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Speculative connections: Port authorities, littoral territories and the assembling of the green hydrogen frontier

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ABSTRACT

This article examines the role of European port authorities in assembling the green hydrogen frontier through the production of speculative connections with prospective hydrogen export zones in the global South. Specifically, it analyses the role of a particular discursive tool, the pre-feasibility report, in fixing the meaning of Namibian territory for the purposes of green hydrogen export, disembedding hydrogen products from the social, political and ecological bases of their production. We argue that the green hydrogen frontier is fundamentally a speculative project insofar as it both accentuates the productive indeterminacy of green hydrogen as an energy commodity and develops a series of discursive strategies designed to measure, map and capture the anticipated value of this commodity. The article's findings advance geographical debates on energy, territory and speculation by demonstrating the role of the port authority - an under-researched actor in the literature on energy transitions - in the reimagination and transformation of littoral territories in the global South.

1. Introduction

> "The Netherlands and the European Union are preparing for huge imports of renewable energy […] This energy will have to come primarily from regions that are sparsely populated and where there is lots of sunshine, lots of strong wind and/or hydro power available. That's where green energy can be generated relatively cheaply, which can then be used to produce green hydrogen"
>
> (Port of Rotterdam Authority, 2022, p. 1)

> "Most proposed markets for hydrogen reflect magical thinking"
>
> (Information Technology and Innovation Foundation, 2024, p.i)

The largest port in the world by cargo tonnage for much of the 20th century,[1] the Port of Rotterdam has been overtaken in recent years by the rapid expansion of ports in East Asia. In response, it has developed a growth strategy focused on becoming the most sustainable and efficient port in the world. Central to this strategy is the import of a relatively new energy commodity, green hydrogen, underpinned by the aim to become an 'international hydrogen hub' by the mid 21st century. An energy carrier rather than an energy source, green hydrogen is produced by splitting water into hydrogen and oxygen via a process of electrolysis powered by renewable sources.[2] It can be converted into several derivative products that can be transported long distances and stored for long periods of time, theoretically resolving two conventional challenges of renewables production. As a result, green hydrogen and its derivatives are seen to provide a spatial fix for decarbonisation in Europe through new forms of territorialisation in the global South. Critically, such forms of territorialisation extend onto coastlines and into the sea, both to provide access to the large quantities of water required by green hydrogen production, and to facilitate the rapid export of hydrogen products back to Europe via shipping routes to Rotterdam.

To date, attempts to generate a global market for green hydrogen have proceeded on the basis of a series of bilateral agreements that connect would-be hydrogen export zones in the global South to import zones in the global North. These agreements have been accompanied by a proliferation of expert texts – investor reports, feasibility studies and MoUs – that seek to assemble green hydrogen as a commodity, conjuring visions of lucrative financial opportunity while readying the ground for

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[1] As measured by annual cargo tonnage.

[2] We use the term 'green hydrogen' throughout the article (as opposed to 'renewable' or 'clean' hydrogen) in line with the focus of rest of the issue, while acknowledging it as a contested term that downplays the ecological and atmospheric impacts of its production.

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investment and export. Yet, as a number of policy and academic observers have argued, such texts reflect a form of speculation, or 'magical thinking', that is often divorced from material realities. This gap between present realities and future imaginations is arguably greatest in the ǁKaras region of Namibia, a semi-arid coastal region located over 12,000 km from Rotterdam which in 2021 became the site of a US$9.4 billion green hydrogen project (Wexler, 2021).

Drawing together critical geographical scholarship on energy, territory and speculation, this article examines the role of port authorities in assembling the green hydrogen frontier through the production of what we term 'speculative connections' with geographically remote regions of the global South. We ask: what is the role of port authorities, and specifically the Port of Rotterdam Authority (PoRA), in the assembling of the green hydrogen frontier? What types of discursive strategies do they deploy? What ideological work do these strategies perform? And what types of action do they make possible in the world? We focus our analysis on the deconstruction of a particular discursive tool, the 'Namibia - Port of Rotterdam Hydrogen Supply Chain Pre-Feasibility Report', in fixing the meaning of Namibian territory for the purposes of green hydrogen investment and export. Following Bridge and Bradshaw (2017, p. 220), we explore the particularity of this connection ('why this spatial form, why now?') in addition to its strategic intent ('for what ends, with what effects?') in order to advance three lines of argument.

Firstly, while the existing geographical literature on energy transitions has emphasised the role of renewable energy infrastructures in transforming *terra firma* (Bridge et al., 2013; Huber & McCarthy, 2017; McEwan, 2017), we demonstrate the role of the green hydrogen frontier in reimagining and transforming *littoral territory* as states, investors and port authorities vie for control of coastal areas and infrastructures in regions of the global South with high levels of 'hydrogen potential'. Secondly and relatedly, we argue that the (European) port authority – an under-researched actor in the literature on energy transitions – has emerged as a key institution in the assembling of the green hydrogen frontier insofar as it enables the production of speculative connections with prospective hydrogen-exporting territories beyond the reach of existing rail and pipeline infrastructures. Thirdly and finally, we argue that the assembling of the green hydrogen frontier is contingent upon a series of disconnections that disembed hydrogen from the local social, political and ecological bases of its production, enabling the decarbonisation of Northern economies at the expense of Southern ecologies.

The remainder of the article is structured in four parts. We first seek to ground our inquiry in critical debates on energy, territoriality and speculation, before outlining our methodological approach. Following this, we provide a critical examination of three key discursive strategies present within the green hydrogen frontier assemblage: *rendering hydrogen technical, enclosing hydrogen territory and conjuring hydrogen technology*. We then highlight three forms of socioecological disconnection produced by and through the frontier assemblage before drawing our conclusions.

2. Critical geographies of energy transitions: the green hydrogen factor

2.1. Transitions and territory

> "[The] cross-border maritime trade in hydrogen has the potential to fundamentally redraw the geography of global energy trade, create a new class of energy exporters, and reshape geopolitical relations and alliances between countries"
>
> (Van de Graaf et al., 2020, p. 1)

A growing number of geographers have called for research on the ways in which energy transitions reconfigure space; not only by demanding it but by reimagining it and remaking it at different scales (Baptista, 2018; Bridge et al., 2013; Calvert, 2016; Huber & McCarthy, 2017; Tornel, 2023). Within this literature, Huber and McCarthy (2017) argue that while fossil fuel production is characterised by a 'subterranean' energy regime, the production of renewables represents a 'return to the surface' insofar as wind and solar production requires between 60 and 400 times the surface area to generate the equivalent 'power density' of a coal mine (ibid. citing Smil, 2015). Green hydrogen, in turn, requires an even larger surface area to generate renewable energy at a scale sufficient to compensate for energy losses during electrolysis and transport.[3] Consequently, the advancement of the green hydrogen frontier necessitates the transformation of space on the earth's surface on an unprecedented scale through the creation of new hydrogen facilities, infrastructures and dwellings, while at the same time being reliant on regimes of subterranean extractivism that manufacture solar, wind and electrolyser technologies (Dunlap & Laratte, 2022; Lennon, 2017).

