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CENTRE FOR GLOBAL CHALLENGES

Pathways to Sustainability

Green Hydrogen in the Global South

Opportunities & Challenges

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Energy in Transition
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Content

Introduction

Green hydrogen derived from renewable electricity has emerged as a promising solution to accelerate the global energy transition. Governments and international organisations worldwide are promoting hydrogen development due to its potential to mobilise new investments in energy transitions, store and transport energy and decarbonise hard-to-electrify sectors (World Bank, 2020). In 2020, fossil-based sources accounted for 99.8% of the world's hydrogen production. According to the International Renewable Energy Agency (IRENA) (2020; 2022a), a rapid global energy transition could see green hydrogen (hereafter 'GH2') supplying as much as 12% of global energy consumption by 2050.

Amidst the growing enthusiasm, several Global South countries have launched hydrogen strategies, embracing GH2 as an energy carrier that could increase energy security, support variable renewables, and leapfrog their economies into the zero-carbon age (World Bank, 2020). As production costs continue declining, many Southern countries seek to exploit their natural resources and favourable climatic conditions for cost-effective GH2 production. Conversely, while Global North countries grapple with energy security amidst climate crises and the Russian invasion of Ukraine, they largely lack spaces for massive renewables growth. Consequently, supporting the production of GH2 in the Global South is considered a critical path to meeting their climate targets (Barnard, 2022). This need has precipitated discussions and plans for investments into GH2 in the Global South in recent years, fundamentally shaping the current iteration of the global 'hydrogen economy' (Van der Spek et al., 2022).

Critical studies have, however, pointed out that energy transition projects can cause environmental and social disruptions in peripheral regions (e.g. Sovacool et al., 2020; Otsuki et al., 2022) – mirroring, to some extent, outcomes of large-scale development projects that focus on economic growth. Furthermore, studies on previous renewable projects in the Global South suggest a tendency for energy transition projects to reinforce neo-colonial power dynamics and global inequality (Kalt & Tunn, 2022; Scita et al., 2020). Scholars generally agree that scholarly and policy communities must prioritise the social dimension of a transition beyond technological and economic dimensions (see Hanusch & Schad, 2021; Raman et al., 2022). In particular, researchers must incorporate critical dimensions such as energy justice, gender equality, and geopolitical contestations into studies which estimate potential GH2 production and investments in the green hydrogen economy (Ayodele & Munda, 2019; Nadaleti et al., 2021; van Wijk & Wouters, 2019).

Against this backdrop, urgent questions arise: Will green hydrogen development differ from the previous experiences of renewable development? Will investors invest more consciously in achieving quality life in peripheral regions to mitigate risks of environmental and social disruptions and ensure energy justice in energy production? What does a transformative investment design entail to ensure equitable distribution of the benefits of GH2 development across the Global North and South?

The project: **Transformative investments in green hydrogen development in the Global South** has explored these questions. Researchers from the networks *Transformative Innovation Policy Consortium* and *Inside the Investment Frontiers* at Utrecht University extended their network by collaborating with experts from universities in South Africa, Brazil, Germany and other institutes in the Netherlands. The project researchers have mapped the state of knowledge and conducted case studies on green hydrogen transitions in the Global South, focussing on Brazil and South Africa. Technological, economic, and socio-environmental implications of GH2 policies and strategies were scrutinised, and possibilities of transformative public and private investments in new GH2 development were explored.

A central proposition of this report is that focusing on the Global South offers timely and productive insights into green hydrogen developments and their implications for sustainability and energy justice objectives. This focus facilitated (i) understanding the dynamics of green hydrogen developments in little discussed yet crucial investment frontiers; (ii) foregrounding perspectives, voices, and territories that remain under-appreciated in current energy transition debates; and (iii) formulating policy recommendations towards globally just, fair, and socially relevant hydrogen futures. These project objectives align with Utrecht Centre for Global Challenges and Utrecht University's Pathways to Sustainability Strategic Theme, the latter generously funded the project through its Energy in Transition Community.

This report accounts for the main results and findings obtained across the project. An extensive academic literature and policy document review established the state-of-the-art green hydrogen development in the Global South. Case studies on ongoing plans and experiences in South Africa and Brazil were conducted to complement this review. In addition, a workshop was held to build a network of researchers, investors and policymakers in Europe, Africa and Latin America and create a platform where the transformative investment possibilities are discussed and researched. Key project outcomes include the Critical Hydrogen Studies Network, inaugurated in December 2022, and the special issue journal proposal on green hydrogen transitions in the Global South planned for 2023. This report presents what has been learned collectively in this project thus far and proposes strategies for future actions and next steps.

1 The State of Green Hydrogen Development in the Global South

This chapter presents the analysis of the current state of green hydrogen (GH2) development in the Global South, drawing on both grey and academic literature. The grey literature review focuses on policy analysis, examining international policy documents and reports by key national and international actors. The academic literature review focuses on the social challenges of GH2 development in the Global South.

Two recent reports by the World Bank and International Renewable Energy Agency (IRENA) were the point of departure for the grey literature analysis. In 2020, the World Bank published *Green Hydrogen in Developing Countries.* This publication was the first comprehensive report by a major development organisation on GH2 in the Global South. IRENA is one of the key actors promoting the widespread trade of hydrogen, annually publishing new policy documents on GH2. A selection of the most relevant grey literature cited by these institutions, including position papers, institutional reports, and project communications, has been read and annotated. In addition, six searches for grey literature were conducted using a standard Google search engine in the following order:

- 'green hydrogen' AND 'global south'
- 'investment' AND 'green hydrogen' AND 'global south'
- 'employment' AND 'green hydrogen' AND 'global south'
- 'sustainable development' AND 'green hydrogen' AND 'global south'
- 'social' AND 'green hydrogen' AND 'global south'
- 'just transition' AND 'green hydrogen' AND 'global south'

The review prioritised documents influential for public and private hydrogen policy decision-making. In particular, documents by the International Energy Agency (IEA), International Renewable Energy Agency (IRENA), World Economic Forum (WEF), and the World Energy Council. In addition, sources written by organisations and authors based in the Global South were highlighted to provide a comprehensive, inclusive perspective on the GH2 in the Global South.

The academic literature review centred on illuminating the social challenges related to GH2 development in the Global South. Eight keyword searches were conducted using the Google Scholar search engine, including 'green hydrogen', 'Global South', 'South America', 'Africa', 'South Asia', 'investments', 'social impacts', and 'gender'. The selection of search terms sought to identify literature that addressed the social implications of the GH2 development in different continents of the Global South.

Search results that did not discuss the Global South explicitly and address green hydrogen were excluded to ensure the relevance and reliability of the literature used in this analysis. In each subsequent search, duplicates and results appearing in previous searches were also excluded to avoid giving them additional weight. In each search containing a new keyword, results were annotated with that keyword as a focus. Finally, per the snowballing method, reference lists of the search results were scanned to find relevant literature that offered new insights or perspectives on these keywords.

Policy document analysis

The policy document analysis of GH2 development in the Global South identified two major themes: (i) investment needs and developments; and (ii) limitations to ensuring sustainable development in the production areas following just transition principles.

Investments

Accelerating GH2 development

Much of the surveyed grey literature revealed an increasing appetite for green hydrogen investment in the Global South, evident across agreements, roadmaps, and Memoranda of Understanding (MoU) between private investors and governments. In 2018, more than twenty countries announced incentives and targets to boost investment in hydrogen (IEA, 2019). Today, over sixty hydrogen strategies are being developed across the world by governments (Figure 1). These strategies demonstrate a shared ambition to grow the applications, infrastructure, and demand for GH2, with often an explicit aim of energy security. For countries in the Global South, there is also a drive to develop GH2 as a new commodity for export.

Figure 1: Hydrogen strategies published and in preparation (IRENA, 2022c, p 23)

The rapidly expanding electrolyser production capacity globally reflects this interest. In 2019, the global capacity to manufacture electrolysers required for GH2 production hovered around 2 Gigawatt (GW) (World Bank, 2020). In 2022, the twenty largest publicly announced electrolyser projects were each expected to exceed 2 GW, with the largest totalling over 30 GW. Approximately half of these projects are in Global South countries (Figure 2).

A diverse set of investors, including private business incubators, multilateral development banks, and governments, are involved in developing green hydrogen (GH2) projects in the Global South, offering government grants, loans and equity investments (Osborn, 2022). For example, South Africa received $8.5 billion from international donors (UN Climate Conference UK, 2021). The Egyptian government committed $40 billion to hydrogen development to attract foreign investment (Hydrogen Central, 2022).

Despite this growing interest, surveyed sources point to a consensus that a scale-up of unprecedented speed and scope is required for GH2 to realise its potential in sustainability transitions. According to the IEA, all hydrogen plans currently under development would only constitute 10% of what is needed to achieve the agency's net-zero scenario by 2050 (IEA, 2021a). Furthermore, most of the planned megaprojects will not be operational for another decade – and whether they will be commissioned on time and within budget remains uncertain (Atalayar, 2022; IEA, 2021b). The GH2 facilities that are operational are currently limited to small-scale demonstration or testing (e.g. Strategy&,

Figure 2: The 20 largest publicly announced green hydrogen projects (IRENA 2022a, p. 87)

2020; Creamer, 2022). However, the energy carrier is considered an essential part of climate mitigation plans, with its uptake being promoted across various grey literature sources – including by NGOs critical of its potential scope, export, or implementation (Molloy & Baronett, 2019; Böll Foundation & Brot für die Welt, 2022).

Scaling-up investments: costs, infrastructure and training

The grey literature extensively examines the challenges of high production costs, infrastructure development, and workforce training and skills development for scaling up GH2 investments in the Global South. Many Global South countries have the theoretical potential to produce large quantities of cheap renewable energy and are prime locations for GH2 production and export. However, while there is optimism about the financial viability and attractiveness of global GH2 exports for private investors (IRENA, 2022a; BNEF, 2020), several sources cite current production costs as a significant barrier (e.g. Control Risks, 2022; World Bank, 2020). To prevent delays and project closures, such as those observed in Egypt and Zimbabwe, lowering production costs are a central focus of proposed policy measures and interventions (World Energy Council, 2022; IEA, 2021a). Without cost reduction and improved financial viability, investments risk being diverted towards blue or grey hydrogen.

The scaling-up of GH2 necessitates extensive production, storage, and transportation infrastructure, making it both expensive and space-intensive (e.g. solar and wind parks), with long lead times for storage and pipeline construction (Clüver & Pardini, 2022). In some Latin American countries, such as Brazil or Trinidad and Tobago, opportunities exist to repurpose potentially stranded assets, such as existing gas infrastructure, to keep average capital costs down (World Energy Council, 2022). However, external investment is needed to construct technical links to ports and other export infrastructure in fiscally constrained African countries without gas assets. Additional efforts may be required to develop markets and stimulate demand for GH2 through road routes across the continent or "hydrogen corridor" agreements overseas (African Hydrogen Partnership, 2022; African Business, 2022).

In addition to production cost and infrastructure challenges, training and retraining energy sector personnel are crucial for successfully scaling GH2 (World Bank, 2020; IEA, 2021a). Skills development is vital for attracting investment and ensuring just energy transitions that benefit the local capacity development. For example, despite the recognised potential in Africa, only 2% of global renewable capacity was developed in the last decade due to a lack of knowledge and qualified engineers (REN21, 2022). While foreign investment has primarily been directed towards lowering infrastructure costs and research and development efforts by foreign experts (Columbia Factsheet, 2021), there is limited information on how such an investment practice leads to knowledge transfer. For example, in South Africa and Benin, academic hydrogen initiatives are small-scale and unlikely to replace the role of foreign experts lined to scaling-up foreign investment for infrastructure and electrolyser production (Clifford Chance, 2021; Germanwatch, 2022).knowledge transfer. For example, in South Africa and Benin, academic hydrogen initiatives are small-scale and unlikely to replace the role of foreign experts lined to scaling-up foreign investment for infrastructure and electrolyser production (Clifford Chance, 2021; Germanwatch, 2022).

What about the Global North?

The challenges faced in scaling GH2 investment are not limited to the Global South. Exploratory discussions with hydrogen industry players, policymakers, and researchers in Germany and the Netherlands, revealed similar challenges. These include no operational large-scale production sites and difficulties finding qualified personnel and funding for their projects. One solution is using temporary employment services as external partners for reskilling workers from the fossil-based energy sector. For example, Japan and Germany have established partnerships that offer worker training and university scholarships (Sookhun, 2022; Creamer, 2022). The Netherlands faces specific challenges, such as limited grid capacity and suitable location, while Germany plans to locate GH2 production in former coal mining regions. In both, political awareness is increasing and blue and green hydrogen imports are planned via the Port of Rotterdam.

