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Green hydrogen for industry and the challenges for an entrepreneurial-regulatory state

Antonio Andreoni and Simon Roberts

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About the authors

Antonio Andreoni is a Professor in the Department of Economics, SOAS University of London and South African Research Chair in Industrial Development, University of Johannesburg.

Simon Roberts is a Lead Researcher for the Centre for Competition, Regulation and Economic Development (CCRED) and a Professor in Economics at the University of Johannesburg.

CCRED: Centre for Competition, Regulation and Economic Development
6 Sturdee Avenue
Rosebank, 2196
E-mail: infoccred@uj.ac.za | www.competition.org.za
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Abstract

Globally, climate change poses several cross-sectoral challenges, while at the same time opening sector-specific opportunities for innovative industrial restructuring, infrastructure retrofitting, and new value chains development. In this paper, we review the potential for the energy change to be linked to a broad-based reinvestment in energy-intensive industries in South Africa as part of driving a broader structural transformation process. We focus on green hydrogen as a feasible option to replace fossil fuels, especially in high-energy intensive difficult-to-abate industries and liquid fuels for heavy transport. Developing a green hydrogen economy, while capturing its structural transformation potential, calls for targeted, aligned, and sequenced policy interventions coordinating sector-specific and cross-sectoral initiatives. Broad macroeconomic policy and horizontal market-driven measures such as carbon pricing cannot achieve such structural transformation alone. The paper addresses the industrial policy and regulatory challenges for South Africa to realise the potential for green hydrogen through an entrepreneurial-regulatory state. Our analytical-policy framework identifies policy levers and coordination requirements across different instruments and institutions including sector-specific scaling-up strategies, infrastructure, development finance and technology diffusion policy for rapid uptake. Such industrial policy can shape and direct industries effectively, only if there is appropriate regulation such that optimal competition is promoted, hence the need for an entrepreneurial-regulatory state.

Keywords: Climate Change; Energy transition; Difficult-to-abate industries; Entrepreneurial-Regulatory State; Industrial Policy; Competition Policy; South Africa

JEL codes: Q57; O13; O14; O17; L51; L52; D4

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1. Introduction

Climate change is the most pressing grand challenge of the twenty first century, perhaps the greatest, truly global challenge humankind has ever faced. In international fora, such as the latest United Nations Climate Change Conference (COP26), it has been often emphasised that 'we are all in this together'. In reality, climate change impacts countries, social groups, industries, and places in very different and asymmetric ways. Climate change risks will increase inequalities within and between countries. Workers are expected to pay the highest cost of green transition and industrial restructuring, and developing countries are already bearing the costs of a climate change crisis not of their making, in a context of limited financial and technological support and looming debt spirals. There are, however, opportunities for countries such as South Africa to leverage advantages in renewable energy into a green growth and reindustrialisation trajectory.

In its most recent roadmap towards 'Net Zero by 2050', the International Energy Agency (IEA) highlighted the need for a dramatic acceleration in clean energy investments, rapid deployment and diffusion of available technologies, and implementation of climate policies across more than 400 sectoral and technology milestones (IEA, 2021). IEA also denounced how countries' commitments have often felt short in implementation. Specifically, the rate of energy efficiency improvements must increase three times more than the average rate achieved over the last two decades. A 4% per year average increase to 2030 is necessary for economic growth to be decoupled from energy consumption. On the technological end this requires a five-fold increase in energy capacity from solar and wind technologies, as well as exploiting wide opportunities arising from advanced batteries, hydrogen electrolysers, and direct air capture and storage. Supporting this energy transition calls for an estimated USD 90 billion of public investments to be mobilised globally, new measures redirecting finance away from new coal plants and crowding in further clean energy investments in the order of more than USD 4 trillion. The tipping point for green hydrogen is expected for 2025, with a reduction in the production cost from renewables down to a third from its level in 2015. And, South Africa is one of the very lowest cost locations in the world for wind and solar energy. Realising this potential depends on linking renewable electricity to hydrogen production and sale. Competitive green hydrogen for industry requires a transformative industrial policy led by an entrepreneurial-regulatory state - which makes the necessary investments in transmission, establishes a highly credible regulatory framework, and shapes incentives for private investment on a large-scale.

Countries face both the challenge of mobilising large technical and financial resources and the challenge of directing them towards sustainable structural transformation. Slow progresses in energy transition and resistance to shift away from the current unsustainable energy model recorded in several countries (Arent et al, 2017), have not simply negatively impacted global climate change mitigation (IEA, 2021). At the national level, especially among low and middle-income countries, the energy problem is a key binding constraint to transformative development.

The energy transition is thus key to unlocking inclusive and sustainable structural transformation, hence promoting green industrialisation, absorption, and diffusion of new technologies, as well as addressing social inequality. In this sense, the energy transition is a quintessentially cross-sectoral political economy challenge, as it affects all productive, re-productive and consumption activities in society from food and industrial production, to housing, and mobility. At the same time, there has been an increasing realisation that the energy transition is also an opportunity and key leverage point for addressing inter-dependent social and economic challenges (Sovacool and Cooper, 2013).

This paper will assess the industrial policy and regulatory challenges for South Africa to realise the potential for green hydrogen through an entrepreneurial-regulatory state. Globally, climate change poses several cross-sectoral challenges, while at the same time opening sector-specific opportunities for innovative industrial restructuring, infrastructure retrofitting, and new value chains development. Increasingly, green hydrogen is seen as a feasible option to replace fossil fuels (especially in high-energy intensive difficult-to-abate industries such as steel, metal foundries, cement, glass, and fertilizer), as well as liquid fuels for heavy transport. On the expectation that in the coming decade green hydrogen will be competitive with fossil fuels for heavy industries, based on reasonable expectations of carbon taxes, then future industry competitiveness depends on decisions taken now.

In this paper, we review the potential for the energy change to be linked to a broad-based reinvestment in energy-intensive industries in South Africa as part of driving a broader structural transformation process. Developing a green hydrogen economy, *while* capturing its structural transformation potential, calls for targeted, aligned, and sequenced policy interventions coordinating sector-specific and cross-sectoral initiatives. Broad macroeconomic policy and horizontal market-driven measures such as carbon pricing cannot achieve such structural transformation alone. The paper frames the industrial policy challenges for such a transformation, reinvestment, and growth strategy, including the development of linkages upstream, mid-stream and downstream. Our analytical-policy framework identifies policy levers and coordination requirements across different instruments and institutions including sector-specific scaling-up strategies, infrastructure, development finance and technology diffusion policy for rapid uptake. Such industrial policy can shape and direct industries effectively, only if there is appropriate regulation such that optimal competition is promoted, hence the need for an entrepreneurial-regulatory state.

Several countries have already taken decisive steps. China already leads hydrogen production globally; the EU developed the comprehensive Hydrogen Strategy for a Climate-Neutral Europe in 2020; and, Chile launched a national strategy to make solar-based hydrogen for use in the mining industry in 2021. The base for low-cost green hydrogen depends on renewable energy generation, and the related infrastructure including transmission and generation. The change involves regulated markets at various levels reflecting the natural monopoly properties in the transmission grid, and the externality effects. In South Africa there is also a patchwork of regulation relating to liquid fuels and gas which hydrogen can replace. The paper reviews the current regulatory structure and the changes required to ensure the appropriate incentives for investment and pricing through the linked activities, to ensure that it addresses the necessary integration of the system. The activities that require integration include electricity generation, the simultaneous supply for transmission into the grid for electricity distribution and for hydrogen production, and for the on-sale of hydrogen (including storage and pipeline transmission) to industry. The requirements of a regulatory regime which is fit-for-purpose to regulate for an integrated green energy transition are set out.

2. Framing the policy challenges of deep industrial restructuring

The IEA (2021)'s Net Zero Agenda has stressed the magnitude of the financial resources and investments required to address the climate change crisis. However, lack of sufficient financial resources is not the most pressing challenge countries face. Governments face a more fundamental political economy challenge, especially in middle-income countries like South Africa. This political economy challenge is about restructuring their industrial sectors – especially the most energy intensive – towards new models of sustainable prosperity, including new patterns of sustainable production and consumption. If we focus on the supply side, this means opening feasible pathways for incumbents – firms and workers – towards new production, technological, organisational models. These pathways need to favour and direct new 'green entrants' while at the same time manage the exit of 'brown firms' from specific industries or technology paradigms. In most of the cases, turning the existing 'brown firms' into 'green firms' will call for 'deep' industrial ecosystem restructuring. It is deep as it entails coordinated changes within firms and across value chains.

