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Maximising the Green Path to Industrialisation in Africa

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Executive Summary

African countries face an existential dilemma: how to advance their economic transformation and industrialisation path while being responsive to required climate change action. In the current climate debate so far, however, there has been little talk of how to join up these efforts in a win-win way. Africa contributes the least to the climate crisis (in terms of cumulative greenhouse gas (GHG) emissions compared to other continents), but it needs the most economic development and support on job creation. In our paper "*A Just Transition for Africa: Championing a Fair and Prosperous Pathway to Net Zero*", we argue that for both African development and action on climate change to be successful, the global response needs to embrace Africa's industrialisation potential in all its forms, while supporting the continent's low-carbon transition as much as possible.

Industrialisation was integral to the economic transformation of high-income countries, with the shift of labour from low value-added sectors to higher value-added ones. Economic transformation led to increased labour productivity, rising GDP per capita, improved livelihoods, high levels of employment and incomes, and the reduction of poverty on a national scale. Industrialisation allowed high-income and upper-middle-income countries to make progress against nearly all the UN's Sustainable Development Goals (SDGs), before the goals had been developed and formalised. The key driver was manufacturing growth, so industrial policies tended to focus on the manufacturing sector. Today, industrialisation is understood in a wider sense, including many more high value-added sectors in manufacturing, services and agriculture, which create jobs and raise household incomes and net exports. The process of industrialisation remains at the centre of development in Africa, driving its economic future and capacity to create jobs at scale for a rapidly increasing young population.

Many industrial products and sectors that are fundamental to industrialisation are high contributors to greenhouse gas emissions. These include steel, cement, aluminium, plastics and ammonia, plus sectors such as food and beverage, textiles and apparel, chemical industries, and electronics and electrical equipment. For these sectors, pathways to a zero-carbon transition remain unclear due to the lack of availability of green technologies and solutions, or their comparatively high pricing compared to traditional solutions, which leads to a high green premium. New technologies and solutions are expensive and challenging in any part of the world, with a high risk of failure and a long-term vision needed for success. Applying them in African nations may prove to be additionally complex and require tailored support.

It is essential for African countries to find a realistic and pragmatic balance between following their industrialisation and development paths and their climate goals, with support from high-income countries (HICs). Green industrialisation aims to decouple economic growth from negative environmental externalities by maximising the application of clean energy, sustainable inputs and green-

production technologies. In the African context, green industrialisation should mean strengthening the industrialisation path that nations have embarked on, hence supporting local capabilities, while also maximising the application of sustainable technologies to accelerate the reduction of carbon footprints and help grow green industries where feasible.

Maximising the green path to industrialisation could provide certain benefits to African countries, including an opportunity to integrate themselves into an increasingly global green economy. There is the possibility of manufacturing greener products and engaging in new activities to improve innovation and productivity. This can be done by designing and implementing industrial policies that aim to enhance green initiatives while pursuing industrialisation paths to reduce poverty and create jobs and sectors of scale. Altenburg and Rodrik (2017) [1] have defined green industrial policies as "any government measure aimed to accelerate the structural transformation towards a low-carbon and resource-efficient economy in ways that also enable productivity enhancements in the economy." One essential feature of these policies must be the active and strategic identification of green activities, sectors and frontier technologies that can be developed by local capabilities and adopted in African economies. A set of tools and instruments, traditionally used in industrial policies, could be employed to facilitate such activities. These include fiscal incentives, R&D, human-capital investment, facilitating access to finance and markets, and investment in green industrial infrastructure.

In this paper, we dive into the realities and exigencies of industrialisation in African nations. We highlight the challenges and opportunities that exist to lower the carbon footprint of pathways to economic transformation, which would also facilitate development across the continent. We explore the industries that contribute the most to the climate crisis and pollution, plus the viable solutions and policies that African countries could adopt to help make such industries greener while continuing on the industrialisation path.

The role of HICs in the gradual green industrialisation of African countries will be critical. HICs must be strategic and long-term partners to facilitate a realistic and pragmatic transition while aligning with the long-term visions of African countries for their own development. HICs also need to guarantee technology transfer and capacity to African countries for new green tech, while bearing the green premiums for critical industrial products and sectors until more affordable technologies are available at scale – and until pathways for green industrialisation are realistic and affordable. It is essential that the global community ramps up its support for African countries to pursue a viable path for their economic transformation. It is also imperative that global climate action is sensitive to the biggest challenges and opportunities faced by African nations in this effort.

