Energy Research & Social Science 120 (2025) 103904

Contents lists available at ScienceDirect

Energy Research & Social Science

journal homepage: www.elsevier.com/locate/erss

Original research article

New development paths through green hydrogen?: An ex-ante assessment of structure and agency in Chile and Namibia

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ARTICLE INFO

Keywords:
Chile
Green hydrogen
Latecomer industrialization
Namibia
Resource periphery
Trinity of change agency

ABSTRACT

Many developing countries seek to participate in the emerging global green hydrogen industry, not only as exporters of green hydrogen and its derivatives to Europe and the Far East, but also to use it for their own energy security and green transition. They hope that new development paths will lead to late-comer industrialisation. This article assesses corresponding prospects in Chile and Namibia, two countries that pursue particularly ambitious plans on green hydrogen. To better understand the chances for path creation ex ante, the authors draft an innovative framework that refers to context factors – that is, structure – and three types of transformative agency. Against the backdrop of information from secondary sources and a series of expert interviews, they uncover sound institutional reforms and initiatives of place-based leadership to promote the green hydrogen industry. However, Chile and Namibia lack Schumpeterian entrepreneurship. It therefore remains to be seen whether new development paths will be inclusive, contributing to in-country development. Typical downsides of extractive industries in resource peripheries might occur.

1. Introduction

Green hydrogen is likely to play a major role for the global energy transition. It is essential to decarbonise hard-to-abate sectors such as cement and steel production and the chemicals industry, in particular fertiliser production and oil refining. First steps have been taken to generate low-emission fuels for air, sea and land transport with green hydrogen. Developing countries with favourable conditions for renewable energy hope to become large-scale exporters, aiming at European and Far Eastern markets. There are expectations that green hydrogen will also increase energy security and drive the green transition in the Global South, pushing late-comer industrialisation through forward and backward production linkages [1,2].

Against the backdrop of these high hopes and the tremendous amounts of money that will, probably, be spent on production facilities and related infrastructure, it is important to know whether participation in the emerging global value chains of green hydrogen will, indeed, be beneficial to the growth and prosperity of Southern nations. In other words, will the green hydrogen industry lead to new, inclusive development paths?

Going beyond an assessment of exports of green hydrogen and its derivatives matters because, in public debates, the Global South tends to be seen as a provider of raw materials that are critical for the energy transition. From that viewpoint, the role of Southern nations – or, in other words, developing countries – in green global value chains is limited to extractive activities. Resource peripheries within these countries make them vital for the world economy, but industrialisation is usually off the agenda.

Benner [3] refers to education, employment and entrepreneurship by/for marginalised groups as characteristics of inclusive development paths. Unlike common industrial paths, inclusive paths contribute to the economic inclusion of disadvantaged social groups.[1] We adopt this approach, but, for us, an inclusive development path articulates disadvantaged, marginalised economies such as resource peripheries at the subnational level and developing countries. Inclusiveness leads to late-comer industrialisation at places that used to stand at the very beginning of global value chains or, even worse, failed to participate in them.

The green hydrogen industry is a vision for the future, not a present-day reality. What this article provides is, thus, an ex-ante assessment. The findings, although substantiated with robust evidence, are marked

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[1] Others, such as Eadson and Van Veelen [73], go further, arguing that inclusive development is about the well-being of people. It aims at environmental and social upgrading, instead of mere economic outcomes. This is, of course, important, but beyond what the present article analyses.

https://doi.org/10.1016/j.erss.2024.103904
Received 24 July 2024; Received in revised form 6 December 2024; Accepted 14 December 2024
Available online 4 January 2025

by obvious methodological constraints. They ought to be read cautiously. Ex-ante assessments typically deal with context factors or, in other words, structure. For example, Andreoni et al. [4] analyse the potential demand by existing industries and the likelihood of their decarbonisation with green hydrogen to better understand the new sector's prospects. Scholvin [5] concentrates on four types of linkages that may result from green hydrogen projects. He refers to characteristic features of the industry and production sites to predict local development effects. An abundance of studies is focussed on the technical details of the production process and resulting costs, which allows reasoning on the industry's future expansion and diffusion [e.g., [6,7]].

The present article refines ex-ante assessments of the green hydrogen industry by including agency in the analysis. Recent academic debates on the formation of new development paths draw attention to agency. Drafted in a seminal article by Grillitsch and Sotarauta [8], the 'trinity of change agency' concept addresses three forms of agency that can transform regional economies: place-based leadership, institutional entrepreneurship and Schumpeterian innovative entrepreneurship. The concept recognises that agency is influenced by context factors – the structure that marks the place under investigation. This structure may be altered, at least partly, by agency.

The trinity of change agency concept is applied here to inspire future research on the green hydrogen industry in the Global South. It is, however, important to note that the concept has been drafted by colleagues who specialise in cases from the Global North, mostly Nordic countries [esp., [9,10,11,12]]. Similar to a recent contribution by Mlilo et al. [13], the article hence tests the concept's explanatory value for developing countries.

The article deals with two potential frontrunners of the green hydrogen industry, Chile and Namibia. Chile seeks to become the least expensive producer of green hydrogen worldwide. Next to the northern region of Antofagasta, where green hydrogen will, first of all, supply the local mining sector, Magallanes in the extreme south may become home to the world's largest e-fuels production facility, powered by gigantic wind farms. In Namibia, the German–British Hyphen consortium plans a mega-project with an electrolyser capacity of 3 GW and green ammonia exports of 1 million tonnes a year. Projects elsewhere in the country will also serve export markets and, ideally, generate in-country forward linkages.

Our assessment leads to the conclusion that opportunity spaces are being created in Chile and Namibia by place-based leadership and institutional entrepreneurship. Yet, there is very little Schumpeterian entrepreneurship in the two countries, which calls the formation of inclusive development paths into question. Context factors, meaning structure, are essential for this outcome, but, at least in Chile, local firms that could engage with the green hydrogen industry also remain hesitant.

The remainder of the article is structured as follows. Section 2 introduces the trinity of change agency with a focus on particularities of the green hydrogen industry. Afterwards, an overview of the cases is provided. The research methods are summarised. Section 4 presents the empirical findings on structure and transformative agency in Chile and Namibia, discussing the effects on new path development.

2. Trinity of change agency and new development paths

The trinity of change agency concept was drafted to draw attention to agency, to the public and private players that shape regional economies, and explain how new development paths emerge [[8,11]; see also: [14,15]]. The starting point of the contributions mentioned in this section is that structure – broadly defined – does not fully explain why some regions grow more than others. We agree that agency matters, but structure must not be neglected, especially not in the Global South, where agency tends to be much weaker than in Europe and North America. Bearing this in mind, the section presents an analytical framework that addresses structure and agency as forces that both influence the green hydrogen industry.

There are three types of transformative agency: place-based leadership, institutional entrepreneurship and Schumpeterian innovative entrepreneurship [8].[2] A distinction has been made between firm-level agency and system-level agency. Firm-level agency is about the formation of new, innovative firms or the introduction of innovative practices in existing firms. System-level agency refers to the transformation of broader systems to make them more innovative [16].