While much of the existing geographical debate on energy transitions focuses on the role of renewable energy infrastructures in the territorialisation of land (Bridge et al., 2013; Huber & McCarthy, 2017; McEwan, 2017), the case of green hydrogen turns our gaze out towards the coastline. A growing literature examines the role of the sea as a key frontier within colonial and contemporary capitalism (Barbesgaard, 2023; Campling & Colas, 2018; Knott & Mather, 2021). Within this literature, Campling and Colas (2018) argue that the sea is territorialised through a combination of governance structures, infrastructural technologies, and value extraction practices that seek to capture and code maritime space through forms of 'terraqueous territoriality'. However, less attention has been paid to the territorialisation of the littoral zone between land and sea for the purposes of renewable energy production; a space critical for the advancement of the green hydrogen frontier insofar as it provides access both to the large quantities of water required for electrolysis, and to the port infrastructures required to facilitate the rapid export of hydrogen products. In response, we examine the role of the green hydrogen frontier in demanding and reconfiguring littoral territory through the production of speculative connections.

2.2. Speculation and frontier making

A growing body of literature in resource and political geography explores the relationship between speculative financial practices and the extraction of subterranean resources including shale, oil, and gold (Himley, 2021; Kama, 2020; Swann-Quin, 2019; Weszkalnys, 2015). This scholarship moves beyond a narrow focus on investment and financialization to explore the 'broader socio-political character of speculation' (Kuchler & Bridge, 2023, p. 2), including how social, cultural, and political factors shape the ways in which speculation enables or constrains the creation of future energy landscapes. In contexts where the determination of potential value is more or less certain, capital injections and investments can be made without recourse to speculation. However, in cases involving the production of new energy resources or commodities such as green hydrogen, the potential capture of value is anything but certain and speculation abounds. It is in this sense that Kuchler and Bridge (2023, p. 3) consider speculation as "a qualitatively distinctive orientation towards future uncertainty - an intention to capture future value in situations where conventional modes of handling indeterminacy … are not effective." Developing this argument, Laura Bear (2020, p. 3) argues that speculation is a two-stage process that first makes 'value uncertain' before offering 'technologies of imagination that can help navigate this uncertainty'.

In this way, speculation operates as a form of 'frontier making', through which space is emptied of historical inhabitations, uses and meanings to enable the 'discovery' of new and uncertain value prospects. There has been a recent resurgence of frontier studies in

[3] Between 27 and 40% of energy is lost through the process of electrolysis alone (Yue et al., 2021).

geography (Barney, 2009; Ioris, 2018; Knott & Mather, 2021; Lee, 2023; Manchanda & Turner, 2024). While diverse in scope, much of this scholarship builds on a Marxist understanding of the frontier as a condition of the "birth and consolidation" of capitalism through the continual search for new sites of resource extraction and commodity production (Moore, 2000, p. 428). We emphasise two recent theoretical directions here that are useful for understanding the production ofrenewable energy frontiers: frontiers as *relational* and frontiers as *assembled*.

Firstly, Barney (2009) approaches frontiers as 'relational spaces produced through scaled interactions which are simultaneously material and representational' (p.147, drawing upon Moore, 1998). In contrast to approaches that conceptualise frontiers through spatial and scalar hierarchies, a relational approach foregrounds the role of local peoples and natures in the making and unmaking of resource frontiers, articulated in relation to a broader assemblage of actors and processes (p.148). Secondly and relatedly, Knott and Mather (2021) develop the notion of the 'frontier assemblage' to foreground 'the complex material and discursive processes that are involved in the making of frontier spaces' (p.800, see also Cons & Eilenberg, 2018). On this reading, frontier space is not 'out there' waiting to be found but is actively assembled through a series of speculative discursive practices that empty diverse socio-ecological landscapes and rewrite them 'in the image of the commodity' (Bridge, 2001, p. 2160). Here the concept of assemblage is useful for highlighting the work that is required to create and sustain resource extraction while also signalling the vulnerability and indeterminacy of any such project (Knott & Mather, 2021; Li, 2014).

What types of work are required in the assembling of a resource frontier? Drawing on the case of land markets in Indonesia, Tania Li (2014) emphasises the role of maps, graphs and tables as 'inscription devices' – akin to Bear's (2019) 'technologies of imagination' – that enable 'new ways of thinking' about land as a 'a singular thing with qualities and potentials that can be … made available for comparison (and investment)' (p.593). Such devices become important vehicles for 'conjuring' visions of profitability in contexts of uncertainty. As Tsing puts it: conjuring 'call[s] up a world more dreamlike and sweeter than anything that exists; magic, rather than strict description, calls capital" (2000, p.120). Applying this notion to Mexico's Burgos Basin, Fry and Murphy (2021) identify a range of 'conjurings' that are used to encourage shale gas investments, including maps, forecasts, and other 'spectacular' visual depictions designed to draw audiences of investors.

A recent report found that the top 25 hydrogen lobby groups spend a combined €75.75 million a year on such conjurings as part of their lobbying of EU institutions; an amount larger than that spent by Big Tech and Big Finance (Corporate Europe, 2023). In this article, we provide a critical examination of the role of maps, images and texts in assembling the green hydrogen frontier, transforming complex littoral landscapes into frictionless export zones that afford a prominent role to European port authorities.

2.3. Ports and maritime economies

The global expansion of fossil industries has been facilitated by the spectacular production of new maritime infrastructures, including shipping lanes, port facilities and coastal megalopolises (Khalili, 2020). By contrast, with the exception of offshore wind, the expansion of renewable energy frontiers has largely taken place over land (Huber, 2015). As such, there is a dearth of critical research examining the role of port and maritime authorities within global energy transitions. Yet ports are envisaged to play a critical role within the emergence and evolution of green hydrogen markets by connecting exporting regions in the global South with importing regions in the global North. The shipping industry is also anticipated to provide one of the largest markets for hydrogen-derivative fuels. In this way, port authorities fulfil a double role as prospective exporters and offtakers within the green hydrogen frontier assemblage.

Over the past two decades, port authorities have evolved from public-facing institutions managed by local and/or national government to into autonomous, commercially oriented organisations (Van der Lugt et al., 2015). In addition to fulfilling the historical 'landlord' model through which they are responsible for the management and development of the seaport, port authorities are increasingly required to generate profits through a broader range of investments, including in regional infrastructural systems and hinterland nodes and links (Ibid.). They have become an object of revived interest in the social sciences through a proliferation of research in anthropology (Bäumer Escobar et al., 2023; Leivestad & Markkula, 2021), management studies (Van der Lugt et al., 2015; Verhoeven, 2010) and the interdisciplinary field of critical logistics studies (Chua et al., 2018). For the most part, these studies take the container and the expansion of containerized trade as their points of departure (see also Levinson, 2016). Yet, while port authorities are seen to have played a central role in the making and remaking of hydrocarbon commodity chains, less attention has been paid to their (emergent) role within low carbon energy markets; for example, in fulfilling the EU's ambition to import 10 million tonnes of renewable hydrogen by 2030 (European Commission, 2022).

