side measures. It currently lacks localisation and demand-market measures.
Actors	Firms in renewables and subnational governments have pushed the agenda. Projects include MNCs like Siemens and Shell.	Mining firms are among key players, while CORFO plays an essential role on the government side. The country builds on available support from international organisations like the EU and IDB.	Established by Sinopec, bringing together private sector firms, SOEs and R&D institutions. SOE companies and subnational governments play crucial roles.	The government has been active, especially through IDC. It also benefits from the support of foreign donors like the EU. MNCs like Anglo American and Sasol are key players.

Source: Elaborated by the authors.

7. Conclusion

In this study we have systemically examined how green hydrogen strategies differ in Brazil, Chile, China, and South Africa. We found they vary primarily due to differences in national priorities, resource availability, and policy focus. Brazil and China adopt technology-agnostic approaches, allowing the production of hydrogen through multiple pathways such as blue and pink hydrogen, rather than emphasising green hydrogen alone. In contrast, Chile and South Africa are prioritizing green hydrogen specifically. The development focus also varies; Chile and South Africa emphasize green hydrogen as a priority in their national agendas, while for Brazil and China, green hydrogen is strategic but not always a top policy priority. This distinction reflects the different industrial linkages each country fosters, with Chile focusing heavily on export markets and South Africa being motivated by the decarbonizing heavy industries but recognising the crucial role of exports to drive the initial demand for their output.

The reasons behind these divergent strategies lie in national resource endowments, energy infrastructure, and market structure. Chile's vast renewable energy resources, particularly solar and wind, coupled with its geographical location, make it an ideal exporter of green hydrogen, especially considering the limited size of domestic demand for green hydrogen. Brazil's large resource base, which includes hydro and biomass, provides alternative decarbonization routes, diminishing the emphasis on green hydrogen. At the same time, green hydrogen appears as interesting albeit it can promote industrialisation, diversifying the activities in the country. China's focus is more on domestic applications, leveraging its vast and diversified market, whereas South Africa's strategy is shaped by its heavy reliance on coal and the urgent need to decarbonise industries like mining, while also relying on exports, especially while the cost competitiveness of green hydrogen does not improve.

However, there are some contrasts when considering the national strategy and the responses in place. Foremost, the connection between promoting industrialisation while fostering green hydrogen development is clearer in the Brazilian case, as incentive benefits are connected to localisation and national purchase efforts. At the same time, the national government has been presenting a slower response to the GWO than the other countries, resulting in projects being in more initial stages and not having benefitted from the support measures yet. In terms of private responses, there currently is an apparent lack of connection between them and the domestic market focus of national strategies, particularly in the case of South Africa, where most projects focus on the external market while the national strategy primarily highlights the domestic market. Furthermore, across all countries, the focus in terms of industrial policy is currently mostly concentrated on the supply side through financial incentives or technology policies, with very little on the demand side.

The green premium plays a significant role, as it hampers demand for green hydrogen without considerable subsidies in place. The fiscal space of developing economies is significantly more limited than that of developed economies, hampering sustaining price subsidies to boost demand while the cost of green hydrogen does not fall. Such limitation, especially in the case of Brazil, Chile, and South Africa, may push projects towards an export focus given the larger market in foreign countries and initiatives like H2Global, which offer an opportunity to take advantage of subsidies implemented by importing countries. Thus, the lack of cost competitiveness of green hydrogen is an element that may contribute to the slower development level of domestic market projects and limited demand-side incentives.

In terms of future policy design for green hydrogen-led development in Global South countries, this study shows that there is no unique pathway being followed to seize GWO in green hydrogen. Natural resource endowments affect the country's competitiveness in global green hydrogen markets and possible decarbonization routes for domestic sectors. Energy and market structure impacts both the investments needs and the demand that can shift to green hydrogen. As many of the economic gains connected to hydrogen lie on downstream linkages, developing the domestic demand is a crucial part. However, the green premium poses a significant challenge that may push for an export-led strategy, at least initially.

The development of the green hydrogen sector hinges on a more proactive approach to incentivise domestic applications and localize hydrogen production capacity. Fostering national demand is crucial to capture more value added in the green hydrogen value chain. However, this highlights the international dimension that is involved in successfully fostering green hydrogen. At the national level, measures to incentivise demand – besides price subsidy – involve enacting standards and certifications and mechanisms like carbon pricing. However, the multiplication of certifications and standards and the lack of alignment between those of importer and exporter may introduce further complexity. Moreover, mechanisms like carbon pricing can mitigate the price differential by increasing the cost of polluting technologies, but it may have undesired effects on the global competitiveness of current industries if countries implement them in an isolated way. Thus, there is a need to enhance hydrogen diplomacy to push for more stringent environmental regulations and the adoption of global policies, as well as ensure the alignment across standards.

This highlights a key distinction between industrial policy in this area and conventional industrial policy: the complex level of coordination that is required. Bringing together the large-scale infrastructure and investments in green hydrogen poses a huge challenge as it involves local and national spheres of government, domestic and foreign investors as well as multilateral lenders and donors.[13] The availability of global climate finance, while positive, also adds further complexity. Partnerships with foreign actors and with the private sector, as well as the academia, have been crucial so far to advance green hydrogen in developing countries. Countries have fostered international agreements from donor countries to develop projects and advance infrastructure and

[13] Global arrangements for green hydrogen development need to integrate 'just transition' considerations, ensuring that the benefits of the transition are equitably shared. Some initiatives, such as the Just Energy Transition Partnerships (JET-Ps), already exemplify this approach. Countries that have historically contributed the most to global emissions could provide support beyond traditional loans, enabling developing countries to not only participate in the transition but also benefit from it. Additionally, the potential for supporting industry deepening in the implementation of JET-IPs should be closely monitored to maximize long-term developmental impacts

regulation. For example, the Brazilian Development Bank has partnerships with World Bank, KfW, and BEI to ensure funding to the energy transition and green hydrogen projects. South Africa has agreements with the EU, Germany, the Netherlands, the US, the UK, and Japan, granting access to funding and project equity (Saldanha Bay: Industrial Development Zone; The European Union et al., 2024). Furthermore, public-private partnerships have been explored to construct common-use infrastructure, for example, alleviating some of the infrastructure constraints. However, this creates further challenges in terms of regulation and governance. In sum, while the development of the green hydrogen sector has substantial potential benefits, it also raises significant difficulties for policymaking and implementation. Lastly, international collaboration in technology transfer and in the development of developing country R&D and commercialisation of technologies, for key technologies such as electrolysers and fuel cells, is also critical for scaling up green hydrogen production in developing countries. In addition, promoting equity partnerships with foreign countries facilitate technology transfer and technology development. Partnerships are also relevant considering the sizable investments needed in green hydrogen plants, which have high CAPEX. Ensuring the participation of the academia in green hydrogen projects facilitate the absorption of knowledge and spillovers throughout the industry.