Place-based leadership, the first form of agency, identifies common interests and orchestrates actions. It pools competences and resources, to make things happen, to get things done [[17]; see also: [18]]. Together with institutional entrepreneurship, place-based leadership may create the right conditions – regional advantages and opportunity spaces – to attract Schumpeterian entrepreneurs or to make them pop up locally [19,20]. For example, the extent to which firms can grow and innovate depends, amongst other things, on externalities. Place-based leadership fosters such externalities at the local or regional level.

Place-based leadership is particularly important for the green hydrogen industry, as this industry requires close collaboration of numerous public and private players across several scales. Licensing and regulatory processes, including environmental regulations, have to be adapted, for instance. Concrete projects are hardly ever implemented by a single company but, rather, by consortia – car makers with an interest in e-fuels, chemicals producers, electricity providers, steel manufacturing companies and others. Collaboration amongst enterprises from these business sectors is uncommon. They cannot refer to past experiences and still have to learn to cooperate, and also connect with local suppliers and tertiary education institutions that can train the future workforce.

Identifying common interests of key players and orchestrating their actions may be insufficient. New development paths do not, often, emerge unless there is substantial institutional change and capacity in the territory under consideration [12,21]. Institutions, which, in broad terms, can be defined as the rules of the game, have been shown to influence the competitiveness and innovativeness of places. Regulations that ease or hamper investment in new business activities are a key example. Often, special economic zones provide a regulatory and tax environment that facilitates new development paths. Researchers have paid considerable attention to local and subnational regional organisations that focus on R&D and vocational training, and institutionalised arrangements that connect these organisations with local firms [e.g., [22,23]].

Usually, institutions are seen as forces of permanence and stability, being resistant to change [esp., [24,25]]. This is not, of course, the institutional entrepreneurship that Grillitsch and Sotarauta [8] have in mind. They conceptualise it as opportunity oriented and risk taking.

Institutional entrepreneurship paves the ground for bottom-up change by creating new institutions and/or transforming existing ones [26]. It reflects learning processes wherein unplanned events and failures require adjusting strategies [12,27]. Further to that, institutions influence the diffusion and growth of new paths. Chlebna and Simmie [28] stress the co-evolution of institutions and development paths, pointing at the importance of beliefs and perceptions. More basically, institutional arrangements can connect local and foreign players, for example through events or collaboration agreements. Financial support for first movers is typically provided through dedicated institutions.

For capital-intensive industries such as green hydrogen, it is an understatement to say that institutional entrepreneurship implies taking

[2] Agency must not be confused with agents. The former is about interventions to produce a desired effect, whereas agents are the players who exercise agency. It is common to attribute certain types of agency to specific players. For instance, Neffke et al. [74] concentrate on innovative entrepreneurship by firms, while Hambleton and Howard [75] see local governments as the drivers of place-based leadership.

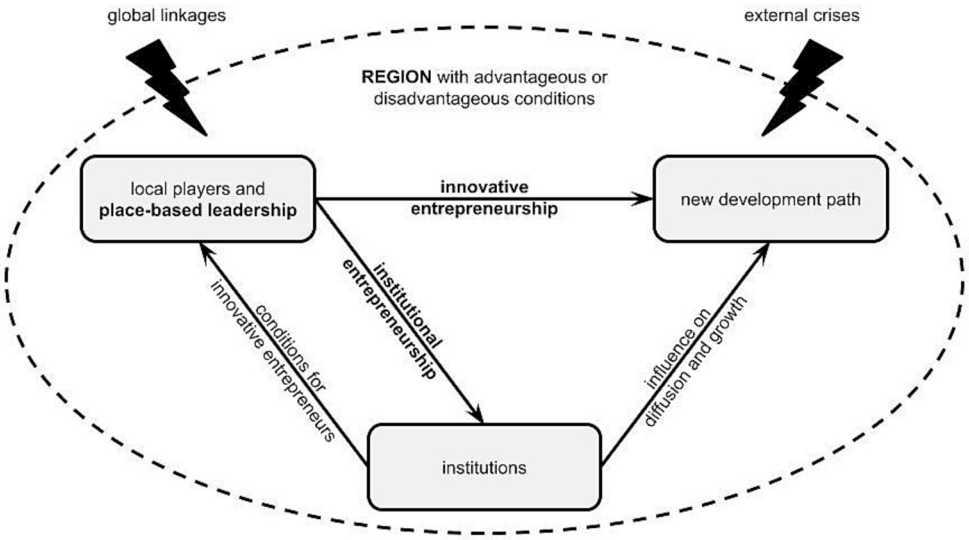


Fig. 1. Agency and structure in path creation
Source: Authors' own draft.

risks. Influential consultants argue that the only viable use of green hydrogen is to replace grey hydrogen, which is currently consumed, for instance, in oil refining and for the production of explosives and fertilisers. That hydrogen is generated with fossil fuels. It has a considerable carbon footprint. Other applications in the chemicals and steel industries might be feasible, but they are more challenging from a cost perspective and, therefore, depend on heavy subsidies. For numerous uses in discussion, especially domestic heat generation and intra-urban public transport, there are cheaper green solutions [29].

It remains to be seen whether this scepticism holds true, but the green hydrogen industry faces substantial uncertainties. The Global South moreover suffers from general investment risks, which range from currency fluctuation to political instability to a lack of supply chains for complex, new industries. This leads to a risk premium on investment that has to be paid to make capital available for green hydrogen projects in developing countries. In consequence, such projects tend to become non-bankable.

Chile and Namibia will only have a chance to participate in this new sector if they de-risk green hydrogen projects, ideally being supported by foreign partners. In a nutshell, a state that engages in de-risking takes steps to decrease the risk that private investors face, when making capital available for projects, industries and entire countries. This way, uninvestable profiles of strategic importance are corrected [30]. Key means discussed for the green hydrogen industry are financial support for first movers and different forms of purchase guarantees, complemented by more general policies of facilitating the development of new value chains [31].

The third form of agency conducive to the emergence of new paths, Schumpeterian innovative entrepreneurship, is the source of potentially ground-breaking innovation that triggers the structural transformation of regional economies [e.g., [9,32]]. Given that the green hydrogen industry is so new, there is plenty of room for innovation, some of which cannot even be anticipated yet. What we do know is that a series of challenges needs to be solved. At present, green hydrogen is not competitive in comparison to fossil fuels because the production process is so expensive. Questions related to the energy efficiency and technical feasibility of large-scale, long-distance transport by ship as well as subsequent onshore storage and distribution remain to be answered.

The mere existence of these knowledge gaps does not mean that Chileans and Namibians will come up with solutions. As described by Schumpeter [33], innovative entrepreneurship is about breaking with existing paths and working towards new ones. Only people who are willing and able to take substantial risks can do that [see also: [34]]. At some places and points in time, entrepreneurs find more opportunities than at others because of access to non-local knowledge and resources [e.g., [35]], a favourable composition of the regional economy [e.g., [10]], support structures for entrepreneurship and innovation [e.g., [36]], and, more generally, a business-friendly environment [e.g., [37]]. Innovative entrepreneurship is, hence, difficult, especially in resource peripheries, which typically perform poorly on the just mentioned conditions.