The Development and Climate Challenge in Africa

African governments are trying to transform their societies and economies so their people can escape widespread poverty and prosper. High-income countries in Europe, North America, South America and Asia have achieved significant improvements in their standards of living and labour productivity through the process of industrialisation, fuelled by the abundant use of low-cost, fossil-fuel energy and, in most cases, facilitated by industrial policies. An industrial policy is a coordinated effort by a government to develop sectors and markets to deliver public objectives, such as job and wealth creation. Such efforts were central to the economic transformation of high-income countries and fast-emerging economies, with the shift of labour from low value-added sectors to higher value-added ones. This was the case in the United States, United Kingdom, Germany and, more recently, China and South Korea. In these countries, economic transformation led to increased labour productivity, rising GDP per capita, improved livelihoods, high levels of employment and incomes, and the reduction of poverty at scale.

In Africa, most countries remain at the early stages of industrialisation and struggle to create enough jobs for their rapidly increasing young populations. The population in Africa is growing at about 2.6 per cent per year, higher than in any other continent. The median age is less than 20 years old. The capacity of African countries to lift people out of poverty, create jobs and integrate into the global economy is strongly linked to their ability to industrialise through the development of manufacturing, agro-processing and value-added sectors in services, often referred to as tradable services. Such sectors tend to include call centres, tourism, finance, ICT and modern tech.

Historically, economic transformation took place through manufacturing growth and industrial policies therefore tended to focus on the development of this sector. Today, industrialisation is understood in a wider sense and includes the development of high value-added sectors in manufacturing, services and agriculture, which create jobs, raise household incomes and net exports. Still, the role of manufacturing remains crucial because it is integral to the development of other sectors in agriculture and services through positive spill-over effects. Manufacturing creates demand for agricultural inputs, thus supporting an increase in agricultural productivity and, at the same time, creating a need for other activities in the services sector such as financial, logistics, business development and real estate. Moreover, manufacturing is generally labour-intensive and creates jobs at scale for low-skilled workers, particularly in low- and middle-income countries (LMICs), while proving critical to raising incomes of the working and middle classes in most high-income countries (HICs). Due to the nature of manufacturing activities, the sector has historically provided opportunities for countries to improve their technological capabilities and helped several East Asian nations to accelerate their technological catch-up in line with

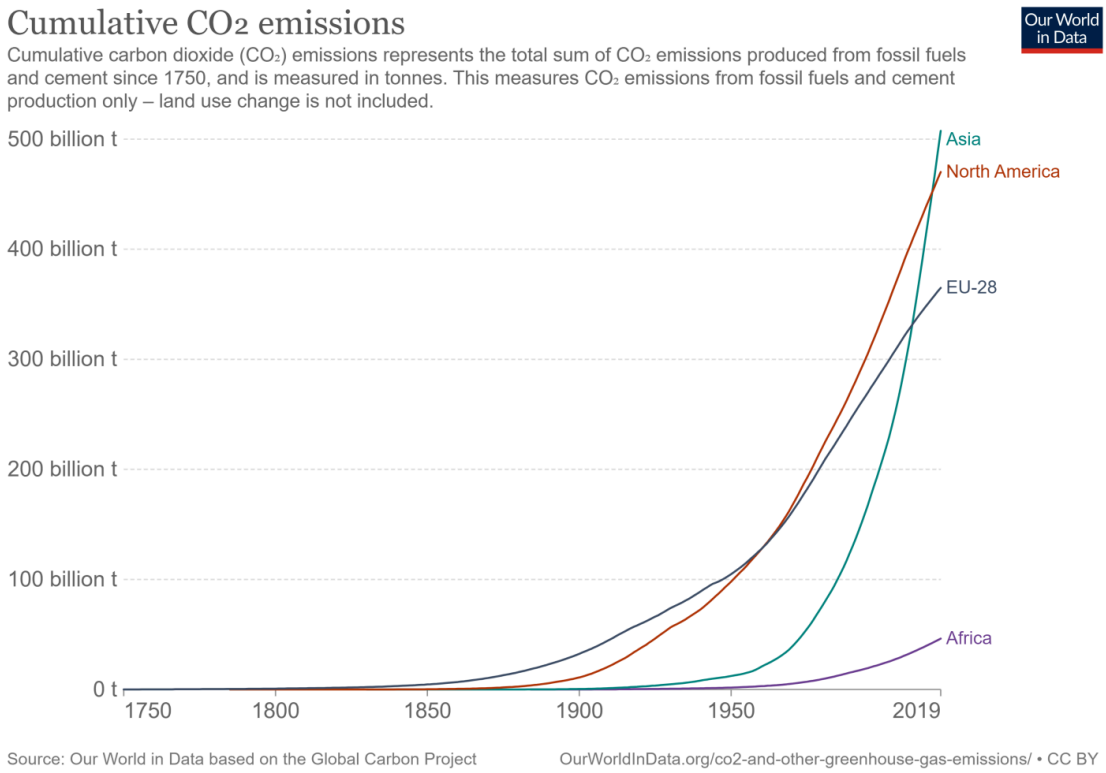
higher-income nations. Finally, manufacturing development also offers countries an opportunity to further engage in trade and integrate into the global economy.

