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Minerals, Energy-Intensive Industries and Development: Green Transition and Employment in Southern Africa[1]

Antonio Andreoni[2] and Simon Roberts[3]

Abstract

Climate change requires rapid, major, and systemic economic changes at the local, national, regional, and global levels. The acceleration in the diffusion of renewable technologies – solar, wind, and also electric vehicle (EV) technology – has created new demands for the extraction and processing of minerals. Global demand for green hydrogen is attracting multi-billion investments and could also create further upstream and downstream linkages with another critical mineral – platinum – while contributing to decarbonisation of energy intensive industries like steel and chemicals (including production of fertilisers). Upstream and downstream linkages running vertically and horizontally between energy, minerals and industrial sectors can be leveraged to drive domestic industrialisation, create new employment and spur diffusion of green technologies. Countries in Southern Africa could leverage mineral endowments, given the global demand pull, to establish a new *developmental energy-mineral complex.* Development opportunities can however turn into development traps if such green transitions are not governed and regulated through a strategic approach aligned to industrial policy and regulatory reforms. Building on ongoing fieldwork and research, in this paper we focus on the employment implications of such green transitions depending on the approach to: developing linkages from renewable energy, upstream and downstream; key challenges in locating the transition in the context of structural transformation; and, the implications for rethinking the role of the state. The paper examines these issues through the position of South Africa. South Africa faces multiple challenges in transitioning away from carbon-intensive industry while addressing extremely high levels of unemployment. Hence, it is an ideal case study to analyse this set of issues.

Keywords

Structural transformation; energy-mineral complex; linkages; green jobs; South Africa

[1] This working paper is forthcoming in 2025 as a book chapter in: J. Stiglitz, A. Noman, & A. Jayadev (Eds.), *Challenges of employment generation in the 21st century*. Columbia University Press.

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1. Introduction

Climate change requires rapid, major and systemic economic changes at the local, national, regional and global levels. In particular, these changes need to happen in the energy sector and energy-intensive industries, including steel, chemicals, and cement, but also other key sectors such as food and transport. The green transition in Southern Africa opens several windows of opportunities for sustainable structural transformation and employment generation, although challenges persist.

The acceleration in the diffusion of renewable technologies – solar, wind, and also electric vehicle (EV) technology – has created new demands for the extraction and processing of minerals. Lithium, nickel, cobalt, manganese, and graphite are crucial to battery performance, longevity and energy density. Rare earth elements (REEs) are essential for permanent magnets that are vital for wind turbines and EV motors. Electricity networks need a huge amount of copper and aluminium, with copper being a cornerstone for all electricity-related technologies (IEA, 2022b). The production of lithium and cobalt may increase by 500 per cent by 2050 to meet clean energy demand alone. The bottom line is that clean energy technologies and related infrastructures require more minerals (World Bank, 2020).

Countries in Southern Africa could leverage mineral endowments, given the global demand pull, to establish a new *developmental energy-mineral complex*.[4] Upstream and downstream linkages can be exploited for the greening of the energy sector, to drive domestic industrialisation and generate employment. However, the employment potential – both in terms of quantity and quality of employment – is dependent on several factors. First, the extent to which minerals extraction is linked to downstream minerals processing and incorporation in the manufacturing of renewable technologies machinery and equipment. Second, the extent to which part of the global and domestic demand for renewable technologies is captured domestically by developing upstream industries producing and servicing such technologies and infrastructures. A third linkage connects renewable energy to downstream green hydrogen and energy-intensive industries.

In countries like South Africa and Namibia, renewable energy can fuel domestic green hydrogen production competitively, given their solar irradiation and wind. In turn, green hydrogen can be used further downstream to transform difficult-to-abate sectors – chemicals, steel, and cement in particular – currently fuelled mainly with coal in South Africa, or as a major source of new export in countries like Namibia where industrial sectors are currently underdeveloped. The greening of these difficult-to-abate industries is becoming a precondition for exporting into global markets where advanced industrial economies are using their regulatory power to accelerate green transition, while protecting their domestic industries.

Global demand for green hydrogen is attracting multi-billion investments and could also create further upstream and downstream linkages with another critical mineral – platinum – a necessary component of the electrodes of fuel cell engines. South Africa is the world's largest platinum group metal (PGM) producer (PGMs include platinum, palladium, rhodium and other metals), producing more than twice as much as all other countries combined (Russia being the second). Indeed, as this example shows, upstream and downstream linkages running vertically and horizontally between energy, minerals and industrial sectors can be leveraged to create new employment and spur diffusion of green technologies.

Development opportunities can however turn into development traps if such green transitions are not governed and regulated through a strategic approach aligned to industrial policy and regulatory

[4] The concept of the energy-mineral complex was originally introduced by Fine & Rustomjee (1996).

reforms. Failure to develop and nurture mineral-energy-industry linkages and related technology capabilities could result in a new exploitative "green minerals" regime, reproducing patterns of dependent economic growth without structural transformation and broad-based industrialisation.

Building on ongoing fieldwork and research, in this paper we focus on the employment implications of such green transitions depending on the approach to: developing linkages from renewable energy, upstream and downstream; key challenges in locating the transition in the context of structural transformation; and, the implications for rethinking the role of the state. The paper will examine these issues through the position of South Africa. South Africa faces multiple challenges in transitioning away from carbon-intensive industry while addressing extremely high levels of unemployment (Andreoni et al., 2021). Hence, it is an ideal case study to analyse this set of issues.

2. Green jobs: a structural transformation perspective for Africa

In 2015, during COP21, 193 countries agreed on a set of shared ambitions and goals which came to be known as the Paris Agreement. In the period between the Paris Agreement and the Covid-19 pandemic, 2015–19, countries have been facing the challenge of decoupling CO_2 emissions from economic growth and, even more critically, from jobs creation. The pandemic shock has also impacted the job market dramatically, and the retention and creation of new jobs has gained even more centrality in policy agendas. Governments have become increasingly aware of the fact that environmental and social sustainability need to go hand-in-hand; hence, while economies need to decarbonise, they need to keep creating jobs. The political and social support for the Paris Agreement, especially in developing economies, requires coupling environmental and social sustainability. Within this discussion, the possibility of a new wave of so called "green jobs" in renewable energy and other green-related sectors has captured governments' attention.

From a global perspective, the most recent reports by the ILO and IRENA (2022), as well as the IEA (2022a), suggest that there are plenty of emerging opportunities for coupling decarbonisation with employment creation in the new green sectors. However, investments and long-term financial commitments are needed to capture these green jobs opportunities and restructure economies, starting from their energy systems. The energy sector accounts for at least a third of all the emission globally, with the share being much higher in countries depending on coal to generate electricity. Generating electricity efficiently from renewable energy plays a systemic role towards decoupling, as all economic sectors rely on electricity generation. Emissions in the industrial sector are also highly concentrated within so-called energy-intensive industries. Specifically, iron and steel, chemicals and plastics, and cement account for more than 50 per cent of all industrial emissions.

Countries across the African continent are among those most in need of capturing these windows of opportunities for sustainable structural transformation, industrial development, and green jobs creation. Unemployment in major African economies remains extremely high, with South Africa being a striking example of how difficult it has been to expand and sustain good quality employment generation (Andreoni et al., 2021). These are also the countries where the energy sector needs to transform the most to become more sustainable, but even more critically to sustain a growing population and drive the much-needed productive transformation of the continent. Again, South Africa is a striking example of a country whose energy system – and its dramatic collapse over the last few years – has constrained the structural transformation of the economy and jobs creation. It is also an energy system whose dependence on coal has the potential to jeopardise the competitiveness of downstream industries, including access to international markets.

While the green transition in Africa could provide a solution to a set of interlocking challenges and transformation gaps – productive transformation, energy system development, and jobs creation – in most cases, the relationships between these challenges and gaps have been approached and framed within a quite narrow perspective, starting with the definition of "green jobs". These have been largely seen as new jobs directly associated with the renewable sector – solar and wind – and a few closely related upstream industries and downstream activities, including services. Jobs associated with the production of lithium batteries or EVs are other examples of green jobs, although many of these jobs are far from being seen in large numbers in the African continent, where many of these medium-high technologies are imported. The quality of green jobs that are more likely to emerge in the short to medium term in downstream service activities has been also questioned. For example, solar panels maintenance does not generate enough good quality jobs, as the experience of South Africa and Brazil show (Hochstetler, 2020).

Even when the creation of green jobs has been framed within a value chain perspective, in value chains like solar panels or batteries, studies and policies have mainly looked at direct green jobs formation. The potential for indirect jobs formation, through unlocking complementary developments mediated by linkages in other parallel upstream and downstream industries, has been largely unrecognised. For example, several African countries such as South Africa, Morocco and the DRC have started targeting opportunities arising from critical minerals with a focus on specific VC upgrading steps, primarily the processing of minerals and production of precursors (Figure 1). In doing so, they have looked at the direct job creation potential. Productive and related employment opportunities in adjacent upstream and downstream industries mediated through linkages formation have remained largely unexplored.