Addressing the political economy challenge of deep industrial restructuring cannot be achieved with so called 'horizontal' measures, that is, policies relying mainly on market pricing coordination. It needs a 'strategic' policy approach that, first, goes beyond a market failure-fixing framework and, second, is not limited to expansionary macroeconomic measures which are often not sufficiently selective in driving and coordinating deep industrial restructuring.

Carbon pricing is a good example of market fixing policies. While these measures might have some role to play (Rodrik, 2014), there has been an increasing recognition of the fact that markets have failed to internalise environmental costs at the scale and speed required. Markets alone have also proven incapable to promote the development and widespread diffusion of green technologies and steer economies towards a much-needed energy and industrial transition. The reason is that the market performs poorly in allocating and committing resources under uncertainty, especially when productive and technology assets are highly specialised, and when specific markets do not exist yet (Chang and Andreoni, 2020).

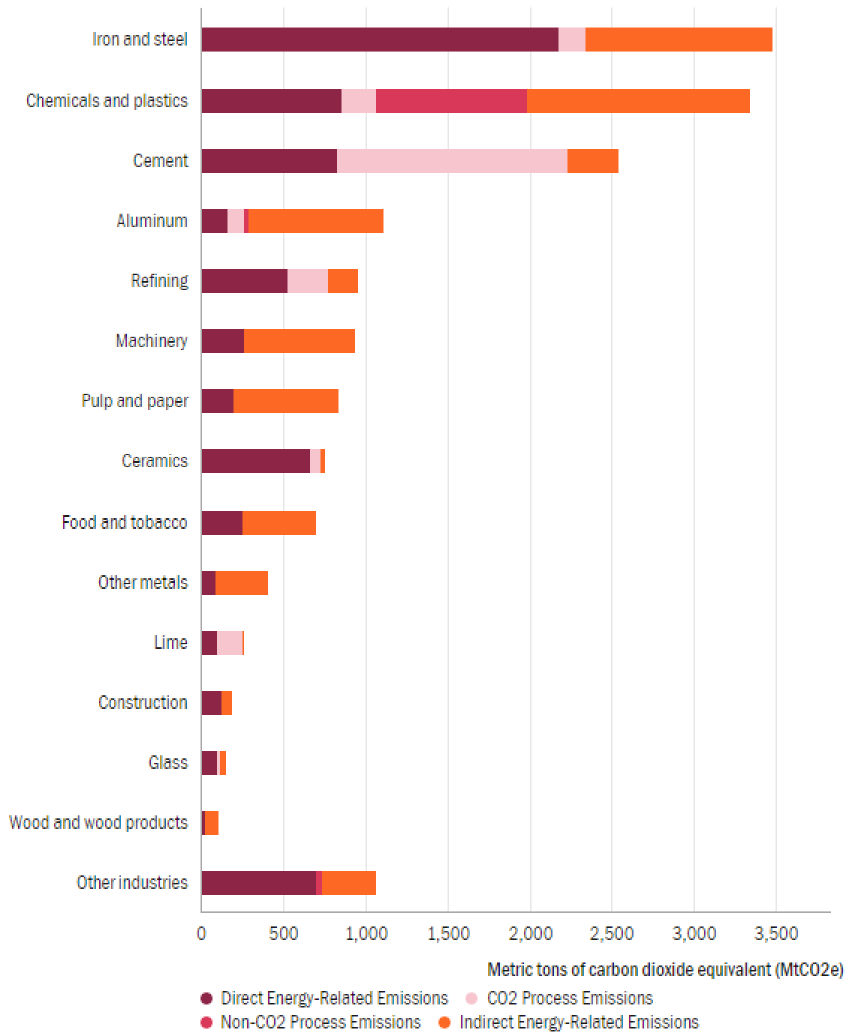
A more strategic industrial policy approach to the climate change crisis is required for the deep economic restructuring, which is needed now, at pace. The framework we advance starts from the recognition of three sets of specific political economy challenges. These are about (1) understanding, leveraging and managing differences across sectors, (2) accelerating the speed of energy transition and industrial restructuring, and (3) directing innovation and its diffusion towards sustainable prosperity.

2.1. Understanding, leveraging, and managing differences across industrial sectors and places

Understanding the different needs, capabilities as well as opportunities for deep industrial restructuring is a first key step towards targeting and coordinating policies for the restructuring of highly heterogeneous and place-specific industrial sectors. Globally, the energy sector generates around three-quarters of greenhouse gas emissions (IEA, 2021), and it is therefore central to this industrial restructuring. However, decarbonisation cannot be limited to the energy sector. All industrial sectors – from agro-food and garments, chemicals and steel, aerospace and automotive industries – contribute to climate change differently in direct, but also indirect and mediated ways. Therefore, each industrial sector requires different restructuring approaches and targeted strategies.

In the case of cement, for instance, Gagg (2014) reports how the use of some dry processing techniques can be half as energy intensive (e.g. GJ/t per clinker, the key energy intensive component of cement) as wet processes. In the case of steel, the use of green hydrogen fed production processes (Hydrogen Breakthrough Ironmaking Technology) and fully recyclable practices can reduce emissions dramatically (Ghoneim et al., 2022). In agriculture, beef has the highest average GHG emissions per 100 grams of protein, but these can range from less than 5 kgCO2eq to as much as 30 kgCO2eq (Poore & Nemecek, 2018). In buildings, solutions must address issues ranging from changing the energy supply, which in itself can draw from various renewable energy technologies, to external and internal thermal insulation, windows, lighting, smart devices (e.g. meters), and Heating, Ventilation, and Air Conditioning (HVAC) systems (Ascione et al., 2017; Luddeni et al., 2018). As an illustration, Figure 2 below illustrates differences in GHG emissions by industry (Rissman et al., 2020).

Figure 1: Global GHG emissions by industrial sectors



Source: Rissman et al., (2020)

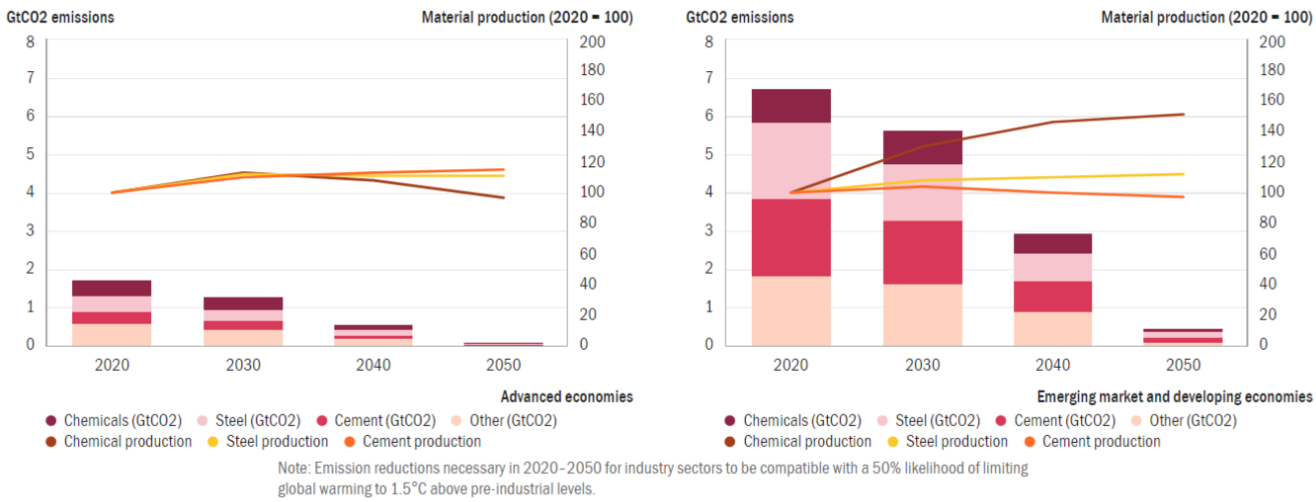
Each industry (and firms within them) are also part of complex industrial ecosystems involving interdependent production, consumption and technological activities spanning along and across regional and global value chains. While decisions about these activities and their impact on climate change are interdependent, achieving coordinated decisions across actors and places towards a more sustainable economy model is difficult given dispersed and unaligned interests, power, and ownership.