For a typical country, the development of industrial structures will lead to new market needs emerging that necessitate improvement and alignment of hard infrastructure, such as roads, ports, telecommunications, electricity and public utilities, and soft infrastructure, such as finance, skills, regulations and institutions. These require the intervention and coordination of the state. A key rationale for industrial policies is to align such infrastructure to the industries with the greatest transformative potential. Industrial policies support a country's structural transformation process, leading to improvements in workers' outputs and GDP per capita as well as lower unemployment and inequality levels.

While many African nations are trying to industrialise using the lessons learned from other countries' experiences, new challenges caused by climate change have emerged. The climate crisis represents an existential emergency for humanity. The overexploitation of natural resources has led to global warming, depletion of land and fish stocks, water scarcity, worsening soil quality and unsustainable deforestation rates. Humans need to drastically decrease greenhouse gas (GHG) emissions to prevent global temperatures from rising by more than 2°C by 2100 compared to the pre-industrial era. The Intergovernmental Panel on Climate Change (IPCC) predicts that if we continue to manage our economies in the same way, the global mean surface temperature will increase by 3.7°C to 4.8°C.

There are huge discrepancies across countries in terms of responsibilities for the climate crisis, as Figure 1 shows. GHG emissions have mostly come from HICs, which have benefitted from low-cost and abundant fossil-fuel energy to develop their industries and economies. Countries in the early stages of industrialisation bear little responsibility. Africa, which accounts for 16.7 per cent of the global population, has contributed only 2.9 per cent of cumulative global carbon emissions. [2] More than half of African countries are categorised by low human development and the continent accounts for two-thirds of the global extremely poor population.

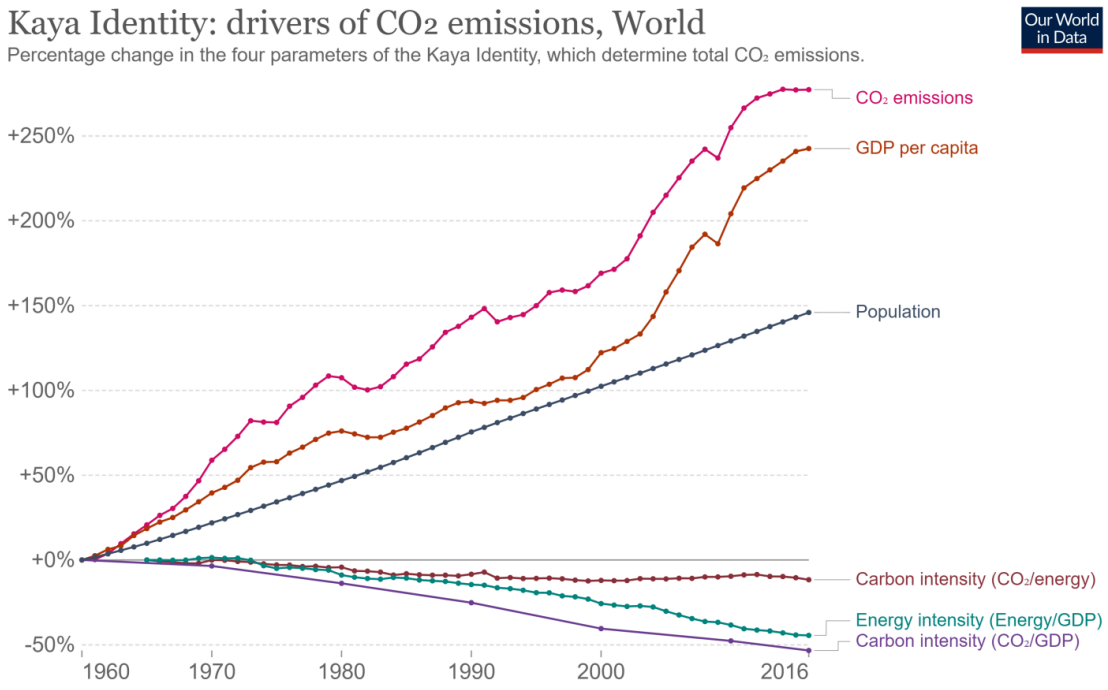
Figure 1 – Cumulative CO2 emissions across different regions between 1751 and 2019