This study contributes to the broader literature by providing a comparative perspective on the green hydrogen strategies of emerging economies. It also emphasizes the role of industrial policy in navigating the challenges posed by infrastructure gaps, technological immaturity, and market uncertainties. It adds to the literature by examining how these countries' preconditions shape their responses. It also highlights how industrial policy and market structure influence the pace and focus of green hydrogen adoption and how responses are being shaped.

Traditionally, the GWO literature looks at the combination of preconditions and responses to understand sectoral outcomes, as done in UNCTAD (2023) and Lema and Rabellotti (2023). Such analyses focus on the capabilities and measures implemented rather than factors affecting the choice of measures. In our study, we adapted the GWO framework to fit green hydrogen analyses and understanding of preconditions that may affect the strategies' pursuit, besides incorporating insights from the green industrial policy literature to enrich the examination of responses. While this study included an initial overview of the actors involved, future research should focus on identifying interest groups and coalitions and their relationship with policymaking that could shape responses. The influence of the domestic industry structure, with a focus on the role of legacy industries in the green hydrogen and energy transition agenda, must also be explored.

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8. Annex:

8.1 Brief literature review on the technical challenges for green hydrogen development

Green hydrogen can be used in power, heating, transportation, and industrial sectors. Its storage capability addresses the seasonality of renewable energy generation, complementing intermittent sources like wind and solar power. In the power sector, hydrogen fuel cells can replace fossil fuel generators in microgrids, while hydrogen and hydrogen-based fuels offer cleaner alternatives for power generation plants, replacing sources like coal. In the heating sector, green hydrogen can serve as the primary heating fuel or be blended into the natural gas grid, among other possibilities (Ansari et al., 2020; IEA, 2019; Oliveira et al., 2021). There are, however, more mature and cost-efficient alternatives that compete with green hydrogen for housing applications (IRENA, 2022a). On the other hand, the mix of green hydrogen in the natural gas grid contributes to the decarbonisation of sectors that traditionally rely on natural gas, with the advantage of leveraging already existing infrastructure. The Indian NTPC Green Hydrogen Blending Project, for example, has initiated this process, initially reaching a 5% blending level that can be scaled up to 20% in later stages (I am Renew, 2024; IEA, 2023b).

The competitiveness of green hydrogen in the transport sector depends on distance and mode. Short-distance vehicles should rely on electric batteries. Hydrogen fuel cells could become competitive in heavy-duty and long-haul transportation due to the lower cost of adding hydrogen storage to a fuel cell electric vehicle than adding further battery packs to battery electric vehicles. Furthermore, the refuelling time is significantly shorter for hydrogen than for electric batteries (Oliveira et al., 2021; Sadik-Zada et al., 2023). China leads the market in heavy-duty vehicles, accounting for 85% of global fuel cell buses and 95 % of fuel cell trucks, while Germany has pioneered hydrogen fuel cell trains (IEA, 2023a). Green hydrogen also emerges as a pathway for decarbonising aviation and shipping due to technological limitations with electric batteries in these contexts (Hoelzen et al., 2022; Stamm et al., 2023). Companies like Airbus are developing hydrogen-powered aircraft, but commercialisation remains distant, mirroring the situation with hydrogen-derived synthetic fuels for aviation. Ammonia is also being explored in demonstration projects for shipping vessels (IEA, 2023a).

Hydrogen already plays a role in the industrial sector, particularly in the chemical industry for ammonia production and refineries. While these applications require little adaptation, grey hydrogen[16] remains predominant. Refineries show limited electrolysis-based hydrogen, with projects from major companies like Shell, Sinopec, BP and HyCC underway. Initiatives like the Unigel project in Brazil for green ammonia production and the European Energy project in the Port of Aabenraa for methanol production may signal a shift towards green hydrogen utilisation.

[16] Hydrogen produced with fossil fuels and no carbon capture and storage (CCS) technology.

Additionally, there is potential for new applications, including heat generation and integration as a reactant in steel production to decarbonise the steel and cement industries.

The primary cost components of green hydrogen production are renewable energy and the electrolyser. While various renewables can theoretically be employed, the predominant method relies on water electrolysis powered by wind or solar energy. The cost of renewable electricity constitutes the major share of green hydrogen production cost, making cheaper renewable energy essential for achieving competitiveness. The second-largest cost component is the electrolysis facilities, with alkaline water electrolysis (AWE) and proton exchange membranes (PEM) being the two most used technologies (IRENA, 2020b). Despite the decline in renewable and electrolyser costs, green hydrogen remains not competitive compared to grey hydrogen. The current production costs of the former are estimated between USD 3/kg to USD 10/kg, depending on geographical location, while blue or grey hydrogen can cost USD 1/kg hydrogen with favourable natural gas prices (Lee and Saygin, 2023).

Similarly, challenges arise in the storage and transportation of green hydrogen. Storage faces obstacles such as high-pressure requirements to compress hydrogen, technological limitations for prolonged storage, geological barriers to underground storage, and safety and regulation concerns (Lebrouhi et al., 2022; Tarkowski and Uliasz-Misiak, 2022, 2022). Regarding transportation, the ideal mode depends on storage technology, geographical, and market characteristics, with options including ships, trucks, or pipelines. Current limitations, both in terms of cost and logistics, hinder the widespread transportation of commercialized hydrogen over long distances (IEA, 2023a; IRENA, 2022a; Lebrouhi et al., 2022).

Barriers to green hydrogen include its cost, lack of infrastructure and regulation, and technological immaturity. Expanding industrial use requires adaptions in the production units, processes, and technology (IRENA, 2020a). Socially, promoting hydrogen acceptance is challenging, and uncertainties in policy, regulations, standards, and certifications persist (Agaton et al., 2022; Fokeer et al., 2023). Despite the technical feasibility of various applications, actual adoption depends on further developments and cost considerations compared to alternatives.