Across developing and middle-income countries, needs, capabilities, as well as opportunities for deep industrial restructuring are highly heterogeneous across industrial sectors. These countries, however, share a fundamental problem, that is, the lack of domestically owned productive, technological, and organisational capabilities, including lack of state capacity in implementing and enforcing green industrial policy. While these countries need financial resources for both climate change mitigation and adaptation, without developing their own productive (and state) capabilities they will remain dependent on advanced countries. Indeed, under these circumstances, green finance and debt reliefs from advanced countries will flow in developing countries and immediately flow back to advanced countries to get access to green technologies. It is essential to locate the industrial restructuring within processes of structural transformation (Andreoni et al. 2021).

2.2. Accelerating the speed of energy transition and industrial restructuring

In the last two centuries, major energy transitions – i.e., the shift from wood to coal, or coal to oil – unfolded over several decades and were delayed by technology lock-in and resistance to change. Evidence from transitions also points to targeted interventions at the sectoral and sub-sectoral levels accelerating energy transitions, especially if these measures are not simply 'encouraging entry' of new technology or actors, but policies are also 'facilitating exit' and restructuring of incumbents (Chang and Andreoni, 2020). In fact, facilitating exit via industrial restructuring is as important as promoting diffusion of new technologies via subsidies such as the feed in tariffs schemes widely adopted by Germany and other EU countries. Figure 2 points to the speed of transition imposed by net zero targets for specific 'difficult to abate' industrial sectors. Specifically, global emissions from steel and cement production will have to decrease by more than 90% by 2050.

Figure 2: Speed of transition in difficult to abate sectors: cement and steel production

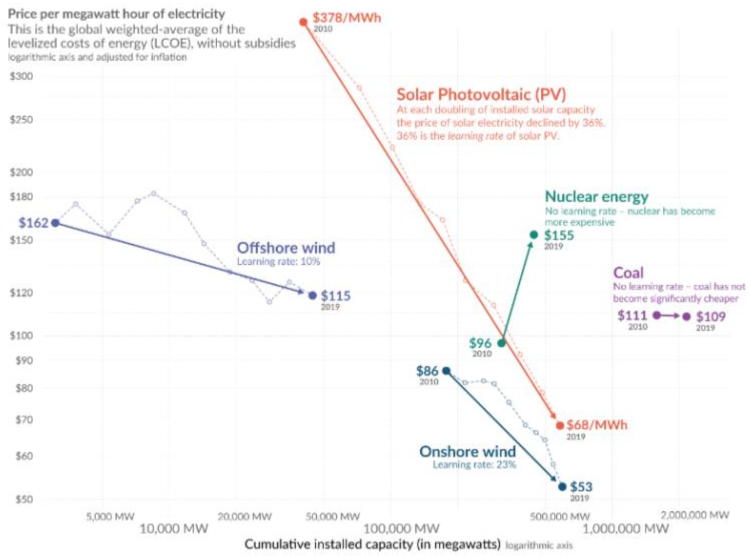


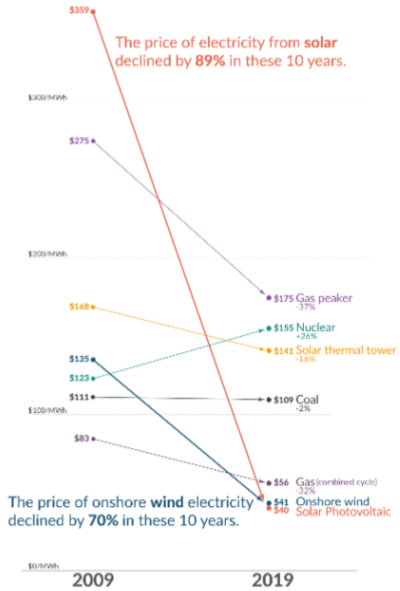
Source: Maltais et al., 2021

2.3. Directing innovation and its diffusion towards sustainable prosperity

The third major challenge is to promote widespread diffusion and continuous innovation in renewables and other low-carbon technologies and, in doing that, seizing the related employment opportunities arising from a green transition. Since 2009, the dramatic decline in the cost of electricity from renewables – solar photovoltaics and wind, on-shore in particular – has offered a viable pathway for accelerating energy transition (IRENA 2021). The steep learning curves associated with these technologies and their increasing installed capacity are responsible for such dramatic shift in prices and the opening of a new windows for green opportunities.

Figure 3: Learning curves and price of electricity from renewable and non-renewable technologies





Source: IRENA, 2021

Behind this dramatic shift, as pointed out by Mathews and Reinert (2014), lies a fundamental difference between non-renewable and renewable energy technologies. The former are bound by the extraction of limited, geographically concentrated non-reproducible resources, hence are affected by decreasing returns and long-term insecurity. On the contrary, renewable energy technologies like solar photovoltaics and wind are manufactured devices. Their manufacturing takes place under a regime of increasing returns whereby costs decline along steep learning curves, and their improvement and deployment is unlocked by structural learning dynamics, hence unfolding of closely complementary technology innovations (Andreoni, 2018). From this perspective, moving away from a Malthusian inspired zero growth or de-growth policy scenario, manufacturing renewable technology for energy transition offer a viable pathway towards a new 'sixth technoeconomic paradigm' (Perez, 2002; Mathews, 2013). Within a techno-economic paradigm framework, successive waves of Schumpeterian industrial transformation are driven by new lead and price-competitive technologies characterised by increasing returns and widespread cross-sectoral applications.

By tapping into nature's continuous flow of present and future energy, rather than past energy stored on the ground, renewable technologies – and their continuous innovation –

coupled with appropriate infrastructure can drive sustainable energy transition. Continuous innovation is needed because even manufacturing development and technologies can hit non-reproducible resource boundaries along the patterns of structural change (Andreoni, 2015; Andreoni and Roberts, 2022a). For example, batteries for electric mobility relies on a limited non-reproducible resource – i.e. lithium – and solar PV manufacturing also relies marginally on some non-reproducible resources. However, continuous innovation in manufacturing processes and product technologies for energy generation can shift these non-reproducibility boundaries, reduce reliance on non-reproducible resources, and make energy transition feasible and sustainable. Furthermore, renewable technologies need innovation and investment in transmission and storage infrastructures to support baseload power for an entire industrial economy. Indeed, system-wide electricity is already more cost-effectively produced by smaller, distributed generation units – typically variable wind and solar – supported by readily dispatchable electricity sources such as from gas.

Green technology innovation and diffusion, as well as complementary investments in enabling infrastructures, should not be seen from a supply-side perspective only. They are in fact major sources of new intermediate and final demand of green products and services which can induce investments and job creation, while opening pathways for incumbents to restructure their industries. Creating and exploiting these new sources of demand to create a broader support for energy transition is as important as promoting supply-side innovation and industrial restructuring.