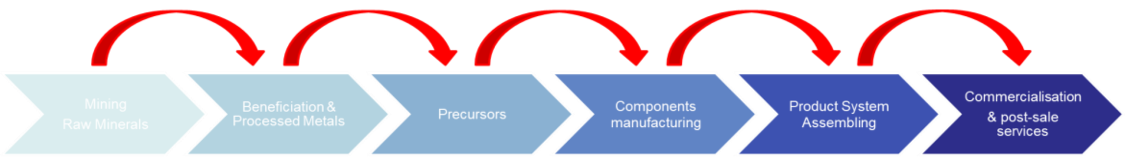

Figure 1. Windows of opportunities and green jobs from a linear GVC perspective. Source: authors

Capturing both direct green jobs along value chains, and indirect green job formation across the economy through linkages, calls for a *structural transformation perspective*. From this perspective, green jobs arise from a dynamic process of employment expansion and local production linkages development spanning across different sectors, each of them with their different shades of "brown" and "green". Indeed, the structural transformation process, captured in the schematic below (Figure 2), portrays a more complex and organic dynamic in which economies do not "jump" directly into a green future; on the contrary, each country explores different potential pathways for diversification and deep industrial restructuring of the economy.

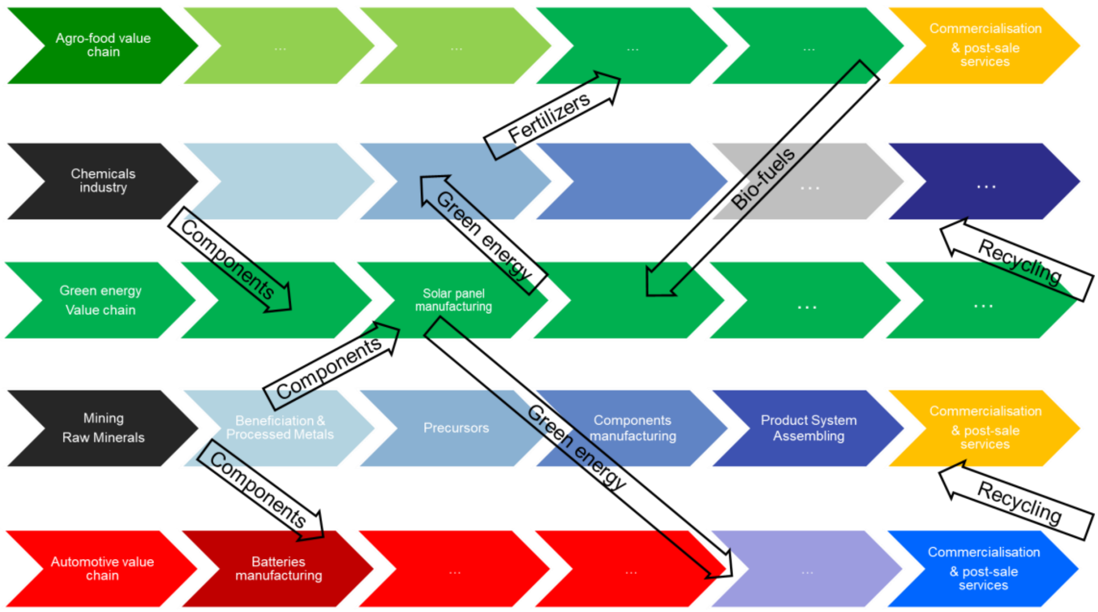

Figure 2. Windows of opportunities and green jobs from a structural transformation perspective. Source: authors

Going back to our example of critical minerals, a structural transformation perspective does not simply point to the importance of increasing the local share of downstream mineral processing, for example, in producing precursors for batteries production; it also points to the ways in which processing downstream entails transformation in the parallel chemical sector. And, in turn, the transformation of the latter can unlock opportunities in other closely complementary but dissimilar sectors (e.g. agriculture through fertilisers). Focusing on these opportunities arising from linkages and multiple interdependencies across sectors also allows identification of potential bottlenecks, such as, for example, the risks of putting unsustainable pressure on certain scarce resources, for example, water.

Further structural transformation pathways highlighted in the schematic in Figure 2 are illustrated in the following sections with a focus on South Africa and specific sets of industries. Notwithstanding this country and industry focus, the structural transformation perspective advanced here has implications for ways in which governments define green jobs and develop policies to seize the green windows of opportunities across broader Southern Africa and indeed the continent.

3. Minerals, renewable energy technologies, and linkage development for employment

In this section we first explore windows of opportunities for both direct and indirect jobs formation arising from minerals extraction, downstream mineral processing, and manufacturing of renewable technologies machinery and equipment. We then focus on the extent to which part of the global and domestic demand for renewable technologies can be captured domestically by developing upstream industries producing and servicing such technologies and infrastructures.

3.1 From critical minerals to mining equipment: downstream industries and employment development

South Africa is the country in the continent where some of the most well-known windows of green opportunities – namely the development of a lithium-ion battery (LIB) value chain for sustainable mobility and just transition – are rapidly materialising. This is due to South Africa's critical mineral endowment and its strategic place in the region and related value chains. If we look at South Africa's export basket of critical minerals (Figure 3), seven minerals account for 80 per cent of the total value of the portfolio. With the exception of the PGM, which is exported completely outside the African continent, looking at the export basket from South Africa to other African countries, there is a significant export of tin (16%), tungsten (21%), graphite (24%) and iron ore (13%) of total continental export of minerals. As the network analysis in Andreoni and Avenyo (2023a) reveals, South Africa is not only an exporter in the continent but also a significant importer of critical minerals. This is due to the presence of large multinational companies which use South Africa as their base for Southern and Eastern Africa operations, but also because South Africa has developed significant mineral processing capacity.

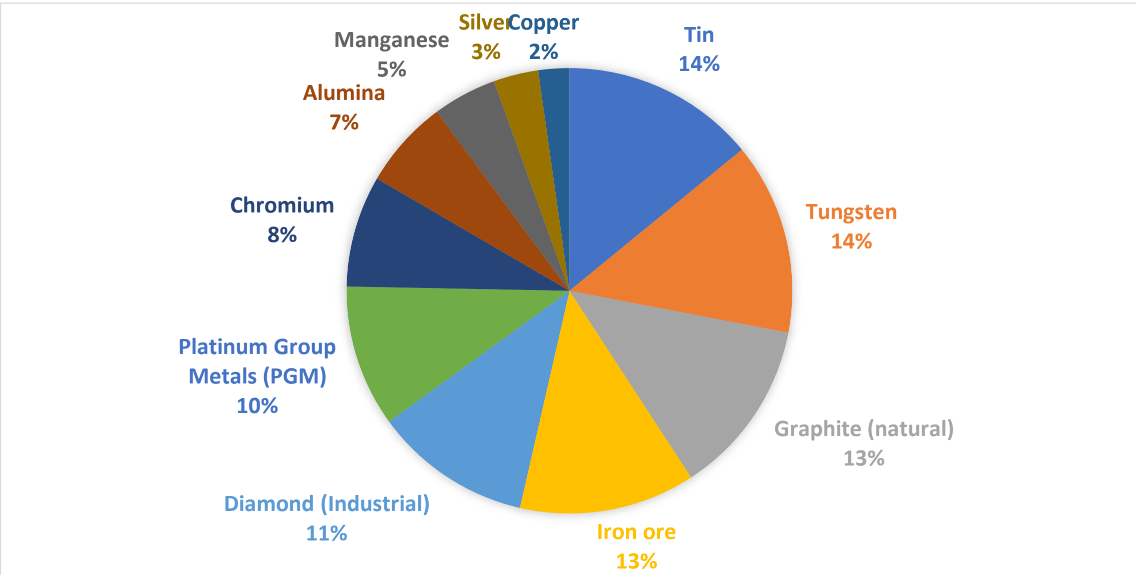

Figure 3. Critical minerals export basket of South Africa to other African countries in 2021. Source: authors based on UNCOMTRADE

Moreover, given its central role in the Southern African Development Community (SADC) region, there is potential for regional industrial integration of these minerals, notably through the implementation of the SADC Industrialization Strategy and Roadmap 2015–2063, and the recent implementation of the African Continental Free Trade Agreement (AfCFTA). Indeed, in SADC are graphite (Mozambique and Tanzania), nickel (Botswana and Zimbabwe), and titanium (Mozambique and Madagascar), amongst others.

A recent report (TIPS & UNIDO, 2021) points out that mining of multiple LIB-relevant minerals, such as manganese, iron ore, nickel, and titanium, is already underway in South Africa and the region. Mineral beneficiation for battery production, while limited, is also present in the country with existing pockets of excellence in manganese and aluminium, and interesting developments in lithium, nickel and titanium. Importantly, battery manufacturing (using imported cells) and battery refurbishing (second-life batteries) is a booming opportunity, with many firms operating in this space, leveraging unique expertise and intellectual property, notably in the development of battery management systems.

By contrast, cell manufacturing, while being explored at the R&D level, is yet to be proven to be commercially viable in the country. Similarly, the development of recycling is still in its early days. The bottom line is that while pockets of technological capabilities and productive opportunities exist in South Africa, the value chain is still emerging and remains disarticulated, with different levels of development along the chain. Outside South Africa, domestic technological capabilities in the mining value chain are limited to some extraction activities and processing of concentrates; however, high-value downstream activities such as manufacturing of batteries are almost not existent.

