Growth Through Inclusion in South Africa

Chapter 4: South Africa's Green Growth Potential

A Report by The Growth Lab
at Harvard University

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About the Growth Lab

The Growth Lab is a research program at Harvard University. With its multidisciplinary team of roughly 50 staff, fellows, and faculty led by Professor Ricardo Hausmann, the Growth Lab pushes the frontiers of economic growth and development policy research. The Growth Lab advances academic research on the nature of economic growth and conducts place-based engagements that aim to understand context-specific growth processes, help address key constraints, and identify promising growth opportunities. Through its research and teaching activities, the Growth Lab has become a global thought leader offering breakthrough ideas, methods, and tools that help practitioners, policymakers, and scholars understand how to accelerate economic growth and expand opportunity across the world. Consistent with the mission of the Harvard Kennedy School of Government, in which the program is housed, the Growth Lab works to expand capabilities for improved economic policymaking such that more people and societies can enjoy higher levels of wellbeing through stronger, more sustainable, and more inclusive economic growth processes.

Growth Lab applied projects utilize a variety of tools from economics and other disciplines with a focus on understanding place-specific growth challenges and enabling learning-by-doing to address these challenges locally. Key frameworks developed at the Growth Lab and applied within projects include Growth Diagnostics and Economic Complexity. Growth Diagnostics is a methodology that identifies the most binding constraints to better growth outcomes, which informs and allows policymakers to take highly impactful actions. Economic Complexity is a growing field of research that leverages network science and machine learning to understand what economic activities a given country or region could expand into next, based on what it currently does. Growth Lab applied projects aim not only to understand constraints and opportunities in specific places, but also to empower local stakeholders in real time and *in situ* to address constraints and seize economic opportunities through training, capacity building, and the development of practical, place-based tools. All applied Growth Lab projects aim to generate publicly available research of relevance to the local community as well as frameworks, tools, teaching resources and learning experiences that strengthen the HKS community.

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4.1 Executive Summary

The South African economy is hampered by supply-side constraints that limit its economic growth. Chapter 2 of this report showed how a collapse in state capacity to supply and maintain key infrastructure and services have slowed growth. Chapter 3 discussed longer-term causes of spatial exclusion and how these have limited South Africa's growth potential by preventing individual capabilities from interacting. These two issues constrain the ability of the South African economy to create and maintain jobs. At the time of writing, the ongoing electricity crisis hinders business productivity, while freight and port operations disruptions limit the productivity of mining and other regional value chains. Problems in network industries also obstruct businesses' capabilities to fulfill demand due to widespread delays stemming from port conditions, electricity shortages, and freight disruptions. Addressing these supply-side constraints is crucial to enhancing the competitiveness of the economy.

The electricity crisis is especially critical because South Africa had previously developed a comparative advantage in electricity- and electricity-intensive industries. Figure 4.1 shows the electricity intensity of South Africa's exports in comparison to other nations.[1] South Africa's electricity intensity of exports has remained consistently high - at around the 90th percentile - relative to the rest of the world from 1995 to 2016. Figure 4.2 shows that the energy consumption by the country's industrial sector (manufacturing, construction, and mining) as a share of GDP is also high compared to the rest of the world. Both South Africa's exports and its domestically oriented industrial sector are highly intensive in electricity and energy use. In other words, South Africa has developed a comparative advantage in industries that demand high levels of energy and electricity. The most prominent example of this can be seen within the mining sector and its downstream activities (products that use mined resources as inputs) and upstream activities (mining services, mining machinery, etc.). However, this also applies to the manufacturing sector more broadly, where the metal and chemical industries consume significantly more electricity per unit of value than mining (Fortunato, 2022). South Africa has

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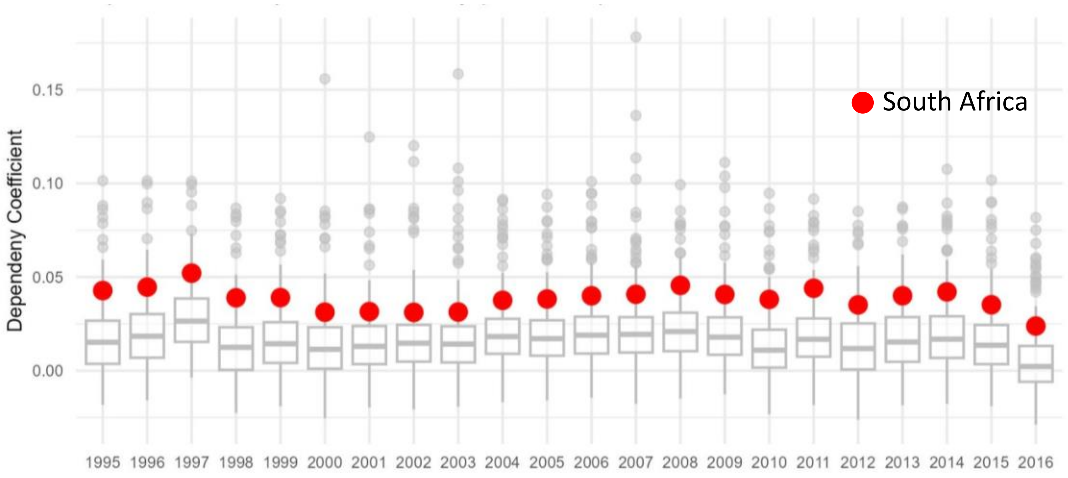
[1] The coefficients were calculated using the same model Rajan and Zingales (1998) used to analyze financial dependence's role on economic growth.

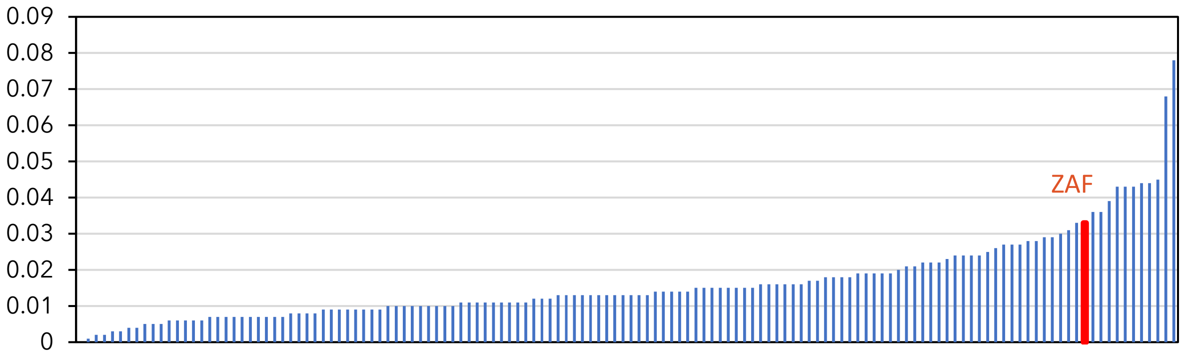
also developed multiple downstream industries with solid linkages with energy- and mineral-intensive activities, like fabricated metals, structural metals, and alloys.

FIGURE 4.1: GLOBAL DEPENDENCE OF EXPORTS ON ELECTRICITY (1995-2016)



Sources: Own elaboration based on International Trade Data from Atlas of Economic Complexity and US BEA Input-Output Tables.

FIGURE 4.2: ENERGY CONSUMPTION OF INDUSTRY (TOE) / GDP (2015 USD PPP) IN 2018



Source: Own elaboration based on International Energy Authority (IEA) World Energy Indicators.

South Africa developed this comparative advantage many decades ago thanks to the availability of cheap energy from coal. Since the 1920s, Eskom has been using abundant deposits of cheap coal. By 1930, Eskom's electricity was one of the cheapest in the world (Eberhard, 2007). Until around 2007, Eskom was able to supply the economy fully with cheap electricity. By that time, energy-intensive customers in the mining, metals, and manufacturing industries represented a large fraction of the electricity demand. Eskom’s sales to direct large-scale customers represented 60% of total sales (Eberhard, 2007). Historically, this ability to provide ample amounts of cheap energy was predicated on the country's capacity to exploit coal. As a result, South Africa has consistently been one of the ten countries that consume the most coal per capita in the world (BP, 2021).

Modern South Africa has lost the ability to transform coal into cheap energy, and coal is not as competitive as an energy source as it used to be. Several factors have changed. First, Eskom lost its capacity to produce energy cheaply. Between 2007 and 2022, electricity prices increased by a factor of 6.5 while the overall price index increased by only a factor of 1.3 (based on data from Eskom and StatsSA), meaning that the real price of energy (i.e., the price after controlling for inflation) increased by more than 200%. This implies a major deterioration in the country's comparative advantage in electricity-intensive production. Part of the initial increase in tariffs was the result of a recognition that tariffs were set below long-run marginal costs and implied not just a comparative advantage but a distortive subsidy. However, the problem is not only with price. At the same time, load-shedding means that actual tariffs do not fully measure the loss of competitiveness of the industry: unreliable supply has become a major source of disadvantage. Moreover, coal has become relatively less competitive as a cheap fuel source for electricity generation, given changes in energy-producing technologies. For example, the relative price of solar and wind energy has declined exponentially over the past decade, eroding the competitive advantage of coal in electricity generation. According to IRENA (2022) estimates, newly installed solar-powered energy plants in 2021 had lower costs than the cheapest coal-fired option in the G20. This implies that relative to the rest of the world and other energy sources, even if Eskom's problems are overcome, South Africa's comparative advantage in coal-fired energy will not be as important as it used to be.

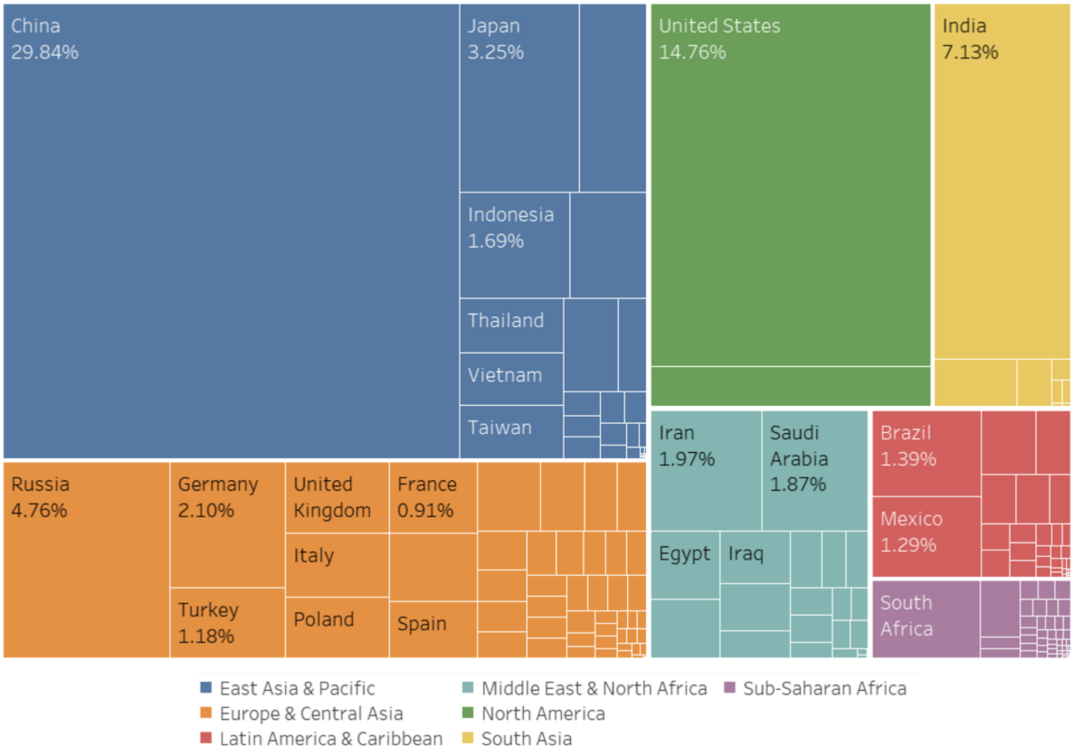
For these reasons, it is vital for South Africa to focus on creating new sources of comparative advantage by leveraging the global changes that the energy transition is creating. As is well known, global emissions of Greenhouse Gases (GHGs), particularly carbon dioxide, are causing climate change. Reductions in GHG emissions will require an energy transition that can only work at a global scale. This represents a fundamental change to the structure of the global economy and the determinants of comparative advantage. Beyond electricity generation, economic shifts are beginning to take shape across transportation, industrial and agricultural sectors, which also produce GHG emissions. While the transition represents a challenge for the countries and industries that rely heavily on fossil fuel energy today or export fossil fuels, it will create ample economic opportunities. This chapter will characterize what these changes might entail and explore ways to exploit them to create new sources of comparative advantage and growth in South Africa.