The formation of new, inclusive development paths in the parts of the world that interest us also tends to be at odds with the dominance of corporations from abroad. These often introduce new paths, not aligning with local suppliers because of disparities regarding expertise and know-how [38]. Yet, as explained in the introduction, the articulation of such suppliers – their participation in global value chains and subsequent upgrading, which implies increasing value capture – defines the inclusiveness of development paths.

It should have become clear from the previous paragraphs that the trinity of change agency literature does not deny that structure matters. Schumpeterian entrepreneurs operate in a context – within a structure that has a profound impact on their business opportunities and, thus, on the emergence of new development paths. As Fig. 1 shows, the institutional context of innovative entrepreneurship, meaning the rules of the game, may be altered by institutional entrepreneurship. The conditions for new path formation that a region offers, meanwhile, are largely beyond the control of players, at least in the short run. The objective for the empirical analysis below is to find out whether the interplay of structure and the three forms of agency can lead to inclusive development paths in Chile and Namibia.

3. Introduction to the cases and research methodology

The most feasible production technique for green hydrogen is electrolysis with associated geothermal, solar or wind power [for details, see: [39,40]]. Since electrolysis and related desalination are very energy intensive, the costs of electricity become almost determining for the location of production facilities. Chile and Namibia benefit from nearly ideal natural conditions for renewable energy. They are, hence, prime locations for green hydrogen production.

Solar irradiation in the Atacama desert in the north of Chile is more than 7.5 kWh per square metre a day. No other place worldwide benefits from such a high irradiation. In Chile's extreme south, wind speed is

more than 14 m per second at some sites. Onshore wind turbines there are as productive as their offshore peers elsewhere in the world. Solar irradiation along the coastal strip of Namibia reaches up to 6.6 kWh per square metre a day. Wind speed is up to 10 m per second. Both countries benefit from a long coastline, easing desalination, and vast areas of available land, where solar parks, wind farms and production facilities for green hydrogen can be built.

Against this backdrop, it is not surprising that the governments of Chile and Namibia have ambitious plans on green hydrogen. Chile's National Green Hydrogen Strategy from 2020 stresses that the objective is to produce the cheapest green hydrogen in the world, with exports accounting for 60 to 70 % of the revenues generated by the sector in the coming decades [41]. The more recent preliminary Green Hydrogen Action Plan proposes that by 2050, 16 to 17 % of domestic energy consumption will be met by green hydrogen. The plan also points at opportunities to export green hydrogen or, rather, its derivatives [42].

Major projects are being considered across Chile.[3] The yet-to-be-built Highly Innovative Fuels (HIF) plant, close to Punta Arenas in the southern region of Magallanes, is the most impressive initiative. HIF will produce methanol and e-fuels, potentially becoming the largest e-fuels production facility in the world. The initiative is driven by Porsche and Siemens from Germany. The Italian energy company Enel will provide the necessary electricity through a wind power mega-project known as Faro del Sur.

In the north, a scheme called Antofagasta Mining Energy Renewable – in short, AMER – is being implemented by a consortium of Air Liquide, EDF Renewables and other corporations. AMER's e-fuels plants will, most likely, be located in the outskirts of the city of Antofagasta or in the industrial zone of Mejillones, a nearby town that hosts a large port and chemicals industries. An electrolyser with a capacity of 80 MW and a yearly output of 60,000 t of green methanol are projected. Another project in the north, called HyEx, is driven by the energy company Engie and the explosives producer Enaex. Its purpose is to produce 18,000 t of green ammonia a year, based on an electrolysis capacity of 26 MW. HyEx will be located in the town of Tocopilla. Needless to say, HyEX and also AMER are expected to expand considerably once their output can be exported.

Smaller projects are located across the entire country, as Map 1 shows. They deal with a variety of applications, ranging from domestic heating to e-fuels for shipping and in-country transport to oil refining and steel production.

Namibia's Green Hydrogen and Derivatives Strategy, embedded in the country's industrial development planning, calls for the establishment of three green hydrogen production areas, so-called Valleys, to reach a production capacity of 12.2 million tonnes a year by 2050. While a significant share will be exported, Namibia also aims for a big push for the domestic economy through the availability of green hydrogen and surplus renewable energy [43]. Map 2 shows the three Valleys.

The largest project, driven by the German–British Hyphen consortium, is located in the Southern Valley near the town of Lüderitz. According to the implementation agreement that the consortium has signed with the Namibian government, USD 10 billion will be invested in solar and wind power, totalling 5 GW. An electrolysis capacity of 3 GW is planned, along with the expansion of the port of Lüderitz to export 1 million tonnes of green ammonia a year. The Southern Valley may, eventually, extend up to the border with South Africa, provided that additional foreign investment can be attracted.

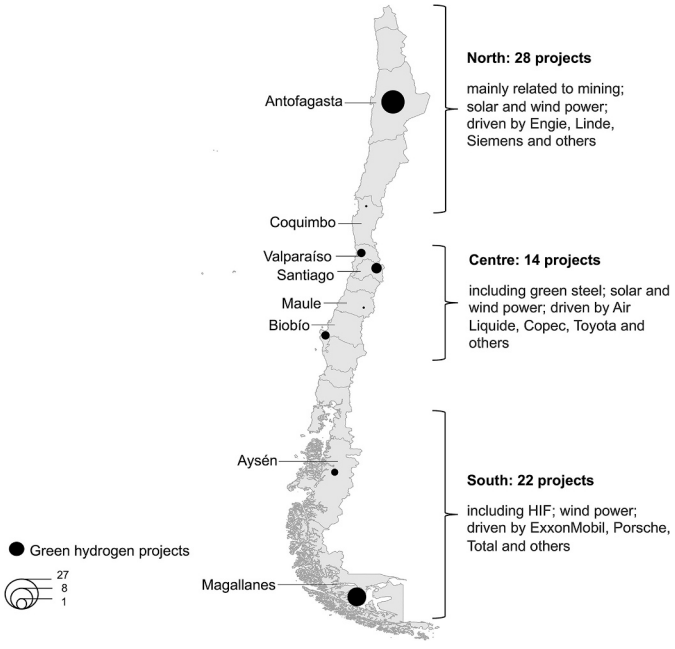
The Central Valley comprises the country's busiest port, Walvis Bay. A number of pilot projects, funded by the German government, have already been implemented there to demonstrate potential domestic uses of green hydrogen, including for decarbonisation of port operations, fertiliser and food production, as well as rail and road transport. For future exports, e-fuels for maritime transport play a key role. The Northern Valley is located at the Angolan border. Green hydrogen projects there are more challenging than they are in the centre and south of the country, first of all because north Namibia lacks a port. A corresponding project at Angra Fria remains to be financed and implemented.