The Port of Rotterdam Authority (PoRA) is working to position itself as a key actor within this landscape. Historically a state-owned institution, PoRA became a limited holding company in 2004 with the municipality of Rotterdam and the Dutch state as its major shareholders. It has since followed an extended 'landlord' model, including investments in inland terminal capacity and transport infrastructure (Van der Lugt et al., 2015). In the context of the rapid and ongoing expansion of Chinese ports, PoRA has also started to pursue an active internationalisation strategy through which hydrogen is seen as a key mechanism to reposition the port at the centre of global energy markets. PoRA's hydrogen strategy includes the co-management of the annual World Hydrogen Summit, the hosting of the 'Hello Hydrogen!' podcast' and the production of speculative connections with prospective hydrogen exporters in different regions of the global South.

3. Researching speculative connections

How might we research speculative connections that are, by their very nature, provisional, suppositional and/or uncertain? Here we draw methodological inspiration from studies of the 'frontier assemblage' developed from the critical agrarian tradition (Barney, 2009; Cons & Eilenberg, 2018; Knott & Mather, 2021; Li, 2014; Tsing, 2000). A frontier assemblage is comprised of a combination of material and discursive elements that render a particular site ready for investment and extraction (Knott & Mather, 2021). Rather than given, the 'resourceness' of this site – and the 'resources' contained within it – has to be actively assembled through a discursive regime that that 'acts as a grid for the perception and evaluation of things' (Foucault, 1991, p. 83, cited Li, 2014, p. 589). Discourse analysis thus provides an ideal methodological tool to deconstruct this process of frontier assemblage, and the role of different actors and interests within it. We use this tool to unpack the green hydrogen frontier assemblage, paying particular attention to the role of port authorities in its production. Through a focus on the Namibian case, we ask: what discursive elements and strategies are deployed by the Port of Rotterdam Authority in the reproduction and extension of the green hydrogen frontier? What ideological and epistemological assumptions underpin these strategies, and what modes of thought and action do they make possible?

The material for our analysis is comprised of reports, statements and press releases published on the Port of Rotterdam website over a five-year period between 2019-2024.[4] These texts are supplemented by reports and press releases on green hydrogen issued by the governments of

[4] A search for 'green hydrogen' on the site returns no results before 2019, illustrating the emergent nature of the green hydrogen frontier.

Namibia the Netherlands over the same period to understand the broader assemblage of actors, discourses and power relations in which PoRA is situated. Particular emphasis is placed on the 'Namibia - Port of Rotterdam Hydrogen Supply Chain Pre-Feasibility Report' (2021), insofar as this text lays the discursive ground for PoRA's involvement in (and reproduction of) the Namibian green hydrogen frontier, as we explain in the following section. The intended audiences for these texts include the energy and shipping industries (including fossil fuel corporations), policymakers, investors and Dutch and Namibian citizens (all the texts are in the public domain). In this way, the discursive elements of the green hydrogen frontier assemblage are directed both at capital and at local populations in an attempt to establish a social licence for investment and export (Knott & Mather, 2021).

Following Rose (2023, p. 22), we subject these materials to discourse analysis to better understand how 'specific views or accounts are constructed as real or truthful or natural' through the deployment of a range of discursive strategies. We coded the texts inductively using basic descriptors to summarise different excerpts before organizing the codes hierarchically to illustrate the relationship between different discursive elements (following Stoffelen & Groote, 2024*)*. The three highest-order codes ('rendering hydrogen technical', 'enclosing hydrogen territory' and 'conjuring hydrogen technology') are used to structure the analysis in the following section. We then extended our coding to identify key absences, or what we term 'disconnections', in the texts, which form the basis of the second analytical section ('socio-cultural dislocation', 'infrastructural exclusion', and 'ecological abstraction').

4. Producing speculative connections

> "The Port of Rotterdam is currently exploring the possibilities for the import of green hydrogen with over 150 projects worldwide. There already are agreements with 25 countries all over the world."
>
> (Port of Rotterdam Authority, n.d.)

A search for the term 'green hydrogen' on the Port of Rotterdam website returns 133 results, including press releases, position papers and feasibility studies.[6] Collectively, these documents represent a series of discursive performances that seek to produce 'dramatic shows of potential' (Tsing, 2000, p. 118), positioning the Port at the centre of a future hydrogen economy (see Fig. 1). They represent a sort of 'magical thinking' through which an astonishing target is set (18 million tons of hydrogen to enter Rotterdam by 2050) and a series of circumstances projected to meet this target; namely, import agreements with 'cheap' green hydrogen exporters in different regions of the world (ITIF, 2024). In this way, the idea of PoRA as a future 'international hydrogen hub' is a relational idea that requires the demonstration of plausible partnerships with prospective exporters.

Within this context, the pre-feasibility report plays an important role as a discursive tool that seeks to substantiate the relational potential of the PoRA, bridging the gap between imagination and possibility. At its most basic level, the feasibility report aims to establish the cost and value of a particular activity in a particular place, generating comparable, quantifiable information that enables officials and investors to prioritise their investments. Over the past three years, PoRA has published a series of pre-feasibility reports to estimate the levelised cost of hydrogen production (LCOH) and import from countries with perceived 'hydrogen potential', including Tasmania, Iceland, Uruguay and Namibia. These reports are conducted in partnership with a relevant branch of the local state (for example, the Tasmanian government, the Uruguayan Ministry of Industry, Energy and Minerals, the Namibian Port Authority) on whom PoRA is reliant for access to local data. The intended audiences for the reports include government representatives, port officials and international investors, for whom they seek to generate a sense of economic possibility and 'awe' (Fry & Murphy, 2021, p. 2). Their findings are mapped on a global projection of 'future hydrogen flows' (see Fig. 1), which codes different regions of the world according to their 'H^2 Price', connecting them via maritime routes to hydrogen 'demand centres' in China, the US and the Netherlands. In this way, the map conjures an idea of the Port of Rotterdam as one of three 'demand centres' within a globalised hydrogen market, connected via maritime routes to a series of hydrogen-producing peripheries predominantly located in postcolonial regions of the global South.