4.2 “Green Growth” in a Decarbonizing World

Though not yet at the pace needed to meet international climate change goals, the world is making substantial strides toward decarbonization. Regardless of whether the Net Zero Emissions (NZE) goals are met sooner or later, there is no doubt that global demand for clean energy and technology will continue to increase. The International Energy Agency (IEA) estimates that to achieve the NZE goals by 2050, solar-powered energy generation needs to grow at an average annual rate of 25% in 2022-2030 (IEA, 2022b). This rate is not impossible, considering that solar PV manufacturing increased at a compound annual growth rate of 25% between 2015 and 2021 and by 35% in 2022 (IEA, 2023b). In addition, electric vehicle (EV) sales have been exploding since 2022. The EV share of the overall car market went from 4% in 2020 to 14% in 2022, and it is expected to reach 18% in 2023, according to IEA’s projections (IEA, 2023a). Battery manufacturing capacity increased by 85% in 2021-2022 (IEA, 2023b). In short, the attempt by many countries to decarbonize their economies is leading to very rapid growth in certain enablers of that decarbonization. These enablers have emerged - after years of research and development - as economically viable technologies. Averting increasingly disastrous global impacts of climate change will require innovation and scaling of technologies that reduce GHG emissions across the economy through a process that is sometimes referred to as “deep decarbonization”.

The international framework that has taken hold through landmark accords such as the Paris Agreement of 2015 is focused on achieving global decarbonization by having each country focus on targets for their own decarbonization. Countries identify and announce their "nationally determined contributions" and international systems attempt to monitor progress toward achieving them. To reach international goals, these commitments must become increasingly ambitious over time. Countries are asked what they can do to reduce their own emissions. Yet, CO_2 emissions are concentrated in a handful of countries (Figure 4.3). China (30%), the United States (15%), India (7%), and Russia (5%) represented 57% of global emissions in 2015-2021. South Africa represented only 1.3% of emissions during the same period. Therefore, drastically reducing South Africa's emissions will have very minor effects on global emissions and climate change.

FIGURE 4.3: CO2 EMISSIONS BY COUNTRY (% OF TOTAL), 2015-2021



Source: Global Carbon Atlas, 2023.

However, there is much more that South Africa can do to contribute to global decarbonization under a different "green growth" paradigm. If one thinks beyond the narrow and constraining notion of "what can you do to reduce your emissions" and instead ask "what can you do to help the world reduce its emissions," South Africa has much more to contribute to the global effort. As the world strives to meet the Paris Agreement goals, demand for a wide set of products will have to increase very significantly. South Africa could become a major exporter of these products. In other words, beyond decarbonizing itself, the country can strive to become a major supplier of the means of global decarbonization. These products have the potential to propel the country by leveraging rapidly growing global markets. The world is going to need a large increase in the products and services that will enable (or supply) decarbonization. This makes the global fight against climate change perhaps the most exciting driver of innovation and growth potential in this generation.

The path toward global decarbonization is full of uncertainties, but there are some clear directions of change based on fundamental economic realities and emerging shifts. First, the world will need to electrify anything that can be electrified. Good examples are electric vehicles for transportation and electric arc furnaces for producing and recycling steel and making alloys. Second, electricity must be made in green ways, leveraging solar, wind, hydropower, and nuclear technologies. Variable sources of energy will require balancing the electric grid with storage, using either grid-scale batteries or pump storage. Transmission lines will have to connect new sources of energy to the grid. All of this will require metals made by refining minerals that must be dug out of the ground. There is no way to decarbonize the planet without a mining boom. Third, manufacturing processes that emit CO_2 for chemical reasons will have to be abandoned in favor of alternative processes. For example, the reduction (i.e., de-oxidation) of minerals to make metals currently use coal and natural gas as reducing agents and emit CO_2 in the process. Technologies using hydrogen as the reducing agent or electrolysis will compete to make green steel and other alloys. Fourth, things that cannot be electrified, such as ships and airplanes, will need green ways of making fuels. Finally, the world is going to need ways to capture carbon. These changes require a major transformation to the global economy and a shift in the underlying determinants of comparative advantage.

We propose a framework to formulate strategies and policies that can explore and exploit these emerging opportunities. We classify the opportunities into three main buckets that are of the highest relevance to South Africa:[2]

1) Make the enablers of global decarbonization,
2) Make green versions of grey products for the global market,
3) Export green knowhow.

Strategy 1: Make the enablers of global decarbonization. To decarbonize, the world will need a vast set of goods that will enable low or zero-carbon electricity systems. This will include equipment for electricity production (e.g., solar panels, wind turbines), transmission (e.g., cables, converters, capacitors), and storage (e.g., batteries, pump storage) of clean energy.

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[2] One additional strategy would be to monetize carbon sinks and carbon storage. Stakeholders are already working on identifying the feasibility of carbon capture and underground storage (CCUS) in South Africa. The national government, in collaboration with partner institutions, has already started a Pilot CO2 Storage Project (PCSP) in a preliminary analysis phase focusing on the onshore Zululand and Algoa Basins (Surridge et al., 2021).

Electric vehicles (EVs), fuel cells, and other products and technologies are emerging that allow for transportation and other human necessities to be done without the use of fossil fuels. Other types of machinery, for example, electrolyzers as a key technology for green hydrogen production, are poised for rapid growth. These goods are also heavy users of metals and rare earth minerals. Strategy 1 involves a move to participate in the emerging supply chains that enable the rest of the world to decarbonize.

Strategy 2: Make green versions of grey products for the global market. Oil and coal are highly energy dense. This makes them cheap to transport. Consequently, the local availability of energy has not constrained the location of production over the last several decades. For example, energy-poor countries such as Japan, Korea, and Germany have been able to specialize in energy-intensive products such as steel. Since the cost to transport energy has been low, they just import energy. Green energy, by contrast, is much harder to transport. Solar PV became the cheapest source of electricity in 2020, providing a levelized cost of electricity of less than 34 dollars by barrel of oil equivalent (BOE) (IEA, 2020). Still, in 2019, storing that energy in the form of green hydrogen increased the cost to over USD 476 per BOE on average (BloombergNEF, 2020). When converting the green hydrogen to green ammonia for more accessible transport, the costs increased to over USD 884 per BOE (Ibidem). Additionally, the transport of green hydrogen requires significantly higher degrees of infrastructure. Hydrogen would need 3-4 times more storage infrastructure to replace natural gas in today's global economy. This is anticipated to come at an expense of USD 637 billion by 2050 if it were to ensure a comparable degree of energy security (Ibidem). This implies that there will be a great incentive to use energy close to where it can be produced efficiently. One implication is that global decarbonization can be achieved more easily if energy-intensive activities such as steel, aluminum, and ammonia production or data storage move to places that, because of their endowments, can produce green energy cheaply. Strategy 2 is based on developing a local capacity to produce cheap green energy to attract energy-intensive industries that must relocate to reduce their carbon footprint.

Strategy 3: Export green knowhow. Much of the knowledge needed to decarbonize will not be embodied in tools – such as solar panels or electrolyzers – or in easily replicable protocols or other codified knowledge that can be easily moved between places. Knowledge will intensively require the deployment of human capabilities in the form of services. For example, projects require engineering, procurement, and construction (EPC), often bundled with finance. Complex manufacturing requires knowledge that may be licensed, such as the Fischer-Tropsch process that SASOL has mastered. These knowledge-intensive services will be in high demand in a decarbonizing world. The strategy aims to maximize the export of such activities to grow by supplying the knowledge needs of a decarbonizing world.

South Africa's green growth strategy should seize these opportunities to capitalize on the changes brought about by global decarbonization. In the rest of this chapter, we analyze a series of topics that are strategic for South Africa under each of the above approaches. This is not a comprehensive list of issues and opportunities but instead a list of opportunities that should be evaluated in the context of a national green growth strategy.

4.3 Strategy 1 – Make the enablers of global decarbonization.

South Africa is well-positioned to supply the world with critical minerals needed for the energy transition and to enter strategic segments of clean energy value chains. Mineral opportunities include those related to platinum group metals, chromium, vanadium, and others. Opportunities of interest in supply chains for energy technologies include the production of membranes, catalysts, and assembly of fuel cells and electrolyzers within the hydrogen supply chain; research, demonstration, and production of flow batteries based on vanadium and other chemistries; the electric vehicle supply chain; and the wind energy supply chain. Policies to promote entry into each of these supply chains must be industry-specific, and depend highly on industry characteristics, South Africa's context, and the component parts of supply chains that South Africa seeks to occupy. The following subsections expand on these opportunities.

4.3.1 Critical Minerals

The world needs a mining boom to develop clean energy systems. Clean energy technologies are significantly more mineral-intensive than technologies based on fossil fuels. For example, an electric vehicle currently requires six times more minerals than an internal combustion engine (ICE) vehicle, and a wind farm requires nine times more minerals than a coal-fired power plant (IEA, 2021b). These technologies are driving huge increases in demand for specific minerals. For example, according to IEA projections (IEA, 2021b), the demand for rare earth minerals could increase three to seven times between 2021 and 2040. The demand for lithium, cobalt, and copper is currently high and projected to increase even further in the upcoming decades.

South Africa is a leading producer of critical minerals. Figure 4.4 lists minerals that have been classified as critical for the green energy transition and reports the share of South Africa in their current global production. South Africa is, by a substantial margin, the world's largest producer of platinum and platinum-group metals (PGMs). These are essential to produce and use hydrogen because they are essential for the membranes that go into electrolyzers and fuel cells. South Africa is also a major producer of chromium. This mineral is used as a catalyst in these membranes, goes into lithium-ion batteries, in high-performance solar panels, and in making stainless steel alloys used in solar, hydro, and geothermal plants. According to IEA, the demand for chromium will double by 2040, in a scenario that only includes currently announced nationally determined contributions (NDAs). It would quadruple in a scenario consistent with achieving net zero by 2050 (IEA, 2021b).

This bodes well for the demand for South Africa's mining products, but these opportunities are constrained by collapsing state capacity. As discussed in previous chapters, the mining industry has been hampered by the electricity crisis, problems in rail and port services, policy uncertainty, and cumbersome licensing and regulations specific to the mining sector. For example, platinum production hit record under-production due to power outages in 2023 (Dempsey, 2023). Since the electricity crisis started to intensify in recent years, exports of platinum have decreased significantly. Even before load-shedding started in 2007, regulations prevented the country from expanding its market share during the commodity super-cycle that started in 2004. If the country is to maximize the benefits of the coming global boom in mineral demand, it will need to address these issues.

FIGURE 4.4: SOUTH AFRICA'S CRITICAL MINERAL RESOURCES

Mineral	South Africa's Global Market Share (2021)	How many countries have the resource?
Chromium	43.5%	Seven countries produce Chromium.
Fluorspar	5%	14 countries produce Fluorspar. Most Fluorspar mining is in China.
Manganese	38%	17 countries produce Manganese.
Palladium	40%	Six countries produce Palladium.
Platinum	73%	Six countries produce Platinum.
Tellurium	< 1%	Eight countries produce Tellurium.
Vanadium	8%	Six countries produce Vanadium. Most Vanadium comes from China.
Zirconium	<1%	Eight countries produce Zirconium.

Source: Own elaboration based on U.S Geological Survey.

To take full advantage of the global mining boom, South Africa must improve its policy framework specific to the expansion of critical minerals exploration, production, processing, and innovation. South Africa has the knowhow needed to claim a place in these markets, but it will need to address the state failures that have limited its potential to date. Projects to supply critical minerals often require significant time to develop. IEA (2022c) estimates that the major mines that began operations from 2010 to 2019 took, on average, over 16 years to progress from the discovery to the initial production stage. However, the exact time frame is context-specific: it can differ based not only on the physical characteristics of the project (e.g., the mineral concentration, location, and type of mine) but also on licensing bottlenecks, regulatory burdens, availability of infrastructure services, and policy uncertainty. Countries like Australia, China, and the United States are pursuing aggressive policies. South Africa would need to change its current practices to seize the opportunity.

4.3.2 Green Supply Chains

Beyond mining, South Africa has the potential to participate in multiple value chains that use minerals. Mineral processing is highly concentrated in China, which holds around 35% of nickel refining, 50-70% of cobalt, and 90% of rare earth elements (IEA, 2021b). This shows that the local availability of the mineral is not enough to translate into a comparative advantage of downstream products in South Africa. Previous research (Hausmann *et al.*, 2008) has shown that countries that are rich in mineral resources do not necessarily acquire a comparative advantage in downstream industries. Conversely, the industries with high potential in each country are not necessarily those that are downstream from their own raw materials. After all, most products do not rely on a single raw material, meaning that the others will have to be imported anyway. If transportation costs are low enough, places can become globally competitive in industries for which they do not have any relevant raw materials locally available. China is a good example of this. In cases where transport costs are more significant, places with locally available raw materials do have an advantage. Currently, geopolitical forces are creating opportunities for countries like South Africa in mineral processing. Excessive dependence on China is seen as a strategic risk both in the US and Europe, who want to diversify their suppliers to "de-risk rather than decouple" from China, as Janet Yellen, the US Treasury Secretary, has argued. South Africa could exploit this moment of opportunity to attract investment in mineral processing, but to do so, it would need to credibly address its electricity, rail, and port issues, among others.