What is more, the Green Industrialisation Blueprint links Namibia's green hydrogen agenda with already existing growth corridor initiatives that connect landlocked Botswana, Zambia and Zimbabwe with the ports of Lüderitz and Walvis Bay. The Blueprint optimistically envisages Namibia as a gateway for trade and low-carbon industrial opportunities, aiming to create an integrated green ecosystem for Southern Africa [44].

It has to be emphasised that most green hydrogen projects are plans that today merely exist on paper. Some pilot plants have been built, but there is no commercial-scale production anywhere in the world. This means that there is no data for a reliable econometric assessment. Reports have been published that predict labour market effects, the impact of green hydrogen production on national and regional economies, etc. [e.g., [45,46]]. Yet, they stand on shaky grounds because even the sector's lead firms do not know exactly how production and the related value chains will be organised.

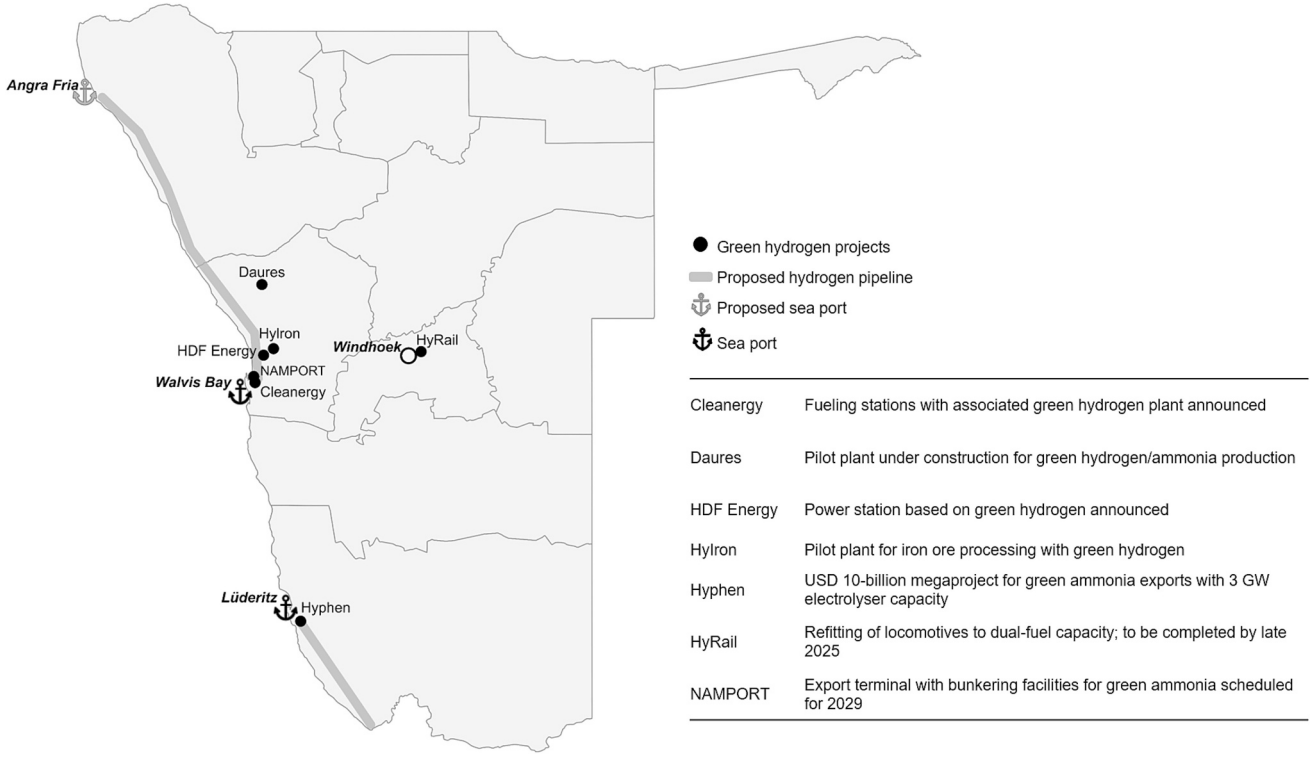
Our analysis relies on information from secondary sources and expert interviews. We refer to government papers, reports from Chilean and Namibian newspapers as well as online news portals, studies by the German Agency for International Cooperation, and the websites of key projects. Media reports made us aware of important events such as firms from a specific industry showing interest in green hydrogen or announcing pilot projects. The other secondary sources contributed to an overview of the state and vision of/for the green hydrogen industry to inform us before the interviews. We later used these sources to complement or cross-check statements by the interviewees.

The interviews were with key players from the public and private sector, as listed in the Annexe. We talked with ten public and nine private stakeholders in Chile. In Namibia, we had eleven interviewees from the public sector and sixteen from private organisations. Public sector interviewees were from foreign development entities, national ministries and related bodies, and subnational authorities. The private sector players include foreign investors, domestic suppliers and business associations. The interviews were conducted with guidelines covering



Map 1. Green hydrogen projects in Chile
Source: Authors' own draft.

[3] The following overview is based on information obtained from Chilean newspapers, the websites of the projects and a website of the network H2Chile, which is available online at: https://h2chile.cl/proyectos.



Cleanergy	Fueling stations with associated green hydrogen plant announced
Daures	Pilot plant under construction for green hydrogen/ammonia production
HDF Energy	Power station based on green hydrogen announced
Hylron	Pilot plant for iron ore processing with green hydrogen
Hyphen	USD 10-billion megaproject for green ammonia exports with 3 GW electrolyser capacity
HyRail	Refitting of locomotives to dual-fuel capacity; to be completed by late 2025
NAMPORT	Export terminal with bunkering facilities for green ammonia scheduled for 2029

Map 2. Green hydrogen projects in Namibia
Source: Authors' own draft.

potential effects in terms of regional development. They comprised follow-up questions if details relevant according to Fig. 1 were not mentioned by the interviewees. All interviews were recorded.

We screened each audio file for insights on context factors, transformative agency and corresponding causal mechanisms that explain, for example, how an institutional reform promotes local participation in the green hydrogen industry or what limitations the lack of previous industrial development implies. Columns labelled 'context' and 'agency' were used in Excel tables – one table per interview – and relevant information was filled in there, along with causal mechanisms for which we used bold writing. We then compared the tables, moving similar observations to the same row. In other words, we approached the interviews and assessment thereof without a predetermined list of potentially transformative actions and presumably relevant context factors. Except for the distinction of structure and agency, which is the guiding scheme of the contextual framework, as presented in the previous section, we followed an inductive approach. Quotes from the interviews in Chile are our own translation. All interviewees shared their personal opinion with us. They did not speak as official representatives of any company or organisation.

4. Structure and transformative agency for path formation in Chile and Namibia

This section presents context factors that influence new path formation in Chile and Namibia. Enabling conditions for plugging into new global value chains are identified, but there are constraints to moving beyond a marginal and subordinate role. We then trace the three forms of transformative agency, uncovering major dynamics in terms of place-based leadership and institutional entrepreneurship, whereas Schumpeterian entrepreneurship occurs in exceptional cases only.