The development of the lithium-ion batteries value chain can follow at least four pathways: 1) battery manufacturing; 2) mineral refining; 3) cell manufacturing; and 4) battery recycling. Each of them can be integrated over time. The TIPS and UNIDO (2021) study noted that developing battery manufacturing and mineral refining is ready for scale-up, while cell manufacturing and recycling could be explored in the medium to long term, provided they prove to be economically sustainable.

These industrial and technological development pathways are, however, dependent on the developmental governance of critical minerals. That is, the extent to which governments are not captured by particular interests and are willing and capable of negotiating mineral rights conditions as part of a domestic industrial policy for structural transformation. In this respect, the introduction of conditionalities on localisation, technology sources and complementary investments are essential (Andreoni & Roberts, 2022).

The promotion of domestic productive capabilities also has to take into account the fact that critical mineral-based industries are dominated by a few global giants. China is the dominant player in manufacturing LIBs, with three-quarters of production capacity. Panasonic and Contemporary Amperex Technology (CATL) are the leading manufacturers of LIBs, while the cell manufacturing market is dominated by LG Chem, BYD Auto and Panasonic. Similarly, the supply of cathodes, anodes, separators, electrolytes, and electrolyte salts is concentrated in a few countries (China, Japan, South Korea, the USA) and a limited number of firms. Correspondingly, looking at patents related to climate change mitigation in transport and LIBs in particular, the landscape is heavily dominated by a few countries (the USA, Japan, Germany, South Korea, France, China and the United Kingdom) (TIPS & UNIDO, 2021).

There are, however, other more viable routes for diversification. South Africa could leverage its large platinum-group metal resources to develop forward linkages in a number of emerging sectors and become an exporter of value-added technologies based on its natural resources. Almost all the fuel cells sold to date use platinum as a catalyst, with smaller amounts of ruthenium. Fuel cells can be deployed in portable power generation, stationary power generation, and power for transportation (DMR, 2013). Fuel cell technology is a pollution-free electricity generation technology. South Africa could develop several stages of the fuel cells value chain on the back of the catalytic converters industry for the automotive sector and its currently installed capacity for coating of PGMs. Given the transition in the automotive sector, companies involved in the production of auto catalysts could re-purpose their capabilities to enter the fuel cells value chain, with positive implications in terms of jobs retention and sustainability. A related route to diversification and industrial innovation can be found in the related mining equipment sector. South Africa is already a leader in mining equipment technologies.

Retaining such a leadership position requires investing in new mining solutions – such as integrating fuel cells technologies into mining equipment.

The impact of the Covid-19 crisis across different geographies has put new pressure on traditional global mining supply-chain structures, which are concentrated around a few equipment vendors from the USA, Europe, Japan and China. Mining companies have been actively exploring alternative and broader sources of supply to reduce reliance on a small number of overseas vendors (Andreoni et al., 2021). On the one hand, this opens-up opportunities for local or regional companies with the right level of technology and production capabilities to enter into such value chains. On the other hand, foreign multinationals supplying mining equipment and other critical inputs to mining houses might decide to progressively relocate part of their production activities closer to their clients' operations, through subsidiaries or collaborative partnerships with local companies. The South African mining equipment sector is well positioned to seize both these opportunities in the domestic and regional mining markets.

Mining equipment production and services are today the most relevant and technologically advanced segments of the broader special purpose machinery industry in South Africa (Andreoni & Torreggiani, 2020). Specifically, the mining machinery and equipment sector represents the largest contributor to employment, turnover, and exports of the special purpose machinery industry, and it also stands out with respect to total plant, property, equipment (henceforth referred to as PPE) and intangible assets, expenditures in R&D, royalties and patent rights, and staff training (Figure 4).

According to South African Revenue Service (SARS) data, in 2017, South Africa-registered companies producing equipment and machines for mining, quarrying and construction contributed more than 67 per cent of the total employment in the special purpose machinery sector (e.g., around 39,000 employees), and around three-quarters of its total turnover (75%) and exports (79%), accounting to around US$ 1.8 billion and US$ 0.6 billion, respectively. The development of a mining equipment ecosystem in the Gauteng province – two-thirds of the employment and turnover are concentrated there – has driven processes of technological capabilities development and diffusion. Indeed, this sub-sector also makes a serious contribution to the total non-current assets (70%) and spending in capabilities development undertaken in the specialised machinery and equipment industry, as proxied by expenditures in R&D (55%), royalties and patent rights (77%), and spending on staff training (88%) (Figure 4) (Andreoni & Torreggiani, 2020 based on SARS data).

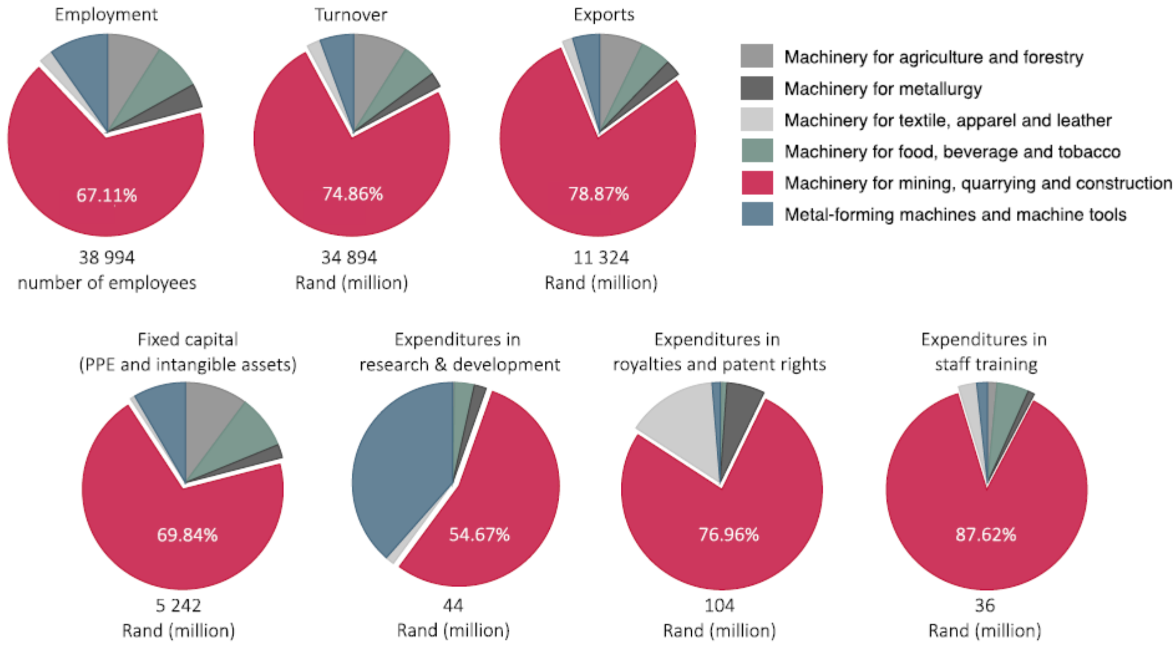

Figure 4. Relevance of mining equipment in the South African specialised machinery industry, 2017. Source: Andreoni and Torreggiani (2020)

The proximity to the mines and the demand for customised and niche technology solutions well-suited to the peculiar geological conditions of South Africa have been critical drivers of learning. The local companies have built global competitiveness with developed production and services operations across major extractive industries and countries, actively engaging with the technological race in the global mining value chain. However, although a number of these companies are large by local standards, they are still significantly smaller than the leading multinationals operating in South Africa. Their expertise and competencies are particularly advanced and at the global frontier only in specific product segments (e.g., deep level mining and related areas).

Local content requirement policies have been combined with measures to increase the participation of black owned businesses (Vilakazi and Bosiu, 2021). These have had very limited effects as they have not been linked to industrial development plans based on a detailed assessment of the products and services to target for local manufacturing (as proposed by Andreoni and Torregiani, 2021). Such an assessment would require a thorough analysis of the product and services to target, and the extent to which these products and services meet quantity, quality and price competitiveness parameters. This measure could be complemented by local content policy reform that would increase companies' compliance with local procurement and content requirements, while promoting exports. Specifically, domestic companies could be given the opportunity of contributing to increasing domestic value addition either by increasing the local content of their products and services in the domestic market or by increasing the value of their products and services in the international export market. In a nutshell, companies would be allowed to import more of the products they need, to the extent that they also increase the local content value of the exported products.

This policy could appeal to several international original equipment manufacturers (OEMs) with or without a local footprint as well as domestic OEMs which are affected by the local content requirements in their production expansion and price competitiveness.

International OEMs willing to invest in South Africa would now have a new development pathway. They would be allowed to increase their imports from their global supply chain for a number of products and services, to the extent that they link up local companies to their exclusive global supply chains and allow them to export internationally. By doing so, local companies would be opening enormous export market opportunities and would potentially become the main suppliers of international OEMs in other major mining countries such as Australia, Canada, Russia and Brazil.