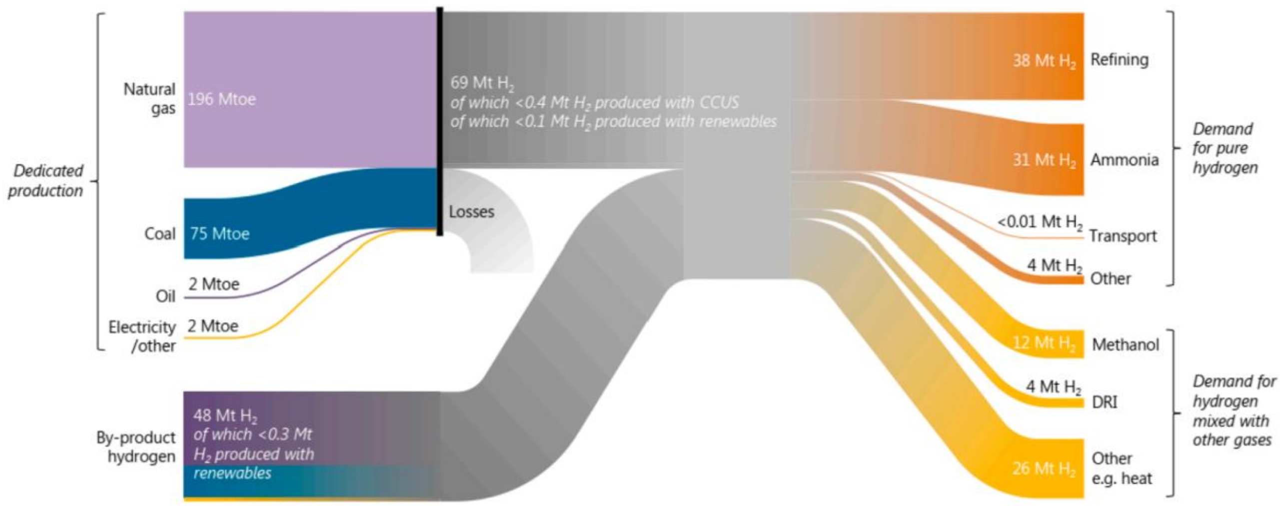
3. The structural transformation potential of green hydrogen

Despite slow progress in energy transition, as stressed above, several countries have been experiencing transformational growth in their energy systems and infrastructure by implementing energy mega-projects and green industrial policies. Across Europe, Germany, the UK, Denmark and Italy are perhaps the most well-known cases, China has also embarked in a dramatic energy transition (Mathews and Reinert, 2014). This 'infrastructural moment' (Bridge et al, 2018), has been inspired by alternative paradigms. In some cases, fossil fuel decarbonisation has been anchored to the mainstreaming of the hydrogen economy, often perceived as a smooth transition pathway. In other cases, the conventional renewables – solar, wind and hydro – have been prioritised. In the case of green hydrogen, that is, hydrogen whose production relies on renewable energy generation, these two paradigms have converged to open the way to a new green paradigm with enormous potential for deep industrial restructuring (IRENA, 2022).

Hydrogen is the most abundant element in the universe. It has been known since the 17th century, however the possibility of using it as a combusted fuel (and in that process being separated from water) goes back to the 1960s when its specific properties – versatility, density, and storability – made hydrogen ideal for space missions (Griffiths et al., 2021). Hydrogen can be generated from both fossil fuels and renewable energy sources. In the former case, depending on the fossil fuel used to produce it, it is known as "brown" (from lignite), "black" (from coal) or "gray" (from natural gas) hydrogen. When combined with carbon capture and utilization or storage technologies is also known as "blue hydrogen". "Green hydrogen", instead, is produced in a sustainable manner via water electrolysis using renewable or zero-carbon emission electricity sources, such as solar and wind or produced from biomass gasification. Once produced, through liquefaction, hydrogen can be transported and stored for a long time; however, these processes from isolation up to transportation are still relatively expensive and prone to leaks which are both dangerous (given hydrogen high flammability) and negative for climate change.

As shown in Figure 4, so far, hydrogen has mainly found industrial applications in oil refining and ammonia production, primarily for fertilizer, and has been produced from fossil fuels (mainly gas). Non-pure hydrogen (that is hydrogen mixed with other gases) has been used in the production of methanol and steel. Alongside these sectors, shipping and aviation are the most promising areas for future application of hydrogen. According to the IEA, around half of these sectors' energy will be supplied by hydrogen by 2070, hence contributing massively to their decarbonisation.

Figure 4: Hydrogen value chain

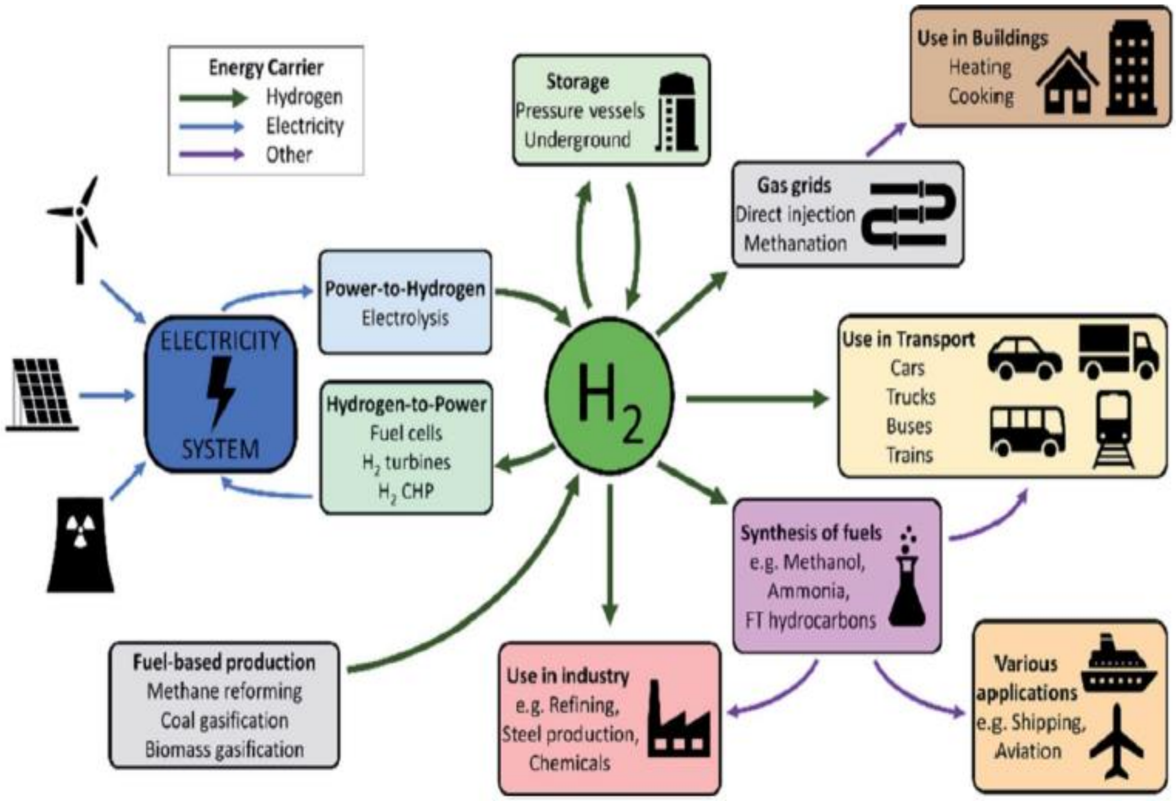


Source: IEA (2019)

At the turn of the 21st century, hydrogen's unique properties have made it an ideal energy vector candidate for green transition across several sectors, especially those industrial sectors relying on chemical transformations that are more difficult to abate. In these sectors, three types of emissions must be considered (Griffiths, 2021). First, direct energy-related emissions, that is, those associated with industrial use of fuels for power and heat. Second, indirect emissions are those related to sourced electricity and heat. The last category is direct process emissions resulting from chemical transformations occurring in industrial processes (e.g., metal oxide reduction processes in both cement and steel manufacturing). As discussed above, deep industrial restructuring goes beyond energy system restructuring to entail fundamental changes in industrial processes, including product formulations. Greening hydrogen in those industrial sectors that need it for chemical transformation is a direct way of reducing emissions. Emissions, however, can be also reduced via widespread use of green hydrogen in upstream value chain processes.

Figure 5 provides a schematic overview of the different potential applications of hydrogen, from deep industrial restructuring as discussed so far, to include energy generation, renewable energy storage, and energy load balancing; fuelling mobility, especially in transport and shipping; heating and cooking in housing. In each of these sectors, hydrogen-related technologies have progressed significantly, especially thanks to the fact that there are capability similarity and synergies between existing industries and hydrogen. Specifically, hydrogen production, storage, transmission, handling and consumption has many overlaps with the current oil & gas industry, and the manufacture of equipment for hydrogen production and utilisation has synergies with existing industrial sectors.

Figure 5: The green hydrogen paradigm: a cross-sectoral perspective



Source: Quarton et al., 2020

It is evident that unlocking the potential requires a combination of an energy regulatory regime which covers generation, transmission, gas and liquid fuels, and an industrial and transport policy which incentives the investments and linkages in key sectors.