Source: Our World in Data

The contribution of African countries to GHG emissions is likely to increase as their economies industrialise and develop. Newly industrialised economies such as China and India are increasingly responsible for a significant share of global CO_2 emissions, driving up the contribution from Asia to the current climate crisis. These dynamics are captured in the Kaya identity, which states that GHG emissions are caused by human activity and are a function of population, income per capita, energy intensity per unit of income and carbon intensity per unit of energy (Figure 2).

Figure 2 – Kaya identity: measuring the drivers of global CO2 emissions



Source: Our World in Data

International collaboration and coordination on the climate crisis have significantly strengthened over recent years. These efforts culminated with the Paris Agreement of 2015 under the United Nations Framework Convention on Climate Change. The agreement commits signatory countries to limit the increase in the global average temperature to well below 2°C above pre-industrial levels; to pursue efforts to hold that temperature increase to below 1.5°C; and to formulate and communicate long-term, low greenhouse-gas-emission strategies.

As part of the ongoing climate crisis, most HICs are shifting towards the formulation and adoption of "green deals" in efforts to coordinate their investments towards environmentally sustainable economies. These deals call for building net-zero, circular economies, which may be challenging for African countries given their nascent industries. As stated in our paper, "A Just Transition for Africa," denying Africa the opportunity to grow in the way the West has would, in the words of economist Ha-Joon Chang, be akin to "kicking away the ladder". Advanced economies cannot ask LMICS to completely shift towards a more sustainable approach while green technologies and solutions remain at higher prices than traditional, carbon-intensive ones.

African countries face a dilemma: how to advance their economic transformation and industrialisation path, which has historically been carbon intensive, in order to pull most of their people out of poverty, while also adapting to the climate crisis. GDP-related carbon intensity has been falling in line with the

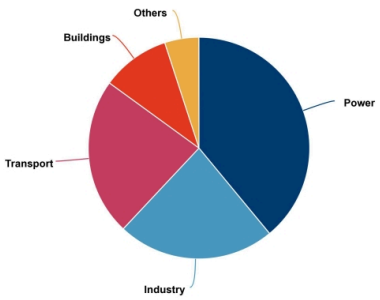
rise of service sectors in economies that have already experienced manufacturing-led industrialisation but in Africa, this trend would be in the opposite direction. It is important for African countries to explore potential investments in green and sustainable manufacturing, and to look for a balance between viable industrialisation paths and maximising green industries.

Climate, Pollution and Industrialisation

What Are the Industries and Products That Pollute the Most?

The production and consumption of key industrial products are essential for much-needed industrialisation in African countries. They include plastics, chemical products, cement, aluminium, steel and polyesters, among others. These are big polluters and contribute to the climate crisis while threatening the environment. This section explores these big polluting industrial products and industries, and the role they could play in Africa's economic transformation.