International OEMs could also integrate the local company into their exclusive supply chains, thus "powering" the local company. Of course, a limited number of domestic companies might be technologically and operationally ready to seize this opportunity. The development potential and growth scope however would be extremely significant. This measure would also create some competitive pressure in domestic backward industries. Local OEMs would have some alternative ways to reach local content requirement, that is, by increasing their exports instead of accepting uncompetitive prices.

Within this more flexible local content requirement regime, specific green conditionalities could also be introduced to incentivise the adoption of those green technologies (e.g., fuel cells) and digital solutions (e.g., predictive maintenance) that would reduce emissions and waste, while increasing employment, improving working conditions, and overall domestic value addition. Increasing the domestic footprint of the mineral sector – especially in the critical minerals segments – and related mining equipment industry can have significant implications for employment in South Africa and the broader continent.

Foreign capital investments for the exploration of minerals have been significant in Africa. These investments have created substantial employment in the mining sector in Africa over the last two decades. Despite lower employment numbers since 2014, two-digit manufacturing data from UNIDO show a steady overall increase in employment in the production of minerals and metals in Africa over time (Figure 5). Trends in employment created in the mining sector differ across different regions of the continent with a concentration of employment in the minerals and metals sector in North Africa, followed by Southern Africa. The Central Africa region is observed to have the least employment concentration in the mining and minerals sectors on the continent. It is anticipated that with the global aim of transitioning to clean energy, more employment opportunities may be created in resource-rich countries (Andreoni & Avenyo, 2023b).

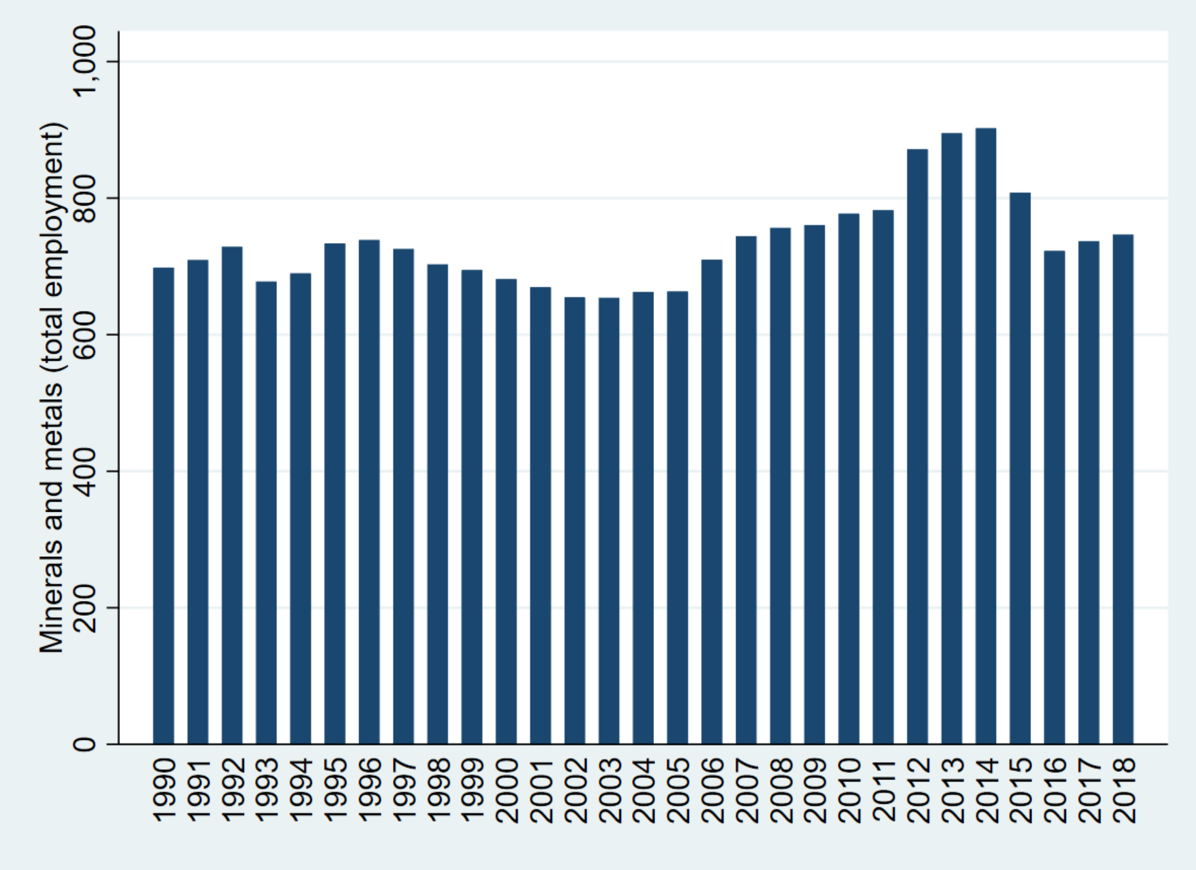

Figure 5. Employment trends in Africa in minerals and metals sector 1990‑2018. Source: authors based on data from UNIDO

3.2 Renewable technologies investments: upstream industries and employment generation

Over the past two decades, investment in renewable energy has grown rapidly globally. Yet of the US$ 2.8 trillion invested globally between 2000 and 2020, only 2 per cent went to Africa (around US$ 60 billion) – despite the continent's enormous potential to generate energy from renewable sources. In Africa, the bulk of investments in renewables picked up in the 2010s, driven by structured renewable energy procurement programmes. These include feed-in tariffs schemes and auctions supported by development finance institutions and multilateral development banks.

Investments remained concentrated in a few regions and countries. The Southern Africa region attracted US$ 22.4 billion, over 40 per cent of total flows over the decade and concentrated in South Africa. Thanks to its Renewable Energy Independent Power Producer Procurement Programme (REIPPPP) (Andreoni et al., 2022), South Africa took in 85% of the region's investment between 2010 and 2020. Solar (PV and thermal) projects accounted for 60% of that investment (US$ 13.5 billion), followed by wind at 35% (US$ 7.8 billion) (IRENA, 2022). In North Africa, in the 2010s, investments totalled US$ 17.5 billion and were concentrated in Morocco (US$ 9.5 billion) and Egypt (US$ 8.2 billion). Investments were concentrated in solar (PV and thermal) (67.5%) and wind (32%).

The impact of foreign direct investments (FDIs) on employment generation remains limited. Aggregating capital investment in renewable energy-related industry clusters (environmental technology; ICT and electronics; industrial; transport equipment) in Africa, the data show that more than half of the jobs that were created between 2003 and 2018 by capital investments are in transport, ICT and electronics. Other sectors like industry and environmental technology follow, with smaller shares of jobs created (Figure 6).

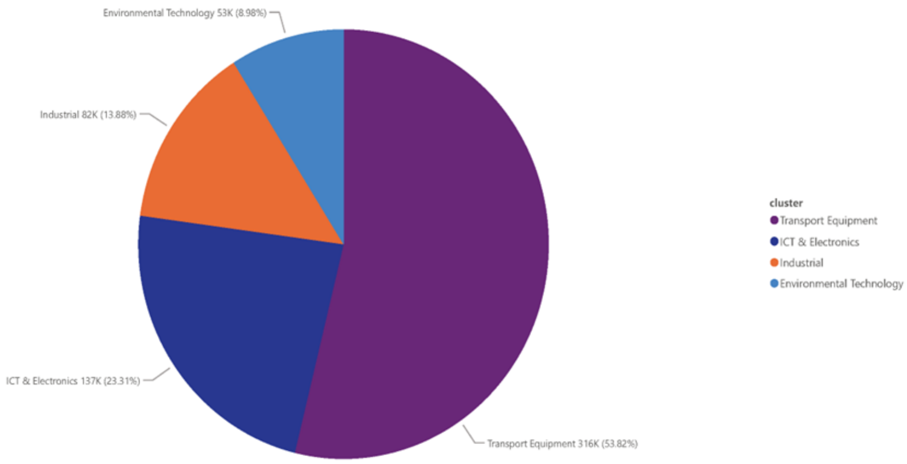

Figure 6. Sum of jobs in Africa created by cluster of FDIs 2003–18. Source: Andreoni and Avenyo (2023b), based on data from the FDI markets database

Notwithstanding, the employment generation potential from renewable technologies is rising globally. A first important attempt to estimate empirically some of the direct effects on jobs comes from recent work by ILO and IRENA (2022). In their analysis of the evolution of global renewable energy employment by technology, between 2012 and 2021, over 12 million new jobs were created, with one-third alone coming from the solar photovoltaic industry (Figure 7). Among the top three contributing sectors are the bioenergy sector, including liquid biofuels, solid biomass and biogas, accounting for another 3.4 million jobs globally, while the hydropower sector alone has created 2.37 million jobs. Wind energy has shown a relatively more modest contribution to jobs creation, partially due to the relatively limited diffusion of the technology and its capital intensity. Solar heating/cooling, geothermal energy, concentrated solar power, heat pumps, and green waste management are among the other sectors in which over a million jobs were created (Figure 7).