4.1. Context factors in Chile

Unlike many Southern nations, Chile has a certain track record of industrialisation. The country's service sector is the most developed one in South America. Private companies have expertise and decent funding. Research facilities, including universities, reach high standards, compared to their peers on the continent. At the same time, Chile's economy, in particular high value-adding tasks, is heavily concentrated in the capital, Santiago. The country accounts for about 25 % of worldwide copper production. Copper concentrate and refined copper are the most important export goods. The share in global lithium production stands at 30 %, with almost no processing prior to export.

Even though HIF in the extreme south is Chile's most impressive green hydrogen project, the new industry is more likely to develop in Antofagasta. This is due to context factors. Antofagasta is one of the world's most important copper mining regions and mining makes it highly attractive to invest in green hydrogen production there. The largest mining companies – Anglo American, Antofagasta Minerals, BHP Billiton and Codelco – are signalling considerable interest in e-fuels based on green hydrogen [47–49]. With hauling trucks that run on e-fuels, mining operations can be decarbonised. Green hydrogen can also be used to process copper.

The decarbonisation of the mining sector is crucial, not only for Chile's own climate change mitigation, but also because the European Union and the United States may impose tariffs on copper extracted and processed with fossil fuels. The Carbon Border Adjustment Mechanism (CBAM), which is part of the European Green Deal, will put a price on the carbon emitted during the production of emission-intensive goods that enter the common market of the European Union, starting in 2026. Goods covered include aluminium, cement, electricity, fertilisers, iron and steel, and hydrogen [for an assessment of the resulting risk exposure of countries worldwide, see: [50]]. Australia, Japan and the United States are evaluating similar measures. CBAM will have a 'renewables pull effect', with locations that can produce renewable energy at low costs becoming highly competitive for emission-intensive industrial activities [51].

Because of large-scale mining, there is also suitable infrastructure in Antofagasta. Harbours can be adapted easily to ship ammonia and

methanol – for export, once production exceeds what can be absorbed by the region's market. These ports, just like railway lines and roads that connect them to the hinterland, are already used for importing bulky, heavy industrial equipment. The regional power grid is strong enough to transmit the electricity that green hydrogen production will need, at least for the first projects. Executives from an international consortium praised these enabling conditions [pers. com., 5 April 2023].

Suppliers of generic inputs are available because local firms benefit from a track record in mining. Meeting the high standards imposed by mining corporations, they should be able to adapt to the requirements of the green hydrogen industry too, as interviewees from the business community explained [pers. com., 29 March, 3 April, 30 May 2023]. It is, moreover, reasonable to assume that the local workforce is sufficiently qualified for the green hydrogen industry or that it can adapt to it. Unlike Antofagasta, Magallanes does not offer any such advantages; Chile's other regions with green hydrogen projects do so to a very limited extent.

Next to mining, there are prospects for forward production linkages with the steel industry. Chile's largest steel producer, CAP, plans to build a pilot plant at its Huachipato works in the region of Biobío [52]. This steel works meets about 25 % of the country's demand.[4] Interviewees furthermore suggested that chemicals hubs centred on green hydrogen could emerge in Mejillones and Tocopilla, benefitting from ties with the mining sector [pers. com., 29 March, 18 April, 29 May 2023]. AMER and HyEx would, obviously, be the respective anchor projects.

Backward production linkages beyond the provision of electricity and water, meanwhile, are uncertain, at best. An official from a national association that represents the largest firms involved in green hydrogen explained that established producers of electrolysers and other industrial inputs benefit from economies of scale abroad, in particular in China. They will probably ship their products to Chile [pers. com., 29 March 2023]. These concerns are reinforced by a report by the German Agency for International Cooperation [46], which found only 817 large and medium-sized companies in Chile that might participate in the green hydrogen industry, providing production inputs. These enterprises were identified according to their classification by the Chilean tax authorities into specific production categories. Hence, it is doubtful that all of them will actually engage with the new industry.

Further to that, about four fifths of these firms have their headquarters in the metropolitan region of Santiago. Interviewees from the Economic Development Agency of Chile, also known as Corfo, pointed out that enterprises at peripheral locations such as Antofagasta and, even more so, Magallanes lack the technology needed to move beyond the provision of generic inputs [pers. com., 4 April 2023]. Representatives of lead firms typically mentioned services such as transport and storage, and the provision of standardised goods like cement, common compressors and tanks for local outsourcing. Other locally available services 'are not in the core of the business' – catering and laundry, for example. Sophisticated, high value-adding tasks such as the consulting and engineering behind yet-to-be-built plants will be contracted internationally or in Santiago [pers. com., 29 and 31 March, 4 and 5 April, 30 May 2023].

4.2. Transformative agency in Chile

Last year, Chile took important steps towards creating an institutional framework conducive of the green hydrogen industry. At the national level, the Strategic Committee on Green Hydrogen was established. It consists of academics and ministers of former governments. A key task for the Committee is to make additional sources of funding available, in particular to the regional governments. The Committee makes suggestions on matters as fundamental as human capital formation and industrial development [53]. The Ministry of Energy has also announced the creation of a consulting council, which will consist of players from the business community.

Further to that, the national government organised a participatory process in 2023 to draft the above-mentioned Green Hydrogen Action Plan, which now complements the National Green Hydrogen Strategy. This process was based on public gatherings in the regions with good prospects for green hydrogen production. Representatives from civil society, companies and research organisations discussed concrete steps to support the new industry. They concluded with an impressive list of 111 measures for the coming years, specifying timeframes and identifying the players responsible for each measure [42].

The regional government in Antofagasta has taken a driving role by creating a regional committee on green hydrogen, which has met several times since early 2023. The committee consists of key players from different government departments, officials in charge of electricity and water supply, representatives of port authorities as well as private companies that plan to generate green hydrogen and/or the related electricity.

These forms of place-based leadership bring players together, coordinating their interests and pooling their knowledge so as to facilitate the new industry. They are complemented by institutions that provide a setting for Schumpeterian entrepreneurship to thrive. Most importantly, Corfo has signed agreements with the Inter-American Development Bank and World Bank. They have made USD 550 million available for credits for green hydrogen projects and measures that contribute to the enabling environment, including human capital development, applied R&D, upskilling of suppliers and the like. Corfo's own contribution is USD 250 million. With additional funding from European sources, the total amount has increased to slightly more than USD 1 billion. It is meant to potentiate private investment by demonstrating the feasibility of certain applications of green hydrogen and, thus, increasing confidence in the sector. The government quite optimistically hopes to reach USD 12.5 billion this way [54].