The role of governments

Government involvement plays a crucial role in unlocking green hydrogen investments, yet the best approach to facilitate this process remains a topic of debate in the literature. Major points of debate revolve around governments either supporting investments through enabling mechanisms, such as negotiating guaranteed offtakes[1] with local industries and creating simplified regulatory environments to help investors anticipate demand (IEA, 2021b; Clüver & Pardini, 2022), or implementing more stringent regulations to ensure sustainability, like site and installation requirements (German Development Institute, 2021; Rosa Luxemburg Foundation & Arepo, 2022). Financial incentives for innovation and public procurement also emerge as key factors in facilitating investments in green hydrogen across various perspectives (IRENA, 2022b; WEF, 2022).

One prominent theme emerging in the literature is **collaboration**, with various forms playing a role in unlocking investments. Many governments have engaged with diverse sets of societal actors to craft their visions for national or regional hydrogen development, providing stakeholders with clear guidance on targeted sectors, export markets, and transportation modes (World Bank, 2020). Additionally, many sources highlight the value of international collaboration through trade agreements that leverage countries' existing infrastructure or demand centres (Figure 3) (IRENA, 2022a; World Energy Council, 2022).

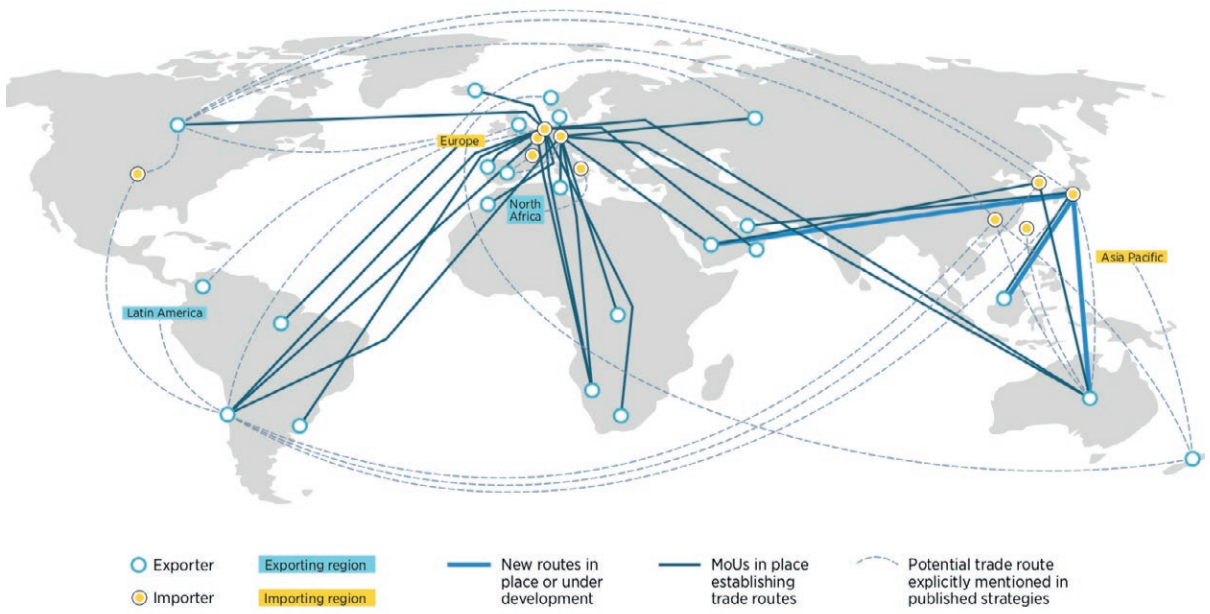

Figure 3: Hydrogen trade routes, plans, and agreements (IRENA 2022a, p 37)

1 A guaranteed offtake in this context is an assurance that a particular actor will purchase (part of) GH2 production during a specified period (and, if not, paid for by the government).

The grey literature review also revealed several collaborative organisations working to develop investment opportunities and promote favourable regulations – as presented in Table 1. Notably, no additional alliances were identified in the academic literature review.

Table 1: Overview of hydrogen collaborations emerging from review search process

Name	Board Members	Aim/Activities
Green Hydrogen Organisation	• Hydrogen business CEOs • Former politicians • Global.	• Developing standards for certification and contracting of GH2 projects • Promoting government collaboration
Hydrogen Council	• Multinational CEOs from fossil energy, transport, manufacturing • Global	• Funding studies on "clean" hydrogen; Recommendations to stakeholders, including governments • Collaborating on a global vision to attract investment
African Hydrogen Partnership	• African energy, engineering, and chemical companies • Global North port, mining, energy representatives	• Developing technologies and business opportunities across Africa for the development of 'carbon neutral' hydrogen, including transport and regulations
African Green Hydrogen Alliance	• Ministries in Egypt, Kenya, Mauritania, Morocco, Namibia, and South Africa • Development banks, companies observing	• Aligning policies and projects to attract investment, capacity building, certification for GH2 • Government led alliance working with the private sector
H2Global Foundation	• German corporates from the fossil industry • Logistics sector	• Financed by the German government • Research and recommendations on the implementation of 'CO2-neutral' hydrogen projects • A market mechanism that allows companies to bid on hydrogen sales to Germany in particular
Clean Energy Ministerial New Hydrogen Initiative	• Ministries across the world, mostly Global North • Knowledge and development institutions, Global North and China	• Led by the EU Commission and the IEA • Aims to encourage policies which accelerate hydrogen commercialisation e.g. via non-binding agreements • GH2 rarely mentioned despite the initiative's name

A few prominent international hydrogen summits and events were identified when reviewing these organisations (Table 2[2]).

Table 2: Overview of hydrogen summits mentioned by the search results

Name	Location	Supported by
World Hydrogen Summit	Netherlands	• Overwhelmingly business and the Global North (particularly UK and NL). • Some representation from Chile and the African H2 Partnership. • Organised by the global business led Sustainable Energy Council (SEC).
World PtX Summit	Morocco	• Public-private sponsored with a mix of Moroccan government agencies and both Global North (Germany and France) and Global South industry and development agency partners.
Green Hydrogen Summit	Oman	• Primarily local and worldwide fossil fuel companies. • IEA and both local and German hydrogen institutes. • Belgium and UK governments represented alongside Oman ministries.

2 Chile also hosted a global green hydrogen summit in 2022, but due to a lack of complete publicly available information on this event and its website being defunct, it was not included in table 2.

In summary, the grey literature and reviewed sources underscore the need for a multifaceted approach to scaling-up GH2 investments. Key focus areas include reducing production costs, expanding critical infrastructure and investing in skills and training of personnel. Governments play a pivotal role in this process, actively engaging in public-private partnerships and international collaboration to advance green hydrogen initiatives. However, a critical question remains: How can scaling GH2 investments address social and environmental concerns associated with fossil fuel and renewable development projects? To ensure that GH2 development is sustainable for the Global South, devising strategies to mitigate potential adverse impacts, promote equitable distribution of benefits, and prioritise long-term resilience and sustainability will likely be critical.

Sustainable Development

Enabling sustainable H2

Evaluating the environmental sustainability of GH2 warrants a closer examination of the term 'green hydrogen'. Many reputable reports adopt a strict definition, emphasising that hydrogen produced using renewable energy holds the most significant potential for industrial development (IRENA, 2022; WEF, 2022). Indeed, the IEA prefers using clean hydrogen, which includes blue hydrogen within carbon emission limits. Several corporate sources agree, with some attributing a significant role to blue hydrogen as a transitional energy carrier (O'Flaherty, 2021; IEA, 2021a). For instance, all collaborations in Table 1 are business or fossil industry-led, and these organisations avoid emphasising GH2 or omit carbon emission limits altogether. Blue hydrogen appeals to incumbent energy industries as it offers continuity and the possibility of using existing extraction assets in the Global South, such as blending green hydrogen with gas to increase demand (IEA 2019). However, NGOs are critical of blue hydrogen for potentially perpetuating investment in fossil extraction and advocate for investing only in new GH2 projects (Barnard, 2022).

Although GH2 can promote renewable adoption crucial for a net-zero transition, some experts question its sustainability. For example, the World Bank (2020) highlights green hydrogen's benefits, such as freedom from air pollution and price volatility (compared to fossil-based hydrogen). However, IRENA (2022a) and TNO (2021) argue that critical material scarcity for electrolysers could result in supply chain uncertainty for green hydrogen production.

A key sustainability concern is ensuring that GH2 projects do not impede more efficient uses of renewable energy by consuming electricity needed for decarbonisation in other areas (World Future Council & Brot für die Welt, 2021). To address this issue, larger GH2 projects in the Global South often connect to dedicated solar or wind parks (IEA,

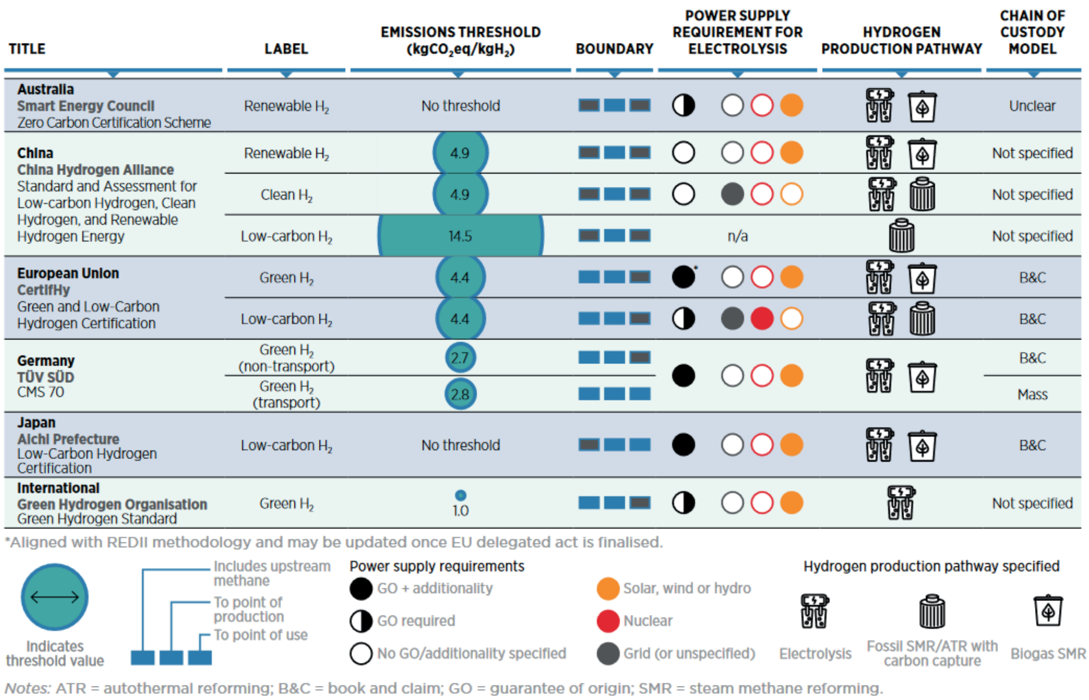

Figure 4: Summary of voluntary market mechanisms (IRENA 2023, p 28)

2021b). However, smaller projects may use existing renewable capacity, relying on power purchase agreements for additional supply (IEA, 2021b). Consequently, the literature advises prioritising green hydrogen for hard-to-electrify processes like industrial heating and chemical manufacturing (IRENA, 2022a). Nonetheless, there are cases of near-term GH2 initiatives in other sectors, such as power generation and personal transport in South Africa (World Bank, 2020).

The literature has not adequately addressed the role of international certifications for additionality in fostering trust in GH2 exports.. This certification could enable competitively-priced green hydrogen from regions like North Africa through carbon pricing mechanisms in the EU (IEA, 2019). However, existing discussions fall short of specifying the necessary standards for establishing certification frameworks for renewables or identifying the regulatory body that would enforce them. This ambiguity has paved the way for business-led initiatives, such as the Green Hydrogen Organisation, to advocate for their own more, lenient requirements (Bartlett, 2022). Figures 4 and 5 provide an overview of the evolving mandatory and voluntary standards for hydrogen.

Ensuring a just transition

Examining the impact of green hydrogen on sustainable development and social equity in the Global South through the lens of a 'just transition' can provide valuable insights. A just transition incorporates social justice and equity issues into energy transitions (The Presidency, 2022). This perspective explicitly considers how transitions to green hydrogen in the Global South can affect local communities and workers while ensuring the fair distribution of benefits. The reviewed literature underscores the need to analyse how GH2 in the Global South can bolster or undermine sustainable development and social equity locally and globally.

Locally, retaining and increasing employment is a critical issue. National roadmaps and reports from the African continent often predict significant economic growth driven by GH2 exports, equating this growth to increased job opportunities. For example, 20.000 annual jobs by 2030 have been tabled as a key outcome of South Africa's GH2 proposition (South Africa Department of Science & Innovation, 2021; Cliffe Dekker Hofmeyr, 2022). Projections also include the repurposing of stranded fossil assets and the continuation of jobs in mining and transportation in those regions (Creamer, 2022; Strategy&, 2020). However, the literature does not clarify *how* to guarantee this employment, given the fierce competition anticipated from GH2 exports (IRENA 2022a). This gap has prompted NGOs like the Böll Foundation and Brot für die Welt (2022) to advocate for guaranteed access to renewable energy and water for local communities where GH2 is produced.