8.2 Projections for the green hydrogen economy

Economic co-benefits from green hydrogen hinge on the country's role in the international value chain. The foundation for green hydrogen production lies in a nation's natural resource endowments, including wind and solar resources, water[17], and land availability. Additional factors like resource quality, technical potential for renewable electricity compared to its electricity demand, and the availability of relevant infrastructure further influence production, investments, and economic activities (Wetzel et al., 2023). Export projections introduce additional considerations, contrasting domestic demand and production potentials and import costs, while factors like capital costs, technology access, governmental support, investment climate, political

[17] Green hydrogen production employing seawater is possible, but it requires a desalination process or advances in seawater electrolysis, which have additional costs and technical challenges (Kuang et al., 2019).

stability, and transport logistics contribute to the competitiveness of green hydrogen (IRENA, 2022a).

Several studies have sought to predict countries' role in the global green hydrogen market. Considering land, solar, and wind power potential, Africa, the Middle East, the Americas, and Oceania emerge as having the greatest technical potential for low-cost green hydrogen, while Europe, Northeast, and Southeast Asia face higher costs (IRENA, 2022a). However, the methodologies used in these projections yield varied findings. For instance, IRENA (2022a) factors in renewables and land endowment, the levelised cost of electricity, and a comparison between production potential and expected demand by 2050. Their conclusion finds Chile as an 'export champion'. On the other hand, Pflugman and De Blasio (2020) consider wind and solar potential, freshwater availability, and infrastructure, classifying Chile as possibly self-sufficient or importer (to complement national production). Eicke and De Blasio (2022) expand their assessment to include domestic industrial applications (ammonia, methanol, and steel), leading to Chile being classified again as an 'exporter'.

Despite variations, these projections commonly position developed European and Asian countries as net importers while developing countries account for a significant share of the production and export potential. The European Union (EU) anticipates a substantial import role, with the REPowerEU plan setting an import target of 10 million annual tonnes by 2030 (European Commission, 2022). Germany, a key player, envisions between half and 70% of its hydrogen demand relying on foreign supply by 2030. To secure this supply, Germany actively supports green hydrogen production in potential exporting countries and is constructing the necessary value chain. An initial commitment of EUR 2 billion for international partnerships highlights these efforts. Germany seeks to establish partnerships[18] and agreements through bilateral collaborations and hydrogen diplomacy offices[19] to foster green hydrogen production and exports (BMWK, 2023; GIZ, 2022b). The H2Global initiative, another pillar of Germany's national hydrogen strategy, employs a double auction mechanism to purchase green hydrogen and its derivatives internationally, selling them to domestic end-users with federal resources covering the price difference (IRENA, 2022b). Additional initiatives and funding, such as the Business Alliance Energy and the Hydrogen Alliance, promote German investments in green hydrogen abroad. Furthermore, Germany actively engages in multilateral fora, supporting green hydrogen markets and participating in international cooperation for research, innovation, skill development, and capacity building in developing countries (Nunez and Quitzow, 2023; Quitzow et al., 2024).

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[18] In 2022, Germany had energy/energy and climate partnerships with Algeria, Australia, Brazil, Canada, Chile, China, Ethiopia, India, Israel, Japan, Jordan, Qatar, Mexico, Morocco, South Africa, South Korea, Tunisia, Türkiye, USA, Ukraine, and the United Arab States. It also has hydrogen partnerships with Australia, Canada, Chile, Egypt, Morocco, Namibia, and Saudi Arabia, as well as energy dialogues with Oman, Uzbekistan, Kazakhstan, and New Zealand (BMWK, 2023). Hydrogen appears as part of energy/energy and climate as well as hydrogen partnerships.

[19] As of November 20th, 2023, there were offices in Nigeria, Angola, Saudi Arabia, Kazakhstan, and Ukraine.

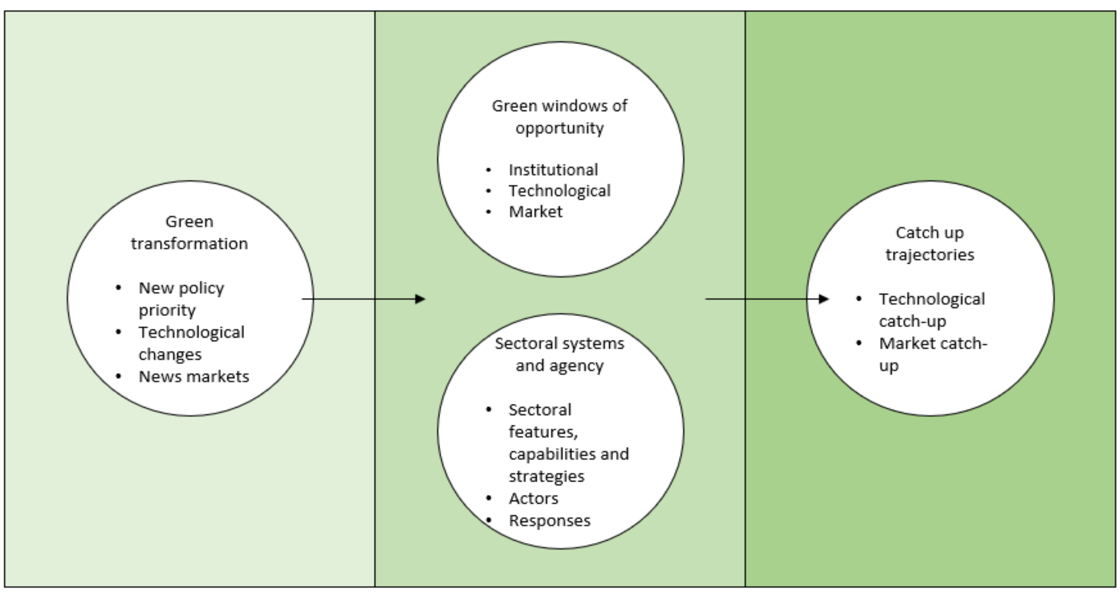
Germany is not the only European actors engaging in hydrogen partnerships. For instance, the port of Rotterdam, Europe's largest port, already has hydrogen trading agreements with various potential exporters, including Australia, Brazil, Canada, Chile, Colombia, Iceland, Morocco, Namibia, Oman, Portugal, Spain, South Africa, United Arab Emirates, and Uruguay (IRENA, 2022b).