For Antofagasta, bilateral agreements are in place with partners from abroad. Already in 2021, Chilean and Dutch ministries, as well as the Rotterdam port authority, signed a memorandum of understanding on collaboration on green hydrogen. Mejillones received particular attention as a future logistics and industrial hub [55]. At the World Hydrogen Summit & Exhibition 2023, public and private sector players including the municipality of Mejillones, the Mejillones port authority and the Rotterdam port authority signed another declaration, stressing their intent to jointly develop green hydrogen value chains [56]. Such measures are meant to de-risk investment, easing the development and growth of new paths.

There is also institutional entrepreneurship in terms of access to knowledge and match-making for lead firms with local suppliers. In 2023, the Centre for Scientific and Technological Research of Antofagasta – CICITEM by its Spanish acronym – carried out a training programme with 107 companies that have experience in mining so as to help them venture into green hydrogen. The programme was not limited to legal and technical issues. It also put the participants in touch with investors and the non-local enterprises that control the technologies for green hydrogen production. According to interviewees from CICITEM, the goal of such measures is for local firms to get familiar with green hydrogen technologies and later even export related services [pers. com., 16 March 2023].[5]

Relatedly, the Institute of Clean Technologies was established in

[4] However, at the time of submission of the manuscript of this article, CAP had stopped its steel production at Huachipato because of cheap Chinese steel flooding the Chilean market.

[5] CICITEM's agenda goes beyond green hydrogen. It was founded in 2006 with the objective to decentralise applied science and make a corresponding contribution in Antofagasta. Focus areas are energy and mining, protection of the environment and water resources. For more information, see: https://cicitem.cl.

Antofagasta last year to provide and share data as well as research infrastructure such as labs and scientific equipment. It brings Chilean universities and foreign research entities such as Fraunhofer together. Large corporations – BHP Billiton and Engie, for instance – are affiliated with it; so are Corfo and the Industrial Association of Antofagasta.[6]

These efforts to create opportunity spaces and technology-centred development paths would receive a boost if manufacturers of key equipment invested in Chile, in spite of the above-mentioned obstacles. For this purpose, Corfo has launched an initiative to attract investment in the production of electrolysers. It hopes to facilitate partnerships with Chilean enterprises and has, apparently, received investment proposals of USD 850 million [57]. An interviewee from that organisation said that the investment depends on a minimum demand that has to be guaranteed for the domestic market [pers. com., 5 May 2023].

The main barrier to new path development in Antofagasta, and even more so in Magallanes, is Schumpeterian entrepreneurship. In addition to structural obstacles in terms of access to know-how and niches within the new value chains, as mentioned in the previous subsection, local companies, and potential entrepreneurs alike, apparently remain reluctant towards the new industry. An interviewee argued that '[they] see green hydrogen […] as very distant. There is lots of ignorance about [how the industry works]' [pers. com., 3 April 2023]. Executives from Corfo added that 'today, [the green hydrogen industry] is only theory and nobody wants […] to take risks' [pers. com., 4 April 2023].

At least in Antofagasta, this problem is reinforced by the fact that local suppliers are busy and comfortable working for the mining industry. They have little need to diversify [see also: 58]. Even worse, for the maintenance of solar parks, which already exist in the region, they have priced themselves out, offering their services at higher costs than non-local competitors [pers. com., 4 April 2023]. An interviewee complained that 'the prices of these providers [from Antofagasta] should be attractive, but […] they are not' [pers. com., 31 March 2023].

4.3. Context factors in Namibia

Namibia is a sparsely populated country of just 2.4 million people. About half of the population depends on agriculture for their livelihood. Taxes on mining activities, ranging from diamonds to copper, gold, uranium and zinc, account for 25 % of state revenues. Tourism contributes a considerable share to gross domestic product. The manufacturing sector is underdeveloped and of low relevance to the national economy. Namibian companies involved in industrial production are small, also because of the lack of economies of scale on the domestic market. As a poorly diversified economy whose exports heavily depend on mineral resources, Namibia is amongst the countries with the highest risk exposure to the European Union's CBAM [50].

Unlike most other African countries, Namibia has a well-maintained road network. It connects the ports of Lüderitz and Walvis Bay to the hinterland, including Namibia's landlocked neighbours. Walvis Bay is well equipped for bulky minerals exports; Lüderitz to a certain extent. An interviewee stressed that with some additional investment, shipping green hydrogen and its derivatives will not be an issue [pers. com., 20 February 2023]. Energy supply, conversely, is insufficient. It depends heavily on imported electricity from South Africa and Zambia. There are few high-voltage transmission lines, which obviously constitutes a bottleneck for large-scale, grid-based green hydrogen generation [pers. com., 2 March 2023].

Against the backdrop of the size and level of development of the Namibian economy, it is not surprising that the potential for production linkages from investment in green hydrogen is limited. In regard to forward linkages, the above-mentioned Green Industrialisation Blueprint points at the processing of minerals with green hydrogen, especially iron ore, lithium and rare earth elements [[44]; see also: [59]]. As explained further below, two pilot projects have been launched to produce green iron and steel, but viable business cases have yet to be made. Interviewees from the Chamber of Mines also mentioned the production of explosives with green ammonia and green hydrogen-based fuel cells for mining trucks [pers. com., 31 March 2023].

The official goals for backward linkages are ambitious. After lengthy negotiations with the government, Hyphen [60] announced a target of 30 % for local content for inputs and services related to its USD 10-billion mega-project. Opportunities are seen in the fabrication of electrolysers, solar panels and wind turbines [[44]; see also: [59]]. However, government representatives deem it difficult to produce what the green hydrogen industry needs in the country, even more so if Namibian firms are to become involved [pers. com., 14 February 2023]. Transnational corporations have expertise in manufacturing electrolysers and they control the corresponding technologies. Their large-scale operations are in China, Europe, Japan and the United States [61], where they benefit from economies of scale.

As it stands, Namibia does not have a wind power industry. The only wind farm in the country has merely three turbines, which reach a capacity of not more than 5 MW. The wind farm was planned and built by a French company. Although 120 Namibian firms carry out assembly and maintenance of photovoltaic systems, they work for small and medium-sized clients [pers. com., 30 March 2023]. Scaling up these operations would require substantial investment into project management and technologies as well as the formation of many skilled workers [pers. com., 3 March 2023]. An interviewee from a business association raised doubts that this is feasible and concluded that domestic participation in the green hydrogen industry will be minimal, perhaps even non-existent in the first years of operation [pers. com., 15 February 2023].

The Hyphen consortium has agreed that 93 % of the 15,000 workers employed during the construction phase will be Namibians [pers. com., 20 February 2024]. Yet, a recent study by the German Agency for International Cooperation [62] points at a significant skills gap. Technicians with vocational training are missing. Employment effects may, hence, be limited to unskilled labour. For later operation and maintenance, university curricula in engineering, environmental science and similar programmes still need to be adapted. An interviewee was concerned that 'the skill set needed, I think, [it's] going to be so vast. […] Namibia will not be able to fill that […]. So we are going to have to import skills' [pers. com., 15 February 2023].