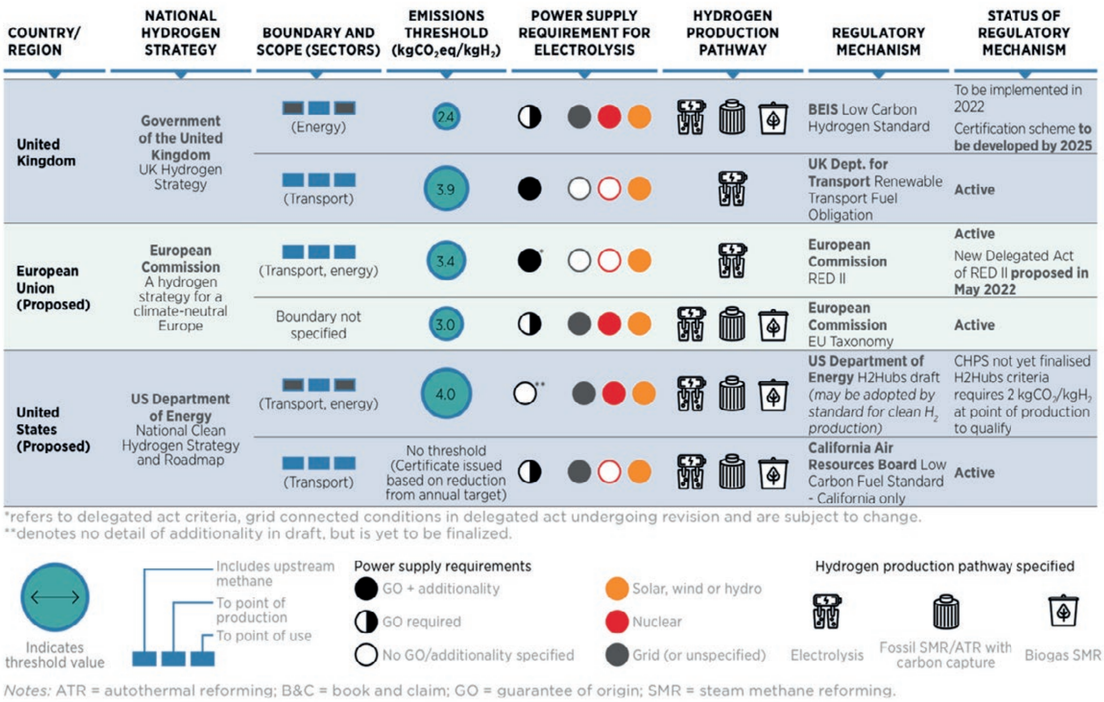

Figure 5: Summary of mandatory market mechanisms (ibid., p 32)

Proponents of a "local first" approach argue that decentralised renewables should prioritise improving local energy access before exports (Barnard, 2022; REN21, 2022). Green hydrogen could be beneficial locally if investments and policies ensure the stability of variable renewables for remote communities (World Bank, 2020). Green hydrogen could also promote investment in desalination plants to address water scarcity in rural regions, thereby creating local value through energy access (Germanwatch, 2022). Barnard for Corporate Europe Observatory and the Transnational Institute suggest that using GH2 for local fertiliser production could help decarbonise the agricultural sector, a significant source of income for African countries (Bernard, 2022).

Critics of the "local first" approach argue that prioritising GH2 exports over local demand would better finance the domestic market (African Hydrogen Partnership, 2022). However, on a global scale, unequal geopolitical dynamics are shaping hydrogen trade. Land use competition is expected to intensify as renewables for GH2 require significantly more land than other renewable projects (IEA, 2022c). If local contexts are not carefully considered, widespread land usage contestations are likely. In a notable example of this tension, the IRENA Geopolitics of Hydrogen report (2022a) asserts that installing renewables in desert regions can reduce competing land use risks. However, planned installations in Tunisia and Morocco have been criticised by the Böll Foundation and Brot für die Welt (2022) for making that assumption, which they claim will limit local pastoralists' access to land.

The German government's involvement with African hydrogen production appears sensitive to this risk, mandating the avoidance of competition with local communities over land and other resources for its engagement (German Agency for International Cooperation (hereafter GIZ), 2022). The GIZ (2022) report emphasises the importance of local research and training to mitigate this risk. However, the report also prioritises securing conditions for cheap imports to achieve German national climate targets – potentially restricting collaboration with local communities or governments (Rosa Luxemburg Foundation & Arepo, 2022). Furthermore, with its parallel development of blue hydrogen, the German government exposes itself to accusations of perpetuating extractive practices (Barnard, 2022).

This trend of limited local involvement extends beyond Germany to the wider Global North engagement with the Global South. For example, as evidenced in Table 1, African involvement in international hydrogen networks remains limited. Many pilot projects on the continent are owned by the same Global North companies previously involved in the extractive fossil economy (Strategy&, 2020). Patents almost always originate outside exporting countries, as depicted in Figure 4. For example, the $8.5 billion international funding allocated to South Africa for its Just Energy Transition has been criticised as lacking transparency and consultancy on its allocation and intended beneficiaries, increasing the risk that this value remains with its Global North funders (Germanwatch, 2022). The recent publication of the Just Energy Transition Investment Plan (The Presidency 2022) makes some headway in clarifying the intended allocation.

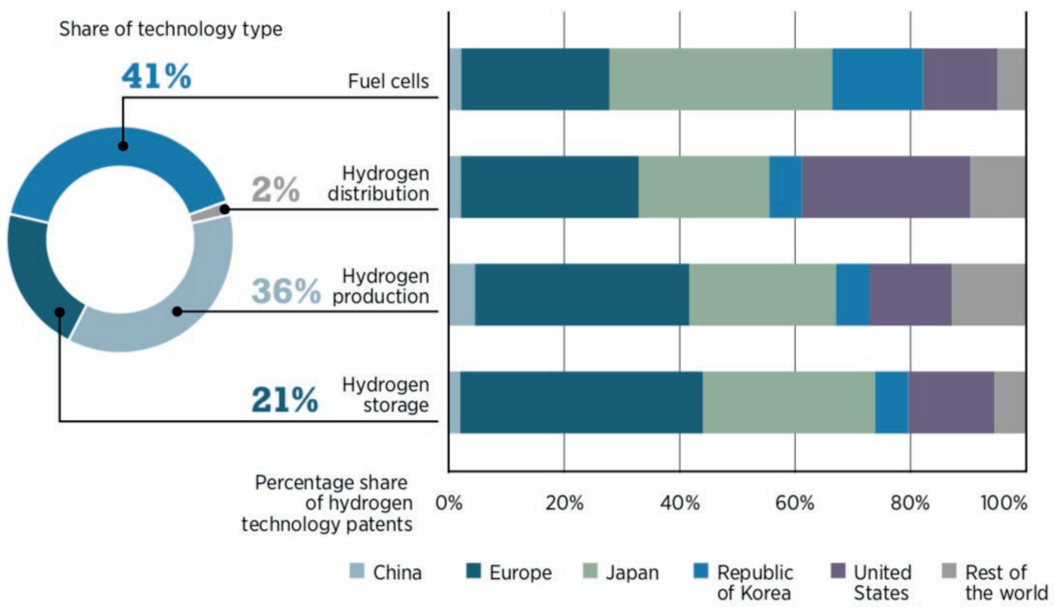

Figure 6: Geographic Distribution of hydrogen-related patent families, 2010-2020 (IRENA 2022a, p 56)

Some sources propose more constructive approaches for green hydrogen in the Global South to foster a global just transition. Energy-intensive sectors such as steel production could relocate near hydrogen production sites, creating new industrial zones like the one envisioned in Boegebaai, South Africa (World Bank, 2020; IRENA, 2022a). Nevertheless, these reports acknowledge that existing industrial clusters are likely resistant to change and will be able to leverage their current status to continue attracting investment for their unsustainable practices.

Consequently, NGOs such as the Böll Foundation and Brot für die Welt (2022, p. 20) argue that hydrogen "must be developed with the appropriate framework conditions for countries of the Global South to prosper as a result" – referencing previously criticised renewables projects like Desertec. This position calls into question roadmaps that specify GDP projections linked to local wealth generation without outlining mechanisms for profit distribution or addressing potential social and environmental impacts, such as displacement. The focus remains on attracting investments through collaborations with the Global North countries without incurring more debt. However, this approach can leave Global South countries vulnerable to project risks, potentially placing them in a weaker negotiating position vis-à-vis ensuring that international investment flows translate into local benefits (Gabor and Sylla, 2023). In conclusion, a deeper discussion on how export-oriented economic development can lead to sustainable development in the Global South is still needed.

Academic debates: emerging issues

Green hydrogen has become an increasingly relevant research topic, with scholars regularly publishing new literature during the period under review (August-November 202). Much of the academic literature examines the potential for GH2 development for the Global South. Studies have investigated the techno-economic potential of Mongolia (Nilsson et al., 2021), proposed a roadmap for the Philippines, which is rich in renewable resources (Agaton et al., 2022), and assessed the prospects for countries like Paraguay (Posso et al., 2022), China (Huang & Liu, 2020), and South Africa (Ayodele & Munda, 2019). These analyses contribute to our understanding of the opportunities and challenges facing different regions in their pursuit of a green hydrogen economy.

While earlier publications primarily address technical and economic dimensions, newer publications encompass a broader range of disciplines. Research from various disciplines, including both natural and social sciences, recognise that energy transitions represent a challenge that is simultaneously technological and social (Perlaviciute et al. 2021, Hanusch & Schad 2021). This perspective has led to the conceptualisation of hydrogen as a sociotechnical system, encompassing a network of systems and interactions across five key components: hydrogen production, hydrogen supply chain, industrial hydrogen use, institutional drivers, and end-use drivers (Griffiths et al. 2021). However, the funding of GH2 production has not been widely discussed in the academic literature – in stark contrast to the grey literature.

Additionally, the literature could further explore the implications of contemporary landscape factors, such as geopolitical tensions, on GH2 development and adoption. Russia's recent invasion of Ukraine is one example that underscores the importance of understanding the potential of green hydrogen to shift power dynamics in the context of energy supply. As countries seek to diversify their energy sources, it remains uncertain whether they will achieve greater sovereignty or if established power relations will persist through the exploitation of renewables from the Global South. Indeed, the Böll Foundation and Brot für die Welt (2022, p. 12) emphasise the importance of understanding and addressing the social dimension of this promising renewable energy technology:

> *"Green hydrogen could become an enormous driver of development and prosperity for the Global South – if the risks are understood and past mistakes are not repeated".*

Challenges to Sustainable Development

The transition to GH2 as an energy source presents various challenges that intersect with sustainable development. In the academic literature, these intersections have converged on geopolitics, energy justice, gender, and water-related issues. Addressing these multidimensional challenges is critical to ensure that the introducing GH2 into energy systems contributes positively to the long-term goals of environmental protection, social equity, and economic growth.

Geo-political implications

The geographical abundance of renewables raises questions about potential changes to energy-related patterns of cooperation and conflict between states (Scholten & Bosman, 2016). Scholars argue that scaling GH2 production may reshape the political landscape concerning energy provision. As a result, the transition to renewables, including GH2, could shift trade partners and transform cooperation patterns between nation-states (Sadik-Zada, 2021; Scholten et al., 2020; Scita et al., 2020).

Sadik-Zada (2021) highlights that GH2 development in the Global South depends on substantial investments in electrolyser capacity and pipeline infrastructure. These disadvantages risk exacerbating the technology disparity between the Global North and Global South, potentially aggravating precarious economic conditions in less developed regions (Sadik-Zada, 2021). Many Global North countries, lacking the renewable production capacity to meet their GH2 demand, aim to import GH2 from the Global South. Consequently, several scholars call for establishing legal requirements and standards for international trade (Perlaviciute et al., 2021, Van de Graaf et al., 2020).

Scita et al. (2020) also emphasise the potential redrawing of international relations while cautioning against the risk of "green colonialism". Other authors use "green extractivism" to describe these processes (see Kalt & Tunn, 2022; Voskoboynik & Andreucci, 2021). Countries such as Germany and Norway have already secured agreements with hydrogen-producing countries, underscoring the importance of interrogating how a GH2-based energy transition may perpetuate the role of Global South countries as raw material providers. Scita et al. (2020, p. 27) further state:

> *"As climate change comes to the forefront of international politics, there is indeed the risk that developed countries externalise their carbon-intensive activities in the Global South, decarbonising their domestic economies, but contemporarily exploiting developing nations' resources and labour. As society makes progress towards the climate emergency, it is fundamental that it does not internalise the colonial principles that have lacerated our societies."*

Furthermore, because GH2 could be produced almost everywhere, Scita et al. (2020) argue that instead of a democratising energy supply, new classes of importing and exporting countries may emerge. Consequently, a hydrogen economy will likely alter relations between the Global North and Global South, with the risk of green colonialism being a key concern (see Müller et al., 2022; Hanusch & Schad, 2021; Scita et al., 2020). To mitigate this risk, Scita et al. (2020) propose developing a common international framework for hydrogen trade and approaching new trade opportunities must with caution to avoid novel (post) colonial structures (Hanusch & Schad, 2021).