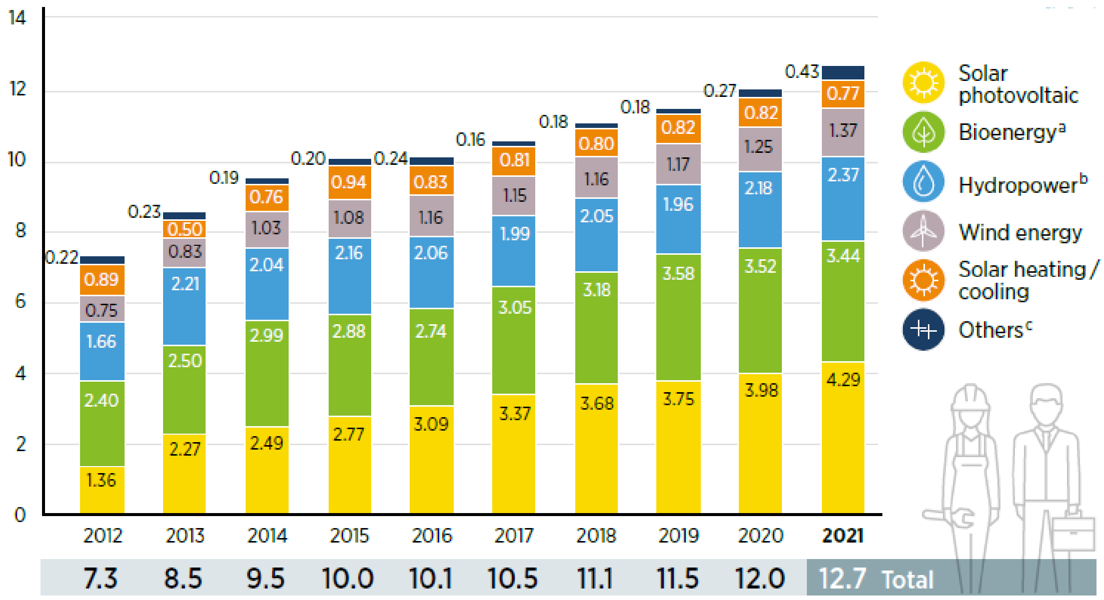

Figure 7. Evolution of global renewable energy employment by technology, 2012–21 (millions). Source: IRENA and ILO (2022)

The potential for jobs creation depends on the technology, its diffusion, and its value chain structure. For example, in their study of the solar photovoltaic (PV) industry, IEA (2022a) estimated that the solar PV industry could create 1,300 manufacturing jobs for each gigawatt of production capacity. To be on track to meet the IEA's Net Zero Emissions by 2050 Scenario, the solar PV manufacturing sector needs to nearly double the number of jobs globally by 2030. These jobs will be differently distributed along the PV value chains and related sectors such as those involving the manufacturing of components such as glass, EVA, back sheets, inverters and mounting systems. These indirect jobs have been estimated to number around another quarter of a million, to be added to the direct jobs. On the contrary, thin-film module manufacturing, which is less job intensive than c-Si technology, creates only around 200 jobs per gigawatt because it entails fewer production steps, and they are mostly automatised (Figure 8).

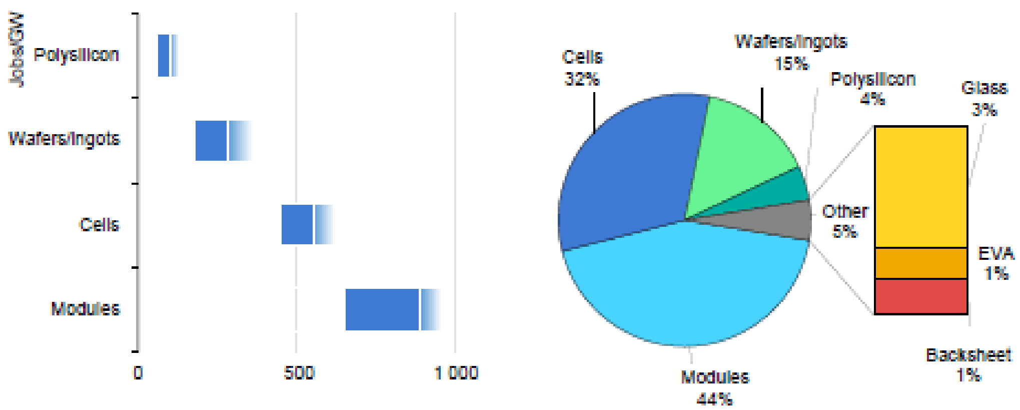

Figure 8. Solar PV sector: jobs per GW of manufacturing capacity and share of jobs per supply chain segment. Source: IEA (2021)

As highlighted in Figure 8, the most jobs-intensive segments along the PV supply chain are module production (requiring 600–900 jobs) and cell manufacturing (450–650 jobs). Their manufacturing involves multiple steps, including in assembly and quality control that are less prone to automation. Over the last decade, however, job automation and automated guided vehicles reduced the jobs-intensity potential of solar PV manufacturing, especially in countries such as China where solar PV have been produced in large capital-intensity and highly automated manufacturing plants (10–20 GW of energy generation capacity). According to the IEA, for smaller manufacturing facilities that cannot realise the same economy-of-scale benefits, labour requirements could increase by up to nearly 60 per cent.

Job creation potential depends on the extent to which the countries investing in PV manufacturing are capable of linking up to GVCs/markets and linking back into their local production systems (Andreoni & Tregenna, 2020). The degree of engagement in technology development also impacts the extent to which created jobs are skills intensive. PV manufacturing requires a diversity of workers, including production engineers, material handlers and assemblers. Due to the current geographical concentration of the solar PV supply chain, the majority of skilled personnel is based in China and Southeast Asia. In many countries, these new skills need to be created and training scaled-up so that windows of jobs opportunities materialise in the local production system. Demand pull for PV technologies is also central to encouraging investments and skills development. Indeed public procurement has become an important policy tool for the green transition.

The potential for green energy generation in South Africa through solar technologies (and wind) is immense. The country's solar energy potential is estimated to be around 500,000 MW, which is more than ten times the country's current energy capacity. South Africa's inability to ensure a reliable electricity supply to the economy has without doubt been an important contributor to its low economic growth and inability to create jobs and economic opportunities for its citizens – its structural transformation (Andreoni et al., 2021). South Africa is also a disproportionate contributor to climate change, and its power generation is largely coal based. Therefore, an accelerated electricity sector transition towards massive upscaling of solar power generation is the key to South Africa's sustained economic recovery.

The prolonged energy crisis resulting in load-shedding has stimulated a much-needed acceleration in the regulatory framework in South Africa and the opening to investments in green power generation. Specifically, from 2021, reforms have been announced to allow a licence exemption for independent power generation projects of up to 100MW. It is also expected that regulations will allow firms to sell excess power to unrelated parties and to "wheel" excess electricity across the grid at a fee.

With the upscaling of green power generation, South Africa is also looking to unlock structural transformation opportunities in critically provinces. In South Africa, coal production and energy generation is also geographically concentrated in the Mpumalanga province. The province faces a multitude of socio-economic and environmental challenges, including high levels of unemployment, inequality and poverty as pressure mounts to transition away from a coal-based economy. The Mpumalanga provincial government has been proactive in exploring opportunities to transition the region to a labour-absorbing green-focused economy, hence creating a positive reinforcing loop between green transition and jobs creation.

Among the many opportunities, the government is focusing on repurposing land, on ultimately decommissioned mines and coal-fired stations to pivot to renewable energy production, utilising the existing transmission assets in the region. Alongside repurposing opportunities, the government is also interested in specific investment opportunities in the agricultural sector where large segment of the population work. Sector-specific opportunities include renewable energy applications, regenerative agriculture, controlled environment agriculture, smart farming / precision agriculture, and agri-waste management. The Mpumalanga Green Cluster Agency was created to capture such opportunities and coordinate efforts between businesses, government, academia and civil society towards a just transition. By supporting these stakeholders, the Agency aims to facilitate more investment and stimulate jobs creation into Mpumalanga's green economy.

4. Green hydrogen for industry and employment

Greening the hard-to-abate industries is becoming a precondition for exporting into global markets where advanced industrial economies are using their regulatory power to accelerate the green transition, while protecting their domestic industries. Measures such as the EU CBAM seek to reduce global emissions but may undermine African industrial development and exports (African Climate Foundation & Firoz Lalji Foundation, 2023) without the appropriate measures to support industrialisation and employment in African countries. The extent of employment creation depends on the linkages being realised. To assess the different trajectories, we consider two of the most important hard-to-abate industries, steel and chemicals, in South Africa. We draw on a range of research to assess the broad employment scenarios from steel linkages to metal products, and from green ammonia to fertilisers with linkages to agriculture.