South Africa may also be able to innovate much more around the development of clean technologies. The world is focused on improving technologies that can balance the supply and demand of electricity in grids that rely on variable sources of energy like sun and wind. Two technologies – grid-scale batteries and pumped storage hydropower – are increasingly used to balance electricity supply and demand. Between 2020 and 2021, the world increased by 100% its installed capacity in grid-scale battery storage, and according to IEA's Net Zero Scenario, it is expected to expand 44-fold by 2030 (IEA, 2022a). South Africa has companies like Bushveld Energy working on making vanadium redox flow batteries (VRFB) cost competitive. It could be strategic for South Africa that this technology succeeds in carving a role for vanadium in this market since South Africa has ample sources of vanadium and a potential first-mover advantage in developing storage technology. To do so, it would need to invest in R&D and get on a more rapid learning curve. This can be enabled by developing a strategic partnership between Eskom and Bushveld Energy to buy and test VRFB batteries. The process could also be accelerated by acquiring foreign firms that have key capabilities in this area. This is a somewhat unique opportunity for South Africa given its natural endowment. At the same time, South Africa may have potential to incorporate more pumped storage hydropower in its electricity system, but it does not have the same noteworthy advantages for innovation and positive economic spillovers through research and development as with grid-scale battery storage.

An area of opportunity for South Africa is to innovate around flow batteries for grid-scale storage of electricity. Flow batteries are considered important for the energy transition but are yet to be employed at scale in energy systems (IEA 2023c). The most mature flow battery chemistry is the Vanadium Redox Flow Battery (VRFB), though many groups are trying to innovate in flow battery chemistries to overcome cost and technological constraints in VRFBs. South Africa is a leading supplier of Vanadium, has companies attempting to commercialize VRFBs (such as Bushveld Energy), and could marshal expertise to innovate around flow battery chemistries. Complexity analysis suggests that flow batteries are a high-potential opportunity in South Africa (below). As an emerging technology, supporting flow batteries involves applied research, piloting, and demonstration projects, attracting frontier knowhow from abroad, and making limited investments to develop knowledge and test assumptions around whether commercialization benchmarks are realistic and achievable (such as those related to learning curves and potential cost reductions for VRFBs). To manage risk across different technologies, South Africa should endeavor to explore multiple battery chemistries, before doubling down on vanadium-based chemistries around which it has expertise.

If the hydrogen economy takes off globally, South Africa has the potential to participate in several ways. Despite a rapid uptick in national strategies for hydrogen production, there remain critical questions about the potential size and reach of the hydrogen economy given its high current costs and challenges in transporting hydrogen. However, if these challenges are overcome and hydrogen becomes a critical fuel vector globally, South Africa is well positioned to play several roles in the supply chain. First, the hydrogen economy will need an ample supply of electrolyzers to convert electricity into hydrogen and fuel cells to convert the energy back into electricity. One of the technologies used in both processes is proton exchange membranes or PEMs. One of the dominant technologies today uses platinum as a catalyst in fuel cell membranes and iridium and ruthenium – two platinum group metals or PGMs – for the PEMs used by electrolyzers. Hydrogen South Africa (HySA) has been investing in these technologies since its founding in 2008 and has established a fully owned subsidiary, Hyplat, to commercialize catalysts for fuel cell PEMs. South Africa could also have strategic advantages in other parts of the upstream supply chain as well as the downstream use of hydrogen in production processes – especially in coordination with the wider region – which is an opportunity discussed under the strategy of utilizing energy resources to "make green versions of grey products," which is discussed in the next subsection.

Fuel cell manufacturing represents an interesting potential entry point for South Africa into the hydrogen value chain. South Africa hosts a nascent ecosystem around fuel cell use and manufacturing, comprising homegrown component makers such as Hyplat, international manufacturers such as Chem SA, and pioneers in frontier applications of fuel cells such as Anglo American (which is developing a fuel cell mining truck). As a technology that is entering commercial deployment at scale (IEA 2023c), policy to support this industry may involve identifying niches in which South Africa is well-positioned, supporting the scaling of supply chains and demand within these niches, and attracting foreign direct investment.

There is in fact a wide range of industries with the potential to take advantage of the global energy transition. Clearly, a decarbonizing world will need massive amounts of more mature products like solar panels, electric vehicles, lithium-ion batteries, transmission lines, as well as emerging products, like electrolyzers and grid-scale batteries. Many more products will likely emerge in the years to come. Each of these products are at the end of long value chains that open many opportunities for participation. We use the product space methodology (Hausmann *et al.*, 2014), and add to it a database of industries and products from relevant supply chain reports using natural language processing techniques.[3] Products comprising this database are not exclusively utilized in green supply chains, which means that they can also cater to other markets. Figure 4.5 below shows each of the identified supply chains along with a high-level disaggregation of stages for some of them. It also shows the total number of internationally traded products involved in each of them, along with the share of those

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[3] Most supply chain reports are from the Department of Energy of the United States (DoE); also utilized IEA reports on critical minerals and green hydrogen; excluded primary cells and primary batteries (HS code 8506), and semiconductor devices (HS code 8541), which are challenging to manufacture.

products present in South Africa with a revealed comparative advantage (RCA>=1). The fact that South Africa produces 50% of the products that are involved in the storage and injection stage of carbon capture does not imply that those products are being utilized for that specific industry within the country. Rather, it indicates that South Africa possesses the capability to diversify into that industry, considering its competitive edge in exporting half of these products. The construction of this database can help identify what are South Africa's areas of opportunity when it comes to green growth drivers.

In the landscape of products involved in green supply chains, multiple opportunities can help drive diversification moving forward. As we can see in Figure 4.6, South Africa's green exports are concentrated in platinum, although this mineral holds a relatively small share of green exports globally. Electronics, machinery products, chemicals, and metals are prominent in global green supply chains, and South Africa has clear capabilities in each of those sectors as shown by its current exports. The rapidly growing demand for many of these products presents a window of opportunity for South Africa to tap into the global just energy transition by developing industries for which the country has productive capabilities. Some of the inputs are utilized in highly concentrated stages of the supply chains, but others are part of stages that are more ubiquitous. For example, some of the products on this list are required for producing semiconductors or solar PVs, so entering their markets might be more challenging because of their concentration levels. In turn, other products that are in the metals, electronics, or machinery sections are used for the distribution, transportation, and operation of green supply chains. For example, developing electric grids requires multiple types of electric devices and metal goods, and green hydrogen distribution requires different measuring and regulating apparatuses.

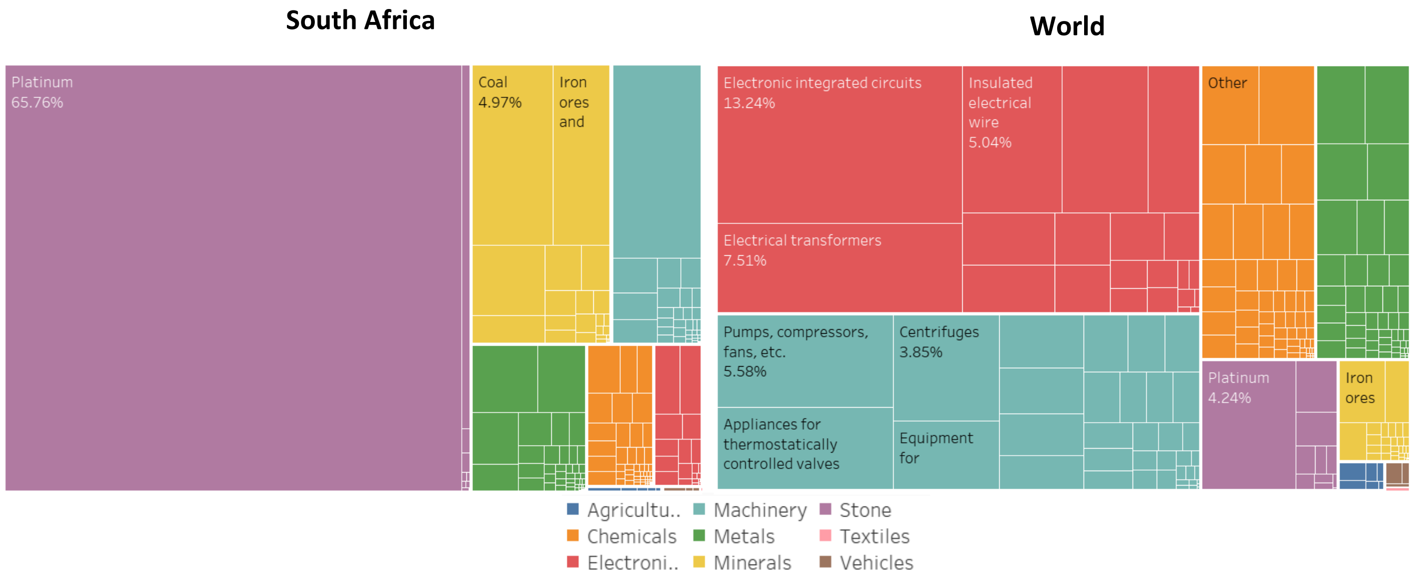
FIGURE 4.5: GREEN SUPPLY CHAIN PRODUCTS

Green Supply Chain	Stage	Number of Products (4 digits)	Products that are present in South Africa (% of total)	Products that are competitive in South Africa (% of total)
Carbon Capture	Capture	22	73%	36%
Carbon Capture	Drying and liquefaction	8	75%	25%
Carbon Capture	Storage and injection	2	100%	50%
Carbon Capture	Transportation	3	100%	0%
Electric Grids	Production	37	68%	22%
Flow batteries	Production	13	92%	15%
Green Hydrogen	Distribution	22	82%	14%
Green Hydrogen	Production	67	90%	24%
Green Hydrogen	Transportation	13	85%	15%
Green Hydrogen	Utilization	6	83%	33%
Hydropower	Production	10	80%	0%
Lead-Acid Batteries	Production	9	89%	56%
Lithium-Ion Batteries	Production	15	73%	27%
Nuclear	Production	45	82%	20%
PGM Catalysts	Production	21	90%	48%
Rare Earth Magnets	Production	19	74%	21%
Semiconductors	Assembly, Testing, Packaging	3	67%	0%
Semiconductors	Fabrication	8	50%	25%
Semiconductors	Utilization	1	0%	0%
Solar PV	Production	28	75%	14%
Wind	Production	25	84%	12%

Source: Own elaboration based on multiple DoE and IEA reports.

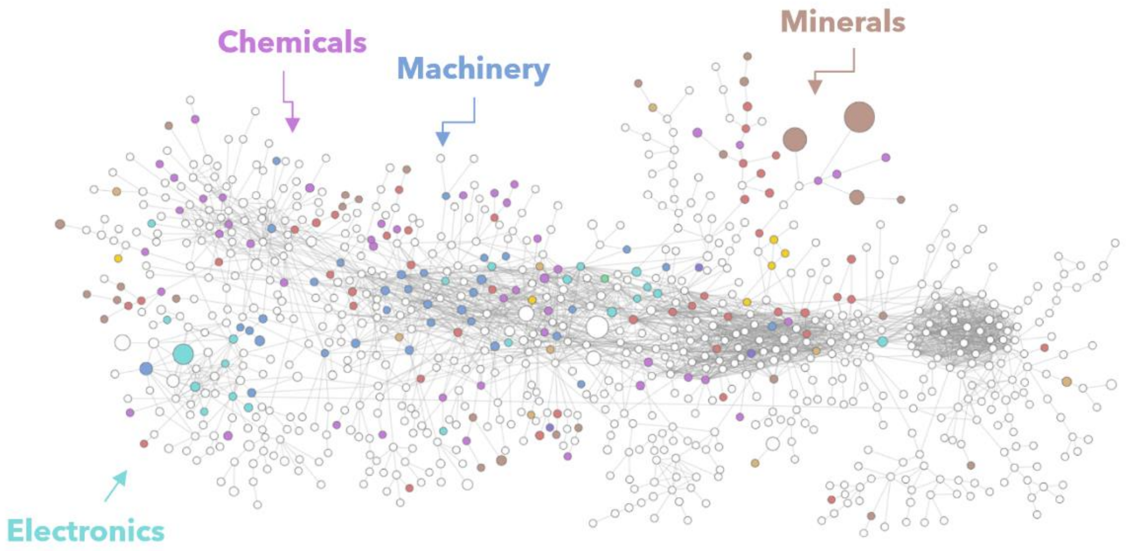
Many products are involved in global green supply chains In which South Africa can become competitive. These represent strong pathways to growth in a decarbonizing world. Figure 4.7 shows the Product Space (Hausmann *et al.*, 2014), which provides a comprehensive perspective on how approximately 1,200 internationally traded products are related in terms of the similarity in the capabilities required in their production. The links between the products are based on a measure of how likely they are to be exported by the same country (proximity) or, in other words, their co-location probability. The proximity of products reflects the overlap in the productive capabilities that are required to be competitive in them. The products highlighted in Figure 4.5 are those that belong to green supply chains. Outside of minerals and primary commodities, these tend to be located at the center of the Product Space, indicating that they share capabilities with many products. As a result, they represent powerful pathways to also develop wider productive capabilities that can strengthen South Africa's comparative advantages in exports over time.

FIGURE 4.6: EXPORTS OF GREEN SUPPLY CHAIN PRODUCTS (2015-2020)



Source: Own elaboration based on international trade data from Atlas of Economic Complexity and Growth Lab internal dataset constructed using DoE and IEA green supply chain reports.