Energy justice and social acceptance of green hydrogen

The potential for GH2 development to perpetuate power disparities between the Global North and South underscores the importance of energy policy frameworks with a strong commitment to energy justice. In this regard, it is crucial to consider local communities and their participation when planning GH2 projects (Nadaleti et al., 2022). Inclusive decision-making that respects indigenous communities and local customs is vital for the projects to be sustainable and socially accepted.

Local communities' acceptance of renewable energy, including green hydrogen, is essential for its successful deployment. Factors hindering such acceptance include a lack of knowledge and understanding of renewables and misconceptions that portray renewables negatively (Ingaldi & Klimecka-Tatar, 2020). Consequently, it is crucial to prioritise improving local populations' lives and ensure that they understand and accept the new technologies (Böll Foundation; Brot für die Welt, 2022; Perlaviciute et al., 2021). Equitable distribution of costs and benefits and addressing potential conflicts arising from GH2 production on indigenous lands must be included in planning processes (Gomes et al., 2021; Nadaleti et al., 2022).

Real-world examples of conflicts involving GH2 projects can be found in Brazil and Africa. In Ceará, Brazil, a planned GH2 production plant is at the centre of disputes over land tenure, water, and environmental pollution between nearby indigenous communities and Pecém Port (Brannstrom & Gorayeb, 2022). Notably, Pecém Port has partnered with the Port of Rotterdam for GH2 exports. Similarly, Müller et al. (2022) introduce the concept of hydrogen justice and examine GH2 projects in Namibia and Morocco developed in partnership with Germany and German companies. The authors propose strategies to implement justice principles across various scales of hydrogen governance to address the resulting hydrogen injustices.

These examples raise the question of whether the justice dimension of a transition will only be considered after GH2 implementation instead of being integrated into the development of technical solutions, as Brannstrom (2022) suggests.

Gender and green hydrogen

Exploring gender dimensions in the green hydrogen transition is another vital aspect of understanding its broader societal implications. Hanusch & Schad (2021) note that research on the societal effects of the hydrogen transition – such as impacts on gender dynamics – remains nascent. They call for more interdisciplinary research to avoid a “social-ecological mismatch”, where the societal consequences of introducing new technology are not adequately considered (Hanusch & Schad, 2021).

Dematteis et al. (2021) draw attention to the vital role women play in adopting and diffusing new technologies. Women often organise social and domestic life and keenly experience both positive and negative effects of energy transitions. Women also serve as critical agents of change at both household and institutional levels. According to Dematteis et al. (2021: 20):

> *“Hydrogen might positively impact women both as a trigger for a more balanced distribution of daily activities connected to family and house management and as a trigger for enhancing the role of women in the decision process toward the adoption of hydrogen solutions through the enhancement of their STEM [science, technology, engineering, and mathematics] skills”.*

The authors also suggest that implementing new GH2 storage systems, in particular, could reshape household organisation, fostering a more balanced division of labour and empowering women by allowing them more freedom in using smart energy and allocating their time. However, more data is needed to understand and evaluate gender aspects of energy transformation fully. Further research is needed to explore the roles of women in households and industries, particularly within STEM fields, and to understand the extent to which they are included in decision-making and policy-making processes.

Water availability

Given the importance of water availability in the production of green hydrogen, it is essential to explore the potential implications and challenges this may present. The electrolysis process used for GH2 production is water-intensive – although opinions on the extent of this impact vary. For instance, Posso et al. (2022, p. 20) argue that up to “85% of the projects formulated up to the year 2020 could require the intensive use of water desalination systems”. Conversely, other researchers contend that the water footprint for GH2 production is relatively low (Fan et al., 2021). In general, renewable energy production is approximately 33% less water-intensive than fossil-fuel energy production (Beswick et al., 2021). Thus, a successful scaling of GH2 production could save significant freshwater compared to the consumption required for fossil fuel-generated energy.

Despite these potential water savings, it is crucial to acknowledge that countries with existing freshwater scarcities may need to invest in desalination systems and address this issue with heightened concern (Fan et al., 2021). Conflicts over water usage and water scarcity are identified as potential challenges of GH2 production, necessitating careful consideration in planning processes (Böll Foundation and Brot für die Welt, 2022). The growth in desalination plants is generally expected to occur alongside GH2 developments (Beswick et al., 2021; Posso et al., 2022).

Discussion

The analysis of policy documents and academic literature reveals an intriguing set of perspectives and questions that merit further exploration in future research. In the grey literature, the information landscape – composed of government reports, news articles, NGO briefs, and consulting pieces – often relies on authoritative sources such as IRENA and IEA and government or private sector announcements. Notably, IRENA staff frequently co-authors influential articles and reports or refer to their work at pivotal moments. This prominence suggests that IRENA's vision for the role of green hydrogen (e.g., meeting 12% of energy demand and provoking geopolitical shifts due to Global South exports) significantly shapes real-world narratives and recommendations.

Furthermore, the German government's widespread involvement in funding, partnerships, research, foundations, and diplomacy is evident in the grey literature, even in reports critical of their efforts. Germany's substantial investment in hydrogen may motivate stakeholders to frame discussions around green hydrogen on their terms to ensure their investments are worthwhile.

While corporate sources often advocate for government support and regulatory easing, NGOs tend to be more critical of export-based strategies, highlighting only limited uses of green hydrogen as conditionally viable options. Nonetheless, a sense of inevitability pervades much of the grey literature on hydrogen. Due to the limited technical alternatives for industrial heat generation, envisioning a decarbonised world without some proportion of hydrogen usage is challenging. However, none of the sources explores potential alternatives (e.g., reduced consumption) or why such alternatives might be preferable.

The academic literature search primarily yielded results from hydrogen or energy-related journals, particularly the International Journal of Hydrogen Energy, including those focused on social perspectives concerning hydrogen development. This pattern validates the calls of authors such as Hanusch and Schad (2021) for more interdisciplinary and transdisciplinary approaches to climate change mitigation. Empirical insights on the interaction between hydrogen and society in the search results are geographically fragmented and lack a unifying framework to connect them with technology-centric discourse. As various search results raise questions about distributive justice, they connect to the broader notion that intersectionality should be an essential lens for evaluating energy system transitions (Bell et al., 2020). For example, exploring how marginalised voices are represented in green hydrogen implementation discussions surrounding and how these voices can be amplified. Indeed, Hanusch and Schad, along with other authors (see Dematteis et al., 2021; Perlaviciute et al., 2021), underscore that "every energy transition is also a cultural transition" (2021, p. 85).

Future research agendas

The current state of GH2 policy and research presents several pressing questions. First and foremost, to what extent does the discourse analysed and presented in this review represent hype rather than substance? Hydrogen has experienced failed resurgences before, and while the economic landscape now includes billions of dollars in commitments, relatively few large-scale projects are underway (World Bank, 2020). Furthermore, global crises could divert attention from the green hydrogen transition, and investors may yet pivot towards electrification if government support and cost reductions do not materialise quickly enough. While renewables and GH2 are closely related and likely need to grow together, the limited number of existing gigawatt-scale hydrogen projects restricts the empirical data available for analysis of the social dimension of GH2 development.

Current research focuses on the technologies underpinning energy transitions, economic estimates for future production capacities, and potential collaboration agreements between different companies and continents (Agaton et al., 2022; Ayodele & Munda, 2019; Huang & Liu, 2020; Nadaleti et al., 2021; Nadaleti et al., 2022; Nilsson et al., 2021; Raman et al., 2022; van Wijk & Wouters, 2019). Future research should closely monitor the few GH2 mega-projects that are operational or nearing completion, which can provide useful, reliable knowledge on the social and environmental aspects of hydrogen production.

Moreover, this review has revealed competing interests, such as stakeholders advocating for exports and blue hydrogen and those promoting local GH2 benefits. Understanding the dynamics of these interests is critical, as the growth and distribution of hydrogen production in the Global South will determine which interests secure the most investment. Continued observation and analysis of this aspect are essential for comprehending the development of the hydrogen industry. Case studies, such as those in this report, may offer valuable insights into the implications of green hydrogen developments in these contexts and provide a foundation for future research.

The scarcity of knowledge on the social implications of GH2 highlights the need for more comprehensive research on this aspect. Many sustainable development issues identified are not directly related to GH2 production but instead concern renewable energy production needed to power it. While several academic sources in the search results do not address potential conflicts and social issues (see van Wijk & Wouters, 2019; Gomes et al., 2021), large-scale renewable energy projects in the Global South (unrelated to GH2) have inspired a substantial body of empirical work on the social implications of renewable energy production. Connecting these studies to green hydrogen research could help address the research gap. While there may be differences in implementation, incorporating the lessons learned from previous renewable energy initiatives can help inform and improve the planning and execution of GH2 projects, ensuring their long-term social and environmental sustainability.

2 Case Studies: Brazil and South Africa

Brazil: An emerging powerhouse?

This section approaches the Brazilian case, exploring key developments, perceptions, and expectations in renewable hydrogen. The overview and findings are based on a literature and document analysis, complemented by a two-week field visit to Brazil between 23 September and 7 October 2022. The field trip consisted of a visit to the north-eastern Brazilian state of Ceará, a key hub for green hydrogen developments in the country, and participation at the 2nd Hydrogen Forum, a conference aggregating experts, governmental entities, and market players in the hydrogen sector, held in Sorocaba, state of São Paulo. Data collection included interviews and interactions with the government, private sector, consultancies, academia, international donors, and field visits to (prospective) producing localities.

This section starts by providing an overview of Brazil's hydrogen market and the opportunities linked to an emerging green hydrogen economy. It then zooms into key national projects and plans in the field. Lastly, it highlights the economic, technical, normative, and social challenges and obstacles linked to green hydrogen developments in Brazil.

Overview & Opportunities

Policy documents, consultancy reports, and interviewees all point to Brazil's enormous potential to produce competitive, low-cost green hydrogen (César et al., 2019; EPE, 2021a; GIZ, 2021; Chantre et al., 2022). Estimates indicate that the country is set to become one of the cheapest sources for generating hydrogen from renewables (Bloomberg NEF, 2022). A key competitive advantage lies in Brazil's high share and competitive cost of renewable generation, which accounts for almost 50 per cent of the energy matrix (EPE, 2021a). Opportunities for green hydrogen are highlighted both in terms of export-oriented investments and domestic consumption, particularly in the ammonia, fertiliser, cement, mining, and steel industries (Chantre et al., 2022). The availability of export-oriented logistics along the Brazilian coastline and a network of natural gas pipelines – which can be repurposed for hydrogen transportation – is also noted as crucial for developing a low-carbon hydrogen economy (GIZ, 2021). Moreover, Brazil's notable expertise in biofuels, biomass residues, and ethanol production can be harnessed to strengthen and regulate local hydrogen production.

While the Brazilian GH2 industry is still in its infancy, hydrogen has long been produced in the country, though almost exclusively from fossil fuels – particularly through natural gas reforming without carbon capture (grey hydrogen). In line with current global uses, hydrogen consumption in Brazil mainly encompasses industrial applications in oil refineries and in the steel, cement, glass, and food sectors. Between 2015 and 2019, the state-owned oil enterprise Petrobras accounted for roughly 95 per cent of Brazil's total hydrogen production, mainly for the firm's consumption at its refineries (GIZ, 2021, p. 44). Notably, ammonia production, the second largest end-use market for hydrogen globally, remains negligible among current Brazilian industrial applications. This phenomenon is remarkable given Brazil's potent agribusiness sector, demanding large amounts of fertilisers and leading to heavy reliance on imports, mainly from Russia (OEC, accessed 2023). Not surprisingly, policy documents, investment plans, and interviewees viewed initiatives targeting "green ammonia" as a downstream product of hydrogen with particular enthusiasm (Porto do Açu, 2021; Unigel, 2021). Such projects could simultaneously serve domestic needs and export markets while acting to decarbonise a hard-to-abate sector.

Government strategies, policies, and measures in the Brazilian hydrogen economy date back to the early 2000s and include fuel cell system programs, technological innovation actions, technical standards discussion, and research and development (R&D). Relevant guidelines on sustainable hydrogen first appeared in the "Roadmap for the Structuring of the Hydrogen Economy in Brazil", produced in 2005 by the Ministry of Mines and Energy (MME) and the Ministry of Science, Technology, and Innovation (MCTI). It established a 20-year schedule to incrementally facilitate a transition from grey hydrogen to blue and renewable hydrogen, mainly through technological routes involving ethanol, water electrolysis, and biomass (EPE, 2021b). However, the discovery of the extensive pre-salt oil reserves in 2007 shifted attention away from hydrogen as a sustainable energy alternative, stalling many of these plans.