Given the transformative potential of hydrogen highlighted by its cross-sectoral applications, especially in difficult to abate sectors, by 2020, around twenty countries had published hydrogen roadmaps and have started deploying industrial policy packages to move towards a green hydrogen economy.

In 2021, South Africa joined this group of countries with a number of initiatives mainly aimed at exploring hydrogen-related opportunities for the overall economy (Hydrogen Society Roadmap for South Africa, February 2022), and specific investments feasibility for three industrial hubs and several upstream industry sectors (DSI, 2021, South African Hydrogen Valley). Indeed, given that South Africa is one of the very lowest cost locations for renewable energy generation through solar and wind, and that the base for low-cost green hydrogen depends on that, the country has the potential to play a central role in the new green hydrogen economy paradigm[1].

[1] South Africa started looking at hydrogen as an alternative source of clean energy and its potential in conjunction with the platinum group metals already in 2008 with the launch of the Hydrogen South Africa or HySA programme under the then Department of Science, Technology and Innovation (now the Department of Science and Innovation).

South Africa, in collaboration with other countries and multi-lateral organisations (e.g. UNIDO), is also playing a pivotal role towards developing hydrogen partnerships in the Southern African region. On 18 May 2022, South Africa, alongside Egypt, Kenya, Morocco, Mauritania and Namibia, launched the Africa Green Hydrogen Alliance, with the intention to foster collaboration and ensure the continent is able to lead in the development of green hydrogen for energy transition.

4. Realising green hydrogen opportunities in South Africa: towards an entrepreneurial-regulatory state

We attempt to frame the emerging debate in South Africa and assess the industrial policy and regulatory reforms needed to seize and capture the opportunities that hydrogen offers towards deep industrial restructuring and overall structural transformation. In this section we set out the plans and key industries. In section 5 we address the central role of rethinking energy regulation for unlocking the very substantial opportunities.

Green hydrogen initiatives in South Africa are framed within the country's overarching National Development Plan (NDP) 2030 which advocates for increased investment in an energy sector that is both economically inclusive and environmentally sustainable. This means increasing sustainable production of energy that is also accessible and affordable, while reducing the overall carbon intensity of the economic structure. For a country like South Africa whose economic structure has historically developed around energy intensive resource-based industries – mining, basic metals and basic chemicals – along with agriculture and automotive, reducing carbon intensity means transforming these industries within a broader structural transformation (Andreoni et al., 2021). South Africa cannot afford the deindustrialisation of such industries closing down and, at the same time, the deep industry restructuring required can be the catalyst for broadening the industry base.

On 14 September 2021, as part of the efforts to re-build the economy after the COVID pandemic, the South African government established the Hydrogen Society Roadmap (HSRM) as a national coordinating framework to facilitate the integration of hydrogen-related technologies in various sectors of the South African economy and stimulate economic recovery, in line with the Economic Reconstruction and Recovery Plan. As sketched in Figure 6, the plan is an ambitious one structured around 6 overarching high-level goals and 70 policy actions for implementation. The policy actions outlined by the HSRM includes the creation of an export market for green hydrogen and ammonia (and related infrastructure investment for hydrogen storage and transport); the development of a Center of Excellence in manufacturing for hydrogen products and include a one megawatt small-scale electrolysis facility piloted by 2025; the creation and scaling up of domestic supply chains and markets for hydrogen with production targets exceeding 500 kilotons of green hydrogen by 2030, and a long term target of 15 GW power generation based on hydrogen by 2040.

The 6 high-level goals listed below are seen as an opportunity to leverage South Africa's natural capital (renewable potential and minerals), its domestic technological capabilities and its role in the Southern African region, towards green jobs and local value creation and capture from hydrogen domestic and global value chains:

- Decarbonisation of heavy-duty transport;

• Decarbonisation of energy-intensive industry (cement, steel, mining, refineries);

• Enhanced and green power sector (main and micro-grids);

• Centre of Excellence in Manufacturing for hydrogen products and fuel cell components;

• Creating an export market for South African green hydrogen; and

• Increase the role of hydrogen (grey, blue, turquoise and green) in the South African energy system in line with the move towards a net-zero economy.

Figure 6: Hydrogen Society Roadmap for South Africa, 2021

Source: Hydrogen Society Roadmap for South Africa, 2021

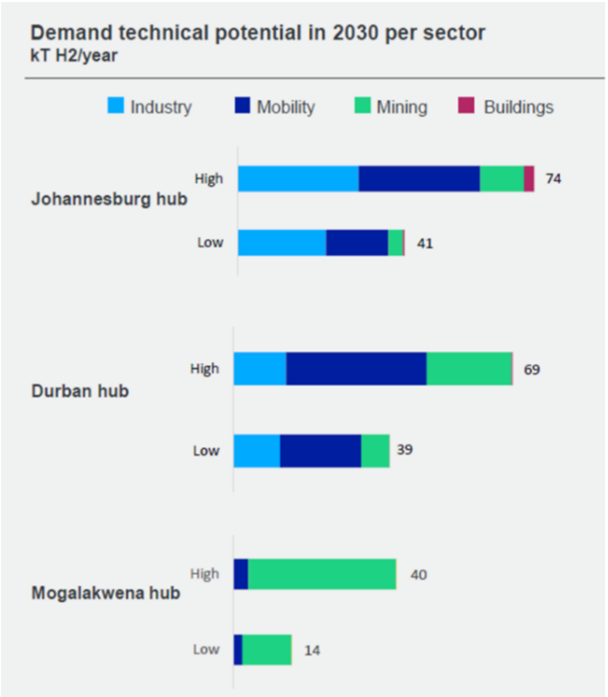
As part of the consultation process with industry stakeholders and civil society, in October 2021 a feasibility analysis report – called 'South African Hydrogen Valley' – was published. This report can be seen as a first attempt to understanding, leveraging, and managing differences across industrial sectors and places in South Africa towards a green hydrogen economy. The feasibility study identified three green hydrogen hubs in the eastern part of the country that had the potential to form a hydrogen valley. These are Johannesburg (and by extension the Gauteng region), Durban (Richards Bay) and Mogalakwena (and Limpopo). For each of these hydrogen valley hubs, the potential demand for hydrogen and its sectoral distribution has been assessed in the feasibility study alongside an assessment of the levelized cost of hydrogen (LCOH) production and transport (Figure 7).

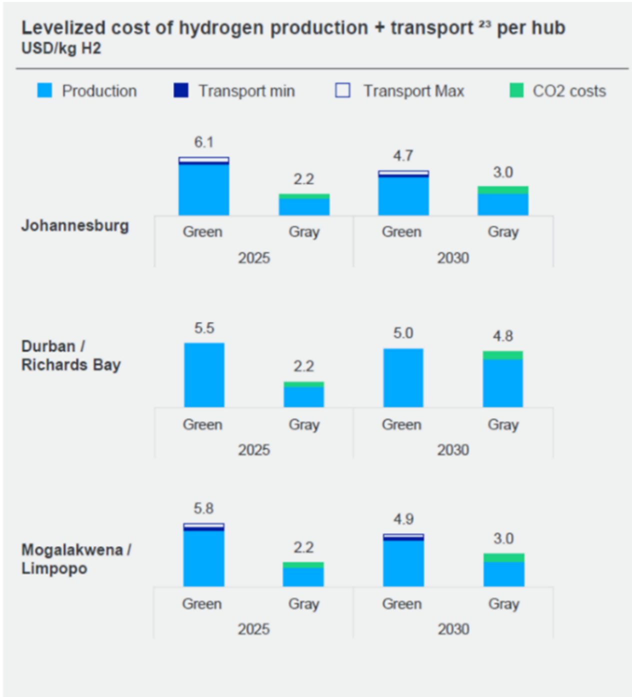
As shown in Figure 7, as a reflection of their industry and demand structure, these three different places/hubs face different sector-specific opportunities for scaling up different shades of hydrogen:

- The Johannesburg hub is expected to be driven by hydrogen-based sectors switching from grey H2, feedstock substitution for ethylene production, fuel and catalyst for iron & steel, public buildings and buses and future private building demand;