The PoRA's hydrogen pre-feasibility reports follow a template format, including sections on 'setting the stage', supply chain components, cost model, sensitivity analysis, risks and barriers, and conclusions and recommendations. They thus reproduce the epistemological gaze of the Port of Rotterdam Authority, interpreting diverse socio-ecological territories through a framework of 'profit oriented material and energy intensive institutional cultures' focused on questions of quantity, price and risk (Dunlap & Laratte, 2022, p. 6). The reports establish a tension between the proposed universality of the hydrogen market ('the world is gearing up'; 'a huge new market') and the localised potential of exporting countries ('Namibia's unique potential'; 'Tasmania's unique selling point'). The imperial nature of the 'partnership' underpinning the pre-feasibility reports is betrayed by the close similarities between the different country reports, and the fact that, in the Namibian case, no one from PoRA visited the country prior to the publication of the report.[6]

The Namibia report was produced in partnership with NamPower, a state-owned energy enterprise. NamPower produces electricity from a combination of hydro (68%), coal (25%) and diesel (8%) but is reliant on neighbouring countries and the Southern African Power Pool (SAPP) for the majority (50–60%) of Namibia's power (Monks Reid Global, 2024). Under the government's Harambee Prosperity Plan, Namibia aims to become more energy secure through 'large-scale, low-cost renewable energy development' that sustainably maximises 'fiscal revenue and local development in renewable energy investments' (Government of Namibia, 2024). Green hydrogen has been placed at the centre of this strategy; the Namibian government established an inter-ministerial Hydrogen Council in 2021 and has publicly pursued international investments in green hydrogen at COP and Davos, positioning the country as a key player within global energy transitions (Gabor & Sylla, 2023; Wexler, 2021). Namibia has subsequently signed MoUs on hydrogen with the EU, Germany, Belgium and the Netherlands. The MoU with the government of the Netherlands explicitly mentions the Port of Rotterdam as a 'special partner' with a history of collaboration in Namibia that includes the production of the pre-feasibility report. It is thus illustrative of the ways in which port authorities are being drawn into emergent forms of 'hydrogen diplomacy' (Van de Graaf et al., 2020).

The following sections examine the work of the Namibia - Port of Rotterdam Authority Pre-Feasibility Report in assembling the green hydrogen frontier through three particular discursive strategies: *rendering hydrogen technical, enclosing hydrogen territory,* and *conjuring hydrogen technology*.

4.1. Rendering hydrogen technical

> "A staged development is proposed. A first stage will require 5.3 TWh of renewable power which will produce in order of 100ktpa H2. Land area requirements are 30k Ha for wind and 2k Ha for solar parks … The price of hydrogen delivered in Rotterdam for the first stage would be reasonably competitive at a level of 3,3 EUR/kg"
>
> (Port of Rotterdam Authority, 2021)

[5] As of 16 October 2024.

[6] The report states that 'in view of the limitations due to COVID-19 no visits to Namibia were possible' (Port of Rotterdam Authority, 2021, p. 4).

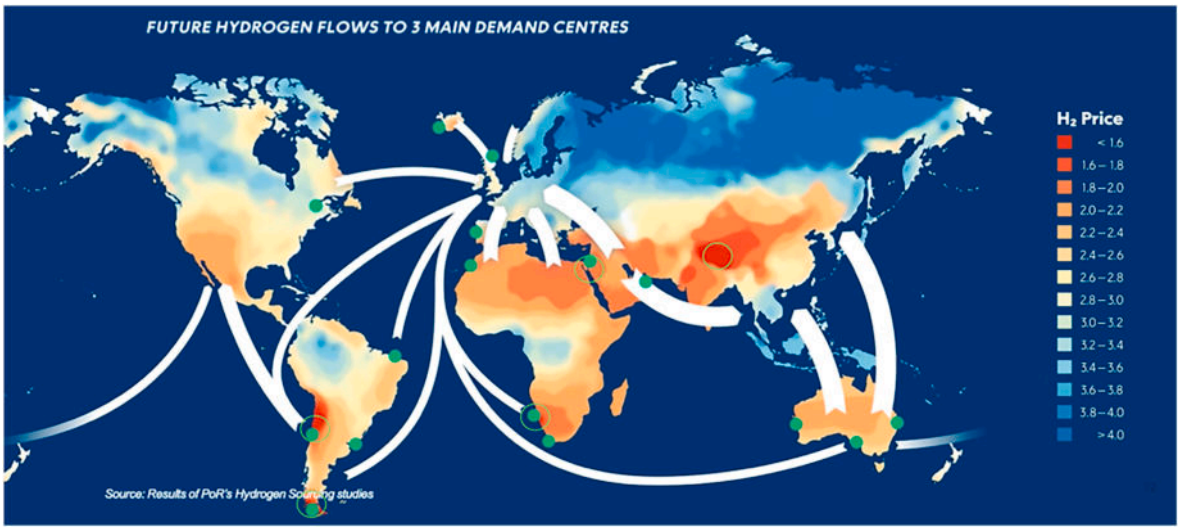

Fig. 1. 'Future hydrogen flows to three demand centres' (Port of Rotterdam Authority, 2021, p.12).

In *Rule of Experts,* Timothy Mitchell (2002) argues that one of the key inventions of colonial modernity was the 'character of calculability' established through the deployment of quantifiable instruments. Such instruments render the world technical by reducing social and ecological problems to a series of abstracted numbers that can be compared according to ostensibly objective standards. They produce simplified, 'transportable' forms of knowledge that can be moved to distant 'centres of calculation', enabling (neo)colonial administrators to make decisions about the allocation of resources without reference to local knowledge (Harris, 2004, p. 176). Critically, they also establish the idea of commensurability, detaching energy commodities from the 'materiality of their local geography' in order to transform them into a common metric, enabling their comparison, competition and trade to distant elsewheres (Fairhead et al., 2012, p.245; Espeland & Stevens, 1998). Commensuration has been theorised as 'a system for discarding information and organizing what remains into new forms' in ways that establish 'new interpretive frameworks' and 're-construct relations of authority' (Espeland & Stevens, 1998, pp. 317, 323). Such forms of knowledge production are central to the creation of new commodity markets and the expansion of the (green) European imperial frontier, through which Southern 'partners' are expected to integrate and assimilate European energy epistemologies at the expense of local priorities and expertise (Almeida et al., 2023 citing Rutazibwa, 2010; see also Dunlap & Laratte, 2022).

Within its 62 pages, PoRA's Namibia Pre-Feasibility report contains a total of 8 data tables, 31 graphs, 32 different acronyms (e.g. LH2, LCOH) and 25 quantitative measurements (e.g. W/m2, Mt/yr). The report begins with a summary that attempts to quantify the country's 'hydrogen potential': a first stage of production would reportedly deliver 100 kilo tonnes of hydrogen per annum (ktpa H2) to Rotterdam at the 'reasonably competitive' price of 3,3 EUR/kg.[7] This calculation of the price (or 'levelised cost') of hydrogen produced in a given territory is presented as a key finding of each pre-feasibility report, highlighted at the start of each executive summary. Critically, this measure ('LCOH') establishes the idea of commensurability; that one Metric tonne of hydrogen produced in Namibia is commensurate with that produced in Iceland or Uruguay. It thus makes it possible for distant port officials and investors to compare the hydrogen price and potential of different territories on a global scale (see Fig. 1) and prioritise their investments accordingly.