FIGURE 4.7: GREEN SUPPLY CHAIN PRODUCTS IN THE PRODUCT SPACE



Sources: Own elaboration based on international trade data from Atlas of Economic Complexity and Growth Lab internal dataset constructed using DoE and IEA green supply chain reports.

South Africa has a presence in or is close to having a comparative advantage in several products in green supply chains. It is possible to measure whether a country has a comparative advantage in an internationally traded product by utilizing the Balassa index to express its revealed comparative advantage (RCA) in trade. The RCA is measured as the share of that product's exports within a country's total exports over the share of that product's exports in global trade. In that sense, it measures whether a country exports more (RCA > 1) or less (RCA < 1) than its "fair share" of that product. South Africa has RCA over 1 in many green supply chain products within the metals sector (e.g., aluminum plates), electronics (e.g., electrical insulators), or chemicals (e.g., lead oxides). However, the country is also close to having a comparative advantage in several other products like primary cells, special-purpose motor vehicles, pumps, and surveying instruments. South Africa's position in the Product Space shows that the country has productive capabilities similar to those required by products in green supply chains. These products are therefore compelling areas to focus attention on because South African firms (or foreign companies looking for investment locations) will be more likely to develop global competitiveness in these products.

The appendix provides a detailed list of South Africa's opportunities for participating in green supply chains. The theory of economic complexity provides tools for evaluating these opportunities based on several factors: a product's complexity (i.e., the span of capabilities the product requires); its density (i.e., how close it is in terms of capabilities to products that South Africa already exports competitively) and its complexity outlook gain (i.e., how developing the capabilities to excel in that product would improve the opportunities for further diversification). Using these three variables, we can construct a composite score that indicates how feasible and strategic a product is for South Africa. Furthermore, we can weigh each of these three variables differently depending on whether we want to put more focus on products that are more feasible because they rely more heavily on existing capabilities (i.e., more weight on density) or that open up more opportunities for further growth (i.e., more weight on strategic outlook gain). The appendix shows a list of five products per green supply chain that rank high in terms of their opportunity score on the "extensive margin" – that is, products that South Africa does not already export with relative comparative advantage. The table contains two different measures of opportunity scores: one that prioritizes the feasibility of a product and another one that prioritizes the attractiveness of a product in terms of its complexity and outlook gain.[4] It also reveals five products within each supply chain that South Africa can

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[4] The first way of constructing the opportunity score belongs to a strategy of parsimonious industrial policy, and the second one to a strategy that prioritizes strategic bets. In the first case, the score is constructed by assigning a weight

leverage in the intensive margin, that is, with an RCA greater than 1. These represent the top five products ranked by their PCI.

The industries involved in green supply chains that have high potential in South Africa are primarily in metals, chemicals, machinery, and electronics. Out of the 66 identified products on the extensive margin, 30% are chemicals, another 24% are machines, 22% are metals, and 15% are electronics. Meanwhile, 50% of the products in green supply chains that are already exported by South Africa (i.e., the "intensive margin") are chemicals. This is a strong indicator of South Africa's potential to repurpose its chemical industries to make the enablers of global decarbonization. South Africa's chemical industries are diversified in terms of products but not in terms of their markets. Over 80% of its chemical exports are destined for the rest of the African continent (and 90% in 2020). South Africa could leverage global decarbonization to increase chemical exports to the rest of Africa and diversify its markets to the rest of the world, where they are in increasing demand. The country also has a comparative advantage in several products within the machinery, electronics, and metals sections, but exports have been steeply declining since 2008 for reasons discussed earlier in this report.

This analysis reveals varying potential in the different green supply chains. Figure 4.8 shows the competitiveness of South Africa in the RCA vs. the average density of products grouped by green supply chain in South Africa. On the horizontal axis is the average RCA in South Africa for products in the indicated green supply chain (in logs), and the bubble size shows how many products within each supply chain are present in South Africa as a percentage of the total number of possible products. The vertical axis is a measure of how feasible it is to develop products that are not currently present in South Africa based on Product Space density. These measures can help understand the potential of each supply chain in South Africa. For example, the lead-acid batteries supply chain shows growth potential in South Africa since the average density of its products is the highest. The average RCA is also high, and over 50% of the products are already competitively made in South Africa. Nevertheless, South African exports of lead-acid batteries as a final product are a small fraction of global exports. Their RCA in 2020 was below 0.3. The figure also shows high density in the supply chain of flow batteries. Meanwhile, green hydrogen and PGM catalysts supply chains both show high RCA

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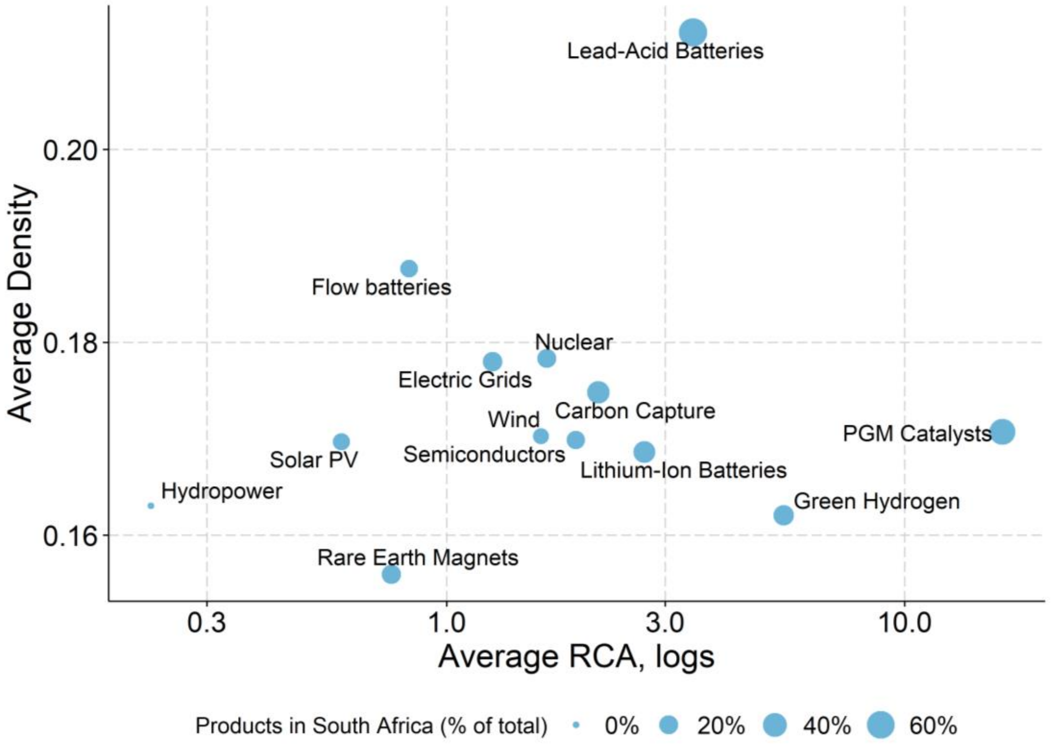
of 60% to density, 20% to PCI, and 20% to COG. In the second case, the score is calculated by giving a weight of 50% to density, 20% to PCI, 30% to COG, and filtering out the PCI that is lower than the mean PCI for South Africa.

on average, but low density, meaning that South Africa is already competitive in producing part of the value chain, but other parts of the value chain are far from South Africa's current productive capabilities. These are long jumps or strategic bets for South Africa because they would involve developing many capabilities that are relatively new to the country.

FIGURE 4.8: DENSITY & PRESENCE OF GREEN SUPPLY CHAIN PRODUCTS IN SOUTH AFRICA (2020)



Source: Own elaboration based on international trade data from Atlas of Economic Complexity and Growth Lab internal dataset constructed using DoE and IEA green supply chain reports

The world is moving quickly towards BEVs, with important consequences for South Africa's automotive industry. Sales of BEVs grew by a factor of 10 between 2016 and 2021 based on Statista and grew by 35% in 2022, moving from 9% to 14% of total sales. This is the consequence not only of policy stimuli but also of technological improvements and cost reductions alongside increasing consumer demand. Capital markets assume that the tangible and intangible assets that companies own to produce ICE vehicles are not going to be worth much. For example, the current combined market value of Toyota, Mercedes, BMW, Ford, Nissan, and Isuzu (6 OEMs present in South Africa) at USD 501 billion,[5] well below that of Tesla

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[5] Toyota at USD 255 billion, Mercedes USD 87 billion, BMW USD 70 billion, Ford USD 60 billion, Nissan USD 17 billion, Isuzu USD 12billion, as of July 2023.

(USD 882 billion) alone, even though these companies produced 30 times more cars than Tesla. Consequently, most major car companies are now playing catch-up. They will have to confront new Chinese entrants such as BYD that produce more BEVs than all the OEMs present in South Africa combined. Given this horizon, it is unlikely that OEMs will be planning to expand capacity and even R&D efforts for ICE vehicles and will concentrate their efforts on the move to EVs. Some may shrink as new entrants such as Tesla and BYD expand their presence, as markets currently expect.

This is problematic for South Africa because the automotive industry represents almost a fifth of manufacturing activity, with over 100,000 jobs and 10% of the export of goods in 2019. Since plants take years to plan and build and are expected to be in operation for at least a decade, it is unlikely that the OEMs present in South Africa and their suppliers will be willing to consider either major investments or greater localization in their current product lines, which are focused on ICE vehicles. The exception that proves the rule is BMW, a company that announced a new investment in South Africa to produce plug-in hybrids (Reuters, 2023), a transition product that currently sells half as many vehicles as BEVs and is expected to be just 1/3 of BEVs by 2028 based on Statista. Moreover, over 60% of South Africa's automotive exports go to high-income countries in Europe, North America, and Japan that are not expected to be buying ICE vehicles by 2035. These markets are likely to move massively towards battery-electric vehicles by that year. Therefore, South Africa faces the choice of seeing its automotive industry shrink significantly or move aggressively towards BEVs through either substantial change in product lines by existing OEMs in the country or the entry of new companies with BEV production.

South Africa's move from ICE vehicles to BEVs is made more difficult because of the electricity crisis. Given the shortage of generation capacity, it makes sense that the authorities have not prioritized the move to BEVs in the domestic market through investment in charging infrastructure and other subsidies at the scale of many other countries. Moreover, charging BEVs with electricity made from coal has scant environmental benefits. However, car manufacturing facilities are long-term investments that take time to materialize. By that time, hopefully, the electricity crisis will be over, and the country will be living through a boom in electricity investments. South Africa would benefit from developing an integrated power and transportation strategy to rebuild the country's comparative advantage. The strategy should leverage the capabilities that the country already has in the value chains that supply ICE cars but will have to be enhanced with capabilities in the production of batteries, IT systems, and other components that play a bigger role in BEVs than in ICE vehicles. It will be important to design a strategy to develop the domestic market by making sure that the country is covered with charging stations as quickly as possible, in a manner consistent with the recovery of the electrical grid. In this respect, off-grid charging stations may be an important contributor. It will be important to explore the possibility of attracting upcoming Chinese players such as BYD in cars and CATL in batteries. Having a large local or regional market is always important to convince OEMs to move their plants and value chains to the country.

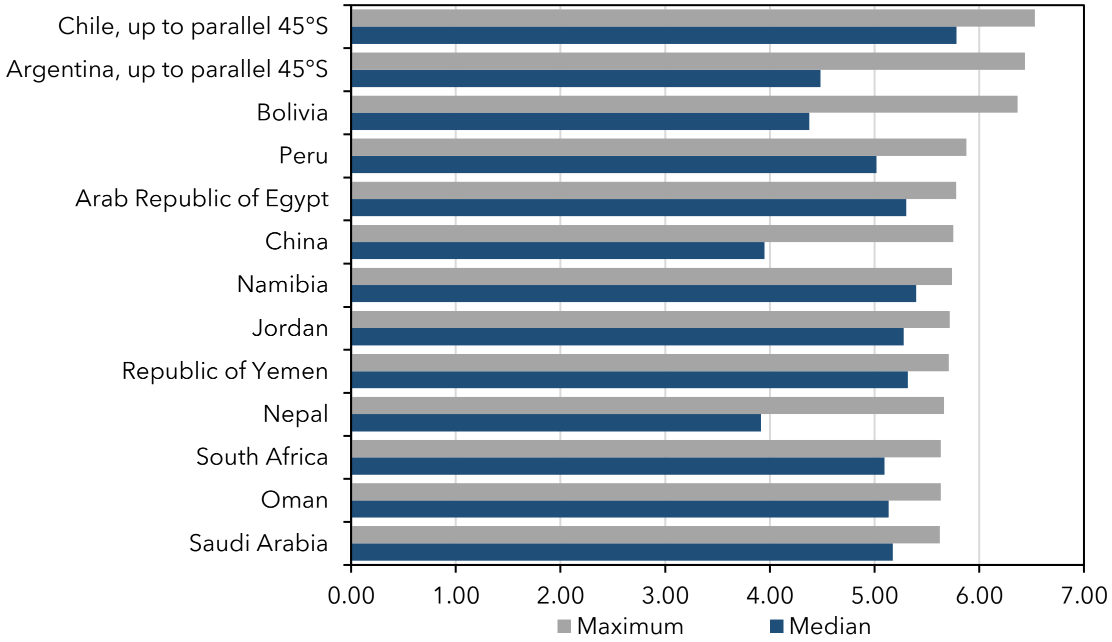
Fuel cell electric vehicles (FCEVs) might constitute a potentially large market in the long term, but a few relevant applications might take off earlier. While BEVs appear to be the dominant emerging technology today, some countries, and U.S. states (e.g., California) are betting on FCEVs for a longer time horizon. The absence of an ample hydrogen distribution system limits adoption, but two features of FCEVs make them attractive for some uses. First, FCEVs, just like BEVs, do not emit noxious gases. Second, FCEVs can be refilled more quickly and made more powerful than BEVs. This is particularly useful for mining equipment, since they need to be very powerful, must be refueled quickly, and not emit gases that might endanger workers in underground mines. Also, pressures to decarbonize minerals and metals may force the adoption of equipment that runs on clean energy. South Africa already has a presence in this industry with companies such as Bell. Becoming a leader in the development of FCEV technology as applied to mining equipment might be an interesting niche.