Interest in sustainable hydrogen only gained traction in 2020-2021 amid unprecedented global momentum in the sector (see the Grey Literature Findings section). The National Energy Plan (PNE 2050), approved by the MME in December 2020, included hydrogen for the first time, noting its disruptive potential for decarbonisation (EPE, 2020). This Plan was followed by the elaboration of the National Hydrogen Program (PNH2) in August 2021, incorporating a set of guidelines structured in six axes: (i) the strengthening of the scientific-technological bases; (ii) the training of human resources; (iii) the energy planning; (iv) the legal and regulatory-normative framework; (v) the opening and growth of the market and competitiveness; (vi) and international cooperation (see MME, 2021). More recently, in March 2022, a draft law (no. 725, 2022) was presented to the Brazilian Senate to regulate GH2 production and uses. It is currently under discussion.

All these efforts have been accompanied by the intensification of hydrogen-related bilateral and multilateral international cooperation initiatives involving Brazilian actors, from governmental entities to the private sector and academia. A notable example is the "H2 Brazil" project, funded by the German Agency for International Cooperation (GIZ), which seeks to support the legal, institutional, and technological development of GH2, geared explicitly towards exportation ambitions to Germany (GIZ, 2022; see the Discussion section on Germany's global hydrogen involvement).

It was also telling to observe during the research period how hydrogen's increased visibility and momentum in Brazil has triggered an explosion of media articles, academic works, and events, with dedicated networks and (online) platforms being formed on different niche dimensions of the hydrogen economy. This interest was noticeable in the 2nd Hydrogen Forum in Sorocaba, São Paulo, where representatives from different Brazilian states and companies showcased their plans and potentials, highlighting emerging initiatives across the country and exchanging information and contacts. The conference also attracted a wide range of professionals and businesses prospecting opportunities to serve and participate in value chains linked to Brazil's emerging green hydrogen economy, such as law firms, consultancies, and equipment manufacturers. Dedicated WhatsApp groups were also formed for those interested in following and sharing information about specific green hydrogen themes. Such developments are vital in promoting knowledge, facilitating experience exchanges, and devising instruments to scale up and accelerate deployment and address obstacles.

Key Projects

Amid increasing interest in developing GH2 in Brazil, the Brazilian Hydrogen Association (ABH2) identifies no less than 40 suitable sites for renewable hydrogen production. Nine Brazilian states have announced hydrogen hubs and strategies (see Figure 7 below). Three particular localities stand out and are often mentioned in discussions and analyses of Brazil's (incipient) GH2 sector: Pecém Port in Ceará state, Açu Port in Rio de Janeiro state, and Suape Port in Pernambuco state. All three localities have signed Memoranda of Understanding (MoUs) and pre-contracts with private investors to create hydrogen hubs. One commonality between these localities is that they are all port facilities aggregating an industrial complex and export-processing zone. Announced investment plans are prominently from foreign companies and prioritise the exportation of hydrogen and its derivatives. While these developments emblematise a market that appears to be gaining traction, they also highlight Brazil's current positioning as a supplier of hydrogen to meet external decarbonisation demands, especially in Europe – despite potential and sound prospects for the creation of a domestic market.

Touted as the 'Brazilian green hydrogen capital', the north-eastern state of Ceará is the most well-known case and, in several respects, stands at the forefront of Brazil's renewable hydrogen developments. The Pecém Industrial and Port Complex (CIPP), located 60 kilometres from the state's capital Fortaleza, is set to concentrate on several companies connected to producing clean hydrogen. CIPP is jointly owned by the Port of Rotterdam, which holds a 30 per cent stake. Its involvement builds on the Dutch enterprise's ambition of becoming a key transit hub for green hydrogen in Europe. Interviewees also viewed the participation of a major global logistics actor in Pecém positively, bringing visibility to the Brazilian hydrogen economy and attracting investments. These initiatives are supported by the establishment of Ceará's Green Hydrogen Hub, stemming from a partnership between the state government, the

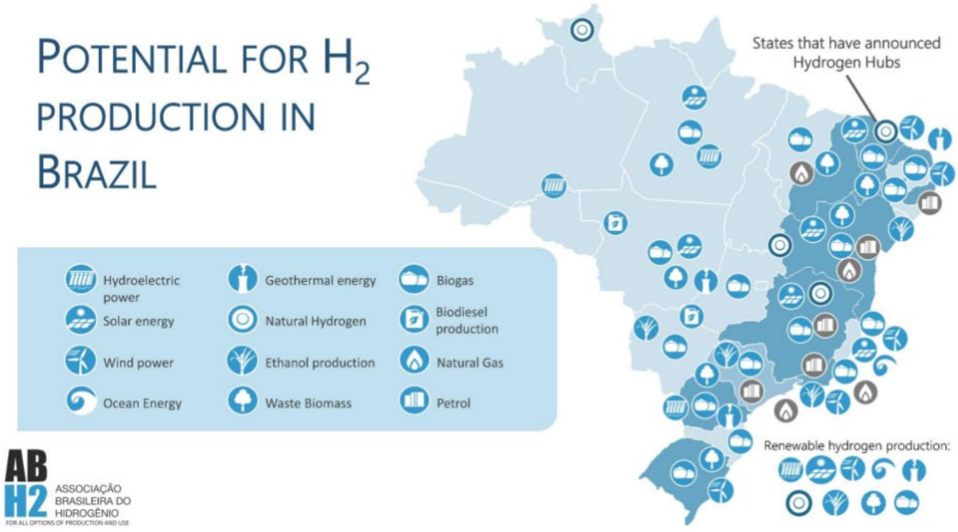

Figure 7: Sites with potential for H2 production in Brazil. Courtesy of the Brazilian Hydrogen Association (ABH2).

Table 3. Overview of announced investments in the Pecém Complex, as of January 2023. Courtesy of the Federation of Industries of the State of Ceará.
** At the time of writing, the expected investment for Casa dos Ventos was not disclosed.*

Company	Country	Energy	Expected investment in USD (bilions)
Fortescue	Australia	2,00 GW	6
Qair	France	2,24 GW	6.95
Energix	Australia	3,40 GW	5.4
AES Brazil	USA	1,00 GW	2
Transhydrogen	Netherlands	3,00 GW	2
EDP	Portugal	1,25 MW	0.05
ENGIE	France	100 MW	0.3
Casa dos Ventos	Brazil	2,4 GW	*
Total		**≈15,00 GW**	**22.7**

state's industry association (FIEC), the Federal University of Ceará (UFC), and CIPP. This Hub serves as a platform for multistakeholder collaborations and initiatives among governmental, academic, and business entities, including R&D, policy deliberations, and investment attraction.

Plans for clean hydrogen in the Pecém area are based on the utilisation of solar and wind energy, both of which have considerable potential in Ceará due to the region's strong and regular wind and solar incidence. The site's privileged location within Brazil, offering the shortest routes to Europe and the United States, is also promoted as a main competitive advantage. As of 2022, CIPP had signed pre-contracts with eight private investors in the field of green hydrogen, amounting to an announced investment sum of approximately US$23 billion and 15GW in energy capacity (see Table 3 below). Future production is mainly intended for export. However, discussions about using hydrogen for CIPP's internal industrial activities and transition commitments are ongoing. This debate comes to the fore in the case of the Portuguese company EDP's green hydrogen pilot project at the Pecém Thermoelectric Complex, whose official launch is scheduled for 2023 (EDP, 2022).

The other set of key national projects in GH2 is located in the Port of Açu, in the state of Rio de Janeiro. These projects consist of MoUs signed with Australia's Fortescue Future Industries and Shell, envisioning the conduction of feasibility studies for renewable hydrogen plants with a capacity of 300MW and 100MW, respectively (Porto do Açu, 2021; Capital Reset, 2022). The electrolysis process will be powered with electricity from an onsite solar park and offshore wind projects. Of relevance in the Açu case is the potential production of green ammonia. The signed MoU with Fortescue envisions, for instance, the manufacture of up to 250,000 tons of the compound – a development which speaks to Brazilian ambitions of building a national fertilizer industry (Porto do Açu, 2021). Notable here is also the co-partnership with a major European logistics entity, as the Port of Antwerp is among the shareholders in Açu.

The Port of Suape in the state of Pernambuco has similarly attracted considerable investor interest. The location's petrochemical industry and export infrastructures, with shorter routes to European and US markets, offer suitable opportunities to produce both green and blue hydrogen and ammonia. The Port has recently approved the lease of a plot to be used by French energy firm Qair, who announced plans to build a US$3.5 billion green hydrogen plant with 1GW of electrolysis capacity produced from desalinated seawater (EPBR, 2022). Moreover, MoUs have been established with firms such as Neoenergia, CTG Brasil, Fortescue Future Industries, and Casa dos Ventos, amongst others (Bnamericas, 2023). A "Green Hydrogen TechHub" was launched in July 2022 in partnership with the Pernambuco state government and the National Industrial Training Service (SENAI) to incubate initiatives aimed at the production, transportation, storage, and management of green hydrogen.

Challenges & Obstacles

However, the development of a green hydrogen economy in Brazil faces multiple economic, technical, normative, and social challenges and obstacles. Ongoing projects are in planning stages or are of an experimental and pilot nature. Low-carbon hydrogen is still a limited reality in the country. The scaling up of production may take time, anchored on variables such as economic feasibility, technical constraints, human resources training, and social acceptance. Chantre et al. (2022) suggest that it may take more than 11 years to reach sufficient technical and economic maturity to allow for large-scale deployment. Interviewees and academic and grey literature on the Brazilian hydrogen economy often point to the lack of regulation and long-term policy frameworks as significant barriers. Such instruments could help to bring confidence and predictability to private investment, create market incentives and demand, develop technical standards, and provide enhanced R&D and social-environmental impact assessment frameworks. The advent of a national program and draft law on green hydrogen are perceived as encouraging developments in this regard. Nevertheless, these normative propositions also contain gaps, for example, in terms of socio-environmental safeguards (Brannstrom & Gorayeb, 2022) and guidelines for certification (Frazão et al., 2022).

Moreover, Brazil's nascent GH2 industry is centrally built on export prospects, concentrated on coastlines and ports. These geospatial characteristics underscore two issues. One speaks to broader geo-economic patterns of developing countries merely extracting natural resources and energy (as "bottled renewables") to meet decarbonisation goals elsewhere. These dynamics often unfold under unequal terms of trade, given their dependency on high value-added technologies (e.g., electrolysers) and intellectual property from the West and China (see the Findings section on just transition). The second issue relates to Brazil's still missed opportunity of building an internal market for GH2, despite the significant potential and strategically relevant outcomes (e.g., the building of a national fertiliser industry). Even if hydrogen-producing sites are mainly located in coastal areas, the country could use its existing network of gas pipelines and tap into its potential for cabotage shipping to facilitate transportation. The Brazilian Development Bank (BNDES) could act as a catalyst by financing studies and projects for the competitive structuring of hydrogen value chains in the country.

Finally, mirroring broader global trends (see the Findings section on a multi-faceted transition), the Brazilian hydrogen economy's existing plans, frameworks, and policies remain overwhelmingly guided by financial and technical considerations. If the development of green hydrogen is regarded as a natural market path, the concerns of (host) societies and socio-environmental questions are yet to be adequately mainstreamed into investment plans, policy frameworks, and public discussions. Hydrogen plants and their associated infrastructures (e.g., wind farms, solar parks, electrical grids) are inevitably entangled with impacts on local societies and environments. Thus, attention to socio-cultural fabrics and ecologies of local territories, along with the creation of livelihood opportunities, is essential to ensure the social acceptance and safety of green hydrogen solutions. In Brazil, sites at the forefront of the hydrogen economy, such as the Pecém and Suape enterprises, have long been associated with negative socio-ecological impacts, including through lasting modes of harm to fishers (Pecém), destruction of mangroves and greater incidence of shark attacks (Suape), labour conflicts, and increase of crime and drug addiction in surrounding communities (see Freitas, 2006; Oliveira, 2013; Guimeiro, 2018).

Such concerns are yet to be adequately mainstreamed and detailed into policy frameworks, investment plans, and public discussions linked to the green hydrogen rollout in Brazil. Particularly illustrative in this regard was the fact that major hydrogen conferences in the country (e.g., Hydrogen Forum) remain heavily focused on investment opportunities and the technical hurdles of building a hydrogen economy, with little to no mention of the socio-environmental impacts, as well as issues of justice and fairness. Among the organizers, sponsors, and presenters, the lack of women and non-white representatives was also telling. This absence emerges as a significant lacuna in a highly unequal society like Brazil and demonstrates that the issue merits further attention and consideration.

South Africa: Realising the Green Hydrogen proposition

In 2022, the South African government continued to affirm the importance of green hydrogen (GH2) to its much-needed national energy transition. As the African continent's leading emitter, grappling with enduring socio-economic challenges, GH2 offers a compelling proposition of decarbonisation, energy security and economic growth. In this section, we present the South African case, exploring critical aspects of the local context and identifying opportunities and emerging challenges. The findings are based on the analysis of primary data collected through the fieldwork undertaken for this author's doctoral research on financing niche innovation for the energy transition and the emerging GH2 sector in South Africa. Secondary data analysed include published academic and grey literature; government documents and publications; and confidential documents pertaining to presentations, meeting minutes, and attendance registers.