8.3 Literature review on Windows of Opportunity and Green Industrial Policy

The basis for the framework applied in this study is comprises two strands of literature: Green Windows of Opportunity and Green Industrial Policy. The Green Window of Opportunity (GWO) framework, depicted in Figure 1, consists of four main elements[20]. First, the green transformation induces technological, market, and institutional changes that create GWO - temporary favourable conditions for latecomer catch-up in green sectors. Countries need adequate capabilities ('**preconditions**') and active efforts ('**responses**') to seize these windows. The combination of these factors leads to different catching-up trajectories (Lema et al., 2020).

The GWO concept posits that windows of opportunity emerge in techno-economic transitional moments that soften path dependence in knowledge, skills, and capital development in a technology trajectory (Dosi, 1982). During transitions, countries and firms with well-established infrastructure, capabilities, and investments in the old technology face higher costs to move into the new disruptive technology, opening opportunities for firms from developing economies with lower sunk costs (Lee and Malerba, 2017; Perez and Soete, 1988).

Figure 1: Analytical model to examine GWO



Source: Lema et al. (2020, p. 1197).

[20] Lema et al. (2020) emphasise that distinguishing these elements, while useful as an analytical tool, is not easy in practice.

Windows of opportunity in green sectors are mainly institutional, driven by policy changes responding to environmental or energy security pressures (Lee and Malerba, 2017; Lema et al., 2020; Yap and Truffer, 2019). However, the predominantly institutional nature of GWO does not negate demand and technical change. Domestic demand creation supported by demand-pull policies remains crucial for green sector development (Dai et al., 2021; Hain et al., 2020; Hansen and Hansen, 2020). Given the limited tradability of green energy products, domestic demand creation is more relevant than global demand (Lema and Rabellotti, 2023). Technical changes must align with demand creation to avoid import dependency or having dormant technological capabilities due to market constraints (Hain et al., 2020; Landini et al., 2020; Lema and Rabellotti, 2023).

Notwithstanding its usefulness as a guiding framework to analyse the catch-up of developing countries in green sectors, the GWO framework has limitations in considering industrial policies, primarily focusing on demand-side policies and their role in opening windows without exploring the state's influence on the supply side or their impacts on the economic benefits of the green transition. Bridging this gap by incorporating insights of the GIP is crucial.

Various elements of green sectors justify the need for industrial policy. Neoclassical scholars highlight two main rationales based on market failure arguments: spillover effects (e.g., cross-firm externalities, industry-wide learning or learning externalities and skill development) and coordination failures arising from the complementarity investments across firms (Juhász et al., 2023; Nurkse, 1953).[21] The systemic features of the transition from fossil fuels to low-carbon energy further enhance the potential for coordination failures (Schmitz et al., 2015).

Beyond typical market failures affecting innovation investments, green sectors face additional challenges. Mispricing of greenhouse gas emissions leads to lower private returns for green technologies compared to their social return (Rodrik, 2014). There are also commitment issues as future government policy is a key determinant of the market size for green industries, and uncertainties regarding it increase investment risk. Lastly, further coordination issues emerge due to complementarities between aggregate investments and pollution regulation (Karp and Stevenson, 2012).

Heterodox economists emphasise the need to move beyond merely correcting market failures to steer investments towards desirable sectors and activities with the necessary scale and scope for systematically developing them. Energy transitions are a complex of megaprojects[22] as they entail changes in all productive and consumption activities. Energy megaprojects demand specialised

[21] Juhász et al. (2023) also add a third rationale, which is that private activities depend on the provision of public goods like education and infrastructure. However, such a provision still involves choices by the government, and each choice affects companies differently considering their different needs – for example, goods that can be transported by roads benefit more than those that require ships once the government chooses to expand the road network.

[22] Projects that often cost over one billion USD, take a long period to be concluded, and involve a high level of uncertainty and multiple stakeholders and multi-tiered supply chains (Andreoni et al., 2022, p. 240).

technological capabilities and digital technologies with adaptations to local conditions and engage numerous stakeholders at different levels. Developing economies often rely on international flows and international institutional investors for funding, and energy technology choices are significantly influenced by the country's political economy and distribution of power (Andreoni et al., 2022).

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Industrial policy for green sectors has specificities in terms of measures and scope. Authors in the GIP literature present instruments used to incentivise green sectors, including feed-in-tariffs, local content requirements, and subsidised loans (Aquila et al., 2017; Rodrik, 2014). As Anzolin and Lebdioui (2021) indicate, GIP has three complementary dimensions: (i) policies targeting consumer behaviour, (ii) firm behaviour, and (iii) a productionist and innovation-centred dimension. These dimensions depend on and reinforce each other, requiring the cohesion of policies affecting each of them. In Ecuador, for instance, the authors argue that the lack of coherence hampered the industrial transformation of the country with the green transition, curtailing the economic benefits it could bring. However, a challenge for coherence is the level of coordination that green industrial policies require. Sustainable development is a cross-cutting issue. Thus, a wide range of government organisations enact policies that affect it, and there are interaction effects between policies that must also be taken into consideration (Nesta et al., 2014; Palage et al., 2019; Pitelis, 2018; Zhang et al., 2013).

8.4 Detailed information on green hydrogen development in Brazil

Brazil is rich in freshwater, solar, and wind energy resources (Table 9). Wind projects in the country count with a high-capacity factor, averaging 45% per year, but ranging up to 70% in months with favourable weather conditions, 50% above the global average. Another advantage is the low variability throughout the year (Kelman et al., 2020). For solar generation, global horizontal irradiation reaches up to 6.12 kWh/m²/day. The country has a good range of solar

[23] Juhász et al. (2023) also add a third rationale, which is that private activities depend on the provision of public goods like education and infrastructure. However, such a provision still involves choices by the government, and each choice affects companies differently considering their different needs – for example, goods that can be transported by roads benefit more than those that require ships once the government chooses to expand the road network.

irradiation throughout the year in all the regions, with the Northeast region having the strongest resources, and the South being in the opposite extreme.

Table 9: Natural resources endowment and cost information for renewables in Brazil

Global Horizontal Irradiation	4.15 - 6.12 kWh/m²/day
Specific photovoltaic power output	3.59-4.89 kWh/kWp per day
Average Wind Speed at 100 meters above ground level (10% of the windiest areas)	7.02 m/s
Renewable freshwater resources per capita, (cubic meters), 2020	26,553
Annual freshwater withdrawals, total (% of internal resources), 2021	1
Land area per capita (m²/person)	39,555
Total energy generation (2023)	
Solar and wind power generation (2023)	
Solar PV LCOE (USD/kWh)	0.034
Onshore wind LCOE (USD/kWh)	0.030
Green Hydrogen LCOH (USD/kg)	1.50-2.00

Source: Elaborated by the authors with data from Global Solar Atlas, Global Wind Atlas, World Bank, IRENA and IEA.