4.4 Strategy 2 – Make green versions of grey products.

As noted earlier, green energy is much more expensive to transport than fossil energy. Therefore, to be competitive, energy-intensive industries that want to decarbonize will need to relocate near cheap sources of green energy. They will also need to be substantially redesigned, justifying new greenfield investments. For example, green steel will either be made with electric-arc furnaces and hydrogen or with electrolysis of iron ore. These processes are sufficiently different from traditional production such that they cannot easily be done as brownfield investments justifying their development in new locations. Regions that develop competitive green sources of energy will be able to participate in this investment trend. The industries that are likely to relocate include *inter alia* chemicals, steel, aluminum, and mineral processing. South Africa has a long history and relevant accumulated capabilities and knowhow in many of these industries.

South Africa has remarkable potential for renewable energy production, which should be an advantage for this second strategy. Figure 4.9 shows the fifteen countries with the highest maximum yields of photovoltaic power, excluding land with identifiable obstacles to utility-scale PV plants. In addition to having high maximum solar yields (comparable to Namibia, Saudi Arabia, or Egypt), South Africa also has high median yields, higher than China, Nepal, or Argentina. South Africa also has enough wind power potential to complement its PV energy. All of which makes it an attractive location for the development of renewable energy projects. The pace at which these picked up after the government allowed the licensing for it in 2022 indicates that the market is aware of this potential.

FIGURE 4.9: PRACTICAL SOLAR POTENTIAL IN 2020 (PVOUT LEVEL 1, KWH/KWP/DAY), LONG-TERM



Source: Own elaboration based on Global Solar Atlas, World Bank, ESMAP and SOLARGIS.

However, in addition to its electricity system failure, South Africa's current energy mix is highly carbon intensive. With over 90% of its generation capacity based on coal, South Africa has one of the most carbon-intensive energy systems in the world. It will take decades for the country to transition towards cleaner energy. In the meantime, electricity from the South African grid will be carbon-intensive on average such that industries that rely on the grid are bound to have a high carbon footprint, negating the incentives to relocate to the country. Moreover, dirty energy will be a competitive disadvantage for existing energy-intensive exporting industries in reaching markets.

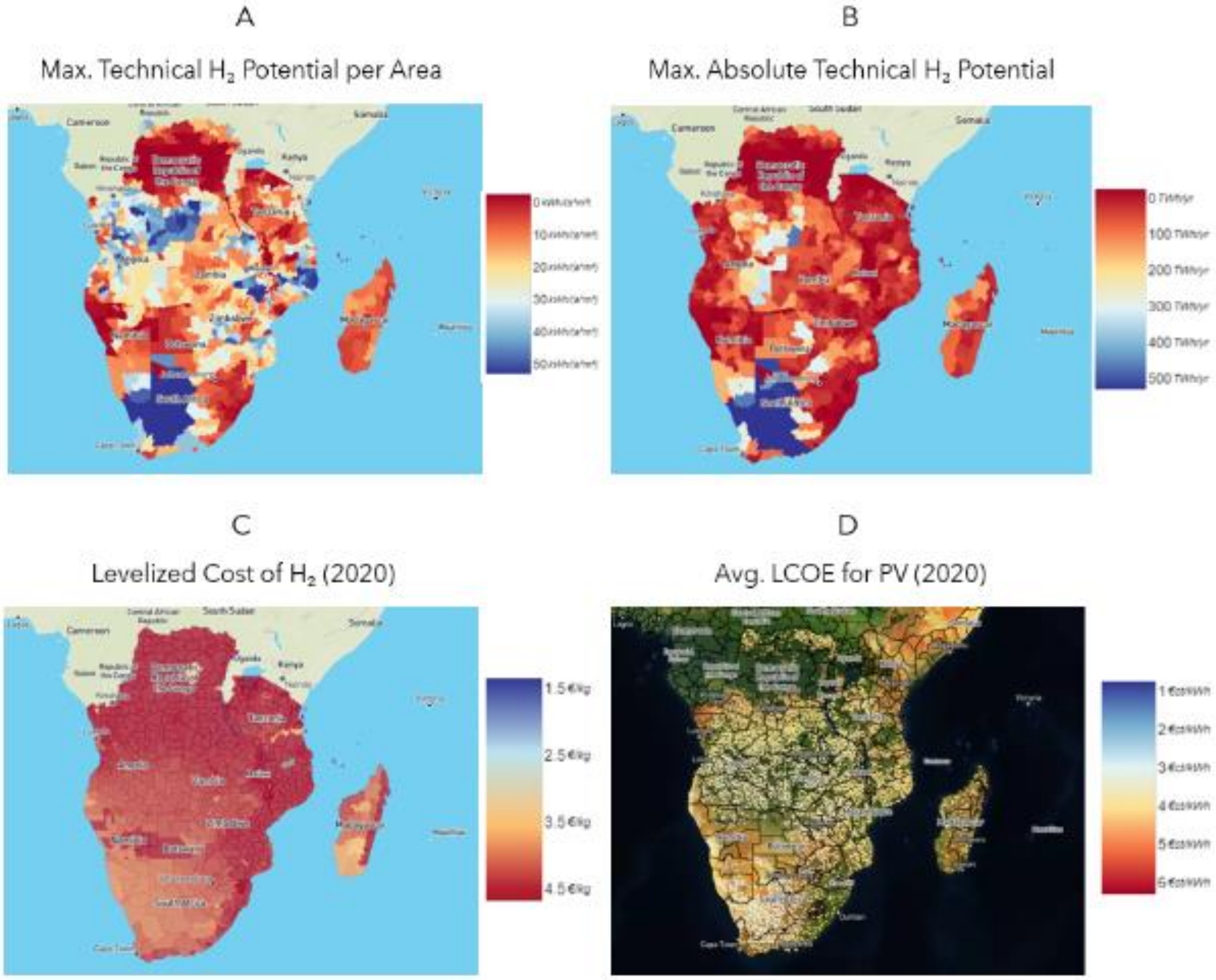
One way to deal with this disadvantage and leverage the country's renewable energy resources is to develop green industrial parks, where dedicated renewable power is supplied to businesses located in the parks. However, it may not be acceptable to global consumers and regulators to simply reallocate green energy sources to some export-oriented industries and increase the share of grey energy in the rest of the economy. Given this risk, green industrial parks must meet specific criteria. First, their establishment must be based on new sources of clean energy, not merely repurposing existing capacity. Second, to prevent non-emission-reducing reallocations, South Africa must still abide by its previously announced nationally determined contributions, or even increase its level of ambition. Third, for the sake of efficiency and stability, it would be important to connect the new green zones to national electricity grids, but this should be conditional on the zones becoming significant net exporters of clean energy to the grid rather than net importers from the grid.

Establishing green industrial parks and their clean-energy resources would not necessarily require government funding. Such real estate and energy investments should be profitable and thus privately financed. Nevertheless, this does not mean that governments should play no role in their establishment. On the contrary, to become competitive, these zones must also strive to compete on the availability of other production inputs, such as human resources, local supply chains, research and development capabilities, logistics, and more. Government can accelerate the process by introducing effective green-energy regulations, facilitating right-of-way provisions for transmission lines, adjusting zoning regulations, building arterial infrastructure, and investing in urban development and human resources. Other countries have already started this process. Indonesia, for example, has an aggressive strategy toward attracting green industries to utilize its renewable energy resources. The Kalimantan Industrial Park Indonesia (KIPI) project aims to attract EV battery manufacturing to utilize its hydropower plants as energy sources (Hafisa, 2023).

The case of the green steel industry stands out as a promising area for South Africa. Devlin *et al.* (2023) have found that locations with renewable energy resources and iron ore mining will likely be cost-competitive for developing green hydrogen-based steelmaking. Within the group of regions identified in that paper, South Africa stands out as one of the places where the cost of producing green-hydrogen-based steel is potentially the lowest. In addition, South Africa has a long tradition of steelmaking which means that it has relevant capabilities and knowhow compared with other locations that also have abundant renewable energy resources. Competitive local provision of green hydrogen would also attract other industries. Some industrial processes require very high temperatures that cannot be achieved by using electricity. These so-called hard-to-abate industries require a green fuel that can play a heating role and green hydrogen is likely to be the fuel of choice. According to IEA (2022d), in the Net Zero Emissions by 2050 Scenario, approximately 65% of the primary steel production in the G7 nations is expected to be achieved through the hydrogen (H2) DRI-EAF method. In theory, it is also a potential solution to decarbonize long-distance heavy transport as it might be more cost-competitive than electric transportation, given the limitations of battery storage systems. In addition, as with green steel, hydrogen can play the role of a reducing agent. So, green industrial parks may choose to offer green hydrogen as an additional valuable input.

The country has clear potential to develop green hydrogen in a competitive way. Figure 4.10 presents four indicators that show South Africa’s potential for green hydrogen production vis-à-vis the rest of Southern Africa. The developers of the indicators calculated the amount of hydrogen that can be produced in each geographical region in theory and considered available resources and conditions. The first two maps (A and B) show that South Africa and, especially, the Northern Cape, has the highest green hydrogen production potential in the region, both per unit of area and in absolute terms. This results in a relatively low cost of hydrogen production (map C), which is partly due to the low cost of electricity from PV (map D). The country shows even more potential for developing green hydrogen production when adding South Africa’s existing infrastructure and its productive capabilities in the metals and chemicals sectors to the mix. According to IEA’s hydrogen projects database, there are five projects currently being evaluated for feasibility, located in Bogoebaai NC (Sasol), Nelson Mandela Bay EC (Hive Energy), Sasoulburg FS (Sasol), Secunda MP (Sasol), and Siyathemba NC (Prieska). The private sector, including influential agents of change like Sasol, is aware of South Africa's potential for green hydrogen development. Nevertheless, to actualize this potential, the country needs to build a comparative advantage in electricity, although this time not through coal but by harnessing renewable sources of energy.

FIGURE 4.10: KEY INDICATORS OF GREEN HYDROGEN POTENTIAL



Source: SADC H2 Atlas, Institute of Energy and Climate Research - Techno-Economic Systems Analysis (IEK-3), Forschungszentrum Jülich, https://africa.h2atlas.de/sadc

For South Africa to develop cheap renewable electricity it must achieve a low cost of capital. The sun shines for free and the wind blows for free. The bulk of the costs are associated with the cost of installing the capacity and the cost of financing that capacity. Therefore, having access to capital at a low cost is one of the main determinants of competitiveness in green energy. Renewable energy projects require a combination of debt and equity, with equity demanding higher returns than debt. The riskier the country, and the industry, the higher the cost of both debt and equity and the larger the share of equity in the financing mix, causing the weighted average cost of capital (WACC) to go up more than proportionally. Countries with good natural renewable resources could squander them because of high financing costs. In the case of South Africa, the weakening of the fiscal solvency indicators and repeated credit downgrades have caused an increase in the yields that the government needs to pay to attract capital. Beyond this so-called sovereign risk, other sources of risk are specific to energy projects. The Cost of Capital Observatory of IEA describes the factors that can influence these variables (Figure 4.11). Off-taker risk is serious because of Eskom's weak performance and balance sheet, requiring repeated recapitalizations. That is why the government has been guaranteeing payments to generation projects, but this comes at a fiscal cost. In addition, several other factors are problematic in South Africa, including land, permitting, regulatory, and political risks. If these are not addressed, they can radically diminish the feasibility of South Africa's green growth prospects.