Putting aside its epistemological implications, the task of calculating the economic 'cost' of hydrogen production in a given location is a complex one that includes various assumptions about the cost and availability of land and water, as well as the types of renewable power, electrolyser technology and hydrogen carriers used.[8] Rather than made explicit, these assumptions form part of a closed 'PoRA Cost Model' which is made available to neither the local partner (NamPower in the Namibian case) nor the general public.[9] This model is one of several black box hydrogen price models developed by European states and corporations, including the Hydrogen Pathway Explorer (HyPE) managed by Deloitte France. According to a footnote in the Namibia report, the PoRA cost model is based on a series of 'guestimates for the future', that the 'accuracy' of the model is 'in the order of ± 50% (roughly)', and its results are 'indicative only and not to be relied upon' (Port of Rotterdam Authority, 2021, p.41).[10] In this way, the PoRA model manufactures data based on one part calculation, one part 'conjuring', combining guesstimates and approximations to produce spectacular numbers designed to draw audiences of policymakers and investors while expanding the institutional power of the port authority (Tsing, 2000). Yet the outputs from this model – quantitative measures of 'H2 price' and 'levelised cost of hydrogen production' – circulate elsewhere as authoritative numbers, abstracted from both the processes of their production and the materialities of their local geographies (see e.g. Fig. 1). For example, at the World Hydrogen Summit in 2022, PoRA declared to an audience of investors, policymakers and industry stakeholders that it could supply 4.6 million mt/year of hydrogen to Europe by 2030' – approximately a quarter of the EU target – based on projections established through its 'projects and plans' (S&P Global, 2022).

We have argued here that the PoRA's pre-feasibility report functions as a sort of 'inscription device' (Li, 2014), rendering hydrogen technical through a series of quantitative metrics designed to convey authority and commensurability, inviting audiences to see the world as a market in which countries must compete to produce the largest quantities of hydrogen ('ktpa H2') at the lowest cost ('EUR/kg'). However, the

[7] The report estimates that the 'local cost for production of hydrogen is just over 60% of the final price delivered in Rotterdam' (PoRA 2021, p.45), hence the discrepancy between the price presented here and that depicted in Fig. 1.

[8] E.g. green ammonia, liquid hydrogen and/or liquid organic hydrogen carriers.

[9] The report states that 'NamPower did not have access to the PoRA Cost Model' (Port of Rotterdam Authority, 2021, p.3).

[10] The report includes a disclaimer in the appendix that states: "In the future the quality of the assessment can be upgraded after real site visits and local interviews… More detailed analyses and engineering will need to be undertaken in following design stages [sic]" (p.59).

methodologies and assumptions that produce these metrics – including the exclusion of the social and ecological costs discussed in section 5 – are hidden from view. Instead, data is extracted from each country partner and inserted into the black box of the PoRA Cost Model in ways that obscure the relationship between the metric and the empirical world, denying the possibility of alternative and intrinsic forms of value (Espeland & Stevens, 1998). In this way, the model functions as an imperial instrument that reaches across vast distances of space and encloses it within an external system of valuation, 'conjuring' a hydrogen frontier into being through the incorporation of Namibian land, water and wind into a Eurocentric hydrogen knowledge economy.

4.2. Enclosing hydrogen territory

Implicit in any calculation about the cost of hydrogen is a set of assumptions about the cost and availability of land. The PoRA's pre-feasibility report estimates that a total of 32,000 hectares of land are required for wind and solar PV energy generation alone during the first stage of development in Namibia. Furthermore, it stresses that subsequent stages of development 'could look at tenfolding' (PoRA, 2021, p.3) this requirement, resulting in the creation of a green hydrogen enclave larger than the size of Belgium. In an attempt to identify and evaluate lands for the purposes of green hydrogen generation, the PoRA report draws heavily on a historical tool of territorialisation: the map (Harris, 2004; Pickles, 2004). It includes a total of 30 spatial representations, the majority of which are scaled at the level of the Namibian national territory, to achieve two different ends.

First, the report uses maps to assess the renewables 'potential' of land in Namibia. The first of these maps are country-level representations of the World Bank's Global Wind Atlas (GWA) and Global Solar Atlas (GSA), which overlay colour-coded indicators of solar and wind power potential on a Mercator projection devoid of any markers of human or non-human presence. These maps are deployed to demonstrate that the West of Namibia 'is ideal for [solar] PV' and the Sperrgebiet area in the South of Namibia 'is one of the world's top 3 locations for wind production' (PoRA, 2021, p.3). Furthermore, they enable the identification of local sites for solar PV (2,500 ha) and wind parks (25,000 ha) sufficient to meet the target of 100 kilo tonnes of hydrogen per annum delivered to Rotterdam. Following the singular logic of the GWA and GSA, these sites are suggested on the basis of the potential renewable power (TWh) generated per hectare (McCarthy & Thatcher, 2019).

Fig. 2 projects two such locations on a satellite image of the

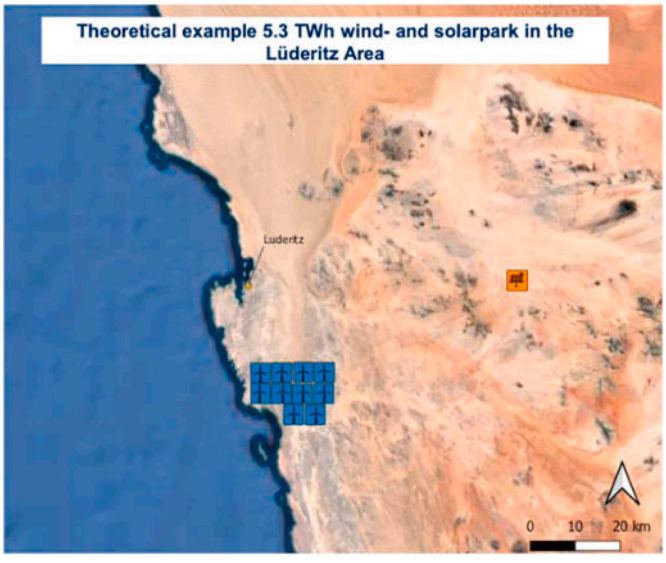

Fig. 2. Map depicting the potential sites of solar and wind parks in Namibia (Port of Rotterdam Authority, 2021, p.18).

(unnamed) ǁKaras region, using boxes containing the indexical signs of the wind turbine and solar panel to indicate the amount of land turned over to renewable power generation, reimagining complex socio-ecological landscapes 'in the image of the commodity' (Bridge, 2001, p. 2160). Following the spatial logics of the GWA and GWA, wind turbines are positioned near the coastline to take advantage of higher wind speeds while solar PV panels are positioned inland to avoid the 'mist--band' along the coast' (Port of Rotterdam Authority, 2021, p.14). The report emphasises the importance of minimising the distances between the wind and solar parks and the industrial port complex to reduce losses, resulting in the projection of a littoral hydrogen infrastructure, centred on the coastline. The only indicator of human presence on the map is a reference to the colonial name of the regional capital, Lüderitz. Absent from the map is any mention of the indigenous name of the broader constituency, *!Nami≠Nüs,* which was decolonised by the Namibian government in 2013. In this way, future projections of renewable energy landscapes in Southern Namibia reproduce colonial projections of the region as a space of European conquest and extractivism. Here Namibian territory is presented as a space of 'bountiful emptiness', full of potential for the realisation of European hydrogen futures (Bridge, 2001).