National green hydrogen strategy

Brazil still lacks a national hydrogen strategy. However, the country has published other governmental documents targeting the sector, dating back to the 2000s. In 2005, the Ministry of Mines and Energy (MME), together with the Ministry of Science and Technology (MCTI), published the Roadmap for the Structuring of the Hydrogen Economy in Brazil. It established 20-year milestones, including the production of hydrogen through water electrolysis in 2020, and possible demand markets, like industrial applications in steel and fertiliser production, as well as transports (Chantre et al., 2022; MME, 2021). Other publications followed, such as the 2021 "Basis for the Consolidation of the Brazilian Hydrogen Strategy", which aims to identify bottlenecks, production pathways, and uses of hydrogen in the country (MME, 2021).

Two of the most relevant and recent documents are the 2021 National Hydrogen Programme's Guidelines (PNH2) and the Triennial Work Plan 2023-2025 of the National Hydrogen Programme, published in 2023. In contrast to the Guidelines document, the Triennial Workplan introduces milestones and necessary actions to achieve them. The first milestone is to disseminate low-carbon hydrogen pilot plants in all the regions of the country by 2025. For that, the document establishes the goal of increasing public and public-oriented investments in hydrogen and fuel cells from BRL 29 million in 2020 to BRL 200 million in R&D for the sector by 2025. The second milestone is to consolidate Brazil as the most competitive low-carbon hydrogen global producer by 2030, followed by consolidating low-carbon hydrogen hubs in Brazil five years later. It also highlights the importance of the state's role in achieving these goals. First, it proposes a governmental programme to establish and stimulate the regulatory framework, infrastructure, R&D, funding sources, and human capital necessary to create the hubs. Furthermore, the three priorities highlighted in the document encompass the definition of a national legal framework for the sector, increasing R&D&I to achieve cost reduction, and enhancing access to funding sources (MME, 2021, 2023).

Industrial policies in Brazil for the low-carbon hydrogen sector

In Brazil, public policies targeting hydrogen go back to the 2000s, albeit with limited scope. The Ministry of Science, Technology and Innovation (MCTI) implemented in 2002 the Brazilian Hydrogen and Fuel Cell Systems programme, which in 2005 became the Science, Technology, and Innovation Program for the Hydrogen Economy (ProH2) (Chantre et al., 2022; MME, 2022). Similarly, the Energy Big Push, a collaborative project of multiple national and international institutions, targeted the development of innovations in the renewables market. Between 2013 and 2018, federal institutions provided funding that amounted to BRL 34 million to 91 projects connected to hydrogen and fuel cells (Chantre et al., 2022). In 2022, the Brazilian Development Bank (BNDES) launched a programme that grants low-interest rate financing to green hydrogen pilot projects targeting the production or usage of green hydrogen as well as technological development (BNDES, 2022). Additionally, the new Brazilian industrial policy package – New Industry Brazil – includes low-carbon hydrogen within its funding priorities, stating the goal of achieving technology self-sufficiency in the green hydrogen production chain, (e.g., PV cells, wind turbines, and electrolysers). It also places production technologies, the production, storage, transport, and usage of low-carbon hydrogen among priority areas to access innovation credits (CNDI and MDIC, 2024, p. 79).

In 2024, the Brazilian government established the legal framework for hydrogen, which implements rules and incentives for this industry in Brazil. The framework defines low-carbon hydrogen as produced with up to 7 kgCO2eq/kgH2 until 2030, irrespective of the production route used. Furthermore, it creates the Low Carbon Hydrogen National Policy as part of the National Energy Policy, and combines different instruments under it, including the National Hydrogen Programme (PNH2), the national certification system, and the Special Incentives Regime to the Production of Low Carbon Hydrogen (Rehidro). Rehidro offers tax benefits for up to five years, starting from January 2025. It entails BRL 18 billion in fiscal incentives for up to 5 years for the low-carbon hydrogen sector. Companies may benefit if they are involved in low-carbon production, transport, distribution, conditioning, storage, and commercialisation, as well as in the production of biogas and renewable electricity to hydrogen production. Eligibility is, however, conditioned on companies meeting a minimum level of national purchase of inputs to the production process – except when there is no national equivalent or national production is insufficient to meet the demand – and of investments in national R&D&I, but such conditionalities are yet to be specified. Lastly, companies located in SEZ are also eligible, without losing other benefits (Lei 14948/2024, 2024; MF, 2024). Furthermore, subnational governments like Ceará, Rio Grande do Norte and Minas Gerais have been proactive in terms of developing strategies to attract investments (De Oliveira, 2022).

However, regulations need to be further developed. For instance, the regulatory authority Brazilian Hydrogen Certification system (SBCH2), a voluntary system to inform the emissions' intensity of the hydrogen production chain, is yet to be defined. Moreover, the Low Carbon Emission Hydrogen Development Programme (PHBC), initially included, was vetoed but it is expected to be established separately later. The PHBC should introduce fiscal credit to the sector, targeting both the selling and purchase of low-carbon hydrogen and derivatives produced in the country, conditional on stimulating technology, and regional, and industrial development while mitigating climate change. Demand benefits should target hard-to-abate sectors like fertilisers, steel, cement, chemicals, refining, and heavy-duty transport (Agência Senado, 2024).

8.5 Detailed information on green hydrogen development in Chile

Chile's natural resources endowments favour the production of wind and solar energy (Table 10). The Atacama Desert, located in the north has the highest mean surface solar radiation rate on the globe, reaching over 7.5 kWh per square meter per day. Meanwhile, the extreme South of the country has significant potential for wind generation as wind speed surpasses 14 metres per second at some locations. Chile is, however, a water-stressed country, with the Atacama Region facing water scarcity, but this should not pose an issue considering hydrogen projects rely on desalination water. Renewables in Chile are quickly expanding, and solar and wind energy represented 31% of the electricity supply in 2023.