It has to be added that operation and maintenance of green hydrogen production facilities is not labour intensive. Given these constraints, Namibia's green hydrogen industry will depend on imported expertise, provided by foreign suppliers, and skilled expat labour – at least initially. Without the creation of substantial forward and backward linkages, it will not have a direct impact on the vast majority of the population and we warn against the hope to solve Namibia's unemployment crisis through the green hydrogen industry [63]. A key task for transformative agency is to make sure that the new global connections trigger in-country dynamics that lead to new and inclusive path development.

4.4. Transformative agency in Namibia

Place-based leadership for Namibia's green hydrogen industry is characterised by a top-down approach. The national government and, even more so, foreign partners are the key players [64]. In 2019, Fortescue Future Industries, a subsidiary of an Australian mining company, proposed an export-oriented green hydrogen project to the government. James Mnyupe, a businessman with considerable experience in international consulting, was appointed economic advisor to the president the following year. When the Inter-Ministerial Green Hydrogen Council was established in 2021 to coordinate all green hydrogen activities and

[6] Unlike CICITEM, the Institute of Clean Technologies rather facilitates research than carrying out research itself. Its purpose is to create an ecosystem suitable for sustainability-related innovation. For more information, see: https://www.asdit.cl.

bundle requests by foreign investors, Mnyupe became the Green Hydrogen Commissioner.

Following Russia's war against Ukraine, the German government signed a declaration of intent with its Namibian counterpart on cooperation on green hydrogen because of the need to reduce Germany's exposure to political risks related to energy supply. It also reflects efforts to exert influence over places incorporated into new value chains for that purpose [65]. Germany then financed the drafting of the above-mentioned Green Hydrogen and Derivatives Strategy. Germany Trade & Invest, an export promotion agency, together with the Southern African–German Chamber of Industry and Commerce, started organising regular business trips to create partnerships with Namibian companies [pers. com., 23 February 2023]. For the renewable energy sector, a Namibian–German business exchange platform has been established in the context of the so-called Business Scouts for Development Initiative by the German Agency for International Cooperation. A key purpose is to make know-how available to Namibian enterprises.[7]

A related instrument to coordinate players and orchestrate interests was the Green Hydrogen Conference of Namibia in 2022, which brought Namibian and foreign businesspeople, policy makers and scientists together. Its objective was to raise awareness for industrial assets in Namibia and connect players. The conference also helped to place green hydrogen on the agenda of high-level policy makers, as an executive of a Namibian renewable energy firm explained [pers. com., 3 March 2023]. Namibia now regularly hosts events on green hydrogen, which have received significant media coverage worldwide.

Namibia has, moreover, taken important steps to attract foreign investors by regulatory reforms. These include a modest liberalisation of the electricity market in 2019 through a modified single-buyer mechanism and the Synthetic Fuels Act, which is still in discussion. The Act is meant to ensure compliance with international standards regarding green fuels certification, environmental protection, and health and safety related to the production process [66,67]. These alterations of the rules of the game are complemented by means of spatial planning that will help to diffuse and grow the green hydrogen industry. Large tracts of land have been made available for green hydrogen projects and a special economic zone in the vicinity of Walvis Bay, dedicated exclusively to the new industry, is on the horizon [pers. com., 14 February 2023].

Unlike Chile, Namibia does not have significant domestic offtakers, not even for the first phase of the envisaged projects. The industry therefore depends on reliable agreements with clients from abroad. In addition to the partnership with Germany, memoranda of understanding have been signed with the Belgian Ministry of Energy, the port authorities of Antwerp and Rotterdam, the South Korean hydrogen producer Approtrium, the ITOCHU corporation from Japan and others [pers. com., 20 February 2023; see also: [68,69]].

Currently, the German energy partnership with Namibia is being extended and elevated to the European level, as exemplified by the European Union–Namibia Strategic Partnership, which was signed last year. This implies an opportunity to mobilise additional funding of up to EUR 1 billion for capacity building through technical and vocational training, infrastructure expansion, regulatory reforms as well as supply chain development with a focus on critical raw materials [70].

Along with many other countries, Namibia benefits from Germany's H2 Global initiative, which is a double auction mechanism for green hydrogen produced worldwide and then shipped for consumption to Germany. Public grants are used to offset the difference between the buying and selling price because production costs for green hydrogen make it uncompetitive at the moment. The commitment of the European Union to using green hydrogen for decarbonisation also contributes to de-risking by reducing uncertainties regarding future demand. Most importantly, European industries that currently use grey hydrogen have to switch to at least 42 % green hydrogen by 2030 [71].

Besides purchase guarantees, de-risking in Namibia, just like in Chile, is about providing financial support to first movers. Already in 2021, the German government made EUR 40 million available for pilot projects in Namibia to demonstrate the use of green hydrogen. One of our interviewees mentioned flagship initiatives [pers. com., 1 March 2023]: HyRail, a collaboration with Namibia's state-owned railway company TransNamib, works on hydrogen-powered trains. Germany's Ministry of Education and Research has supported this project with EUR 7.4 million. Cleanergy aims to decarbonise port operations in Walvis Bay and establish an e-fueling station for ships. Other projects, mainly in the Central Valley, are about fertiliser production with green ammonia and, as noted, iron and steel processing with green hydrogen.

Significant efforts are being made to strengthen R&D capacities and improve educational institutions that could train the future workforce so as to create competitive advantages that will contribute to new path formation. The Green Hydrogen Research Institute, which is part of the University of Namibia, conducts applied research on green hydrogen technologies, focussing on challenges that apply to Namibia such as making pipelines withstand the harsh environmental conditions of the desert. Also at the University of Namibia, the curricula of two master programmes in renewable energy are being revised to adjust to the needs of the green hydrogen industry [pers. com., 27 February 2023]. Namibian PhD students of subjects related to green hydrogen already benefit from a scholarship programme that enables them to study at German universities.

Considering the dominant role played by foreign lead firms and the specific context of Namibia as a small developing country with practically no risk capital and few networks that connect local players with the global hubs of innovation, there are obvious constraints regarding Schumpeterian entrepreneurship. Still, it appears that even though Namibian players have not yet taken concrete steps to venture with the new sector, there is considerable interest amongst companies engaged in renewable energy to partner with European corporations and expand into green hydrogen [pers. com., 30 March 2023]. Some Namibian firms are on track to obtain licences to build wind parks. These could supply green hydrogen plants [pers. com., 16 February 2023].

As said, iron ore processing and steel production are potential downstream linkages. The Namibian company HyIron is involved in a pilot plant in Lingen, Germany, partnering with RWE from Germany and the steelmaker Benteler. Having demonstrated the feasibility of the technology, a commercial-scale facility for green iron is now under construction in Namibia, as part of the Central Valley. A company called Lodestone, also from Namibia, pursues similar plans for green steel. In this case, a feasibility study remains to be concluded.[8] Nonetheless, such success stories that hint at prospects of engagement with green hydrogen value chains through Schumpeterian entrepreneurship are few, which certainly reflects the above-mentioned limitations for production linkages.