Second, the PoRA's pre-feasibility report uses maps to identify and compare the potential of coastal sites for the construction of hydrogen port complexes. The proposed deep water port facilities are designed to accommodate Very Large Gas Carriers (VLGCs) through the construction of jetties and breakwaters. It is suggested that these facilities include desalination plants, required to generate the large quantities of water required by electrolysis, powered by 'Delft Offshore Turbines', a partner of the Port of Rotterdam. Four proposed coastal sites are identified on a series of nameless satellite images (Fig. 3) in which red boxes are used to indicate the potential location of hydrogen production and export zones, each of which include an 'onshore land requirement' of 100 hectares. These sites are evaluated in a table against four criteria which serve to categorise and code littoral territory: i) existing facilities and need for expensive breakwater ii) environmental impacts and safety, iii) availability and suitability of land for onshore facilities and future expansions, and iv) accessibility. They include one site located in a national park (Angra Point) which the Namibian government previously discounted on the grounds of an Environmental Impact Assessment, and one in close proximity to a site of significant historical and cultural heritage (explored in section 5.1). Based on the report's criteria, the site at Walvis Bay is awarded the most points and thus deemed the most appropriate site for deep-water port development. An accompanying map of hydrogen infrastructure in Namibia uses a red arrow to indicate the ultimate destination of the hydrogen products processed at the proposed port (Europe), betraying the extractive logic of the proposed infrastructures.

Six months after the publication of the pre-feasibility report, the state-owned Namibian Ports Authority (Namport) signed an MoU with the Port of Rotterdam Authority designed to 'position our ports to become green hydrogen export hubs and facilitate the … growth and flow of the green hydrogen supply chain from Namibia to Rotterdam' (Namport, 2021). In a supporting statement, Namport announced that it had 'set aside three hundred and fifty (350) hectares of land at the Port of Walvis Bay North Port for allocation to Green Hydrogen related industries' (Namport, 2021). The following year, the Namibian Government commissioned PoRA to co-design a second hydrogen port complex in the South of the country – the 'Luderitz Port Masterplan' – at another site recommended in the report (Angra Point), which had previously been discounted on environmental grounds. In the MoU, Namport committed to leasing these territories under the landlord model – the latter as part of a larger 'green economic zone' – facilitating the transfer of littoral territory in Namibia from public to private ownership.

In summary, the cartographic projections deployed in the PoRA pre-feasibility report encourage the reader to think about Namibian territory as marginal, uninhabited space, which can be categorised and compared

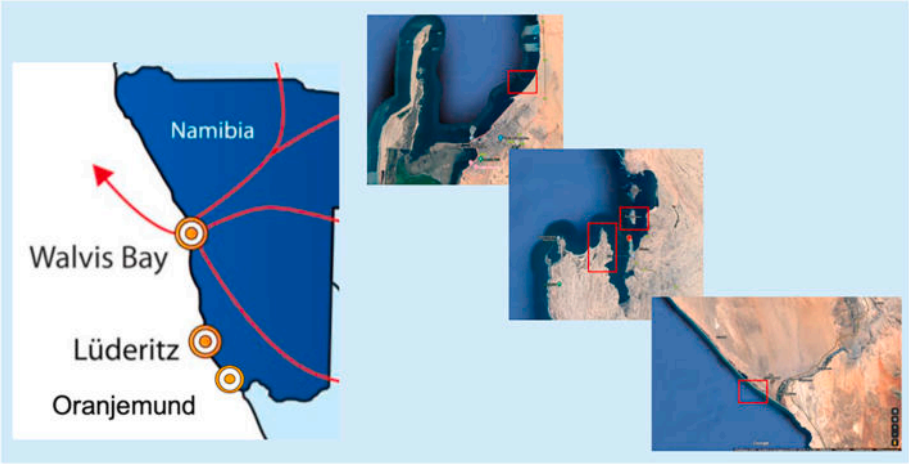

Fig. 3. Location options for H2 Industrial port complex (Port of Rotterdam Authority, 2021, p.28).

according to a set of objective criteria for the purposes of green hydrogen conversion and export. In this way, they produce "a new way of thinking about 'underutilised land' as a singular thing with qualities and potentials that can be rendered commensurable according to different criteria" and made available for comparison and investment to international audiences (Li, 2014, p. 593). The territorial form of the green hydrogen infrastructure projected in the report centres on the coastline as a key zone of conversion and export. As critical energy geographers have argued, such projections do not simply represent territory, they *actively produce* it by inscribing 'new visions of development, accumulation and 'sustainability'' upon the land; visions that supersede other uses and values (McCarthy & Turner, 2019, p.242). These new visions help to create and legitimate 'zones of exceptionality' governed by new constellations of territorial authority, including overseas companies and port authorities (McEwan, 2017). In the case of the green hydrogen frontier, such forms of territoriality place particular value on littoral space as industries and investors seek access both to the water required for the production of green hydrogen and the port infrastructures required for its export, directing a shift in land use towards export-oriented hydrogen production.

4.3. Conjuring hydrogen technology

In addition to metrics, models and maps, technology forms an important part of the green hydrogen frontier assemblage. As Tania Li argues, once a 'resource' has been identified, technology and capital represent the 'magic mix' that renders this resource investible and productive (2014, p.596). Extending this metaphor, Norman Girvan (1978, p. 153) argues that "modern technology … has become a kind of 'white magic' whose ability to 'work developmental wonders' remains unquestioned in spite of its continued reliance on deeply uneven terms of production and trade. In this way, the promise of resource productivity through technological advancement relies on a kind of magical thinking that conceals the neocolonial nature of the transfer of technology from North to South (see also Hickel et al., 2021; Müller, 2024).

The PoRA pre-feasibility report is replete with computer generated images and digital renders of fantastical hydrogen technologies. Measured in terms of 'CapEx' (capital expenditure), the most significant technologies represented in the report include electrolysers, hydrogen carriers (ammonia reactors), and ships, in addition to the wind turbines and solar panels required for renewable electricity generation. Notably, the report includes a digitally rendered conceptual image of a liquid hydrogen carrier vessel; a sleek, futuristic-looking ship traversing an unspecified waterway, emblazoned with the word 'New' (Port of Rotterdam Authority, 2021, p.26). A Google search reveals that the image used in the report was created by Kawasaki, who have recently constructed the first liquid hydrogen carrier (Hydrogen Council, 2022). In its liquid state, hydrogen needs to be stored at around −253 °C, nearly 80° lower than Liquid Natural Gas (LNG). As such, the transport of liquid hydrogen is both an expensive and a potentially dangerous endeavour. The world's first liquified hydrogen carrier vessel – constructed by Kawasaki in 2022 – emitted 1-m-high flames a day after loading its first hydrogen shipment, leading to a one-year investigation by the Australian Transport Safety Bureau (ATSB, 2022). It remains unclear what role, if any, liquid hydrogen carrier vessels will play in future hydrogen markets. Deployed as part of the green hydrogen frontier assemblage however, the image of the vessel serves to conjure a dramatised idea of technological novelty and opportunity; that this is 'the first time, the pioneering move' (Li, 2014, p. 597).