Table 10: Natural resources endowment and cost information for renewables in Chile

Global Horizontal Irradiation	2.64 – 7.41 kWh/m²/day
Specific photovoltaic power output	2.41-6.53 kWh/kWp per day
Average Wind Speed at 100 meters above ground level (10% of the windiest areas)	14.12 m/s
Renewable freshwater resources per capita, (cubic meters), 2020	45,854
Annual freshwater withdrawals, total (% of internal resources), 2021	4
Land area per capita (m²/person)	38,157
Total energy generation (2023)	
Solar and wind power generation (2023)	
Solar PV LCOE (USD/kWh)	0.025
Onshore wind LCOE (USD/kWh)	0.021
Green Hydrogen LCOH (USD/kg)	1.30-1.80

Source: Elaborated by the authors with data from Global Solar Atlas, Global Wind Atlas, World Bank, IRENA and IEA.

National green hydrogen strategy

Chile has published its National Green Hydrogen Strategy (NGHS) in 2020. The document presents clear objectives and a timeframe for the expansion of green hydrogen production in the country, identifying the high insolation in the north and strong winds in the south are emphasised as Chile's competitive advantage in the sector. The key objective outlined in the NGHS is to produce the cheapest green hydrogen in the world, projecting investments of USD 5 billion to reach an electrolysis capacity of 5 GW – operating and under construction – by 2025, with at least two operational green hydrogen hubs with an output of 200,000 tonnes yearly by then.[24] According to the document, investments are to reach USD 2.5 billion a year by 2030, and green hydrogen output should grow at an annual rate of 15% for which the associated renewable electricity needs to increase from 40 GW in 2030 to 300 GW in 2050. The NGHS also outlines different types of incentives, including a blending quota for green hydrogen with natural gas, launching a 50 MUSD funding provision, providing public funding for R&D&I, and acting to enhance human capital (Ministry of Energy, 2020).

In 2024, Chile released the Green Hydrogen Action Plan with the next steps to reach the NGHS' goals. The plan provides a roadmap to the development of the green hydrogen sector in Chile and outlines 81 actions to address 18 dimensions related to green hydrogen development, ranging from ensuring a multistakeholder engagement and participation to promoting an enabling regulatory environment and R&D&I. The Plan establishes ten milestones, setting a roadmap to develop the sector between 2023 and 2030 (Gobierno de Chile, 2024).

Industrial policies in Brazil for the low-carbon hydrogen sector

In Chile, the state takes the role of a facilitator that brings foreign lead firms and local suppliers together, taking additional support measures to overcome market uncertainties. The current constitution also limits the space of state action through instruments like content requirements, and state-owned enterprises are run by boards that are independent from the government. Policies are taking shape for the sector in the country. In 2021, the Chilean Economic Development Agency (CORFO) launched a call to select proposals to receive USD 50 million as co-finance for green hydrogen development. Six projects were awarded[25] and must be operational by December 2025 (CORFO, 2021). In 2024, the country established a subsidy scheme targeting electrolysers. Companies interested in constructing new manufacturing factories or assembly facilities could apply to receive up to USD 10 million in support per plant (Collins, 2024).

Furthermore, the government announced the USD 1 billion Green Hydrogen Development Fund to derisk hydrogen projects by catalysing private investments in production and demand projects as well as related infrastructure and the institutional framework. The initiative is supported by organisations like the Inter-American Development Bank (IDB), the World Bank, the German Development Bank (KfW), and the European Union. With additional funding from private sources, it aims to gather USD 12.5 billion to further expand the credit scheme (Ministerio de Energia, 2023; Ministerio de Hacienda, 2023).

In addition, the Chilean government also supports access to resources and R&D. In 2021, it launched the National Plan "*Ventana al Futuro*" to accelerate green hydrogen development. The

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[24] However, interviews conducted by the author suggest that large-scale production will not begin before 2030.

[25] Proyecto Faro del Sur, HyPro Aconcagua, "HyEx – Green Hydrogen Production, Antofagasta Mining Energy Renewable (AMER), Antofagasta Mining Energy Renewable (AMER), and H2V CAP

plan provided public land concessions for the development of projects (Silva and Purcell, 2024). In terms of R&D, green hydrogen benefits both from non-targeted initiatives as well as from the Green Hydrogen Accelerator Programme, implemented by the Agencia de Sostenibilidad Energetica and funded by the Ministry of Energy. It aims at co-financing the necessary technology to produce or consume hydrogen (Agencia de Sostenibilidad Energética, n.d.).

Lastly, the government is also supporting domestic demand. CORFO has announced new calls for proposals to the programme "Use and Adoption of Green Hydrogen in the Chilean Industry" (*Uso y Adopción de Hidrógeno Verde en la Industria Chilena*), together with a call for a programme targeting the manufacturing of components of the hydrogen industry. Together, they entail USD15 million in subsidies offered over 5 years, with an additional USD 12 million coming from private resources (Ministerio de Economía, Fomento y Turismo, 2024).

8.6 Detailed information on green hydrogen development in China

China is rich in wind, water, and solar energy resources (Table 11). However, water availability might pose a limitation. Furthermore, depending on the renewable generation technology employed to produce green hydrogen – specifically, if it entails onshore generation – China may also face land availability restrictions (Tonelli et al., 2023).

Table 11: Natural resources endowment and cost information for renewables in China

Global Horizontal Irradiation	2.64 - 5.93 kWh/m²/day
Specific photovoltaic power output	2.21-5.82 kWh/kWp per day
Average Wind Speed at 100 meters above ground level (10% of the windiest areas)	8.93 m/s
Renewable freshwater resources per capita, (cubic meters), 2020	1,993
Annual freshwater withdrawals, total (% of internal resources), 2021	20
Land area per capita (m²/person)	6,729
Total energy generation (2023)	
Solar and wind power generation (2023)	
Solar PV LCOE (USD/kWh)	0.045
Onshore wind LCOE (USD/kWh)	0.040
Green Hydrogen LCOH (USD/kg)	1.80-2.50

Source: Elaborated by the authors with data from Global Solar Atlas, Global Wind Atlas, World Bank, IRENA and IEA.

National green hydrogen strategy

Similar to Brazil, China has multiple governmental documents for green hydrogen development but lacks a formal green hydrogen strategy. Most of the documents are still at a general level, and policies are comprehensive and guiding in nature (Gong and Quitzow, 2024). China's Medium and Long-Term Plan for Hydrogen Energy Industry Development (2021-2035) outlines the country's strategy to position itself as a global leader in hydrogen energy. It clarifies the strategic positioning of hydrogen in China's green and low-carbon energy transformation and puts forward the three-phased targets for green hydrogen development, repeating the NDRC target for 2025, the wide application of green hydrogen by 2030, and the proportion of green hydrogen in terminal consumption by 2035 to be significantly increased. The document identifies hydrogen as a crucial energy vector to achieve China's carbon neutrality goal by 2060. Additionally, the plan emphasizes the importance of establishing a comprehensive supply chain, including infrastructure for hydrogen production, storage, transportation, and utilization, particularly in industrial hard-to-abate sectors. The long-term vision (2030-2035) centres on expanding the scale of green hydrogen, optimizing industrial applications, and integrating hydrogen with smart energy systems.