De-carbonising the hard-to-abate industries of steel and basic chemicals is a key part of the green industrial transformation required globally (IEA, 2021; Griffiths et al., 2021). How this happens will have major implications for employment in middle income countries, especially those like South Africa, in which these industries are well-developed on a foundation of cheap fossil fuel energy. The wider employment effects also depend on the linkages of the heavy industries producing key intermediate products and diversified manufacturing. At one extreme, the changes could lead to (further) deindustrialisation. At the other, the advantages in terms of renewable energy provide an opportunity to place their decarbonisation at the centre of an employment-generating green structural transformation to realise diversified industrialisation.

Historical industrial policies in South Africa built internationally competitive industries around large-scale, previously state-owned national champions. However, these did not become the base for wider industrialisation due to the industrial policies followed and the market power of the lead companies (Andreoni et al., 2021; Black & Roberts, 2009; Mondliwa et al., 2021).

The pivot to green hydrogen for these industries to decarbonise requires industrial, energy and regulatory policies. The design of these policies will influence not only the changes in the upstream industries but the terms on which they are supplied to downstream sectors, with implications for downstream competitiveness.

4.1 Steel to metal products

The South African steel industry is dominated by ArcelorMittal South Africa, which was formerly the state-owned ISCOR. AMSA has the only flat steel mills in sub-Saharan Africa, with a large integrated blast oxygen furnace mill inland operating at a scale exceeding South African demand such that there are substantial exports. It also owns a more modern electric arc furnace "mini-mill" on the coast at Saldanha, which was built for export. High electricity prices, constrained generation and weakened iron ore linkages have meant that the Saldanha plant was mothballed in 2020.

South Africa's industry is underpinned by low-cost high-quality iron ore (ideal for the Direct Reduction of Iron ore (DRI) method for green steel) and cheap energy, while coking coal used as a reductant is imported (and is relatively high cost). Changing to using hydrogen for steel-making means replacing coking coal as a reductant, to reduce high-quality iron ore to sponge iron by extracting the oxygen. The iron is then processed into steel typically through the use of electricity in electric arc furnaces or coal in blast furnaces.

The carbon intensity of the process, along with the potential of renewable energy and green hydrogen, means steel has been identified as a lead industry for green hydrogen in South Africa and globally (IDC, 2022). South Africa is one of the most attractive international locations to make green steel, including for European export, given its renewable energy potential, existing industry base, high quality iron ore, and infrastructure (Trollip et al., 2022).

As green steel standards are adopted and enforced, including for steel embodied in diversified manufactured products, the competitiveness of steel production around the world will depend on the costs of renewable energy and green hydrogen. Technological developments and reductions in renewable energy costs mean that it is expected that near-zero emission steel should approach the cost of high-emission steel, in the most favourable locations, by 2030. For example, India, one of the world's largest DRI steel producers, has targeted bringing the cost of green hydrogen down to US$ 1.50/kg and to reach 5 million tons per annum of green hydrogen capacity by 2030, placing it among the cheapest GH2 producers worldwide.[5] Australia is targeting a GH2 price of US$ 2/kg by 2030, while Chile's roadmap targets it being the cheapest GH2 producer on the planet, at less than US$ 1.5/kg by 2030. To translate renewable energy into low cost GH2 requires linked policies for investment, transmission and production.

The benefits of lower renewable energy costs in countries with huge potential for solar and wind energy may be countered by subsidies in the USA and EU. Based on GH2 costs in 2022, which at around US$ 6/kg are around three times that of alternatives, it has been estimated that a 30 per cent higher green steel cost for European steel producers would need to either be compensated through subsidies or balanced by the application of carbon taxes on non-compliant steel, or a combination of the two (Meldrum et al., 2023). The global restructuring of the steel industry under decarbonisation is thus going to depend on the combination of GH2 costs, coordinated policies for local industry competitiveness, international carbon duties, and subsidies. The investment and production decisions are being made by multinational companies which are optimising their operations across regions in response to the prevailing government policies. The USA and EU are pressing ahead with support for their industries under the guise of green new deals.

South Africa had among the lowest quartile costs in steel production in the 2000s, based on iron ore, coal, and historic industrial policy support. The industry was competitive and exported into European markets. As of 2019, approximately 5,000 jobs in the basic iron and steel industries were accompanied by the direct formal employment of 228,000 tin downstream fabricated metals and machinery industries (or 21 per cent of total manufacturing employment).

Employment in downstream industries has, however, been undermined by a combination of monopolistic conduct by AMSA and a failure of appropriate policies – including skills and technology – for the manufacture of metal products and machinery (Andreoni et al., 2021). While steel recorded substantial net exports (around half of production when the plants operated at capacity), downstream industries have maintained substantial net trade deficits. AMSA priced steel for local buyers at import

[5] See National Hydrogen Mission.

parity prices, some 50 per cent higher than AMSA earned on exported steel (Black & Roberts, 2009). Discriminatory pricing for local customers meant prices even higher than those delivered to customers in Europe (Roberts, 2008).

Realising the potential for relatively low-cost green steel in South Africa requires a set of linked policies. The global move to renewable energy and green hydrogen for steel making is an opportunity for South Africa as green hydrogen replaces coking coal as a reductant, together with the advantages of abundant high quality iron ore and existing infrastructure. However, the employment trajectory in the green transition will depend on linkages to green downstream steel-using sectors.

The danger of the dominant steel firm dictating the policy agenda, coupled with the international incentives and border taxes, means that green steel is exported in primary form. This will have fundamental consequences for employment. The plans being developed by AMSA in South Africa over 2021 and 2022 are for exports of primary sponge steel to Europe and other markets – not to ensure that South African manufacturing has competitive green inputs. This lacuna is also evident in the approach to renewable energy – competitive green electricity is essential for diversified manufacturing, and not only in energy-intensive heavy industries. Provision of renewable energy to diverse customers requires the transmission infrastructure to match investments in generation. The South African government has delayed making the changes required.

The international concentration of the steel industry in a few countries and a few large companies makes strategic engagement with the leading multinational businesses even more important. The top five countries produce 75 per cent of world steel, with China alone accounting for 50 per cent. The top five steel companies are ArcelorMittal, three Chinese companies (Baowu Group, Ansteel Group, Shagang Group) and Nippon Steel of Japan. The industry is organised with the International Iron & Steel Institute for industry, and the OECD Steel Committee bringing governments and industry together.

The alignment of industry interests in the EU and USA, together with the failure of the South African government to respond to the opportunities, means that the green steel pivot in South Africa is likely to serve green industrial transformation in Europe, with exports of commodity sponge steel from the renewable energy endowment and enclave GH2. It will avoid the steel industry closing, with the loss of further jobs in the thousands, but does not realise the industrialisation potential across Southern Africa from the wind, solar and mineral endowment, with employment potential in the hundreds of thousands.

4.2 Fertilisers

Nitrogenous fertilisers account for around two-thirds of all fertilisers and are produced from ammonia, generally using natural gas. Their production is an important source of emissions which must be mitigated: production of ammonia from fossil fuels is nearly twice as emissions-intensive as crude steel production and four times as intensive as cement production in direct emissions (Chung et al., 2023 citing IEA, 2021). Seventy per cent of ammonia is used for fertilisers consumed by agriculture. Fertiliser supply and pricing is key for agriculture and food security, which faces major challenges of adaptation to climate change and is a substantial employer.

Green hydrogen to green ammonia for fertiliser is the second most important positive tipping point identified for a breakthrough in a recent study, after electric vehicles (Meldrum et al., 2023). Three green ammonia projects are already operational around the world and the first commercial-scale facility is due to come on stream in 2023.

Green ammonia can also act as a transport medium for hydrogen, and GH2 can be utilised as a fuel for electricity generation and powering large vehicles such as ships (Jones, 2022; IEA, 2021).

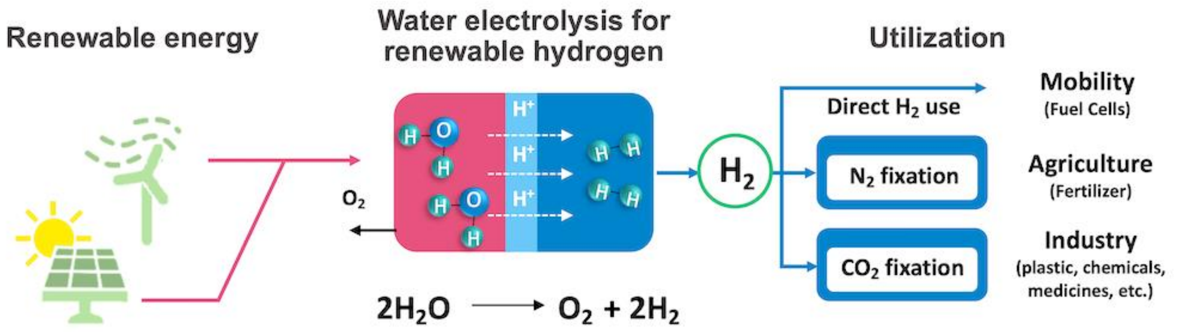

Figure 9. GH2 transition opportunities and utilisation in the chemicals sector. Source: Phillips (2022)

In contrast to steel, South Africa is a substantial net importer of ammonia and of fertiliser. Agriculture across Southern Africa is faced with fertiliser prices that are substantially above world prices. Given transport costs, this means that fertiliser prices have been some 50–100 per cent higher than world prices for benchmark products, meaning the business case for green fertiliser is even stronger in South Africa, all else being equal. However, there are parallels with steel in that the country faces a choice between investments in export enclaves of green ammonia to supply the rest of the world, or production of green ammonia for fertiliser for local usage. By replacing high-priced imports, the shift to green ammonia and fertiliser at scale could reduce prices across Southern Africa and improve food security. There is a further parallel with steel in that a single company, Sasol, is the only producer of ammonia in Southern Africa.