- The Durban hub is expected to be driven by fuel for heavy- and medium-duty trucks via N3 freight corridor, fuel for port activities including handling equipment and electricity, oil refining switching from grey hydrogen, medium grade temperature heating, and some export potential (to be sized via developing the infrastructure to store and transport either green hydrogen or green ammonia);
- The Mogalakwena hub is expected to be driven by developing mining trucks fuel for diamond, copper, titanium, and platinum and some demand from heavy- and medium-duty trucks via N1

Figure 7: South African Hydrogen Valley hubs





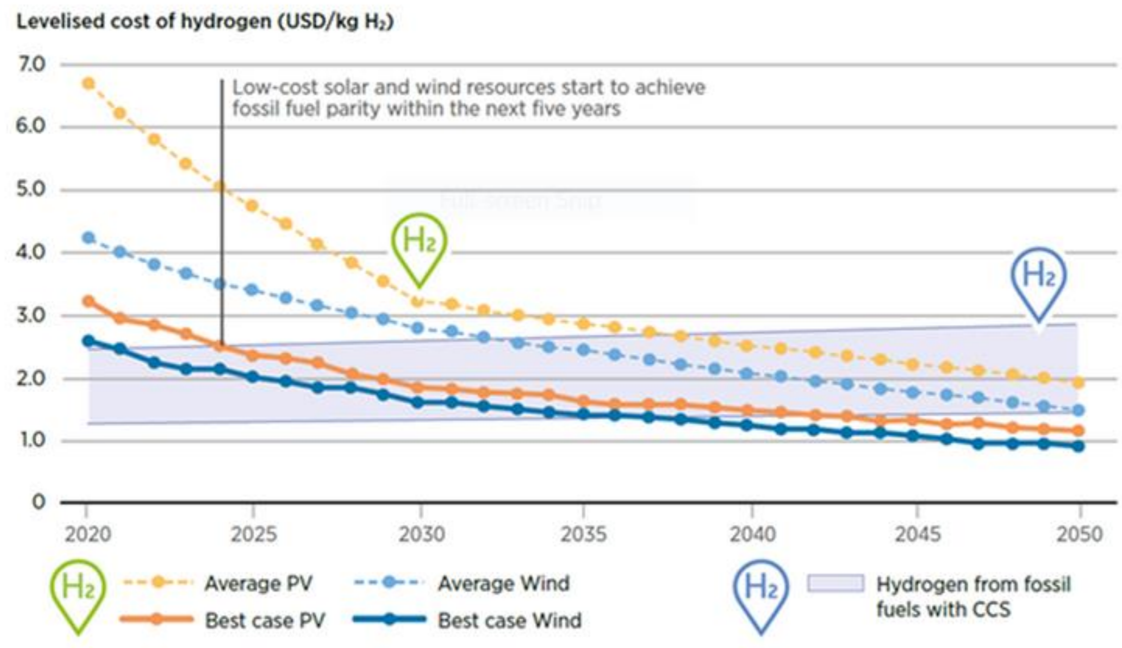
Source: South African Department of Science and Innovation, Report October 2021

The study also identified nine promising pilot to kickstart the Hydrogen Valley in the mobility (mining trucks, buses), industrial (ammonia/chemicals) and buildings (fuel cell power) sectors. The development and scaling up of these pilots critically depends on the increasing competitiveness of different shades of hydrogen and the extent to which opportunities in targeted sectors are seized and investments directed and aligned towards sustainable structural transformation.

Estimation of the LCOH differ based on different hypotheses related to both technologies and markets. According to the 'South African Hydrogen Valley' feasibility study, by 2030, green hydrogen LCOH is expected to be around $4 per kg Hydrogen across hubs, still more expensive than grey hydrogen, with a green premium of $2-$2.5 per kg. Costs in 2030 will be relatively lower in
Johannesburg (4.08-4.11 USD/kg H2) due to higher solar irradiation levels. These costs are higher than the average PV and wind estimates around $3/kg (IRENA, 2021), with 'best case' below $2/kg even while South Africa has among the best renewable energy potential in the world, for a number of reasons. First, the study makes conservative assumptions about the

cost reductions to 2030, and outcomes may be much better. Second, figures are used for PEM (proton exchange membrane) electrolyzers than the lower cost alkaline electrolyzers, due to the higher platinum content in PEM and the response to demand flexibility. Third, the report recommends using off-grid renewable energy supply to mitigate against grid reliability issues and charges. Transport costs also add the price.

Figure 8: Hydrogen price trends



Source: IRENA

It is apparent that policy decisions across equipment manufacture and scale, transmission of electricity and transport and storage all have material implications for the costs of green hydrogen to users.

Opportunities in three main strategic sectors – green energy, hydrogen technology and root industries (chemical and steel) – have started already materialising, with key stakeholders having announced important steps in the direction of developing green hydrogen solutions. Despite these positive developments, old sector-specific constraints remain and, in some cases, new challenges might end up locking hydrogen development opportunities.

4.1. Green energy and export

South Africa is ideally located for renewable energy generation given to high solar irradiation – DRI and wind speed; still almost 70% of energy comes from coal-fired plants operating at very low level of production capacity given chronic lack of investments and broader problems within Eskom. Despite significant acceleration in 2021 after COP26, the energy transition has proven very challenging in South Africa and resistance to opening the sector remains strong (Andreoni et al., 2022).

Given DRI and wind, if these constraints are removed, South Africa has a high potential for green hydrogen production and export (TIPS Report 2020). Green hydrogen would allow to diversify and increase the resilience of the energy sector via increased storage capacity, hence terminating painful load shedding. Ongoing regulatory reforms in energy procurement are however only a first step in the direction of developing the green energy and export potential of green hydrogen. There is an increasing demand for green hydrogen in key markets such as the EU, as proven by the EU willingness to commit resources for a multi-billion green hydrogen investment in Namibia. However, to reach these markets, an entire hydrogen infrastructure must be built. This mega-project investment is particularly challenging in South Africa, even if a certain amount of retrofitting of the existing infrastructure could play a bridging role.

4.2. Hydrogen technology: Critical minerals and fuel cells

South Africa is the world's largest platinum producer (PGMs include platinum, palladium, rhodium and other metals), producing more than twice as much as every other country on Earth combined. Russia is the second producer, but with the Ukrainian war Western markets have been closed to its exports. Platinum is a necessary component of the electrodes of fuel cell engines (acting as electrocatalyst), hence its development is closely complementary and integral to hydrogen technology development for transport and heavy trucks.

Investments in hydrogen technologies for mining equipment are already underway. On 6 May 2022 Anglo American launched in South Africa a prototype of the world's largest hydrogen-powered mine haul truck (2MW hydrogen-battery). The company's overall strategy is to move towards what they call 'nuGen' solutions for green mining: fully integrated green hydrogen system, consisting of production, fuelling and haulage system, with green hydrogen to be produced at the mine site.

While South Africa is ideally located to lead a green mining revolution, persistent high concentration in the global mining industry and endogenous power asymmetries in the global-local mining value chains might prevent South Africa from capturing value from technological capabilities and green mining innovation (Andreoni et al., 2021). Hence, while the hydrogen technology opportunities exist, industrial and competition policies will be needed to turn these opportunities into reality.

4.3. Root industries: Green Steel and Chemicals

Two key root industries in South Africa are traditionally difficult to abate sectors. In both cases, steel and chemicals, there is a dominant firm in South Africa with technological capabilities to move towards green steel and chemicals production. They are Sasol and ArcelorMittal South Africa (AMSA) within the largest world steel producer.

In July 2021, Sasol and the Industrial Development Corporation (IDC) concluded a memorandum of cooperation to jointly develop and shape an enabling environment to advance South Africa's green hydrogen economy, including exploring international financing options. At the Africa Green Hydrogen Forum, held in November 2021, Sasol also announced that it aimed to start producing green hydrogen by 2023. It has also committed to developing ethylene and ammonia from green hydrogen. Sasol can already leverage proprietary gas to liquid technologies (Sasol SPD Process) which is central in the process of liquification of hydrogen for storage and transport.