Figure 3 – Direct CO_2 emissions by sector globally, 2017

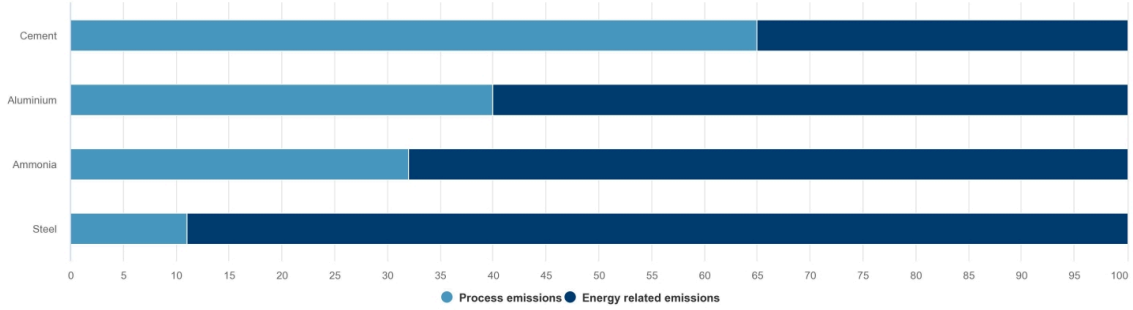


Source: IEA

Power and transport attract a lot of attention in the climate debate because they account for around 62 per cent of global GHG emissions and are the main consumers of fossil-fuel energy. However, industrial production is also a significant contributor, responsible for approximately a quarter of global CO_2 emissions (Figure 3). It also consumes up to 40 per cent of global energy demands. The most carbon-intensive industrial products include heavy manufacturing such as steel, cement and aluminium. Many products and industries in light manufacturing are also highly polluting, such as plastics, ammonia, textiles and apparel, as well as the food and beverage industry.

Some essential industrial products for development have a high-carbon footprint because of the chemical and physical reactions required for their production. These are called process emissions and represent about one-quarter of industrial emissions. Tackling process emissions will not be solved by renewable energy sources, and will require new technologies and innovation to change the outputs of the chemical reactions.

Figure 4 – Distribution of process emissions and energy-related emissions for heavy industrial products, 2019



Source: IEA

Heavy manufacturing products, including steel, cement and aluminium, are the main industrial polluters in terms of GHG emissions and have the highest process emissions (excluding electricity). It is estimated that the production of 1 tonne of steel leads to the emission of about 1.8 tonnes of carbon, of which 12 per cent are process emissions. The production of 1 tonne of cement produces 0.9 tonnes of carbon, of which 65 per cent are process emissions. It is estimated that the production process of steel and cement alone accounts for around 12 to 14 per cent of all GHG emissions. According to the International Energy Agency (IEA), primary aluminium production also has a high level of process emissions, amounting to 40 per cent of total emissions in the sector. Currently, China is by far the biggest global producer and consumer of steel, cement and aluminium. It makes 57 per cent of the world's steel, 55 per cent of cement and more than 54 per cent of aluminium. China will likely drive the future growth of demand for these products; however, other developing countries, including India and those in Africa, are expected to play a more prominent role in producing and consuming these products.

Africa represents a minimal share of global **steel** production, with only 17.4 million tonnes produced in 2020, just 0.9 per cent of global output, compared to 1.2 per cent in 2010, and 2 per cent of the consumption of finished steel products in 2020. [3] The consumption of **cement** in Africa is estimated to be 110 kilograms per capita in 2015, equivalent to 109.5 million tonnes in total and 2.7 per cent of global cement output. African countries consumed about 421,000 metric tons of aluminium in 2020, as part of a decreasing trend over the past decade. [4] By comparison, excluding China, Asia produced on average 2.3 million metric tonnes between 1990 and 2010. It is worth noting that Guinea has the world's largest reserves of bauxite (25 per cent of the global total), which is used in aluminium production.

African countries will need to rely on the production and consumption of these important products for infrastructure, urbanisation and industrialisation. The demand for cement will most likely increase exponentially because the continent has some of the fastest-growing cities in the world. Cement is essential for making concrete, the primary material used in construction and infrastructure, whether housing, roads, schools, hospitals, dams or ports. Other consumption patterns of high- and middle-

income countries show that as an economy develops and industrialises, the yearly per-capita consumption of cement steadily increases to peak at around 800–1,000 kilograms, before declining to an average of 300–600 kilograms (in markets with a GDP per capita of more than $25,000). For example, in Vietnam, which is successfully industrialising, the consumption of cement multiplied by a factor of three between 2005 and 2019. [5] The country's GDP more than doubled, its population rose from 83.8 million to 96.5 million and exports increased by a factor of 7.6. [6]

Steel, a major input for engineering and construction, is critical for railways, cars, buses and ports as well as for electrical products such as refrigerators and washing machines. Since 1971, global steel demand has increased by a factor of three, cement by nearly seven and plastics by over ten, while the global population has doubled and global GDP has increased fivefold. [7] Similarly, **aluminium** is a critical material for development as it is used in many industries and products, particularly in construction, transportation, power transition lines, consumer electronics and packaging. The demand for primary aluminium rose exponentially alongside industrialisation, reaching 128 million tonnes in 2020 and multiplying by a factor of six since 1971.