Sasol was built under state ownership on a coal-to-liquid fuels technology, which is extremely emissions-intensive. This was to produce petrol, diesel and kerosene. Sasol's Secunda operation is the largest single source of CO_2 in the world. Ammonia is produced by Sasol as a by-product from the coal-to-liquid fuels process and from natural gas as a feedstock.

De-carbonisation by Sasol is thus an existential challenge for the company. Green hydrogen is central to its transition, with the question not being 'if', but when and how.

The choices around green ammonia and links to fertiliser represent critical policy challenges about how the green transition happens and who benefits, with the impacts on employment and livelihoods in agriculture perhaps directly affecting a greater number of people than any other change in the green transition. This is a challenge for industrial policy and the regulatory regime that has facilitated Sasol's growth while enabling the company to retain its entrenched and vertically integrated position (Mondliwa & Roberts, 2019).

Sasol planned to transition its flagship Sasolburg plant as early as 2023 to act as the company's green hydrogen production base (Creamer, 2021). Sasol's transition is aided by plans to develop a green hydrogen special economic zone, supported by local and international funders such as the German government. These ventures include ammonia in the proposed Boegoebaai special economic zone in the Northern Cape province (Sasol, 2022). The Boegoebaai development is similar to the Namibian investments located along the south-west coast of the continent, which offers the highest yielding wind and solar renewable energy potential (IEA, 2021).

They plan to produce GH2 and ammonia at scale for export, with green ammonia being used to replace heavy fuel oil as shipping fuel (SA GH2 Commercialization Strategy, 2022). This large-scale development aims to support 40GW of electrolyser capacity by 2050.

The economic case for green ammonia for fertiliser in Southern Africa depends on the costs of the alternative. International ammonia costs have averaged US$ 300/tonne (t) from 2011 to 2020 (Meldrum et al., 2023). With the energy price spikes in 2021 and 2022 associated with the Russia-Ukraine war, prices increased to US$ 1,000/t. Green ammonia was produced at around US$ 700/t in 2022, with the first utility project at scale under construction at NEOM (in Saudi Arabia) expected to have substantially lower costs. Costs of green ammonia are projected at US$ 500/t in 2025 in planned exporting locations such as Namibia and Brazil, with a GH2 price of US$ 2.2/kg. These are predicted to fall by a further 20–30 per cent by 2030. This means that a carbon tax of US$ 100/t would increase prices of ammonia from natural gas to parity with green ammonia in 2025.[6] By 2030, green ammonia from locations where renewable energy costs are low should be competitive in international markets.

When the relative prices in Southern Africa are taken into account, green ammonia is already competitive in the region. As a net importer of ammonia and of fertilisers, prices have been more than US$ 200/t above international prices on an ongoing basis (Figure 10). Prices in Zambia have been even further above world prices (apart from when the government subsidised fertiliser for farmers, as in March to June 2022). The case for local green fertiliser production is much stronger than for exports. Exporting countries of green ammonia must also subtract transport costs to supply into international markets, reducing the net returns from these sales.

[6] As close to 2 tonnes of hydrogen are required for 1 tonne of ammonia, the carbon tax increases the cost of fossil fuel ammonia by close to US$ 200/t. For example, the NEOM facility is going to produce 1.2mn tpa of ammonia from 2mn tpa of GH2 (ACWA Power presentation at GH2 summit, Cape Town, December 2022).

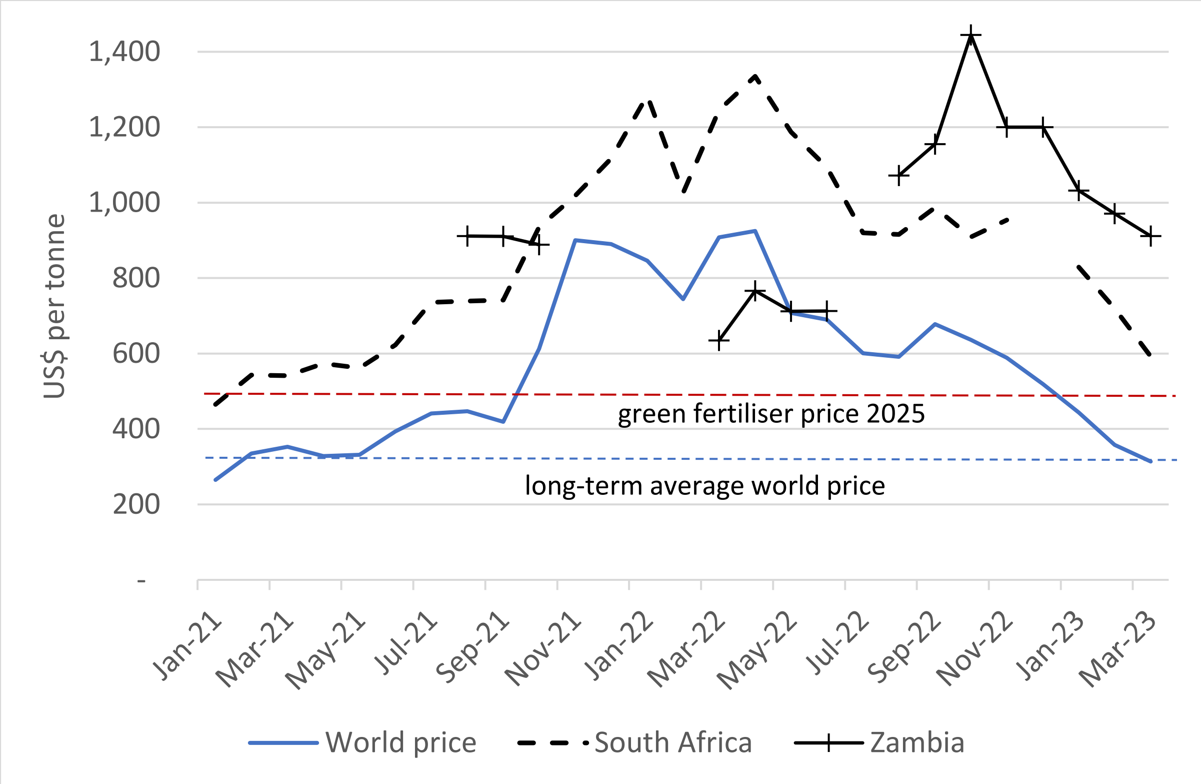

Figure 10. Urea fertiliser prices. Source: world price from the World Bank; Eastern Europe & South Africa prices from Grain SA

It should not be a choice between a green fertiliser industry for Southern Africa and an export enclave of green ammonia for international markets. The outcomes, however, depend on the major investment decisions made by the large companies.

Sasol's interests are to transform their operations, with maximum government support, in a way that ensures the best returns. The best returns depend on maintaining their dominant position in basic chemicals, including ammonia. This position has been entrenched by previous state support, rights to feedstock including coal and natural gas, and infrastructure provision such as pipelines. The South African government has failed to use industrial policy, and regulatory and competition policy tools to discipline Sasol's exercise of market power from its entrenched dominant position (Mondliwa & Roberts, 2019).

The opportunities represented by GH2 and fertiliser demand can mean investments by competing green ammonia and fertiliser producers with huge gains for agriculture across Southern Africa. South Africa has had three large-scale producers of ammonia-based fertiliser (and explosives). One fertiliser producer closed operations and the second is dependent on Sasol and imports for its ammonia. Green ammonia represents the potential for a diverse set of producers once again.

While Sasol paints a picture of being too-big-to-fail in order to lobby government for favourable treatment, its inherent advantages in the production and technology base means it is in pole position already to invest in renewable energy and green hydrogen production. The risks from carbon taxes means it has to do so. Moreover, it has realised huge windfall profits from high energy prices due to the Russia-Ukraine war. For competitive regional pricing and linkages to agriculture it is essential that green industrial and energy policies support rival producers as well as Sasol.

5. Conclusions: the role of the state and policy directions

The complex challenges posed by the green transition highlighted in this chapter in the context of South Africa – specifically the need to coordinate several structural interdependencies and opportunities, while avoiding development traps – call for a renewed emphasis on the role of the state. The cases presented highlight how capturing green windows of opportunities, especially in terms of jobs creation, requires a focus on structural transformation. We have stressed how the necessary holistic approach to policymaking must be grounded in an understanding of both direct green job opportunities, and indirect employment generation dynamics in adjacent sectors of the economy. Jobs creation opportunities are nested along different sectoral value chains and linkages cutting across sectors. These opportunities can be unlocked only if linkages with minerals extraction and processing are developed, and traps of enclave development are avoided with strategic policy interventions.