The green hydrogen supply chain, as represented in PoRA narratives and flow charts, begins with 'renewable power' in the form of wind, solar and hydro power generated on the ground in Namibia. On this reading, technology arrives fully formed at the green hydrogen frontier, detached from the material geographies of its production. Absent from this presentation is any mention of the up-stream supply chain, and, critically in the case of green hydrogen, the uneven global divisions of minerals, finance, labour and property that underpin the production of electrolyser technologies. Recent research by IRENA (2022) shows that the largest number of electrolyser patent family applications are registered in China, Japan, South Korea, Germany and France (see also Vezzoni, 2024). In other words, green hydrogen-producing countries in the global South are currently locked out of the capital-intensive race for electrolyser technologies. Furthermore, the advancement of the green hydrogen frontier is dependent on a double boomerang through which rare earth minerals are exported from Southern Africa to Europe and China for use in the manufacture of electrolyser technologies that are then sold back to Southern Africa for use in energy projects that ultimately produce hydrogen for export to Europe.

In the absence of any representation of the uneven global geographies of the production of hydrogen technologies and infrastructures, the green hydrogen frontier assemblage reproduces a neocolonial imagination of technology as a form of 'white magic' brought by Northern partners to enable productive activity in 'underdeveloped' regions of the global South (Müller, 2024). For example, in an MoU signed with the Namibian government in 2023, PoRA, together with the Dutch-state owned companies Gasunie and Invest International, claims to add value to Namibia through 'the development of hydrogen and port infrastructure … a key enabler of the development of the broader hydrogen economy' (PoRA 2023). This framing of European companies as technological and infrastructural 'enablers' continues a (neo)colonial cycle in which Southern economies are locked in a state of technological dependence, reliant on Northern intermediaries for their access to

international markets.

5. (Re)producing socioecological disconnections

We have argued above that the production of the green hydrogen frontier proceeds through particular forms of knowledge production that render territories technical, divisible, and governable and investible to distant actors and investors in the global North. But what of the role of Namibian cultures, infrastructures and ecologies? Developing Barney's (2009) conception of frontiers as 'relational spaces', this section foregrounds the (invisibilised) role of local peoples and natures in the making and unmaking of the green hydrogen frontier through three forms of disconnection: *socio-cultural dislocation, infrastructural exclusion* and *ecological abstraction*.

5.1. Socio-cultural dislocation

> "Shark Island has got historical meaning to the Nama and the Ovaherero people, and it should have the same historical meaning and heritage meaning for the entire Namibia and for the world"
> Sima Luipert, Nama Leaders Association of Namibia (Angula, 2024)

The question of local engagement in, and utilisation of, green hydrogen is largely absent from the PoRA pre-feasibility reports. We have shown above how the Namibia report deploys cartographic representations that erase human connections to, and claims on, territory, reproducing an imagination Namibian land as an empty repository for green hydrogen technologies and infrastructures. The report devotes just one of its 64 pages to the question of the 'local utilisation' of green hydrogen, including through the production of 'green fertilisers' and 'green mining trucks'. No mention is made to jobs, or the role of Namibian labour in the construction and maintenance of green hydrogen infrastructures beyond the observation that a 'lack of trained staff' may represent a social risk. The report makes only brief reference to the 'local population', listing'resistance by NGO's [sic] and local population' in a table of 'risks and barriers' (PoRA, 2022, p.53). In this way, rather than partners, workers and/or beneficiaries of green hydrogen infrastructures and investments, Namibian citizens are presented as 'risks' to be managed through carefully choreographed forms of 'stakeholder communication'.

To understand why Namibian citizens might be considered a 'risk' in the language of the green hydrogen frontier assemblage, we need to re-historicise and re-populate the spaces evacuated by dominant forms of hydrogen cartography (see e.g. Figs. 2 and 3). Much of the ǁKaras region of Namibia, declared by PoRA as 'one of the world's top 3 locations for wind production', was fraudulently acquired by the German colonial merchant Adolf Lüderitz from a descendant of the indigenous Nama people in 1883 (Gewald, 1998). Renamed 'Lüderitzland', the German colonial government later declared it part of the Sperrgebiet ('prohibited area'), in which human inhabitation was forbidden following the discovery of diamond deposits. In response to local resistance, the German colonial authorities oversaw a genocide of the Nama and Herero people in which thousands of people were killed – many of them on Shark Island – and their remains thrown into the sea (Forensic Architecture, 2024). In this way, rather than natural or inevitable, the 'emptiness' of the region – and thus its suitability for large-scale green hydrogen developments – is the product of historical territorial projects, including those of colonial enclosure and genocide. The descendants of those killed in the genocide, including representatives of the Nama Leaders Association of Namibia, have opposed the construction of a deep-water port complex at Angra Point on the basis that its development risks desecrating graves in the seabed and dislocating the Nama and the Ovaherero people from key sites of cultural heritage and memorialisation (Angula, 2024; Kimeu, 2024). In opposing the development, indigenous, civil society and activist groups have thus invoked the notion of incommensurability; that the value of land is intrinsic, established through historical socioecological relationships that cannot be valued and compared in tabular form (Espeland & Stevens, 1998). By rehistoricising diverse socio-cultural landscapes in Namibia, the activism of these groups makes explicit the ways in which the green hydrogen frontier builds – quite literally – upon a previous project of (colonial) frontier-making in the region, exacerbating historical patterns of socioecological dislocation.

5.2. Infrastructural exclusion

We showed above that the territorial form of the green hydrogen infrastructure imagined by the PoRA in Namibia centres on the coastline as a key zone of conversion and export (see Fig. 3). This infrastructure exhibits low levels of regional 'connectivity' and 'contiguity' (Bridge et al., 2013); all lines lead to a port (and then to Rotterdam), reproducing an extractive spatial logic indicative of the production of an enclave export economy. Furthermore, it is positioned at a distance from existing energy infrastructures (absent from the PoRA's projections), which are predominantly located in the more densely populated central and northern regions of Namibia.[11] Such low levels of infrastructural connectivity in Namibia and Southern Africa stand in contrast to PoRA's representations of future hydrogen infrastructures in the Netherlands and Western Europe (see Fig. 4) which depict Rotterdam's 'excellent intermodal connections' to European 'hydrogen networks'.

Fewer than 20% of rural households in Namibia currently have access to power (including via off-grid sources) (Government of Namibia, 2024). PoRA estimates that the proposed infrastructure would be required to transport and convert 5.3 terawatt hours (TWh) of energy to deliver the stated target of 100 kilo tonnes of hydrogen per annum (ktpa H2) to Rotterdam during the first phase of development; an amount roughly equivalent to a quarter of total annual energy consumption in Namibia (22 TWh). Were this energy to be connected to the Namibian grid via an integrated electricity infrastructure – rather than connected to an electrolyser and port via an exclusive hydrogen infrastructure – it could make a significant contribution to Namibian energy security. A similar argument can be made for water insecurity, which is at risk of being exacerbated rather than addressed by green hydrogen infrastructures (Tunn et al., 2024).