The plan stresses the importance of innovation, calling for advances in technology, materials, and cost reduction to make hydrogen commercially viable. It also encourages international cooperation and investment to drive the development of hydrogen technologies, making China a global hub for hydrogen energy innovation. This strategic approach underscores China's commitment to transitioning to a cleaner energy future while reducing its reliance on fossil fuels.

Industrial policy for low-carbon hydrogen

China's public response to green hydrogen development is still incipient. The country has multiple governmental documents for green hydrogen development. However, they are still at a general level, and most of the policies are comprehensive and guiding in nature, remaining unclear in terms of production pathways and other priorities, for example. The central government also does not prioritise the development of green instead of blue hydrogen, in particular, as a decarbonization route and balance strategy to stabilise solar and wind energy provision (Gong and Quitzow, 2024).

The production of renewable hydrogen is often listed as one of the top priorities for the government. The National Development and Reform Commission (NDRC) set in the National Hydrogen Energy Plan the annual production target of hydrogen from renewable energy of 100-200,000 tons by 2025, which may be considered a modest goal. The medium and long-term development plan for the hydrogen energy industry (2021-2035), released in March 2022, clarifies the strategic positioning of hydrogen in China's green and low-carbon energy transformation. It explicitly puts forward the three-phased targets for green hydrogen development, repeating the NDRC target for 2025, the wide application of green hydrogen by 2030, and an increase in the proportion of green hydrogen in terminal consumption by 2035.

Chinese plans for the usage of green hydrogen focus on the reconfiguration of the power system, fuel cell vehicles, and the decarbonisation of industrial processes. One of the few national-level demand-side incentives targets fuel cell vehicles for urban applications (Wang et al., 2022). Hydrogen is a key piece of the energy transition in China as hydrogen storage is devised as necessary to balance the seasonality of renewables. More recently, hydrogen also figures as a pathway to decarbonize the industrial sector. The 2016 13th Industrial Development Plan of Strategic Emerging Industries highlighted hydrogen production, storage, and refuelling stations as strategic industries to achieve technological leadership (Gong and Quitzow, 2024).

One of the main priorities of the central government is acquiring the relevant technological knowledge. The promotion of hydrogen-related technologies remounts back to 1986 when the government established the State Plan of High Technology Research and Development (Gong and Quitzow, 2024). More recently, in terms of national-level policy plans and key R&D programs for 2022, China's emphasis on green hydrogen technology has increased significantly, with a focus on the production, transportation and storage of liquid hydrogen, the localisation of fuel cells, and construction of hydrogen power networks. To that end, several initiatives to promote innovation were proposed, including the provision of policy guarantees and organisational facilitation for the construction of innovation systems (Wang et al., 2022).

Consequently, R&D in green hydrogen increased considerably. while only three R&D projects were conducted from 2018 to 2020, this grew to 16 between 2021 and 2022. The country's R&D direction for water electrolysis technology is also being refined and gradually expanded towards other technologies. It is also moving from production to downstream application research. In terms of spatial layout, China encourages green hydrogen production in Shanxi, Inner Mongolia, Henan, Sichuan, Shaanxi, Ningxia and other provinces and regions rich in coal mining, which could be seen as a way to accelerate coal reduction and substitution (TrendBank, 2023).

Subnational (local and provincial) government and state-owned enterprises (SOEs) are filling to some degree the gap left by the central government. Subnational governments have established their own development plans and targets, which sometimes surpass those of the central government (Gong and Quitzow, 2024). As of the end of March 2023, a number of local governments in China have planned for a combined production of more than 900,000 tons of hydrogen from renewable energy sources. Some regions, such as Inner Mongolia, Gansu Province, Ningxia Province, Jilin Province, Sichuan Province, Qinghai Province and Jiangxi Province have specified green hydrogen production for 2025 in their corresponding policies, while eastern regions, such as Shanghai, Shandong, and Guangdong, are more interested in the application of renewable hydrogen production in transportation, especially in integrated hydrogen production and refuelling stations. Policies in the western region emphasise the production and industrial application of renewable hydrogen (TrendBank, 2023).

Hydrogen fits the Chinese longstanding project of developing FCEV and related technologies, and the transport sector figures among the priorities of multiple governmental documents, including the National Hydrogen Development Plan, which designs a phased approach to the adoption of hydrogen fuel cell vehicles, setting the goal of 50,0000 FCEVs by 2025 (Gong and Quitzow, 2024).

However, the primary focus of China's current hydrogen policy is not on the demand side, but mostly on improving supply-side capacity. In particular, almost every policy mentions the need to accelerate the construction of the hydrogen production chain, reflecting the fact that the country has not yet established a large-scale supply capacity (Wang et al., 2022). This, again, also highlights the priority given to acquiring the relevant technological know-how in the hydrogen value chain.

The government is also advancing in terms of hydrogen standards. The China Hydrogen Alliance has put in place in 2020 the Standard and Evaluation of Low-carbon Hydrogen, Clean Hydrogen and Renewable Hydrogen, which differentiates low-carbon and clean hydrogen according to their emission, with renewable hydrogen being a subtype of the latter. The central government also aims to establish technology and safety standards for hydrogen (Gong and Quitzow, 2024)

8.7 Detailed information on green hydrogen development in South Africa

South Africa is rich in natural resources, having extensive solar and wind resources, as well as mineral wealth (Table 12). South African mineral resources are another asset. Platinum group metals (PGMs) are an important component of the hydrogen economy considering, for instance, their usage as inputs for electrolyser production, and South Africa accounts for approximately 72% of global PGM supply (Department of Trade, Industry and Competition, 2021, pp. 26–27, 37). Lastly, while freshwater resources are constrained, the long coastline allows access to seawater. Thus, green hydrogen production could rely on desalination plants, which could also meet demand from other sectors.