Hydropower and pumped storage could accelerate the energy transition in South Africa. It is hard to incorporate sun and wind into an electric grid because these sources of energy are not dispatchable (i.e., they cannot be adjusted up or down at will). To absorb more sun and wind generation, the system needs more sources of dispatchable energy. The dominant technology today is natural-gas or diesel turbines, which depend on fossil fuels. The green alternatives include grid-scale batteries as well as hydro and pump storage. South Africa could explore expanding both hydropower and pumped storage by exploring the complementarities with Lesotho. Currently, Gauteng buys water from the Lesotho Highlands Water Project. The project and resource have been historically conceived of as a source of water rather than as a source of energy. When the last deal was negotiated in 1985, South Africa did not perceive a need to import electricity, given its ample coal-fired generation. Today, things are radically different. Not only is there a shortage of electricity generation in South Africa, but Lesotho could provide two important elements that are extremely valuable to South Africa. First, hydropower is dispatchable and hence can be used to balance the grid so that it may absorb a larger supply of sun and wind generation. Secondly, the waterworks can be used as storage, pumping water up the mountain in periods of excess sun and wind generation and using the water at peak times. The potential of the Lesotho Highland Water Project should be evaluated in the context of a strategy to green South Africa's electricity supply. South Africa will be able to absorb more solar and wind generation in the presence of more electricity generation and storage capacity in Lesotho.

FIGURE 4.11: RISK FACTORS AFFECTING CAPITAL AND DEVELOPMENT COSTS

Risk name	Description of risk
Political	Changes in expected revenues/return as a result of political or social instability
Regulatory	Fear of changes in law/regulation
	Unclear laws/regulations
Sovereign	Risk of public debt becoming unsustainable and the government not being able to pay its debt obligations in time and form
Currency	Risk of changes in foreign exchange rates
Transfer	Inability – or complicated processes – to convert local currency to hard currency, or to repatriate hard currency
Off-taker	Delays in the payment of power purchased by off-taker(s)
Bankability of PPA	Delays in the signing of PPAs; higher-than-expected project costs relative to a fixed-price contract
Land	Low availability of land
	High land cost
	Long lead times
	Complications arising from overlapping planning permits, fragmented ownership, or unregistered land
Transmission network and evacuation	Insufficient exchange of electricity and system services across states, which can hamper balancing
	Risks around the infrastructure available to evacuate power (e.g., uncertain availability of local grid connections)
Permitting	Long lead times
Volume	Curtailment of power
	Low electricity demand
	Meteorological variations
Technology	Underperformance of technology
	Little experience with the technology being used in the country
	Faulty operation and maintenance, etc.

Source: Cost of Capital Observatory, IEA.

South Africa could become a major producer of green hydrocarbons, including sustainable aviation fuels (SAF). One of South Africa's unique technological capabilities is the mastery of the Fischer-Tropsch process by Sasol. Initially developed to make liquid hydrocarbons out of coal, the process can be adjusted by changing the feedstock to make low-carbon fuels. Sasol is currently developing a plant capable of using green hydrogen and the CO_2 captured from other industrial processes – such as the Arcelor-Mittal's South African steel plant – to make hydrocarbons. Burning such hydrocarbons emits CO_2, but those molecules had already been emitted by a previous industrial process. According to European Union rules, fuels made from captured CO_2 will be considered green until 2040 in the hope that other cleaner technologies will have been developed by then. Air travel is one of the hardest to abate industries, making SAF a promising market for the coming decades. South Africa has several unique advantages to becoming a major supplier: unique expertise in the Fischer-Tropsch process; good natural endowment of sun and wind to produce green hydrogen; and industrial sources of captured CO_2. Mastering the technology will require further research and development to control the kind of hydrocarbons that the process creates, by tweaking the catalysts that are used. By 2040, captured CO_2 will need to be substituted by biomass, direct air capture (DAC), or other more sustainable sources of carbon.

4.5 Strategy 3 – Export green knowhow.

South Africa has a long history of innovation in technologies that are relevant to the energy transition, but the country appears to be losing innovation capacity. Figure 4.12, Panel A shows the number of patents[6] in green technologies and processes that were issued to South African assignees in 1994-2016,[7] as documented by the European Patents Office (EPO) in the Worldwide Patent Statistical Database (PATSTAT). The surge in the registration of patents until 2002 indicates that South Africa had the capability to create green technologies[8]. However, after that, the number of green patents stopped growing at a time when they ballooned in the rest of the world. As a consequence, measures of relative innovative capacity show a significant decline. This decline is true whether one looks at the number of total patents issued to South African assignees as a share of the U.S. (Panel B), upper-middle income countries (Panel C), or Sub-Saharan African countries (Panel D).

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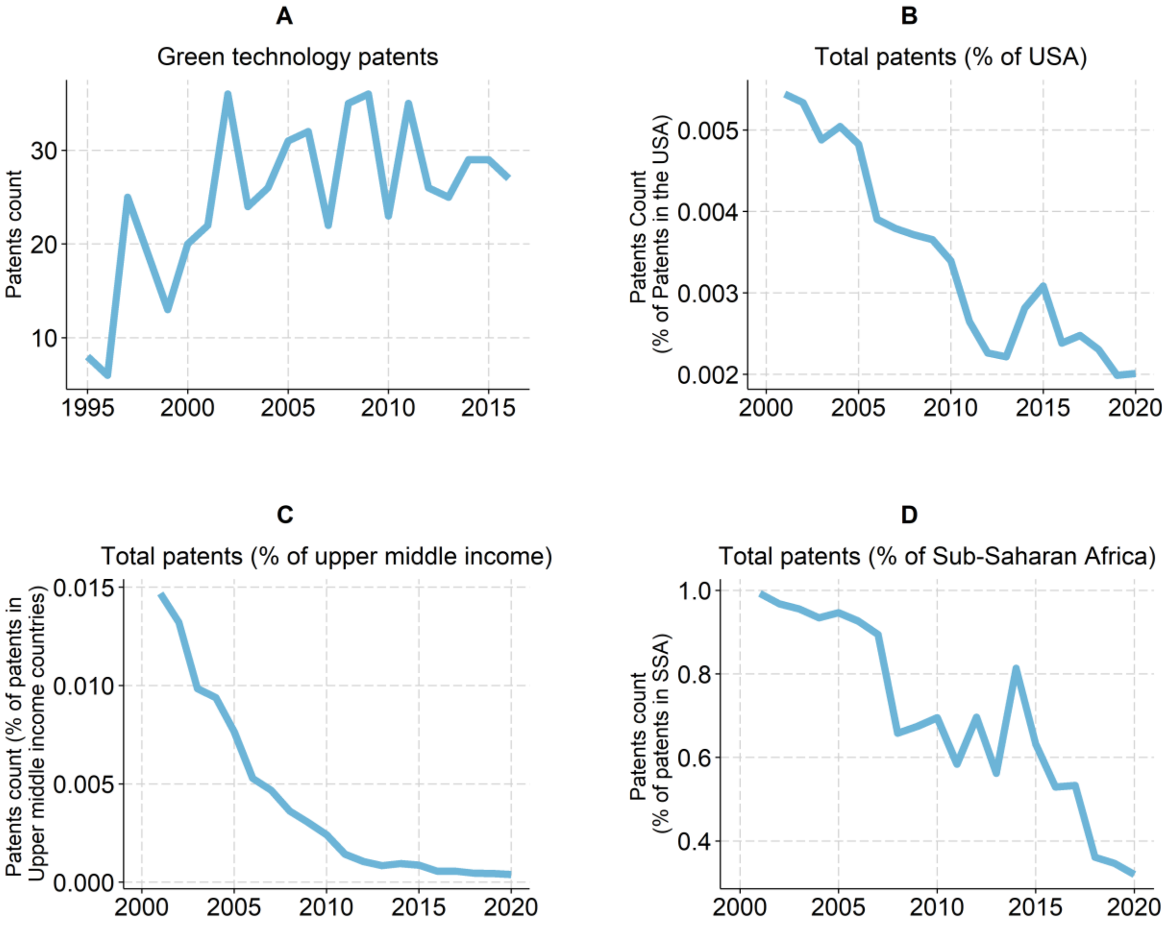
[6] Patents counts normally just sum the total number of patents awarded in all patent offices. These include patents that have been registered in more than one location, leading to double- or multiple-counting. In these numbers, we use so-called patent families that correct for this issue.

[7] As classified by the United States Trademark Office (USTO) under Y02 to Y02W.

[8] According to IRENA, many of the green patents that were registered in South Africa during the period until 2011 are within a diverse group that IRENA calls "enabling technologies" (38% in 2011): smart grids, energy efficiency, CCUS, fuel cells, electromobility-related technologies, and others. A number of patents were also filed for solar energy (33% in 2011). Source: IRENA's patents evolution data in https://www.irena.org/Data/View-data-by-topic/Innovation-and-Technology/Patents-Evolution

Figure 4.12: Evolution of Green and Total Patents in South Africa



Note: Panel A shows patent families of "climate change technologies as classified by USTO under Y02 to Y0W.
Source: Own elaboration based on PATSTAT and World Bank Data.

South Africa must achieve a higher pace of innovation to keep up with the development of green knowhow worldwide. Figure 4.10 shows a comparison between the assignees that filed patents in 2001-2008 and those that did so in 2009-2016 in South Africa. These numbers are broad estimations given the data's limitations when it comes to identifying assignees.[9] Several patterns stand out when comparing the two periods. The number of green patent families decreased overall, even as many new assignees registered patents in the latter period. Few individuals filed patents during both periods. Rather, most of those who filed patents in the earlier period did not do so in the later period and most of the assignees in the later period were new. Taken together, these patterns show a clear shift in green patents in recent years.

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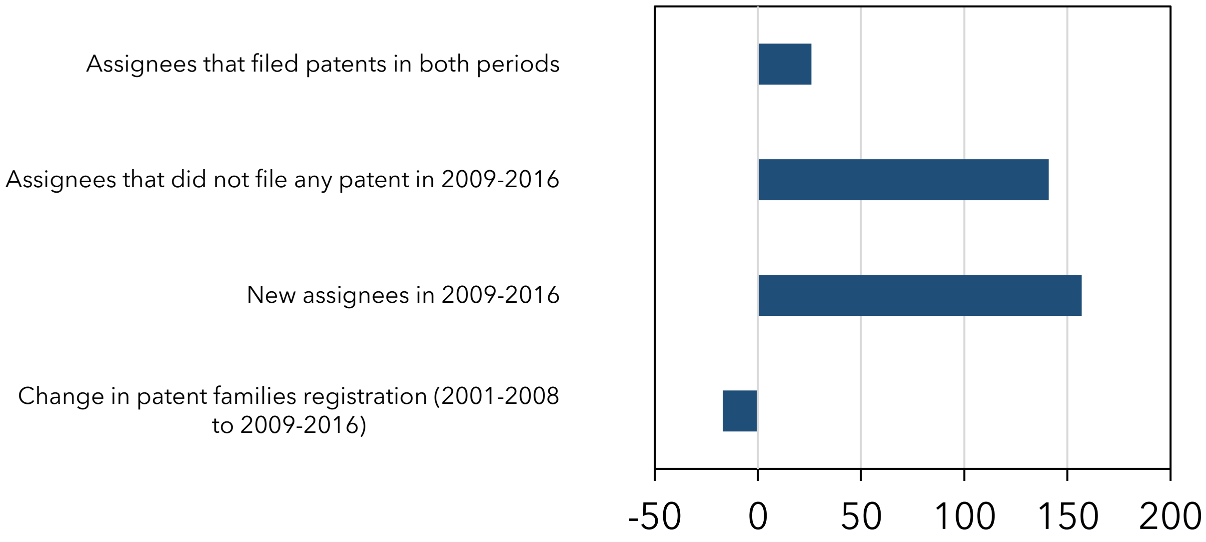
[9] Many of them change their name in time or fil patents under different names. The registry of patents might have duplicated names or firm ids.

Thus, as South Africa's general environment for patenting has weakened a few areas of strength appear to be emerging.

FIGURE 4.13: COMPARING GREEN PATENTS IN SOUTH AFRICA BETWEEN 2001-08 AND 2009-16



Source: PATSTAT.

South Africa may be able to better leverage these emerging sources of innovation. The case of Hydrox Holdings LTD[10] is illustrative since the company was granted a special distinction in the 2022 Monaco Prize for Innovation in Renewable Hydrogen[11] for their innovations in the development of a membrane-less electrolysis system. Another illustrative case is Solar MD[12] (Parker, 2021; Kuhudhai, 2023). The company assembles batteries with components imported from CATL and sells them in South Africa and across Southern Africa. They developed a 14.3 kWh pack that filled a gap in a market where customers facing load-shedding needed more storage capacity than the one provided by the batteries directly imported from China. The company has also created its own battery and energy management system. Because of the electricity crisis, the company faces such high demand that, as of March 2023, it had a three-month backlog for delivering orders (Kuhudzai, 2023). Finally, they are exporting decarbonization knowhow since the company expanded its operations to Bulgaria in 2023 (Todorovic, 2023). The development of businesses like this one can help South Africa

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[10] See: https://hydroxholdings.co.za/home/
[11] See: https://monacoh2.org/prize-2022/
[12] See: https://www.solarmd.com/

spur its green growth process. The energy storage solutions are especially strategic for the country, given their upstream and downstream linkages with the metals sector.