ArcelorMittal has technological capabilities in green steel production and already tested partial replacement of gas with green hydrogen to produce DRI (direct reduced iron) in its steel plants in Germany and France. The company has been downsizing in South Africa, despite receiving significant government subsidies and support to retain manufacturing capabilities in the country. Directing the existing technological capabilities towards significant investments in South Africa would require introducing and enforcing conditionalities towards green steel production innovation in the country.

One of the main industrial development challenges over the past three decades has been how to address the cost advantages and market power of these two upstream businesses which meant that linkages were not built with diversified downstream industries using steel and chemicals as intermediate inputs (Andreoni et al., 2021; Mondliwa and Roberts, 2019). The pivot to green hydrogen with substantial state support to ensure these businesses are internationally competitive must at the same time ensure that the businesses are part of competitive value chains and not islands of low cost production.

5. An entrepreneurial-regulatory state approach for green hydrogen

The energy transitions for industrialisation require engagement with the ways in which economic regulation works to incentivise investments, as part of appropriate industrial policies. The mapping of possible transition paths has, however, thus far paid little attention to the importance of, and challenges for, economic regulation for the dynamic reshaping of markets required. Regulation has been identified as a major concern by investors in Europe, including the lack of an integrated strategy across hydrogen and electricity.[2]

The attention to providing a coherent regulatory framework is even more essential in South Africa where different regulatory frameworks apply to the supply of different forms of energy including electricity, liquid fuels and natural gas. In electricity regulation was informed by moves to corporatize and then have private participation, notwithstanding that private participation was not going to happen at prevailing prices. In the liquid fuels and gas industries regulation addresses access to essential public and private infrastructure and concerns about market power in pricing by concentrated private suppliers. The South African regulation of prices and facilities is undertaken concurrently by National Energy Regulator of South Africa, the relevant government department (over liquid fuels), and the competition authorities. Note that the electricity, transport fuels and gas networks are all regional - reaching across Southern Africa.

There is therefore a patch-work of rules and authorities with different objectives, standards and powers, within South Africa, where ideally there would be a coherent energy regulation regime in Southern Africa.[3] There are different regulatory approaches, including even for different fuel pipelines. The regulatory and policy regime has been demonstrably very bad in inducing appropriate investment decisions as South Africa has suffered from power outages for many years. There has been extensive litigation over more than a decade relating to gas prices, and many major competition cases relating to fuels and related products. The Renewable Energy Independent Power Producers Programme has been viewed as a success in supporting investment and learning, with rapidly declining costs over successive rounds.

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[2] See European Investment Bank (2022) Unlocking the hydrogen economy — stimulating investment across the hydrogen value chain Investor perspectives on risks, challenges and the role of the public sector. EIB

[3] See das Nair and Roberts (2017); Paelo et al. (2017); Montmasson-Clair and das Nair (2017); das Nair et al. (2015).

However, this required National Treasury guarantees to the producers and effectively succeeded in spite of, rather than because of, the regulatory regime in place.

The issues relating to the appropriate regulatory regime are complex and difficult to address. One approach is simply to ignore them or wish them away. However, this is not tenable and the complexity of the issues means getting to work on them sooner than later. For one thing, transmission investments are critical to the transition, take longer from planning to commissioning than renewable generation, and must be front-loaded. The Hydrogen Valley (DSI 2021) proposal to have off-grid transmission (adding to costs) reflects the poor state of what is critical infrastructure and the rules governing its use. The government's 10-point power crisis plan announced on 25 July 2022 allows businesses to connect private generation to the grid and appears to allow for wheeling through the grid to buyers.

The grid is a (cross-border) natural monopoly requiring effective regulation. Duplication rather than effective investment and operation of the grid simply means a higher cost base. The returns on investment in the transmission infrastructure depend on the investments in renewable generation which in turn depends on the credibility of the regulatory regime and the investment plans. The lessons from the track record over the past two decades urgently need to be learned.

5.1. The importance of South Africa's energy transition

It is well recognised that South Africa is one of the most carbon-intensive energy suppliers in the world. The vast majority of electricity is from coal-fired power stations. A large proportion of the diesel and petrol is produced by Sasol's synfuels plants. These have produced fuels from coal-to-liquids processes, with extremely high emissions. An increasing proportion is being produced from gas-to-liquids, from gas supplied via pipeline from Mozambique.

Historic over-investment in electricity generation capacity under apartheid meant a windfall in that electricity could be priced for additional use at prices covering variable cost. This was benefit was given to a small number of highly energy-intensive heavy industries in basic metals and minerals. The variable costs were incredibly low as the low-quality coal used in the inland power stations could not practically be exported and the mining costs did not price in the negative externalities of pollution. It was therefore among the very lowest electricity prices in the world. In effect, the concessional electricity prices to heavy industries were a massive export subsidy for capital-intensive resource-based sectors, including in neighbour Mozambique (see Andreoni, et al. 2021). This further skewed the economy, compounding the legacy of industrial policy support and cheap finance, with long-lasting consequences. Industrial policy and state support had also entrenched substantial market power in liquid fuels dominated by Sasol, on a regional basis.[4]

When government in the late 1990s and early 2000s followed IFI advice to open new generation to independent power producers (IPPs), plans for investment by Eskom were shelved. Unsurprisingly, the IPPs would not invest at the prevailing low prices which did not cover investment costs. Then, when the country was running short of capacity Eskom had to

[4] See Mondliwa and Roberts (2019); Mondliwa, Roberts, Ponte (2021).

bring back generation investment plans and 'panic buy' power stations at the peak of the commodity boom.

There has been a failure for the policy and the regulatory regime to *anticipate*, and to set prices reflecting their impact on the *structure* of the economy.

Looking ahead, South Africa is one of the best locations in the world for a combination of wind and solar energy generation. Wind and solar is already 40% cheaper than coal on a levelized cost basis, with further ongoing cost reductions.[5] South Africa has the potential, and the imperative, to pivot to a new energy paradigm integrating renewable energy investments through to green energy for industry and transport.[6] The main emphasis in such a shift has been on calculating the investments required, how it can be financed and the transition process of moving away from coal – on the part of Eskom and the communities and workers whose livelihoods depend on coal. These are essential considerations for a transition which is just, around which a coalition for change can be built.

A just green energy transition requires addressing the economic regulation record and options, the political economy of economic regulation and, the role of an entrepreneurial-regulatory state for a rapid transition.

5.2. Economic regulation

Green hydrogen requires linking renewable electricity to hydrogen production and sale. To ensure the appropriate incentives for investment and pricing through the linked activities requires a complete overhaul of energy regulation to ensure that it addresses the necessary integration of the system. The activities that require integration include electricity generation, the simultaneous supply for transmission into the grid for electricity distribution and for hydrogen production, and for the on-sale of hydrogen (including storage and pipeline transmission) to industry.

Regulation in South Africa followed the orthodox recommendations which were based on mature industries, such as the UK, with prices being set using measures to reflect costs plus a reasonable return on investment to maintain and improve services. Access to essential facilities was to be ensured, and externalities priced-in through appropriate taxation.

South Africa demonstrates how inappropriate such an approach to economic regulation is where transformational changes are required. It assumes regulatory institutions are in place and disputes are resolved quickly. It is essentially static and assumes markets are efficient if market failures are 'corrected' and that entrenched market power can be readily policed. The result has been under-investment, incorrect price signals; and state capture (corruption). An overhaul of the regulatory regime is required in South Africa, in any event. However, if the lessons are not learned then the regulations and institutions cannot be adapted to be fit for purpose, and any plan is likely to get stuck in a regulatory morass.

An appropriate regime needs to turn the presumptions of the existing regime upside-down. The first priority is creating the incentives for the investments required to *change* the system of provision, in other words, to realise the potential. As a result, there will be more affordable and reliable energy supply. Three concrete examples are as follows. First, retiring coal generation has a direct return for which measures must be incorporated (taking into

[5] Blended Finance Taskforce and Centre for Sustainability Transitions (2022).
[6] Andreoni, Creamer, Mazzucato, Steyn (2022); Montmasson-Claire (2020); Patel (2021).

account expected future pricing of carbon, as well as the impacts of pollution on communities in South Africa).[7] Second, discount rates based on interest rates in financial markets do not correctly reflect inter-generational valuation of the changes in energy systems. Third, credible commitment on transmission will realise investments in generation as investors leverage finance for green energy and industry. These sunk investments provide the basis for reliable and low-priced electricity for households.