5. Conclusion and outlook

This article analysed whether the formation of new, inclusive development paths in the Global South can be expected to result from the emerging green hydrogen industry. Inclusiveness implies late-comer industrialisation, the participation in global value chains and subsequent upgrading by economies that have, so far, been marginalised. The article focussed on Chile and Namibia – two likely frontrunners – and shed light on structure and agency. Existing infrastructure and favourable natural conditions for solar and wind power are the main enabling factors for green hydrogen production in the two countries. In Chile's north, there is also a suitable labour force and set of suppliers. However,

[7] For more information, see: https://www.giz.de/en/worldwide/93161.html.

[8] For more information, see: https://hyiron.com and https://lodestonepty.com.

Table 1
Transformative agency for the green hydrogen industry in Chile and Namibia.

	Chile	Namibia
Place-based leadership	Strategic Committee and consulting council at the Ministry of Energy; participatory drafting of the Action Plan; regional committees (e.g., in Antofagasta)	Inter-Ministerial Council and Commissioner; business exchange platform, business trips and conferences with German partners
Institutional entrepreneurship	USD 1 billion credit scheme with foreign participation; cooperation agreements with potential offtakers and value chain partners, also for match-making; new research facilities at peripheral sites for diffusion of know-how	EUR 40 million loan for pilot projects and European Union–Namibia Strategic Partnership (up to EUR 1 billion); partnerships with potential offtakers; special economic zones and regulatory reforms; new research facilities and adjusted university programmes
Schumpeterian agency	Reluctance by potential suppliers in Antofagasta; few to no potential suppliers elsewhere in the country; risk-taking initiatives by large mining corporations and CAP	Apparent interest by local firms, but few take concrete steps; risk-taking initiatives by foreign investors and exceptions like HyIron and Lodestone

Source: Authors' own draft.

other context factors raise concerns.

Complementing a structure-oriented analysis with insights on transformative agency was helpful to uncover how Chile and Namibia address disadvantageous conditions. Major steps to facilitating new path formation have been taken through place-based leadership and institutional entrepreneurship. Committees, special advisors and different forms of fora/gatherings are being used to coordinate stakeholders and enable them to influence policies. Institutions promotive of the new sector have been established. They range from regulatory adjustment and financial support to international collaboration on value chains to upskilling of local suppliers and workers. Opportunity spaces have been opened up this way.

Still, the usually high-flying visions that mark the public discourse on the green hydrogen industry ought to be seen with caution. Besides structural obstacles typical of extractive industries in the Global South, the main reason for our reluctance is that we found little Schumpeterian agency. Whereas non-local corporations – mining giants in Chile and the Hyphen consortium in Namibia – are willing to take risks and invest in green hydrogen, only a few local firms have taken concrete steps to plug into the new value chains. Cases like the iron producer HyIron and the steelmaker CAP are exceptions. In other words, there is significant system-level agency to create opportunity spaces, but hardly any endogenous firm-level agency that uses these opportunities. Table 1 summarises our findings on transformative agency:

Against this backdrop, we are concerned that Namibia as a whole and Chile's regions of Antofagasta and Magallanes might develop new paths that are not overly inclusive, perpetuating the drawbacks of extractive industries. The worst-case scenario corresponds to what Nilsen et al. [72] describe as 'vulnerable resource-based regions'. The fate of these territories depends on the worldwide demand for the raw material they export. Sunk costs in physical infrastructure and an inflexible labour force make it difficult to bounce back after an external shock.

Things can, of course, turn out much better. Place-based leadership and institutional entrepreneurship are already well articulated in Chile and Namibia. Yet, it remains to be seen whether Chilean and Namibian companies will be able and willing to participate in the emerging global green hydrogen industry, ideally acting as Schumpeterian agents of late-comer industrialisation. With regard to the trinity of change agency concept, this article indicates how difficult the formation of new, inclusive development paths is in the Global South. Effective place-based leadership and institutional entrepreneurship, combined with a partly advantageous structural setting, may prove insufficient if local enterprises are unable or unwilling to overcome entry barriers.

CRediT authorship contribution statement

Sören Scholvin: Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Linus Kalvelage:** Writing – review & editing, Writing – original draft, Methodology, Investigation, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgement

The authors are grateful to Ledys Franco for preparing the maps included in this article. The research on Namibia was funded by the German Research Foundation (funding code CRC228/2).

Annexe.

Interviews in Chile

Description of the interviewee(s)	Date
Executives of CICITEM	16 March 2023
Official of Chile's maritime authorities	29 March 2023
Executive of an association of the green hydrogen industry	29 March 2023
Director of a solar energy company	29 March 2023
Director of a start-up that develops technology related to green hydrogen applications	31 March 2023
Executive of a solar energy company	31 March 2023
Director of a solar energy company	3 April 2023
Retired official of the German Agency for International Cooperation	4 April 2023
Executive of an engineering company that specialises in renewables	4 April 2023
Official of a town in Antofagasta	4 April 2023
Officials of Corfo	4 April 2023
Executives of an international consortium	5 April 2023
Executive of a chemicals company	5 April 2023

(*continued on next page*)

(*continued*)

Description of the interviewee(s)	Date
Official of an industrial association in Mejillones	18 April 2023
Official of Corfo who participates in Chile's National Green Hydrogen Committee	3 May 2023
Official of InvestChile	25 May 2023
Official of the delegation to Antofagasta of the Ministry of Energy	29 May 2023
Executive of a chemicals company	30 May 2023
Official of the Ministry of Economics	2 June 2023

Source: Authors' own draft.

Interviews in Namibia

Description of the interviewee(s)	Date
Officials of a town council	11 Feb 2023
Executive of a Namibian green hydrogen project developer	13 Feb 2023
Officials of a government agency	14 Feb 2023
Official of a business association	15 Feb 2023
Member of a civil society organisation	16 Feb 2023
Executive of NAMPORT	20 Feb 2023
Executive of a local consulting company	20 Feb 2023
Member of a civil society organisation	21 Feb 2023
Member of a civil society organisation	21 Feb 2023
Executive of a Namibian green hydrogen project developer	22 Feb 2023
Executive of a foreign green hydrogen project developer	23 Feb 2023
Official of a research institute	27 Feb 2023
Executive of a foreign green hydrogen project developer	1 March 2023
Executive of a Namibian renewable energy company	2 March 2023
Official of the Electricity Control Board	2 March 2023
Executive of a Namibian renewable energy company	3 March 2023
Official of a German political foundation	3 March 2023
Executive of a Namibian green hydrogen project developer	8 March 2023
Official of the Walvis Bay Corridor Group	16 March 2023
Official of the German Agency for International Cooperation	23 March 2023
Official of the Environmental Investment Fund	29 March 2023
Official of a renewable energy association	30 March 2023
Officials of the Chamber of Mines	31 March 2023
Executive of a foreign renewable energy company	31 March 2023
Official of a development cooperation organisation	4 April 2023
Official of the German Agency for International Cooperation	6 April 2023
Official of Namibia Business Angel Network	14 April 2023

Source: Authors' own draft.

Data availability

The data that has been used is confidential.

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