Overall, Sasol stands out as a key source of knowhow in South Africa. Increasingly, South African research universities may play a greater role. As noted previously, Sasol's mastery of the Fischer-Tropsch process is one source of intellectual property that may be adapted for future green growth uses. By measure of patents, Sasol is also the most innovative company in South Africa, with 14% of patents filed in 2001-2008 and 12% in the following period (Figure 4.14). Sasol already exports this knowhow as it is now utilizing a flexible approach that combines licensing of its technology, entering partnerships, advisory agreements, and other forms of collaboration. Producing at home and exporting knowhow are not substitutes but complements. It is because the company produces at home that it can master, test, improve, and develop the technology so that it becomes a more effective and credible exporter of knowhow. Figure 4.14 also highlights that some of the shift in patenting that has occurred over the last two decades has come through an increasing role of several South African universities. This is a promising development to build upon through partnerships that combine university resources and capabilities with the production and market knowledge of private companies.

FIGURE 4.14: CLIMATE CHANGE PATENTS BY ASSIGNEE IN SOUTH AFRICA

Assignee	2001-2008	2009-2016
Sasol	50	47
PEBBLE BED	35	4
BHP BILLITON	25	2
Anglo American	12	2
ESKOM	10	2
University of Cape Town	9	11
North West University	7	12
MINTEK	6	6
University of Witwatersrand, Johannesburg	6	11
Azoteq PTY	5	3
University of Stellenbosch	0	44
The South African Nuclear Energy Corp LTD	0	5
University of Pretoria	0	5
CSIR	0	4
HYDROX Holdings LTD	0	4

Source: Own elaboration based on PATSTAT.

South Africa can further capitalize on its productive capabilities to expand its engineering, procurement, and construction (EPC) exports. In addition to Solar MD, other companies have the potential to expand exports of green services and energy systems solutions. PVinsight,[13] for example, is a company in Port Elizabeth developed by researchers from Nelson Mandela University that offers consulting and testing services for solar projects. Companies like PVinsight can take advantage of the fact that EPC services are and will continue to be an essential element in the deployment of renewable energy worldwide and on the African continent.

4.6 Summary of Green Growth in South Africa

While the previous chapters discussed two fundamental constraints to growth in South Africa, this chapter explored growth opportunities moving forward in the context of global decarbonization. These noteworthy green growth opportunities show that the South African economy could have a promising future, but the nature of these opportunities also highlights the ongoing damage from collapsing state capacity. Many of the opportunities explored here are disincentivized by the failing electricity system, collapsing state capacity in other critical public goods, and high cost of capital. Addressing these problems will be central to achieving the promising green growth future that is possible for South Africa. Given that these opportunities depend on reaching the global market, policies focused on boosting demand through fiscal means or localization policies can be of limited benefit. In fact, given the country's precarious creditworthiness, a demand-side focus would run the risk of raising interest rates and the cost of capital of green investment. South Africa’s growth potential moving forward comes from the supply side of green growth – that is, capitalizing on its potential to help the world decarbonize through producing many goods, services, and knowledge that global decarbonization will require.

Fully addressing the electricity system failure and rebuilding state capacity are urgent challenges that not only undermine green growth today but in the future. The opportunities of decarbonization favor first movers. This historical opportunity will relocate industries to places that can provide cheap green energy. However, once industries start to cluster in new places, late entrants will have a harder time gaining a foothold in maturing

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[13] See: https://www.pvinsight.co.za/page/about

industries. China was able to become a world leader in manufacturing solar systems, electric vehicles, and batteries because they started long before the cost of electricity from PV became lower than the cost of coal-fired electricity. Meanwhile, South Africa doubled down on and then lost its comparative advantage in cheap electricity via coal. A wide range of countries are pursuing aggressive strategies to develop first-mover advantages. The Inflation Reduction Act (IRA) case in the U.S. is noteworthy, though a similar approach that is heavy on state subsidies would be infeasible and likely counterproductive in the South African context. Many other countries (e.g., Australia, Chile, Indonesia, and Namibia) are also gaining strength on the road toward green growth by focusing on their existing and potential comparative advantages. South Africa needs a strategy that matches its strengths and its limitations.

South Africa needs an active strategy for pursuing green growth opportunities that would allow the country to build new comparative advantages. Based on the opportunities previously identified, this strategy should be based on three pillars: (1) making the enablers of global decarbonization; (2) making green versions of grey products for the global market; and (3) exporting green knowhow. In addition to solving cross-cutting economic issues, this strategy requires industry-specific policies that target each of the areas of opportunity that have potential in South Africa. Rather than relying on government procurement and localization, which have become South Africa's main approaches to industrial policy as the economy has stagnated, the strategies explored here would be far more targeted and focused on capturing expanding demand in the global market in areas where South Africa has clear possibilities to grow. This has obvious advantages versus reliance on government's highly strained fiscal resources and the weakening domestic market.

Within Strategy 1 (making the enablers of global decarbonization), two main areas of opportunity are taking advantage of the mining boom and promoting the development of industries that are both likely to see rapid global demand growth and are consistent with South Africa's knowledge base. In addition to addressing collapsing state capacity, which constrains many of these opportunities, South Africa also needs targeted approaches. South Africa needs tailor-made mining and industrial policies. In the first case, a focus on exploration, production, and innovation is required to ensure that the country maximizes the benefits of mineral resource extraction. A revision of the mining policy framework is crucial for South Africa to take advantage of the critical minerals boom. In the case of other green supply chains, the government must be an enabler rather than a central planner. Some emerging opportunities might need supply-side measures to enhance competitiveness via a more efficient provision of public inputs; others might need targeted demand-side policies to ensure they are price-competitive during their early stages. Pursuing one-size-fits-all solutions without considering the industries' specificity would be less effective than defining industry-specific policies. Generally, companies that are first movers in emerging supply chains need easy access to imports and markets. This makes local content requirements (LCRs) a risky policy tool in many cases. However, LCRs may be powerful instruments in select cases and there is also a role for government procurement to be used to spur innovation within South African companies. The analysis included in this chapter merely provides a starting point for understanding emerging opportunities, and this information could be leveraged within emerging strategies and "masterplans" in development in South Africa today.

For Strategy 2 (making green versions of grey products), the electricity crisis is by far the most fundamental constraint. South Africa needs a boom in renewables to make green versions of grey products, and a boom in renewable generation also requires a rapid expansion of transmission in storage. South Africa has advantageous natural conditions for renewable energy generation but major disadvantages in electricity market design and the cost of capital for project development. Therefore, South African policymakers should focus on establishing a long-term market for electricity and lowering capital costs by reducing sovereign risk. Reducing development costs chiefly depends on state capacity. These improvements will take time, but South Africa also has high potential to kickstart this strategy through the development of green industrial parks. These parks could crowd in both dedicated generation and storage, which could be exported to the grid, and electricity-intensive manufacturing for exports. Green industrial parks should not be a public investment but rather a private sector opportunity that is enabled by government policy, including expedited permitting, and supporting infrastructure. The operators of parks would be capable and highly motivated to find tenants and create the environment that they need to succeed. These tenants may include such industries as mineral processing, green steel, ammonia-based fertilizers, as well as highly electricity-intensive services like data centers.

Strategy 3 (exporting green knowhow) presents South Africa with the opportunity to employ its top-tier technological resources to address global and regional challenges.

South Africa has several examples of companies that have developed solutions that are much needed in a decarbonizing world. Sasol's capacity to utilize the Fischer–Tropsch is rare in developing countries, making it a strategic player in exporting that technology to other parts of the world. At the same time, South Africa has seen noteworthy success in private innovators in the green economy and has advantages in the research capacity of its university system. Building on these advantages requires bringing capabilities of the private sector and academia together and mixing South African talent with global talent. For this strategy, the issues discussed in Chapter 3 on spatial exclusion are of particular importance. Additionally, South Africa's highly restrictive policies on high-skill immigration and inefficiencies in business travel are very problematic. For businesses that cannot bring the complementary human resources that they need into South Africa, the natural response is to move their businesses out of South Africa. Finally, South Africa should be well-positioned to expand its position in engineering, procurement, and construction globally, but especially across Africa. However, this industry requires the flexible movement of people, which is limited by South Africa's immigration policies. Ultimately, excelling in the green knowhow space will depend on South Africa becoming a place where talent from across the country and from around the rest of the world can more easily come together. South African metros have the building blocks to be such hubs, but their full potential is constrained by policy.

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Appendix

List of Strategic Products within Green Supply Chains

Parsimonious industrial policy

HS Code (4 digit)	HS Name	HS Code (2 digit)	Section	Opportunity Score	PCI	Green Topic
2910	Epoxides	Organic chemicals	Chemicals	1.05	1.62	Carbon Capture
8481	Appliances for thermostatically controlled valves	Industrial Machinery	Machinery	1.04	1.51	Carbon Capture
8414	Pumps, compressors, fans, etc.	Industrial Machinery	Machinery	0.95	1.14	Carbon Capture
8419	Equipment for temperature change of materials	Industrial Machinery	Machinery	0.93	1.09	Carbon Capture
8104	Magnesium	Other base metals	Metals	0.80	0.81	Carbon Capture
7225	Flat-rolled products of other alloy steel, width > 600 mm	Iron and steel	Metals	1.03	1.50	Electric Grids
8541	Semiconductor devices	Electrical machinery and equipment	Electronics	0.95	1.44	Electric Grids
8547	Insulating fittings for electrical machines	Electrical machinery and equipment	Electronics	0.91	1.02	Electric Grids
8546	Electrical insulators of any material	Electrical machinery and equipment	Electronics	0.89	0.98	Electric Grids
8532	Electrical capacitors	Electrical machinery and equipment	Electronics	0.88	1.06	Electric Grids
8413	Pumps for liquids	Industrial Machinery	Machinery	1.00	1.39	Flow batteries
8419	Equipment for temperature change of materials	Industrial Machinery	Machinery	0.93	1.09	Flow batteries
8506	Primary cells and primary batteries	Electrical machinery and equipment	Electronics	0.89	1.09	Flow batteries
6815	Articles of stone or of other mineral substances	Articles of stone, plaster, cement, etc.	Stone	0.85	0.88	Flow batteries
7019	Glass fibers	Glass and glassware	Stone	0.69	0.40	Flow batteries

9027	Instruments for physical or chemical analysis	Apparatuses (optical, medical, etc.)	Machinery	1.11	1.80	Green Hydrogen
7318	Screws and similar articles of iron or steel	Articles of iron or steel	Metals	1.09	1.60	Green Hydrogen
3914	Ion-exchangers based on polymers	Plastics	Chemicals	1.09	1.69	Green Hydrogen
8481	Appliances for thermostatically controlled valves	Industrial Machinery	Machinery	1.04	1.51	Green Hydrogen
9031	Measuring instruments	Apparatuses (optical, medical, etc.)	Machinery	1.02	1.41	Green Hydrogen
8481	Appliances for thermostatically controlled valves	Industrial Machinery	Machinery	1.04	1.51	Hydropower
8482	Ball or roller bearings	Industrial Machinery	Machinery	0.98	1.21	Hydropower
8454	Machines used in metallurgy	Industrial Machinery	Machinery	0.89	0.96	Hydropower
8501	Electric motors and generators	Electrical machinery and equipment	Electronics	0.81	0.74	Hydropower
7326	Other articles of iron or steel	Articles of iron or steel	Metals	0.81	0.75	Hydropower
8506	Primary cells and primary batteries	Electrical machinery and equipment	Electronics	0.89	1.09	Lead -Acid Batteries
7804	Lead foil <2mm	Lead	Metals	0.59	0.04	Lead -Acid Batteries
3915	Plastic waste	Plastics	Chemicals	0.33	-0.84	Lead -Acid Batteries
7801	Lead refined unwrought	Lead	Metals	0.13	-1.53	Lead -Acid Batteries
3818	Chemical elements for electronics	Miscellaneous chemical products	Chemicals	1.10	1.96	Lithium-Ion Batteries
3910	Silicones in primary forms	Plastics	Chemicals	1.05	1.57	Lithium-Ion Batteries
8541	Semiconductor devices	Electrical machinery and equipment	Electronics	0.95	1.44	Lithium-Ion Batteries
8507	Batteries	Electrical machinery and equipment	Electronics	0.90	1.10	Lithium-Ion Batteries
8506	Primary cells and primary batteries	Electrical machinery and equipment	Electronics	0.89	1.09	Lithium-Ion Batteries

8481	Appliances for thermostatically controlled valves	Industrial Machinery	Machinery	1.04	1.51	Nuclear
8413	Pumps for liquids	Industrial Machinery	Machinery	1.00	1.39	Nuclear
8406	Steam turbines	Industrial Machinery	Machinery	0.97	1.16	Nuclear
8408	Compression-ignition internal combustion piston engines	Industrial Machinery	Machinery	0.97	1.23	Nuclear
7505	Nickel bars, wire etc.	Nickel	Metals	0.97	1.29	Nuclear
8543	Electrical machines with individual functions n.e.c.	Electrical machinery and equipment	Electronics	0.95	1.34	Platinum Group Metal Catalysts
5911	Textile articles for technical use	Impregnated, coated or laminated textile fabrics	Textiles	0.90	1.04	Platinum Group Metal Catalysts
8506	Primary cells and primary batteries	Electrical machinery and equipment	Electronics	0.89	1.09	Platinum Group Metal Catalysts
2915	Saturated acyclic monocarboxylic acids	Organic chemicals	Chemicals	0.75	0.73	Platinum Group Metal Catalysts
8108	Titanium	Other base metals	Metals	0.72	0.51	Platinum Group Metal Catalysts
8414	Pumps, compressors, fans, etc.	Industrial Machinery	Machinery	0.95	1.14	Rare Earth Permanent Magnets
8505	Electromagnets	Electrical machinery and equipment	Electronics	0.93	1.17	Rare Earth Permanent Magnets
8417	Industrial furnaces	Industrial Machinery	Machinery	0.90	1.05	Rare Earth Permanent Magnets
8542	Electronic integrated circuits	Electrical machinery and equipment	Electronics	0.90	1.14	Rare Earth Permanent Magnets
8471	Computers	Industrial Machinery	Machinery	0.83	1.03	Rare Earth Permanent Magnets
3818	Chemical elements for electronics	Miscellaneous chemical products	Chemicals	1.10	1.96	Semiconductors
9031	Measuring instruments	Apparatuses (optical, medical, etc.)	Machinery	1.02	1.41	Semiconductors