This section begins with an overview of the GH2 proposition in South Africa, summarising the national strategy. A summary of the current state of play is presented next, followed by anticipated investment needs and key insights into the local context. The section concludes with a review of identified opportunities and emerging challenges shaping the GH2 pathway in South Africa's energy transition.

South Africa's green hydrogen proposition

In South Africa, the political discourse on energy transitions has coalesced around achieving a just transition that recognises "the direct and indirect impact that the energy transition has on livelihoods, workers, and communities" (The Presidency, 2022, p. 1). This objective underscores South Africa's dualistic approach to developing a GH2 export industry that supports (and is supported by) sustainable, local GH2 demand. By positioning South Africa as a major supply node in the international trade of GH2 and derivative products, the government hopes to realise opportunities for minerals beneficiation and localised industrialisation to propel GDP growth, job creation and skills development (Council for Scientific and Industrial Research (CSIR), 2006; Department of Science and Technology (DST), 2007; Department of Science and Innovation (DSI), 2021). Establishing a GH2 export industry is thus a key policy priority, as evidenced by the *Just Energy Transition Investment Plan (*The Presidency 2022, p. 89):

> *"The foundation to scale the GH2 economy must, therefore, be established in South Africa by 2030 for GH2 to become a globally competitive industry that supports the world's decarbonisation efforts and establishes new global energy trade routes."*

By one estimate, South Africa's annual demand for GH2 in 2050 could reach as much as 9.5 million tons, with 6 million linked to local demand and 3-4 million to exports (National Business Initiative (NBI), 2022, p. 25). However, establishing a GH2 export industry is perceived as a critical precursor to developing the local market and accelerating the local energy transition. Policy documents from key government actors suggest a consensus that securing global off-take is critical to justify investment in local production (DSI, 2021; DTIC, 2022). However, as stated by The Presidency (2022, p. 89), its potential role in South Africa's energy transition is not insignificant:

> *"GH2 is critical to decarbonising the economy, with the potential to remove 10-15% of South Africa's carbon emissions, while protecting and growing major downstream industrial sectors such as chemicals, cement, iron, and steel".*

Key sectors targeted for decarbonisation include transport, mining, chemicals and manufacturing, with an intended early focus on localised industrial applications where the cost of distribution infrastructure can be constrained (DTIC,

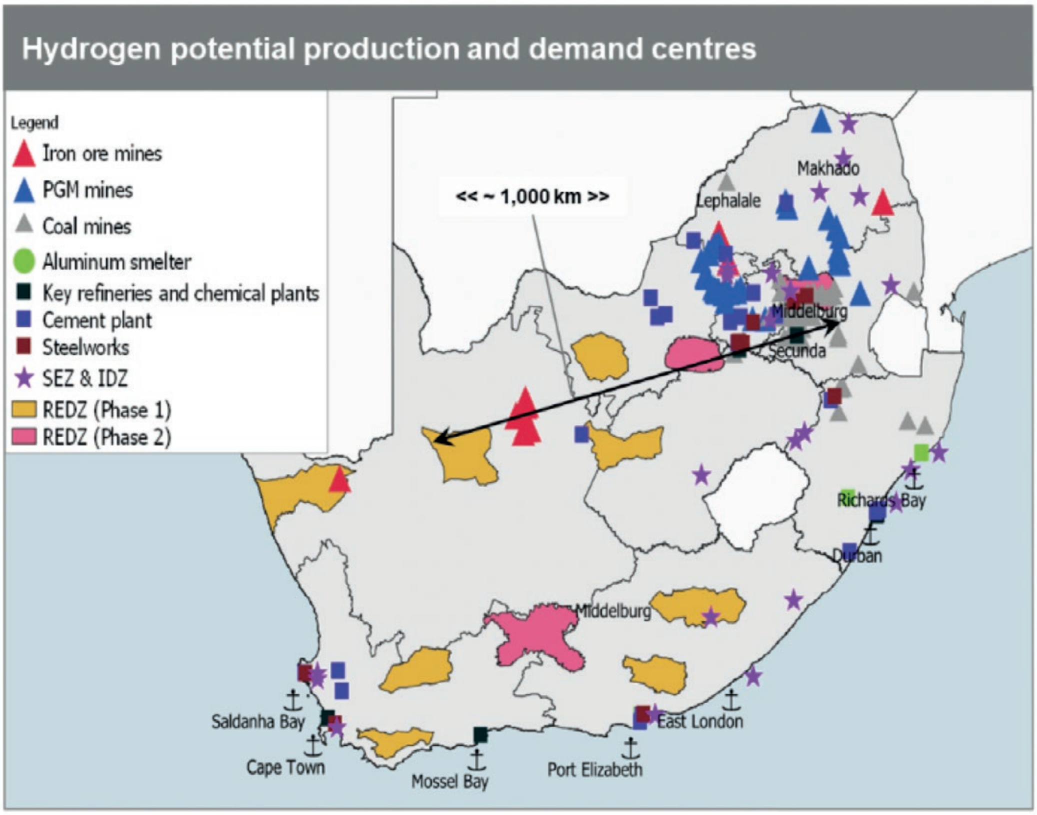

Figure 8: Potential hydrogen production and demand centres in South Africa. Reproduced from IHS Markit (2021, p. 12)

2022, p. 11). However, limited local demand is expected in the short- to medium-term, emerging from 2030, driven by energy price parity with fossil fuels and economies of scale (DSI, 2021; DTIC, 2022). Developing a phase-out plan from grey and blue hydrogen is anticipated to take place between 2025-2030, scheduled to be championed by the Department of Minerals and Energy (DMRE) when GH2 reaches parity with grey hydrogen (DTIC, 2022, p. 67).

The State of Play

Public records reveal that policymakers, scientists and researchers began to mobilise around hydrogen and fuel cells as early as 2003, with the first *National Hydrogen and Fuel Cell Technologies Research, Development and Innovation Strategy* published in May 2007 (DST, 2007). The launch of the *Hydrogen Society Roadmap for South Africa 2021* in February 2022 represents a key policy milestone, tabling key targets, policies and sectoral routes to GH2 integration into the national energy mix (DSI, 2021; IRENA, 2020; World Energy Council, 2021). Through an extensive public and private sector stakeholder consultation process, South Africa's Roadmap identified several "catalytic" initiatives aimed at accelerating the uptake of GH2 (DSI, 2021, pp. 69 – 78).

Chief among them is the multi-province Platinum Valley corridor connecting the mining industry to South Africa's largest port, incorporating the industrial, mobility, and building sectors (DSI & Engie Impact, 2021). Other core projects seek to capitalise on global market opportunities for aviation fuel, carbon capture, and international GH2 and green ammonia exports. Project synergies will also be critical to leverage economies of scale, reduce costs and increase efficiency (Fig 9). West and Southeast coastal projects are primarily geared towards domestic and export markets, with inland activities primarily servicing domestic demand (DTIC, 2022). With limited national pipeline infrastructure and negligible gas usage in energy supply, activities and projects aim to spur and expand the demand for grey, blue, and green hydrogen to shore up the market.

Local GH2 production remains limited to small-scale stationary demonstration projects. The *Green Hydrogen Commercialisation Strategy for South Africa* – published for public comment until 3 February 2023 – lists over 30 active projects and initiatives (DTIC, 2022, pp. 148 – 158). These initiatives encompass mobility and stationary applications

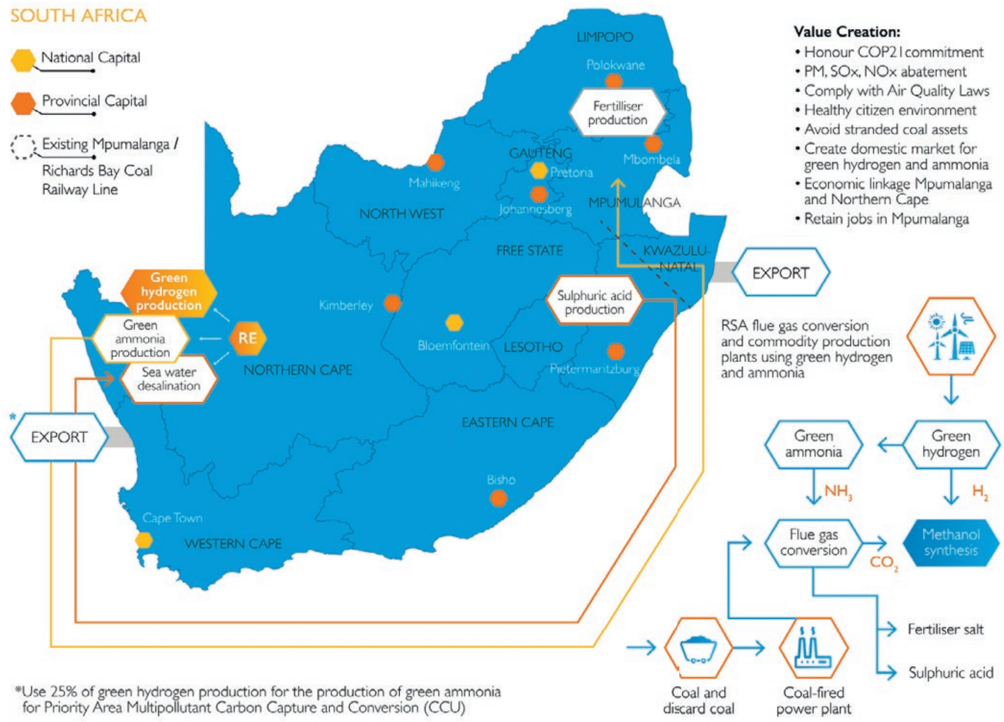

Figure 9: Synergies between the Boegoebaai and CoalCO2 -X programmes. Reproduced from DSI (p. 76, 2021)

in various stages of development, from concept and feasibility to demonstration. This list reveals the government's strategy of attracting well-resourced, powerful private-sector actors – local and foreign – in mining, energy, chemicals and transport to spearhead industry development. International and multinational firms Anglo American, Sasol, Impala Platinum, Toyota, Enertrag, Linde and Engie are notable inclusions.

The South African context

Country-specific contexts are critical to determining how national governments will apply GH2 in their energy transitions as varying sectoral priorities, available supply sources, and policy tools and mechanisms underpin individual country contributions (World Energy Council, 2021). South Africa's energy landscape boasts climatic advantages for renewable energy, particularly wind and solar resources, typically used in GH2 production (Fraunhofer IWES & CSIR Energy Centre, 2016). These advantages are, however, not currently reflected in an energy mix dominated by coal and (to a lesser extent) petroleum products (Fig. 10).

South Africa's slow transition to renewables, and the concomitant, enduring electricity-supply crisis, are inextricably linked to the national power utility, Eskom Holdings SOC Ltd (Eskom). Eskom is responsible for electricity generation,

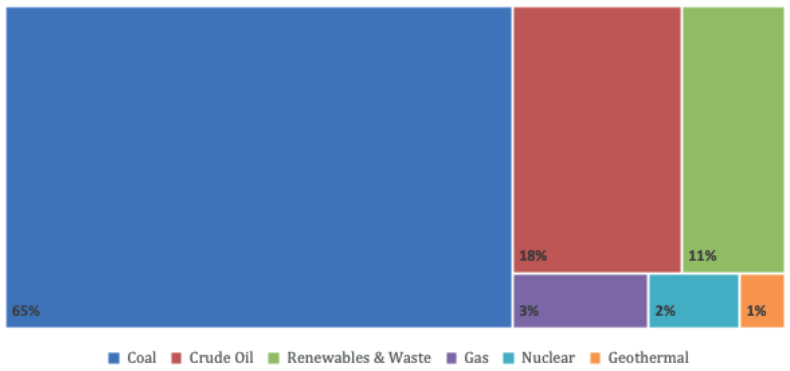

Figure 10: South Africa's total primary energy supply, 2018. Adapted from DMRE (2021, p.12)

transmission, and distribution[3] and is the country's largest GHG emitter. However, the state-owned company is struggling to meet electricity demand. Financial, operational and infrastructure challenges have manifested in nationwide rolling blackouts hampering economic and social activity (CSIR, 2022; Mbomvu et al., 2021). Vested interests have hindered attempts to broaden South Africa's in-crisis coal-powered energy sector due (in part) to the strong connections between the energy and mining industries (Baker, 2015, 2016; Baker et al., 2014; Hanto et al., 2022). As noted in the preceding section, South Africa's GH2 proposition is contingent upon transitioning South Africa's power sector.

The scale of funding required to meet projected GH2 demand (and, indeed, the broader clean energy future) can be juxtaposed with a decidedly precarious economic context. Macroeconomic variables point to staggering inequality, significant unemployment and an urgent need to remedy structural challenges inherited from the nationalist Apartheid regime in 1994 (World Bank, 2022). Fiscal policy remains focused on restoring budgetary sustainability by narrowing the budget deficit and reducing debt-service costs while leveraging infrastructure investment and employment programmes to bolster economic growth (National Treasury, 2022b). South Africa's fiscal constraints underscore the importance of mobilising the private sector and development funding to meet investment needs for the GH2 sector (Fig. 11). The US$ 8.5 billion offered by the International Partners Group (comprising the governments of Germany, France, the United Kingdom, the United States and the European Union) for the period 2023-2027 is one such prominent example (United Kingdom Cabinet Office & Sharma, 2022).