Around $250bn of investment is required under an ambitious decarbonisation plan (BFT & CST, 2022), the majority coming from private sector sources with little de-risking. But, what does the energy regime look like for this investment?

First, the investment required in transmission needs to be valued based on the transformation it enables. It implies state leadership and socialised costs (this under the National Transmission Company in South Africa). These investments literally shape the energy markets – linking generation with demand. Finance is justified at below market rates (the future social and economic basis of South Africa depends on the investment). Ramping up the pipeline of transmission investments under Eskom's separate National Transmission Company is essential for government's commitment to the transition.

Second, a transparent process needs to determine relative prices based on anticipating future needs. The speed of change implies that these need to be more regularly reviewed. This is commonly held to introduce more uncertainty which undermines investment, however, if the basis for decision-making is clear and transparent it improves predictability. Decisions which are not well-founded are subject to ongoing litigation which increases uncertainty.

This relates to the third area of more effective and responsive decision-making. Credibility is essential for the commitments made for investments. Lessons can be drawn from the competition authorities which have established themselves as independent institutions with transparent and effective decision-making able to respond to changing circumstances in tackling price-gouging cases during covid, for example. The rapid transition will mean new sources of entrenched market power (for example, in pipelines and storage for green hydrogen). The credibility of the overall system means effective rules for responsible conduct put in place upfront and being seen to be enforced. This is also in the interests of the firms with market power otherwise their position will be attacked in other ways which will undermine the framework overall.

Fourth, rules must address pricing and conduct across the energy supply system, rather than piecemeal. The current regulatory patchwork undermines rather than facilitates the integration required. It is based on a completely outmoded view of the energy system which separates liquid fuels and gas from electricity, while in reality the transition is based on renewable electricity as the base for green hydrogen and electric vehicles. The capital investments for which rules are required run across: renewable energy generation; transmission & distribution to expand the grid and system capacity; storage to support grid stability; and green industrialisation. The returns on each these are dependent on the overall system.

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[7] BFT and CST (2022)

6. Political economy considerations and an 'entrepreneurial-regulatory state'?

The credibility of the regime for the transition requires it to have broad support. This means engaging with what is fair and just.[8] We must tackle inclusion along with the transformation in production systems. The regulatory regime is central to this as the rules must balance interests, ensure fair reward and be accessible. In the absence of these rules, the market economy has no legitimacy. The competition authorities point the way forward here, in South Africa and elsewhere. For example, unfair prices under Covid-19 were tackled by the South African Competition Commission, as well as by authorities in other countries (Kenya was the first to do so, in fact). And, competition authorities have been good at ensuring that otherwise excluded interests have voice and are championed.

The developments with regard to digital platforms provide pointers to the ways in which appropriate rules, institutions and governance arrangements can be developed to address fast-moving industries with entrenched market power in some firms. The proposals for digital platforms are setting out tests for 'strategic market status' and 'outstanding relevance across markets' where the regimes being developed are quasi-regulatory market monitors. The institutions will be able to set expectations ex ante, and at the same time flexibly monitor, investigate and enforce. The regulatory regime for green energy transition needs to rise to similar expectations.

In parallel with setting out the necessary regulatory framework is coalition-building behind the changes. A powerful referee will only be created if interests are aligned behind the energy transition. Mapping-out the value creation potential is essential for this mobilisation. In the absence of demonstrating the opportunities, and the steps required to realise them, the just transition process is one of simply how to compensate losers and not a constructive agenda. To realise this opportunity requires linking the energy transition to a programme for reinvestment in the industrial base, as part of renewal and structural transformation. At the core of the green energy for industry strategy is thus a programme for rapid industrial growth which builds strong linkages from energy-intensive industries through to diversified economic activities.

The choice of different technologies and their governance models create potential winners and losers in the short run, even when in the long run everyone (future generations) will benefit from sustainable energy transition. The short run distributional consequences among groups, places and countries, makes energy transition highly political. Notwithstanding this, the management of conflicting claims in energy transition, and more broadly in industrial policymaking, is often considered as an aside and ex post problem. This despite the fact that the history of successful industrial policy making has been about promoting change, as much as making sure that those that are potentially going to lose are given an exit option and are steered towards their restructuring and transformation. Michael Kalecki (1976) was among the first scholars to frame industrial development as a political economy process in which different groups (and sub-groups within them) organise their power to protect and promote their interests. Government institutions are themselves expression of different interests, partially reflecting the broader political economy context in which they operate. Therefore, as much as managing conflicting interests among groups

[8] See Montmasson-Claire (2021); Patel (2021)

(and sub-groups) within the broader society, governments will face the challenge of managing conflicts within themselves.

Two types of measures can be distinguished in order to r20educe conflicts involved in industrial policy: 'reactive measures of conflict management' and 'anticipatory measures of conflict management' (Chang and Andreoni, 2020). Reactive measures can be temporary or more long-term, depending on the nature of the problem and have to be about avoiding the losers preventing necessary changes from happening. With regard to the energy transition, given the significant industrial and infrastructural restructuring involved, in the majority of cases measures have to be long-term and perceived as permanent. Anticipatory measures are ex ante interventions and announcements that push forward roadmaps with credible and enforceable performance requirements. Credibility requires financing, procurement and conditionalities integrated with performance requirements. They are enforceable only if coalitions of capabilities, interests and willing are built.

The energy transition has clear supporting constituencies, yet the slow progress in implementation of green policies and regulations suggest that the constituencies are fragmented in space and time, and hence we need to build green coalitions along different geometries (Roberts et al., 2018). Several analyses of climate policies in China, India, Brazil and South Africa have pointed out how most stakeholders and actors that are, on paper, supporting energy transition have in fact multiple, sometimes conflicting, objectives including energy security, building competitive green industries, creating jobs or ensuring future public revenue (Schmitz, 2017; Arent et al., 2017; Hochstetler, 2019). And of course, the problem is not simply understanding what green coalitions can be built behind an energy transition agenda at the national and international levels. The problem is also understanding how coalitions against energy transitions are formed, how they leverage financing and capabilities. Transforming incumbents and recruiting actors from the coalitions blocking change towards green coalitions is strategically important.

An 'entrepreneurial-regulatory state' works with these constituencies and can set out a roadmap for accelerated action, enabling creative changes and rewriting rules to shift decisions and create learning paths (Andreoni and Roberts, 2022b). It may seem unrealistic to ask that relatively weak states take on these roles. However, with the mobilisation of broad constituencies, another way of looking at it is for the state to be an 'effective gardener',[9] cultivating the soil for a 'diversity of firms to flourish' while ensuring the basic conditions are in place. This involves providing the core infrastructure in advance of the new growth, and the package of measures to provide development finance and effective support for skills and technology adoption. These are part of green and inclusive industrial policies tailored to sectors and value chains, measures that invest in shared infrastructure, advisory services and finance as part of a green industrial policy.[10] There are examples on which to build: industries are moving ahead; Namibia has ambitious green energy plans underway including recognising South African market opportunities; South Africa is leveraging finance for the transmission investments required; and, the previous REIPPP programme in South Africa demonstrated the learning which can take place with an appropriate framework.

Recognising the dynamic nature of value creation and extraction in evolving business models means rethinking the role of the state and regulation. An 'entrepreneurial-

[9] Wu (2020)
[10] Andreoni, Mondliwa, Roberts, Tregenna (2021).

regulatory' state is required to link the energy transition to industrialisation. This differs from a state with separate regulatory bodies on sectoral lines and separate government bodies to address market failures in areas such as development finance, research and development and skills. The state needs to be entrepreneurial in being flexible, responsive and analytical. It is regulatory in making, adapting and applying rules to ensure open markets that reward innovation, effort and creativity, while holding accountable entrenched dominant businesses.[11]

We have argued that at the heart of the entrepreneurial-regulatory state is the integration of industrial, regulatory and competition policies for appropriate market-shaping changes.[12] We propose a framework through which uneven development can be analysed and transitions mapped-out, to escape the 'middle-income traps' in which countries are stuck.

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[11] See also Swilling et al. (2022)
[12] Andreoni and Roberts, 2022b

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