A cursory comparison of PoRA's representation of future hydrogen infrastructures in Namibia (Fig. 3) with those of the Netherlands (Fig. 4) reveals the existence of very different spatial logics – restricted vs. expansive; exclusive vs integrated; extractive vs. distributed – and associated energy politics. The absence of actually existing energy infrastructures in Namibia in PoRA's representations (see also Fig. 2) obscures the relationship between the proposed green hydrogen infrastructure and existing forms of political power in Namibia, including the potential of this infrastructure to exacerbate, rather than redress, existing energy inequalities.

5.3. Ecological abstraction

In their analysis of the European Green Deal, Dunlap & Laratte critique the idea that the energy transition will bring about a world in which 'growth is decoupled from resource use' (2022, p.5). The idea of decoupling, which mobilises fetishised discourses of renewables as abstracted and immaterial energy sources (Rignall, 2016), is prevalent within the green hydrogen frontier assemblage. For example, the process of constructing the hydrogen infrastructures and facilities depicted in the PoRA report is one with significant ecological implications, involving large-scale land clearances for the purposes of solar and wind park construction, seabed dredging for the purposes of deep-water port

[11] According to the 2023 census, just 110,000 people (3.6% of the population) reside in the ǁKaras region in which the majority of hydrogen infrastructures are projected to be located.

Fig. 4. Distribution of hydrogen products in the Netherlands and Western Europe (Port of Rotterdam Authority, 2021, p.38).

construction, and saltwater sludge disposal for the purposes of water production via desalination. In the Namibian case, a number of these infrastructures and facilities are planned to be constructed in the Tsau ǁKhaeb National Park which is reported to contain 'nearly 25 per cent of the entire flora' of Namibia and 'the highest diversity of succulent flora globally' (NMET, 2023). Critically, these infrastructures also extend into fragile coastal environments, where ecologists and fishing communities have expressed concerns about the impacts of deep-water port construction and sludge disposal on local fishing stocks (Grobler et al., 2023).

Yet questions of ecological value are absent from both the PoRA's cost model and its mappings of Namibian territory (see above). Where ecology is represented in the report it is through the language of risk; for example, 'environmental impact' is listed as a criterion in the evaluation of sites for the port development, where it is noted that the Namibian government previously halted the port development at Angra Point on the basis of the findings of an Environmental Impact Assessment. Furthermore, 'access to key land in nature parks' is listed in a table of 'risks and barriers' (alongside 'resistance by NGO's and local population') as a consideration that requires 'careful planning' and 'strong stakeholder communication' (Port of Rotterdam Authority, 2021, p.53), rather than a factor that might undermine the very premise of the project. By framing the ecological impacts of constructing an industrial energy project in a national park as an external 'risk' to be mitigated, the PoRA report abstracts the infrastructures and facilities of green hydrogen production from their local ecologies, rendering these ecologies manageable and controllable. In this way, it serves to obscure and depoliticise the uneven ecological burden of a green hydrogen frontier that decarbonises European economies at the expense of African ecologies, accentuating a 'global division of decarbonisation' (Brannstrom & Gorayeb, 2022).

6. Conclusions

Speculation has been conceptualised in the critical geographical and anthropological literature as a one-two punch of producing uncertainty and developing imaginative technologies to interpret, direct and capture this uncertainty (Bear, 2020; Kuchler & Bridge, 2023; Li, 2014). We have argued that the green hydrogen frontier, as an assemblage of material and discursive processes, is fundamentally a speculative project insofar as it both accentuates the productive indeterminacy of green hydrogen as an energy commodity ('a huge new market') and presents a series of discursive strategies and inscription devices designed to measure, map and capture the anticipated value of this commodity. Within this assemblage, we have highlighted the role of three discursive strategies reproduced through the texts of the Port of Rotterdam Authority: *rendering hydrogen technical, enclosing hydrogen territory* and *conjuring hydrogen technology*. Taken together, these strategies make it possible for audiences of investors, firms and policymakers to reimagine littoral territories in the global South as green hydrogen export zones that compete for Northern technology and investment to produce the largest quantities of hydrogen ('ktpa H2') at the 'cheapest' price ('EUR/kg'). As an epistemological project, the green hydrogen frontier assemblage is governed by particular forms of knowledge production, exemplified by the PoRA Cost Model, that rationalise the transfer of the socioecological risks of green hydrogen production from territories and societies in the global North to the global South.

The findings of the article advance geographical understandings of energy, territory and speculation in two key ways. Firstly, in contrast to the conventional focus on the role of renewables in transforming *terra firma*, we have argued that the territorial form of the green hydrogen infrastructure projected in the frontier assemblage centres on the coastline as a key zone of conversion and export. This spatial logic encourages the production of new forms of littoral territoriality, directing shifts in land use towards export-oriented hydrogen production leased to external firms under the landlord model. Secondly and relatedly, we have demonstrated the emergence of the (European) port authority as a key actor within the green hydrogen frontier assemblage through its production of speculative connections with 'cheap' hydrogen-exporting territories located beyond the reach of existing rail and pipeline infrastructures, providing a spatial fix for European decarbonisation. Furthermore, in addition to this function, port authorities such as PoRA occupy a middle ground between the state and private sector, providing European states with a strategic distance from more aggressive forms of territorialisation in the global South while also de-risking energy investments through the mobilisation of public funds.

When does a speculative frontier assemblage become a material reality? A recent report by the International Energy Agency (2024) found that the number of 'low-carbon' hydrogen projects that are under construction or have reached a financial investment decision is 'very low', representing less than 3% of the total volume of hydrogen due to be traded by 2030 (p.108). The vast majority of projects, including the US

$9.4 billion Hyphen project in Namibia, are still at the feasibility stage. In this way, the green hydrogen frontier assemblage remains 'more dreamlike and sweeter than anything that exists' on the ground (Tsing, 2000, p. 120). Yet, its speculations produce real effects that should not be underestimated. For example, the global spike in hydrogen stocks in 2021 – the year that the Namibia-PoRA pre-feasibility report was published – enabled early investors to sell off shares at a significant profit prior to the subsequent crash, leaving others to pick up the pieces. In the Namibian context, the government issued an amendment to the Nature Conservation Ordinance that empowers the Minister of Environment and Tourism to 'establish a renewable electricity source' within a national park for 'the combating of climate change', while Namport advanced plans for a deep-water port at Angra Point through a public private partnership, in spite of growing opposition both on environmental and socio-cultural grounds. These developments constitute a significant shift in the direction of land use and control in the country, irrelevant of whether they are ultimately used for the purposes of green hydrogen export or not. In this way, the green hydrogen frontier assemblage operates not just in the realm of economic and infrastructural futures, but also in the social, political and ecological presents of the territories it seeks to transform.

CRediT authorship contribution statement

William Monteith: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Vinzenz Bäumer Escobar:** Writing – review & editing, Writing – original draft, Funding acquisition, Formal analysis, Data curation, Conceptualization.

Declaration of competing interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: Vinzenz Bäumer Escobar reports financial support was provided by the European Research Council. The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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