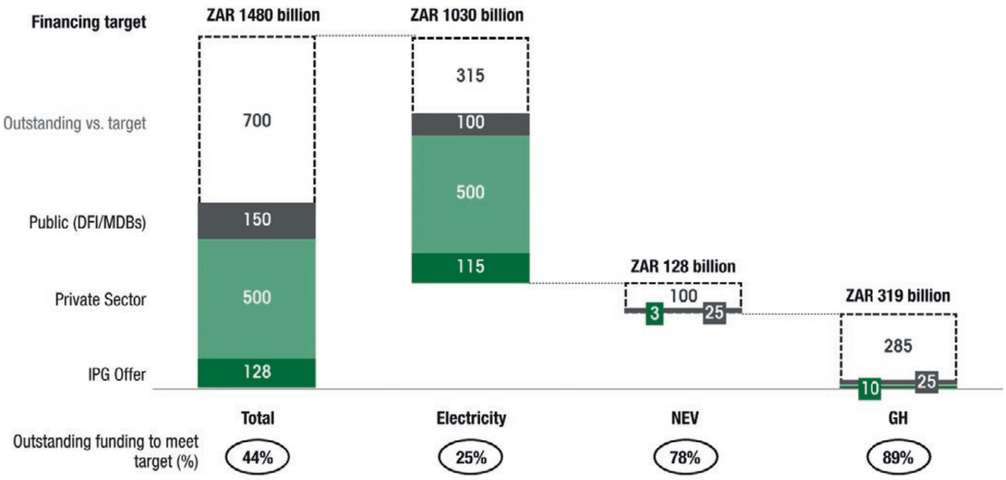

Figure 11: Projected funding needs and estimated availability by source for priority areas of electricity, new energy vehicles (NEV) and green hydrogen (GH). Reproduced from The Presidency (2022, p. 15)

While Global North nations are likely better positioned to capitalise on the opportunities that GH2 offers (and, indeed, to overcome challenges), they are also at a relative advantage in implementing climate mitigation and adaptation measures (UN). Like many other developing and emerging economies in the Global South, South Africa is increasingly vulnerable to the impacts of climate change. The country has faced several climate-related national disasters in the last decade, including extended droughts and devastating floods (Davis-Reddy & Vincent, 2017). Ageing infrastructure, maintenance challenges and municipal dysfunction compound these vulnerabilities. As highlighted in Chapter 1, with water being a key input into the electrolysis process, investments in desalination capacity are also considered essential (DSI, 2022).

3 Municipalities also play a key role in distribution, often overlapping with Eskom distribution networks (National Treasury, 2018). Regulations are being amended to facilitate generation by municipalities in good standing. The state-owned entity has also formally commenced unbundling its transmission division (Eskom, 2022).

Investing in GH2

Of late, more accurate predictions of GH2 investment needs to meet projected demand (and anticipated shortfalls) are being tabled (Table 4). Indeed, the JET IP plan published in November 2022 initiates a much-needed process of determining the granularity about how (and for whom) the GH2 and the broader energy transition will be financed. During interviews, both financing and innovating actors in South Africa expressed concern about the lack of transparency concerning international climate finance, such as that offered by the IPG.

Table 4. Tabled estimates of financing needs for South Africa's GH2 sector. Collated from DTIC (2022), National Business Initiative (2022a), and The Presidency (2022)

Funding time horizon	Department of Trade, Industry and Competition	National Business Initiative[1]	The Presidency
Initial	US$ 1 billion	US$ 1.65 billion (2030-2040)	
2023-2027	US$ 18.4 billion		US$ 21.2 billion
2050 Cumulative	US$ 178 billion	US$ 92 billion	US$ 178 billion

[1] Exchange rate of USD/ZAR 15.04 applied to facilitate comparison

Approximately US$ 1 billion in seed funding may be required to develop an initial 20 Ktpa and a further US$ 18.4 billion from 2023-2027 to scale production to 270 Ktpa (DTIC, 2022, p. 55). This figure tallies (somewhat) with the JET IP, which estimates five-year investment needs of US$ 21.2 billion for the GH2 sector (The Presidency, 2022, p. 97). The JET IP allocates the bulk of funding needed (81%) for this period to capital expenditure, notably US$ 9.95 billion for port infrastructure capital and US$ 7.2 billion for GH2 and green ammonia projects. The DTIC (2022, p.55) presents a cumulative US$ 178 billion to realise 7.0 Mtpa GH2 production by 2050, while the membership-based National Business Initiative (NBI) (2022a, p. 26) estimates a cumulative capital expenditure of US$ 92billion to meet local and foreign demand of 7.7 Mtpa in 2050, excluding GH2 capacity for converting synthetic fuel assets to green assets**.** Initially, it is envisioned that the bulk of the funding for GH2 will be allocated through the fiscus (The Presidency, 2022).

The scale of investments needed is mirrored across both supply and demand nodes in the emerging global hydrogen economy. Significant financing needs are being tabled for South Africa's key competitors, such as Australia, which has announced an investment pipeline valued at US $92-US $128 billion (Singh, 2022). On the African continent, Morocco has estimated cumulative financing needs of 1,000 billion dirhams (≈ US$ 96.5 billion) between 2020 and 2050 to meet its forecasted demand of between 17.57 GW and 35.11 GW in 2050 (Ministère de l'Énergie des Mines et de l'Environnement, 2021, pp. 14-15). Countries seeking to import GH2 have also pledged funding to support the development of supply nodes. Japan, a key potential export market for South Africa, has pledged US$ 1.5 billion in funding until 2030 to support local and international production and distribution infrastructure (World Energy Council, 2021). Germany, another important potential offtake partner and funder for South Africa, has committed €7 billion (≈ US$ 7.49 billion) for national production and a further €2 billion (≈ US$ 2.14 billion) to develop international partnerships (World Energy Council 2021).

Meeting projected GH2 demand would also require considerable investment into renewable electricity capacity. To give a sense of scale, in 2021, South Africa's Variable Renewable Energy fleet (wind, solar PV, and CSP) had a wholesale nominal capacity of 5.7 GW, just over 10% of the total nominal capacity of 53.7 GW (Council for Scientific and Industrial Research (CSIR), 2022, p. 2). For South Africa to reach net zero by 2050, the NBI (2022a, p. 26) estimates that some $188 billion will be needed to deploy 150 GW of wind and solar (almost quadruple current coal-generated capacity). The DTIC (2022, p. 42) projects that 13 GW of electricity will need to be carved out (or created) to produce 1.9 Mtpa of GH2 for export. For further reference, the sixth bid window under the Renewable Energy Independent Power Producer Procurement Programme[4] (REIPPPP) will procure an additional 4.2 GW of wind and solar power to come online in 2025 ((DMRE) Department of Mineral Resources and Energy, 2022).

4 The Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) is an initiative by the South African government to promote private sector investment in grid-connected renewable energy.

Capitalising on Opportunities

Arguably, the challenging local context has helped promote GH2 in South Africa as a viable pathway to addressing critical economic and energy challenges. The consultative process underpinning South Africa's Roadmap may well account for the increased visibility in media, government and parliamentary oversight committees from circa 2019 onwards. Macroeconomic impacts look promising: the JET IP claims that "promoting a GH2 export industry…can increase GDP by 3.7% by 2050" (The Presidency, 2022). By comparison, GDP growth has been forecasted to average 1.8% across 2022-2025 (National Treasury, 2022a).

Notably, the beneficiation of platinum group metals (PGMs) for catalysers and fuel cell components has been a core objective underpinning hydrogen-related research and development (DST, 2007). With South Africa commanding an estimated 75% of known world PGM reserves, the mining sector looks to continue its pivotal role in the country's energy future (IRENA, 2020b). Localisation of manufacturing and assembly will underpin the value-add to PGMs.

South Africa's Roadmap clearly articulates job creation as the primary mechanism through which wealth distribution will occur. However, how this economic growth will translate to job creation remains to be elucidated in detail. Official unemployment currently stands at 32.9%, equating to 7.7 million unemployed persons. South Africa is ranked the most unequal of 164 countries in the World Bank's global poverty database (Statistics South Africa, 2022; World Bank, 2022). In its study on South Africa's net zero transition, the NBI (2022b) estimates that some 2.5 million cumulative job years could be created by 2050 with a localised GH2 value chain. The catalytic projects in South Africa's Roadmap are projected to create as many as 20 000 jobs per year by 2030 – although fieldwork revealed considerable scepticism about both the quantity and quality of the jobs that will be created (DSI, 2021).

The benefits of robust domestic demand are anticipated to emerge from 2040 onwards, scaling up as and when (or, indeed, if) energy cost-parity is achieved (DTIC, 2022). South Africa currently produces approximately 2% of the world's grey hydrogen – primarily to support synthetic fuel production by energy and chemicals company Sasol Ltd. After Eskom, Sasol Ltd is South Africa's second-largest emitter and the world's largest hydrogen producer – suggesting a viable decarbonisation pathway using GH2 in its production processes for national impact (Environment Forestry and Fisheries Portfolio Committee, 2021; Sasol, 2021). Transitioning to green hydrogen in the petrochemicals and chemical sector may also lessen risks related to the EU's 2023 Carbon Border Tax Adjustment scheme (The Presidency, 2022).

Sasol's synthetic fuel production is also linked to the decarbonisation of South Africa's transport system, where petroleum-based products meet as much as 98% of South Africa's energy demand for transport applications (DMRE, 2021). The company's patented Fischer-Tropsch Coal-to-liquid fuel process has been foregrounded as a competitive advantage, using GH2 for synthetic hydrocarbons (e.g. methane, diesel, and jet fuel) (DSI, 2021). Several mobility prototypes have been introduced through the 15-year Hydrogen South Africa research programme, often in conjunction with large corporates and SOEs such as Impala Platinum and the South African Post Office (GIZ, 2017; Pollet et al., 2014).

Emerging Challenges

With more than 30 countries having published national hydrogen strategies, the global GH2 market is shaping up to be decidedly competitive. South Africa lags behind competing countries such as Morocco, Chile, Australia and Saudi Arabia, all vying to be preferred suppliers to wealthier, energy-intensive countries (World Energy Council, 2021). Driving value chain efficiency to lower cost will, therefore, be critical to securing global market share. The South African government has prioritised relationship-building with potential off-takers such as Germany and the UK. Arguably, the need to secure off-take agreements may account for reportedly limited regional and continental collaboration (e.g. Onyango, 2021).

One significant competitive disadvantage compared to low-cost producers like Brazil is South Africa's limited pipeline infrastructure, requiring substantial infrastructure investment and likely increasing the cost of hydrogen transportation. Another is the high manufacturing cost of electrolysers relative to other countries, which may hinder the localised industrialisation envisioned (DTIC, 2022). South Africa's Special Economic Zones (which offer tax, financial and other incentives) are important mechanisms for galvanising private-sector investment in GH2 and derivatives targeting export markets (Ramokgopa, 2021).

Reflecting South Africa's ongoing focus on achieving social and economic justice for marginalised citizens, its Roadmap has foregrounded the use of Gender, Equality and Social Inclusion (GESI) metrics and methodologies to ensure inclusivity and economic redress. As indicated in the literature review discussion, this is an important dimension of sustainability transitions and energy justice. The relative success thereof will emerge as plans progress, but fieldwork reveals that the implementation lacks clarification. Journalists have also reported on limited community engagement in some constituencies, hinting at the possible marginalisation of civil society (Jordan, 2021a, 2021b). Other avenues for greater public participation include municipalities: implementing the national vision will require consultation and capacity building at the municipal level. However, local government is currently characterised by service delivery gaps, poor financial management, and high levels of dysfunction, suggesting caution in project implementation forecasts (Department of Cooperative Governance, 2022). Encouragingly, local government challenges are increasingly foregrounded to understand how these may constrain and enable energy transitions more broadly (e.g. The Presidency, 2022).

As the GH2 landscape continues to develop, political economy analyses of South Africa's energy transition are well worth considering in any interrogation of GH2 as a transition pathway. Particularly given how competing interests have undermined efforts to diversify the country's in-crisis coal-based power sector (Hanto et al., 2022). Useful parallels may be drawn with the power sector, with many powerful actors in South Africa's energy system positioning themselves as primary beneficiaries of the emerging GH2 economy.

3 Workshop Insights & Future Research Prospects

On 12 December 2022, expert scholars, industry representatives and public stakeholders gathered in Utrecht, the Netherlands, to share their experiences of green hydrogen development in the Global South and consider how they can together imagine and bring about globally just hydrogen projects, societies and futures.

The workshop was structured along three panels: (i) a presentation of the project's results and case studies; (ii) the prospects and benefits of an interdisciplinary approach to the global hydrogen transition; and (iii) reflections on impact assessment frameworks for green hydrogen projects. Across these panels, both presenters and the audience raised critical questions about the discussed contents and laid out their own experiences in the fields of green hydrogen and sustainable development. Against this backdrop, this section describes some of the main insights and take-aways from the workshop, along with envisioned prospects for future collaboration.