Within this sustainable structural transformation perspective, it becomes clear how seizing and capturing green windows of opportunities requires the strategic integration of different policies. For example, we have emphasised the importance of integrating policy for critical minerals with specific local content requirements and green conditionalities in the mining equipment industry, where large employment opportunities exist in South Africa. To take another example, we have seen how aligning energy policy and industrial policy is essential for unlocking opportunities from green hydrogen to the chemical and steel industries, with cascade effects along several downstream industries.

The transformation of the energy-mineral complex, particularly central for South Africa, also requires integrating electricity regulation and industrial policy to plan, direct and coordinate investments in critical infrastructure in grids, pipelines and storage.

Market-shaping competition and regulatory rules are critical to creating a viable and predictable business environment in the context of technological change and to avoid capture of the trajectory by the largest firms. The rules need to foster optimal levels of competition in sectors characterised by economies of scale and network effects and that are prone to concentration. Developmental finance is also essential given the long-term nature of these investments and the need to combine multiple developmental goals. Overall, this implies the state must play a dynamic industry-shaping role, influencing value creation and capture through regulatory rules and industrial policies.

Making these green transformations real in South Africa and across the continent cannot be feasibly achieved by compromising on the inclusiveness of these industrial transformations. Indeed, the green transformation needs to be politically sustainable. Mainstreaming jobs creation is key to achieve such politically sustainability. Strictly defined, "green jobs" are far too few to support a coalition for much-needed greening. Our structural transformation perspective provides some insights on how to mainstream jobs creation and broaden the horizon to create politically feasible pathways for change.

References

African Climate Foundation, & Firoz Lalji Foundation. (2023). *Implications for African countries of a carbon border adjustment mechanism in the EU*. https://africanclimatefoundation.org/news_and_analysis/implications-for-african-countries-of-a-carbon-border-adjustment-mechanism-in-africa/

Andreoni, A., & Tregenna, F. (2020). Escaping the middle-income technology trap: A comparative analysis of industrial policies in China, Brazil and South Africa. *Structural Change and Economic Dynamics*, *54*, 324–340.

Andreoni, A., & Torreggiani, S. (2020). *Mining equipment industry in South Africa: Global context, industrial ecosystem, and pathways for feasible sectoral reform*. CCRED Report for Masterplan. CCRED Working Paper 2020/3.

Andreoni, A., Mondliwa, P., Roberts, S., & Tregenna, F. (2021). *Structural transformation in South Africa: The challenges of inclusive industrial development in a middle-income country*. Oxford University Press.

Andreoni, A., Kaziboni, L., & Roberts, S. (2021). Metals, machinery, and mining equipment industries in South Africa: The relationship between power, governance, and technological capabilities. In A. Andreoni, P. Mondliwa, S. Roberts, & F. Tregenna (Eds.), *Structural transformation in South Africa: The challenges of inclusive industrial development in a middle-income country*. Oxford University Press.

Andreoni, A., Lee, K., & Torreggiani, S. (2021a). GVCs, "in-out-in" industrialization, and the global patterns of sectoral value addition. In A. Andreoni, P. Mondliwa, S. Roberts, & F. Tregenna (Eds.), *Structural transformation in South Africa: The challenges of inclusive industrial development in a middle-income country*. Oxford University Press.

Andreoni, A., & Roberts, S. (2022). *Geopolitics of critical minerals in renewable energy supply chains: Assessing conditionalities on the use of technology, market capture and the implications for Africa*. African Climate Foundation.

Andreoni, A., & Avenyo, E. K. (2023a). *Critical minerals and routes to diversification in Africa: Opportunities for diversification into batteries and fuel cells and mining equipment technologies – the case of South Africa*. Background paper commissioned by the UNCTAD secretariat for the 2023 edition of the Economic Development in Africa Report. UNCTAD, United Nations.

Andreoni, A., & Avenyo, E. (2023b). *Critical minerals and routes to diversification in Africa: Linkages, pulling dynamics and opportunities in medium-high tech supply chains*. Background paper commissioned by the UNCTAD secretariat for the 2023 edition of the Economic Development in Africa Report. UNCTAD, United Nations.

Andreoni, A., Bell, J., & Roberts, S. (2023). *Green hydrogen for sustainable (re)industrialisation in South Africa: Industrial policy for hard-to-abate industries and linkages development*. CCRED Working Paper 2023/8.

Avenyo, E. K., & Tregenna, F. (2022). Greening manufacturing: Technology intensity and carbon dioxide emissions in developing countries. *Applied Energy*, *324*, Article 119726.

Black, A., & Roberts, S. (2009). The evolution and impact of industrial and competition policies. In J. Aron, B. Kahn, & G. Kingdon (Eds.), *South African economy policy under democracy*. Oxford University Press.

Chung, C., Kim, J., Sovacool, B. K., Griffiths, S., Bazilian, M., & Yang, M. (2023). Decarbonizing the chemical industry: A systematic review of sociotechnical systems, technological innovations, and policy options. *Energy Research & Social Science*, *96*, 102.

Creamer, T. (2021). Sasol aims to begin producing green hydrogen in Sasolburg from 2023. https://www.engineeringnews.co.za/article/sasol-aims-to-begin-producing-green-hydrogen-in-sasolburg-from-2023-2021-11-22/rep_id:4136, accessed 28 November 2022.

DMR. (2013). *Fuel cells and the future role of South Africa through its platinum resources*. Report R99/2013, Department of Mineral Resources, South Africa.

Fine, B. & Rustomjee, Z. (1996). *The political economy of South Africa: From minerals-energy complex to industrialisation*. Witwatersrand University Press.

Griffiths, S., Sovacool, B. K., Kim, J., Bazilian, M., & Uratani, J. M. (2021). Industrial decarbonization via hydrogen: A critical and systematic review of developments, socio-technical systems and policy options. *Energy Research & Social Science*, *80*, Article 102208.

Hochstetler, K. (2020). *Political economies of energy transition: Wind and solar power in Brazil and South Africa*. Cambridge University Press.

IDC. (2022). *South Africa's green hydrogen commercialisation strategy*. Released for comment, December 2022. Industrial Development Corporation.

IEA. (2021). *Ammonia technology roadmap*. Paris. https://www.iea.org/reports/ammonia-technology-roadmap

IEA. (2022a). *World energy employment report*. https://www.iea.org/reports/world-energy-employment

IEA. (2022b). *Special report on solar PV global supply chains*. https://iea.blob.core.windows.net/assets/2d18437f-211d-4504-beeb-570c4d139e25/SpecialReportonSolarPVGlobalSupplyChains.pdf

ILO, & IRENA. (2022). *Renewable energy and jobs: Annual review 2022*. https://www.ilo.org/global/publications/books/WCMS_856649/lang--en/index.htm

IRENA. (2022). *Renewable energy market analysis: Africa and its regions*. https://www.irena.org/publications/2022/Jan/Renewable-Energy-Market-Analysis-Africa

Jones, N. (2022). From fertilizer to fuel: Can "green" ammonia be a climate fix? https://e360.yale.edu/features/from-fertilizer-to-fuel-can-green-ammonia-be-a-climate-fix

Meldrum, M., Pinnell, L., Brennan, K., Romani, M., Sharpe, S., & Lenton, T. (2023). *The Breakthrough Effect: How to trigger a cascade of tipping points to accelerate the net zero transition*. Systemiq, University of Exeter and Bezos Earth Fund. https://www.systemiq.earth/wp-content/uploads/2023/01/The-Breakthrough-Effect.pdf

Mondliwa, P., & Roberts, S. (2019). From a developmental to a regulatory state? Sasol and the conundrum of continued state support. *International Review of Applied Economics 33*(1), 11–29.

Mondliwa, P. Goga, S., & Roberts, S. (2021). Competition, productive capabilities and structural transformation in South Africa, *European Journal of Development Research*, *33*, 253–274.

Roberts, S. (2008) Assessing excessive pricing – the case of flat steel in South Africa, *Journal of Competition Law and Economics 4*(3), 871–891.

Sasol, & ITOCHU. (2022). *Announcing Memorandum of Understanding (MoU) on green hydrogen and ammonia*. https://www.sasol.com/media-centre/media-releases/sasol-and-itochu-announcing-memorandum-understanding-mou-green-hydrogen-and-ammonia, accessed 28 November 2022.

TIPS, & UNIDO. (2021). *Opportunities to develop lithium-ion battery value chain in South Africa*. https://www.tips.org.za/images/Battery_Manufacturing_value_chain_study_main_report_March_2021.pdf

Trollip, H., McCall, B., & Bataille, C. (2022). How green primary iron production in South Africa could help global decarbonization. *Climate Policy*, *22*(2), 236–247.

Vilakazi, T., & Bosiu, T., (2021). Black Economic Empowerment, barriers to entry, and economic transformation in South Africa. In A. Andreoni, P. Mondliwa, S. Roberts & F. Tregenna (Eds.), *Structural transformation in South Africa: The challenges of inclusive industrial development in a middle-income country*. Oxford University Press.

World Bank. (2020). *Minerals for climate action: The mineral intensity of the clean energy transition*. https://bit.ly/3EGa3EP.

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