Table 12: Natural resources endowment and cost information for renewables in South Africa

Global Horizontal Irradiation	4.36 - 6.39 kWh/m²/day
Specific photovoltaic power output	4.00-5.66 kWh/kWp per day
Average Wind Speed at 100 meters above ground level (10% of the windiest areas)	7.73 m/s
Renewable freshwater resources per capita, (cubic meters), 2020	762
Annual freshwater withdrawals, total (% of internal resources), 2021	47
Land area per capita (m²/person)	20,251
Total energy generation (2023)	
Solar and wind power generation (2023)	
Solar PV LCOE (USD/kWh)	0.040
Onshore wind LCOE (USD/kWh)	0.035
Green Hydrogen LCOH (USD/kg)	1.60-2.20

Source: Elaborated by the authors with data from Global Solar Atlas, Global Wind Atlas, World Bank, IRENA and IEA.

Green hydrogen strategy

South Africa's hydrogen documents date back to the 2000s. The 2008 Hydrogen South Africa Strategy was launched to undertake research and development in the hydrogen and fuel cell market. A number of hydrogen initiatives followed, including the Hydrogen Society Roadmap (HSRM) and the Green Hydrogen Commercialisation Strategy for South Africa (GHCS). The HSRM outlined as objectives the decarbonisation of heavy transport and energy-intensive industries, developing associated manufacturing, and hydrogen exports. Complementing it, the GHCS encompassed six dimensions to achieve the goals for green hydrogen: (1) prioritise exports (2) stimulate the domestic market (3) support localization (4) secure financing (5) proactive socioeconomic development (6) role of government in policy and regulatory support. It argues for diversified government support to private sector investments given the fiscal constraints that make large-scale subsidies unaffordable. The GHCS establishes ambitious targets for the domestic market and exports – for example, 2-7 million tons per annum (Mtpa) of green hydrogen to secure a 7% global market share of traded green hydrogen. The domestic market target in the short term (3-5 years) is 300,000 tpa which would require capital investments of $USD 13 billion (Department of Science and Innovation, 2021a; DTIC, 2023).

More recently, the government published the Just Economic Transition Investment Plan (JET-IP), which is the official response to a USD 8.5 billion package of partly concessional loans from the US, UK, and EU to promote an accelerated green transition. JET-IP includes a green hydrogen component, projecting that the development of green hydrogen exports and associated industries could create up to 1.8 million more jobs across the economy compared to scenarios without green hydrogen (The Presidency, 2022).

Industrial policies for the low-carbon hydrogen sector

There is strong government support for the development of the green hydrogen economy at the level of plans and policy recommendations. They date back to the 2008 Hydrogen South Africa (HySA) Strategy, launched to undertake research and development in the hydrogen and fuel cell market. Afterwards, a number of hydrogen initiatives followed, including the Hydrogen Society Roadmap (HSRM) involving stakeholders across the public and private sectors and organized civil society (Department of Science and Innovation, 2021b). Its objectives included decarbonising heavy transport and energy-intensive industries, developing associated manufacturing, and hydrogen exports.

The 'Green Hydrogen Commercialisation Strategy for South Africa' (GHCS) has six elements; (1) prioritise exports (2) stimulate the domestic market (3) support localization (4) secure financing (5) proactive socioeconomic development (6) role of government in policy and regulatory support (DTIC, 2022: 98). It was developed under the guidance of the Industrial Development Corporation (IDC) and the Green Hydrogen Panel (GHP), the latter established by the Minister of Trade, Industry and Competition. It argues for diversified government support to private sector investments given the fiscal constraints that make large-scale subsidies unaffordable (DTIC, 2022).

The GHCS establishes targets for the domestic market and exports – for example, 2-7 million tons per annum (Mtpa) of green hydrogen to secure a 7% global market share of traded green hydrogen. The domestic market target in the short term (3-5 years) is 300,000 tpa which would require capital investments of $13 billion (DTIC, 2022, p. 8). The longer-term targets would require massive investments in solar, wind, electrolysis, and ammonia.

Under the current legislation outlined by the DMRE, the deployment of renewable energy projects related to green hydrogen production will be exempted from electricity policy planning and regulatory requirements (licensing) if it is "islanded" from the grid. However, it is essential that such projects are able to sell surplus power via the grid. Further support measures include initiatives such as the DTIC's Energy One Stop Shop and the Energy Resilience Fund. High-level government support was offered to a range of proposed green hydrogen projects such as the Hive Energy project in the Eastern Cape. Included in this have been commitments around infrastructure development, regulatory approval, and some financing support. There have also been several publicly funded research initiatives, some undertaken jointly with big firms like Sasol.

A number of provinces and some cities/local municipalities are encouraging green hydrogen development. The Northern Cape provincial government has been supporting the proposed Boegoebaai project with promises of facilitation, support for suppliers, and plans for infrastructure investment, such as new port facilities that would require close to USD 1 bn in investment. The provinces of KwaZulu-Natal, Mpumalanga, Gauteng, and Free State have engaged with the Hydrogen Valley initiative, with the Gauteng provincial government and the eThekwini Municipality (Durban in KwaZulu-Natal) developing plans to support the green hydrogen sector. The Western Cape is a key player in the Special Economic Zones of Saldanha and Atlantis, both of which have been identified for green hydrogen-related activities. Similarly, the Eastern Cape and KwaZulu-Natal have been promoting Coega and the Richards Bay IDZ as locations for project activities related to green hydrogen.

The policy intention is that locations for the primary production of green hydrogen optimise the locational interdependencies of these natural resource endowments. The DSTI Hydrogen Valley document (Engie Impact, 2021) sets out how a number of hubs can optimise these resources together with important infrastructure, production assets and future fields of demand. These hubs – in Johannesburg, Durban/Richards Bay, and Mogalakwena/Limpopo – will be set up to host pilot plants to establish a hydrogen economy in the 'Hydrogen Valley' (Department of Science and Innovation, 2021a, p. 3). A number of other green hydrogen schemes have been given some level of national endorsement, including the Boegoebaai project in the Northern Cape, the Saldanha project in the Western Cape and the Coega project (with Hive Energy) in the Eastern Cape (DTIC, 2023, pp. 53–54).

Another important development has been the Just Economic Transition Investment Plan (JET-IP), which is the official response to a $8.5 billion package of partly concessional loans from the US, UK, and EU to promote an accelerated green transition. JET-IP has a large green hydrogen component, projecting that the development of green hydrogen exports and associated industries could create up to 1.8 million more jobs across the economy compared to scenarios without green hydrogen (The Presidency, 2022).

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