8541	Semiconductor devices	Electrical machinery and equipment	Electronics	0.95	1.44	Semiconductors
8542	Electronic integrated circuits	Electrical machinery and equipment	Electronics	0.90	1.14	Semiconductors
2903	Halogenated derivatives of hydrocarbons	Organic chemicals	Chemicals	0.85	0.94	Semiconductors
3818	Chemical elements for electronics	Miscellaneous chemical products	Chemicals	1.10	1.96	Solar PV
2812	Halides of nonmetals	Inorganic chemicals	Chemicals	1.01	1.73	Solar PV
8483	Transmission shafts	Industrial Machinery	Machinery	1.00	1.27	Solar PV
9030	Instruments for measuring electricity	Apparatuses (optical, medical, etc.)	Machinery	0.97	1.27	Solar PV
8541	Semiconductor devices	Electrical machinery and equipment	Electronics	0.95	1.44	Solar PV
7226	Flat-rolled products of other alloy steel, width < 600 mm	Iron and steel	Metals	1.04	1.56	Wind
7225	Flat-rolled products of other alloy steel, width > 600 mm	Iron and steel	Metals	1.03	1.50	Wind
8483	Transmission shafts	Industrial Machinery	Machinery	1.00	1.27	Wind
8414	Pumps, compressors, fans, etc.	Industrial Machinery	Machinery	0.95	1.14	Wind
8542	Electronic integrated circuits	Electrical machinery and equipment	Electronics	0.90	1.14	Wind

Strategic bets

HS Code (4 digit)	HS Name	HS Code (2 digit)	Section	Opportunity Score	PCI	Green Topic
8481	Appliances for thermostatically controlled valves	Industrial Machinery	Machinery	1.03	1.51	Carbon Capture
2910	Epoxides	Organic chemicals	Chemicals	1.02	1.62	Carbon Capture
8414	Pumps, compressors, fans, etc.	Industrial Machinery	Machinery	0.92	1.14	Carbon Capture

8419	Equipment for temperature change of materials	Industrial Machinery	Machinery	0.91	1.09	Carbon Capture
8104	Magnesium	Other base metals	Metals	0.74	0.81	Carbon Capture
7225	Flat-rolled products of other alloy steel, width > 600 mm	Iron and steel	Metals	1.02	1.50	Electric Grids
8547	Insulating fittings for electrical machines	Electrical machinery and equipment	Electronics	0.89	1.02	Electric Grids
8541	Semiconductor devices	Electrical machinery and equipment	Electronics	0.88	1.44	Electric Grids
8546	Electrical insulators of any material	Electrical machinery and equipment	Electronics	0.86	0.98	Electric Grids
8532	Electrical capacitors	Electrical machinery and equipment	Electronics	0.82	1.06	Electric Grids
8413	Pumps for liquids	Industrial Machinery	Machinery	0.98	1.39	Flow batteries
8419	Equipment for temperature change of materials	Industrial Machinery	Machinery	0.91	1.09	Flow batteries
8506	Primary cells and primary batteries	Electrical machinery and equipment	Electronics	0.84	1.09	Flow batteries
6815	Articles of stone or of other mineral substances	Articles of stone, plaster, cement, etc.	Stone	0.81	0.88	Flow batteries
7019	Glass fibers	Glass and glassware	Stone	0.63	0.40	Flow batteries
9027	Instruments for physical or chemical analysis	Apparatuses (optical, medical, etc.)	Machinery	1.10	1.80	Green Hydrogen
7318	Screws and similar articles of iron or steel	Articles of iron or steel	Metals	1.09	1.60	Green Hydrogen
3914	Ion-exchangers based on polymers	Plastics	Chemicals	1.07	1.69	Green Hydrogen
8481	Appliances for thermostatically controlled valves	Industrial Machinery	Machinery	1.03	1.51	Green Hydrogen
9031	Measuring instruments	Apparatuses (optical, medical, etc.)	Machinery	1.01	1.41	Green Hydrogen
8481	Appliances for thermostatically controlled valves	Industrial Machinery	Machinery	1.03	1.51	Hydropower

8482	Ball or roller bearings	Industrial Machinery	Machinery	0.96	1.21	Hydropower
8454	Machines used in metallurgy	Industrial Machinery	Machinery	0.85	0.96	Hydropower
7326	Other articles of iron or steel	Articles of iron or steel	Metals	0.77	0.75	Hydropower
8501	Electric motors and generators	Electrical machinery and equipment	Electronics	0.76	0.74	Hydropower
8506	Primary cells and primary batteries	Electrical machinery and equipment	Electronics	0.84	1.09	Lead -Acid Batteries
7804	Lead foil <2mm	Lead	Metals	0.52	0.04	Lead -Acid Batteries
3915	Plastic waste	Plastics	Chemicals	0.23	-0.84	Lead -Acid Batteries
7801	Lead refined unwrought	Lead	Metals	0.01	-1.53	Lead -Acid Batteries
3818	Chemical elements for electronics	Miscellaneous chemical products	Chemicals	1.07	1.96	Lithium-Ion Batteries
3910	Silicones in primary forms	Plastics	Chemicals	1.03	1.57	Lithium-Ion Batteries
8541	Semiconductor devices	Electrical machinery and equipment	Electronics	0.88	1.44	Lithium-Ion Batteries
8507	Batteries	Electrical machinery and equipment	Electronics	0.85	1.10	Lithium-Ion Batteries
8506	Primary cells and primary batteries	Electrical machinery and equipment	Electronics	0.84	1.09	Lithium-Ion Batteries
8481	Appliances for thermostatically controlled valves	Industrial Machinery	Machinery	1.03	1.51	Nuclear
8413	Pumps for liquids	Industrial Machinery	Machinery	0.98	1.39	Nuclear
8406	Steam turbines	Industrial Machinery	Machinery	0.96	1.16	Nuclear
8408	Compression-ignition internal combustion piston engines	Industrial Machinery	Machinery	0.95	1.23	Nuclear
7505	Nickel bars, wire etc.	Nickel	Metals	0.94	1.29	Nuclear
8543	Electrical machines with individual functions n.e.c.	Electrical machinery and equipment	Electronics	0.90	1.34	Platinum Group Metal Catalysts
5911	Textile articles for technical use	Impregnated, coated or	Textiles	0.87	1.04	Platinum Group Metal Catalysts

		laminated textile fabrics				
8506	Primary cells and primary batteries	Electrical machinery and equipment	Electronics	0.84	1.09	Platinum Group Metal Catalysts
2915	Saturated acyclic monocarboxylic acids	Organic chemicals	Chemicals	0.68	0.73	Platinum Group Metal Catalysts
8108	Titanium	Other base metals	Metals	0.66	0.51	Platinum Group Metal Catalysts
8414	Pumps, compressors, fans, etc.	Industrial Machinery	Machinery	0.92	1.14	Rare Earth Permanent Magnets
8505	Electromagnets	Electrical machinery and equipment	Electronics	0.88	1.17	Rare Earth Permanent Magnets
8417	Industrial furnaces	Industrial Machinery	Machinery	0.87	1.05	Rare Earth Permanent Magnets
8542	Electronic integrated circuits	Electrical machinery and equipment	Electronics	0.84	1.14	Rare Earth Permanent Magnets
8501	Electric motors and generators	Electrical machinery and equipment	Electronics	0.76	0.74	Rare Earth Permanent Magnets
3818	Chemical elements for electronics	Miscellaneous chemical products	Chemicals	1.07	1.96	Semiconductors
9031	Measuring instruments	Apparatuses (optical, medical, etc.)	Machinery	1.01	1.41	Semiconductors
8541	Semiconductor devices	Electrical machinery and equipment	Electronics	0.88	1.44	Semiconductors
8542	Electronic integrated circuits	Electrical machinery and equipment	Electronics	0.84	1.14	Semiconductors
2903	Halogenated derivatives of hydrocarbons	Organic chemicals	Chemicals	0.80	0.94	Semiconductors
3818	Chemical elements for electronics	Miscellaneous chemical products	Chemicals	1.07	1.96	Solar PV
8483	Transmission shafts	Industrial Machinery	Machinery	0.99	1.27	Solar PV
2812	Halides of nonmetals	Inorganic chemicals	Chemicals	0.96	1.73	Solar PV

9030	Instruments for measuring electricity	Apparatuses (optical, medical, etc.)	Machinery	0.93	1.27	Solar PV
8541	Semiconductor devices	Electrical machinery and equipment	Electronics	0.88	1.44	Solar PV
7226	Flat-rolled products of other alloy steel, width < 600 mm	Iron and steel	Metals	1.02	1.56	Wind
7225	Flat-rolled products of other alloy steel, width > 600 mm	Iron and steel	Metals	1.02	1.50	Wind
8483	Transmission shafts	Industrial Machinery	Machinery	0.99	1.27	Wind
8414	Pumps, compressors, fans, etc.	Industrial Machinery	Machinery	0.92	1.14	Wind
8542	Electronic integrated circuits	Electrical machinery and equipment	Electronics	0.84	1.14	Wind

Intensive margin

HS Code (4 digit)	HS Name	HS Code (2 digit)	Section	Opportunity Score	PCI	Green Topic
8421	Centrifuges	Industrial Machinery	Machinery	NA	0.94	Carbon Capture
2901	Acyclic hydrocarbons	Organic chemicals	Chemicals	NA	0.44	Carbon Capture
8112	Other metals	Other base metals	Metals	NA	0.27	Carbon Capture
2841	Salts of oxometallic acids	Inorganic chemicals	Chemicals	NA	0.24	Carbon Capture
7606	Aluminum plates > 0.2 mm	Aluminum	Metals	NA	0.43	Electric Grids
7309	Tanks etc. > 300 liters, iron or steel	Articles of iron or steel	Metals	NA	0.29	Electric Grids
8112	Other metals	Other base metals	Metals	NA	0.27	Electric Grids
2850	Hydrides, nitrides, azides, silicides and borides	Inorganic chemicals	Chemicals	NA	1.67	Green Hydrogen
2914	Ketones and quinones	Organic chemicals	Chemicals	NA	1.17	Green Hydrogen
7110	Platinum	Precious metals and stones	Stone	NA	1.15	Green Hydrogen
3815	Catalytic preparations	Miscellaneous chemical products	Chemicals	NA	1.00	Green Hydrogen

8421	Centrifuges	Industrial Machinery	Machinery	NA	0.94	Green Hydrogen
2824	Lead oxides	Inorganic chemicals	Chemicals	NA	0.45	Lead -Acid Batteries
3902	Polymers of propylene	Plastics	Chemicals	NA	0.29	Lead -Acid Batteries
3801	Artificial graphite	Miscellaneous chemical products	Chemicals	NA	0.58	Lithium-Ion Batteries
7219	Flat-rolled products of stainless steel of a width > 600 mm	Iron and steel	Metals	NA	0.99	Nuclear
8421	Centrifuges	Industrial Machinery	Machinery	NA	0.94	Nuclear
8101	Tungsten (wolfram)	Other base metals	Metals	NA	0.83	Nuclear
3801	Artificial graphite	Miscellaneous chemical products	Chemicals	NA	0.58	Nuclear
7308	Structures and their parts, of iron or steel	Articles of iron or steel	Metals	NA	0.37	Nuclear
7110	Platinum	Precious metals and stones	Stone	NA	1.15	Platinum Group Metal Catalysts
3815	Catalytic preparations	Miscellaneous chemical products	Chemicals	NA	1.00	Platinum Group Metal Catalysts
8421	Centrifuges	Industrial Machinery	Machinery	NA	0.94	Platinum Group Metal Catalysts
2808	Sulfonitric acids	Inorganic chemicals	Chemicals	NA	0.29	Platinum Group Metal Catalysts
7115	Other articles of precious metals	Precious metals and stones	Stone	NA	0.09	Platinum Group Metal Catalysts
8112	Other metals	Other base metals	Metals	NA	0.27	Semiconductors
7308	Structures and their parts, of iron or steel	Articles of iron or steel	Metals	NA	0.37	Solar PV
7110	Platinum	Precious metals and stones	Stone	NA	1.15	Wind
7308	Structures and their parts, of iron or steel	Articles of iron or steel	Metals	NA	0.37	Wind