First, as a starting point, workshop participants reaffirmed our notion that **the green hydrogen industry is still nascent**. They spoke of many projects in early development whose viability is dependent on costs coming down and, for example, safety regulations catching up, even if plans in countries like Germany (import) or Brazil and Spain (export) are of massive scale & ambition.

Second, discussions gave more detail on how **hydrogen needs to be considered as more than just a technological fix – it is social and political**. There are myriad applications and rationales behind hydrogen projects, from transport to energy security and just transition. This diversity means they should be assessed according to the social, institutional, and material infrastructures which contextualise them. Hydrogen could be viewed as an instrumental case of larger questions of what a fair global economic system entails. Pertinently, addressing these questions requires social science approaches. Examples were given of such approaches being excluded from decision-making: in Namibia, many energy policymakers were not involved in the creation of their national hydrogen strategy. In academia, some participants observed an under-representation of female, queer, and minority scholars in hydrogen discourse, leading to paternalistic discourses towards Global South realities and populations. In the Netherlands, both government and business are promoting hydrogen without much concern for the social and environmental challenges, said a speaker. After all, engineers, rather than social scientists, dominate impact assessment frameworks.

When social-ecological impact assessments are completed with a focus on justice, it becomes clear that hydrogen projects harbour risks from water stress to land conflicts and community development. The open question remains: **can true global partnerships emerge?** In the current experience of industry experts, most Global South jobs are only created during the installation phase of projects, while operating jobs are very specialised. Projects tend to negate technology transfer in favour of creating export markets for Global North technologies. Finally, it can be a political struggle to resist these kinds of green energy proposals in Brazil because if they do, the alternative might be fossil fuels. Amid such significant challenges, it was good to be reminded that each country and company has their own reasons to promote hydrogen as an opportunity – from using existing fossil fuel assets before they get stranded (in the case of blue hydrogen) to meeting climate targets or reducing reliance on tourism (Spain).

Third, and perhaps most important, participants in the workshop were adamant that **there should be ways of influencing current narratives around GH2**, to firmly involve local communities that might be affected by land acquisition and mega-infrastructure development. However, information sharing and local discussions are still largely absent. A Brazilian researcher asked: Will local populations ever accept foreign energy exports if they know it will negatively impact their food security, as is the case in the Brazilian state of Ceará? Indigenous groups in the region are thus trying to regain control over their territories after the extensive wind farm project for GH2 development started to enclose various areas, limiting access for the indigenous communities to access their land and farms. On the contrary, in the South of Brazil, local populations get financially compensated for wind farms being put in their communities, and therefore companies have greater social acceptability in their operations.

As researchers, our attendees agreed that they should be active in co-designing new solutions that are context-dependent rather than just signalling and criticising projects – which could be a fair criticism of reports like this one. However, it was also considered that supporting communities in knowing their rights and the possible implications of hydrogen projects allows them to protest – and communities who protest tend to get better impact assessments that ensure more local benefits. A wide variety of **potential solutions,** from all-encompassing to specific, were put forward: regionalisation of hydrogen trade, being careful to promote systemic change to more organic agriculture alongside fertiliser made from GH2, cumulative impact assessments which combine multiple renewables projects and the infrastructure that comes with them, community-led impact assessments, and the mapping of indigenous communities and their territories through social cartographies.

Finally, two quotes, in particular, resonated during the workshop as summarising critical social science points of view on green hydrogen in the Global South:

> *"The lack of legal protections for land of traditional communities and an economic structure which permits exploitation is more important to the justice outcome than which technology (green or blue) is used eventually."*

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> *"System change is needed through reducing production and consumption of energy – and after that just a little bit of GH2 should be produced domestically – and after that just a little bit can be exported. For exports, there should be very strict environmental standards, and trade should fit into a wider framework of Global North-South climate reparations."*

With these words in mind, on 13 December 2022, a small group of contributors to the workshop gathered to lay the foundations for a "Critical Hydrogen Research" network and research partnerships. The network, comprising scholars of varied disciplinary and geographical backgrounds, will take its first steps by organizing a special issue approaching the diverse scales and manifestations of green hydrogen developments in the Global South, encompassing (intersecting) dimensions of geopolitics, international cooperation, territorial implications, justice, knowledge production, and discursive framings, among others. In particular, this special issue will seek to speak to energy scientists and policymakers to weave critical energy perspectives into narratives of green hydrogen planning, which are currently seen primarily from a technical or financial perspective. This issue will contribute towards better-informed policy prescriptions towards globally just, fair, and socially acceptable hydrogen futures.

Conclusion

The current state of literature and practice of GH2 development in the Global South reveals a field in development as hydrogen investments aim to grow from almost zero to play a significant role in global energy supply and decarbonisation. As demonstrated in the literature review, major commercial, governmental, and international agencies' reports describe the need for a truly unprecedented scale-up compared to current hydrogen production to reduce costs, create the necessary infrastructure, and address a lack of trained personnel. Particularly in the Global South, being able to produce and export GH2 at low costs is considered wholly dependent on such efforts materialising. One crucial element, according to the surveyed reports, is government financing and collaboration. These ideas are mirrored in the findings among the surveyed academic works, as the majority of existing research on GH2 deals with the technological capacities of GH2 production in countries regarded with high potential.

In making sense of such trends, critical scholars, in particular, observe how sustainable development is a contested issue, as public and private actors tend to diverge (or remain silent) on the conditions under which GH2 contributes to climate action. In academic scholarship and among civil society groups, scepticism is directed to labels such as "green" or "sustainable", hinting at issues of justice and fairness behind the massive scale-up of GH2 use. Moreover, contention remains about the extent to which allegedly clean alternatives such as blue hydrogen should also be championed as sustainable. Locally, NGOs contend that hydrogen can only be compatible with a just transition if it is green and comes second to local energy through electrification and water access. Conversely, other sources consider GH2 a possible catalyst for investment in local renewables and desalination. Globally, civil voices are critical of suggestions that the Global North's engagement with hydrogen imports from the South can be equitably beneficial, for example, through the emergence of new industrial zones. They see neo-colonial dynamics already being perpetuated through opaque financing and technology ownership.

Critical perspectives are also growing more prominent in academic work on GH2. Especially challenges such as geo-political implications, possible land conflicts, and energy justice are discussed with the aim of expanding research on social issues in the future. To ensure a fair energy transition, scholars from different disciplines argue that further interdisciplinary research is crucial in accompanying future GH2 developments (Dematteis et al., 2021; Hanusch & Schad, 2021; Vallejos-Romero et al., 2023). To overcome these issues, scholars argue that among other efforts, the following endeavours are central: local participation, gender mainstreaming in GH2 projects, citizen education about the technology and ongoing reflection and action to avoid the reproduction of (post)colonial structures (Brannstrom & Gorayeb, 2022; Dematteis et al., 2021; Hanusch & Schad, 2021; Kalt & Tunn, 2022).

Many of these trends, insights, and challenges were observed in the Brazilian and South African cases. In Brazil, the renewability of the energy matrix presents a key competitive advantage to produce GH2, especially regarding export ambitions. There are also prospects and opportunities to develop a chain of domestic consumption, both to decarbonise hard-to-abate sectors and establish strategically relevant national industries, such as manufacturing fertilisers to reduce import dependencies. Nonetheless, if technical, economic, and normative considerations are usually seen as the main barriers in policy and industry circles, the Brazilian hydrogen economy is fraught with socio-ecological risks and vulnerabilities. Often, these are manifested through environmental damage, dispossession, and social harms caused by "green" infrastructures to communities, bodies, and territories already structurally marginalised.

The South African government has galvanised considerable public and private support for its vision of the role of GH2 as a pathway to clean energy and economic development. The current energy strategy seemingly elevates the export market to provide the impetus to develop capacity for local demand while capitalising on opportunities for minerals beneficiation, localised industrialisation and global supply chain participation. Certainly, cautions about novel (post) colonial structures emerging in the global GH2 economy are apposite. Dependence on foreign offtake from the global North to realise this vision underscores the vulnerability inherent in achieving South Africa's socio-economic objectives. Equally pertinent are the calls for further scrutiny of community involvement and environmental impacts to avoid their marginalisation in pursuing much-needed job creation and economic growth.

Indeed, both cases highlight how hydrogen's "green optimism" entangles with vulnerabilities, dependencies, and socio-ecological disruptions enforced and imposed by market logic, as well as promises of progress and economic growth.

All in all, at current, real-world knowledge on GH2 in the Global South remains alarmingly limited to a few projects and actors, suggesting that the narratives emerging in influential grey literature and academic discourse might play a role in key decisions made on the global energy transition over the following years – whether warranted or not. Apart from asking critical questions and making visible the different – at times problematic – consequences of GH2, it is therefore crucial that researchers constructively engage with policymakers, industry actors, and concerned publics to think of and propose socio-ecologically just and fair transitions.

During the Green Hydrogen in the Global South Workshop, some ideas emerged on further cross-sector collaborations, integrating social and political concerns in hydrogen transition debates, and ensuring greater involvement of local communities in project design and assessment. We hope that our newly established Critical H2 Research network will continue to drive these conversations, starting with a global collaborative special issue and moving onwards to broader, more interdisciplinary collaborations.

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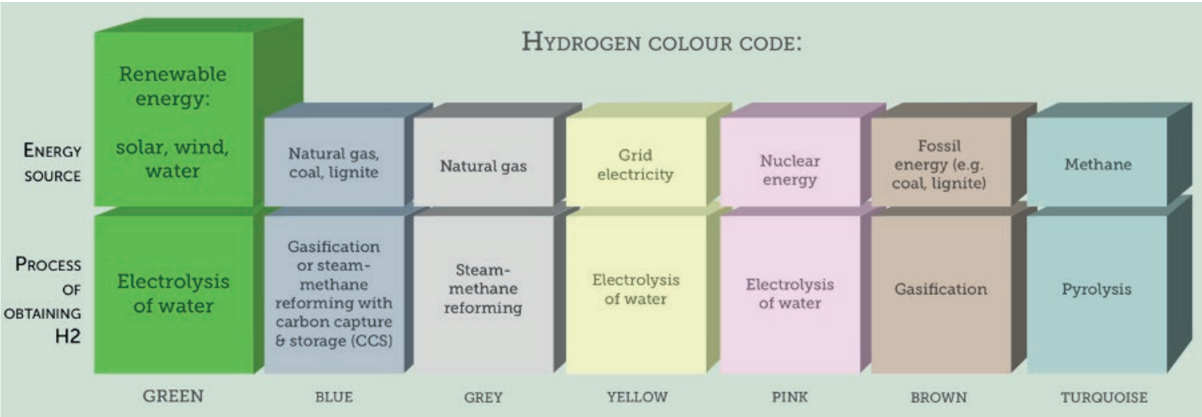
Appendix 1



Germanwatch, 2022, p. 2

Hydrogen burns clean at the point of use, leaving only water vapour as residue – so its harmful emissions, if any, come from the production. Green hydrogen uses only renewable energy sources to generate the electricity needed to split water into oxygen and hydrogen. Blue hydrogen uses methane from natural gas, coal, or lignite – all fossil fuels – to create hydrogen directly and then uses carbon capture and storage to abate the harmful emissions from this process. Unfortunately, due to methane leakages in storage, transport, and the fossil extraction process, the emissions from blue hydrogen are still significantly higher than for green – even if labelled "carbon neutral". Hydrogen leakage can occur for both green and blue but has fewer environmental issues associated – although safety and certification are important due to the high pressure at which flammable hydrogen is stored.

Appendix 2

Differentiating between electrolyser technologies – a layman's basic understanding (see also Lebrouhi et al. 2022; Ishaq et al. 2022; Hebling et al., 2019)

Alkaline: Advantage of proven technology, well understood process, common materials used (nickel and steel)

PEM (Polymer-Electrolyte Membrane): Also relatively old, more flexible and easier to use at small scale, flexible and quick reaction to fluctuations therefore good to integrate with renewable energy sources, slightly more expensive and can be a bit more efficient, uses rarer materials (platinum, iridium – from South Africa)

SO (Solid Oxide): More efficient in theory, but still quite newly developed in labs, needs residual heat to be available nearby in order to be advantageous, also uses rare materials (from China – e.g. Zirconium, Lanthanum, Cerium)

Joining researchers from networks Transformative Innovation Policy Consortium part of Navigating Deep Transitions and Inside the Investment Frontiers at Utrecht University and collaborating experts from universities in South Africa, Brazil, Germany and other institutes in the Netherlands, the **Transformative investments in green hydrogen development in the global South project** has produced an overview of current developments as well as case studies on challenges and opportunities for sustainable development through public and private investments in green hydrogen in the Global South, with particular attention to South Africa and Brazil. One outcome has been the founding of a 'Critical H2 Research' network which aims to connect research on the social and environmental implications of green hydrogen with other disciplines and actors within this emerging space.

If you have any questions or want to get in touch, please reach out to:
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