Besides heavy manufacturing, several **light-manufacturing** sectors also have climate and pollution implications due to their GHG emissions, primarily due to process and energy emissions, and the level of waste produced. Their industrial effluents can affect the air, water and soil, causing environmental degradation and sometimes affecting human health. The sectors include food and beverage, textiles and apparel, the chemical industry, and electrical and electronic equipment (EEEs).

We define the **food and beverage** industry as covering the full lifecycle from farm to fork. At a global level, the full lifecycle is estimated to contribute to GHG emissions through: i) the usage of fertilisers in agriculture, cattle breeding and consumption for meat and dairy; ii) the supply and cold chains necessary for the transportation and retailing of food and beverage products; and iii) food waste. In agriculture, livestock represents about 14.5 per cent of all GHG emissions, with cattle (raised for both beef and milk) responsible for about 65 per cent of this share. The supply and cold chains for food systems consume about 15 per cent of mostly fossil-fuel energy. Moreover, the level of food waste in the industry is problematic: it is estimated that about one-third of all the food produced in the world goes to waste with a footprint, including land-use change, estimated at about 8 per cent of all GHG emissions.

The global **textiles and apparel** industry is worth around $2.4 trillion (3.1 per cent of GDP in 2019) and employs more than 75 million people. However, the industry contributes up to 10 per cent of annual global GHG emissions. Material production – including synthetic fibres and polyester, which represent 52.2 per cent of global fibre production – accounts for 70 per cent of the industry's emissions, mainly due to fossil-fuel-energy consumption. The sector consumes a large amount of water annually, about 93 billion cubic metres, and represents about 20 per cent of global wastewater, which is often polluted with chemicals from dye. The industry also generates a huge level of fibre waste, valued at $500 billion

annually, due to a lack of recycling. Some 87 per cent of the total fibre input used to produce clothing ends up as waste.

The **chemical** industry is also a significant contributor to GHG emissions. Globally, the industry is one of the most important because chemical products are used as inputs in many other industrial and household items, such as rubber and plastic goods, paints and adhesives, consumer-care products (soap and detergents), pharmaceuticals and agro-chemicals including fertilisers and bio-tech. Considering the variety of products in the chemical industry, it is challenging to estimate the GHG emissions for the sector; however, these are dominated by a relatively small number of key outputs including ethylene, ammonia and other organic chemicals, such as nitric acid, adipic acid and caprolactam. These products are generally used in producing plastics, fertilisers and synthetic fibres such as polyester (mainly used by the textiles and apparel industry).

Ethylene is mainly used to produce **plastics** that have an extremely long degradation process, leading to serious poisoning of soil and maritime life. It is estimated that 60 per cent of all the plastics ever produced (around 4.9 billion tonnes) are currently in landfills, oceans and other natural environments. This endangers soil and maritime life through their decomposition into microplastics. GHG emissions from the manufacturing of plastics accounted for about 1 per cent of global carbon emissions in 2015. Ammonia [8], another chemical product, is estimated to represent about 1.8 per cent of global GHG emissions, mainly through methane and nitrous oxide emissions. Ammonia is mainly used to make fertilisers, with agriculture accounting for between 80 and 90 per cent of total ammonia emissions globally. Beyond GHG emissions, many products within the chemical industry contribute to water, soil and air pollution. For instance, ammonia contributes to soil and water acidification, which can be harmful to human health and could lead to global declines in biodiversity. Furthermore, the production of plastic goods offers low recycling possibilities and greatly contributes to the pollution of ecosystems. Other products such as soaps and detergents can affect marine life through eutrophication. [9] Water pollution is also relatively significant in the pharmaceutical industry, with industrial effluents discharged into water sources, leading to the formation of pools of bacteria and viruses that can contribute to the emergence of new infectious diseases.

It is important to acknowledge that the production and consumption of plastics and fertilisers within African countries remain very low. Africa's plastics imports represented only 3 per cent of total global production between 1990 and 2017. [10] With an average consumption of 16kg per capita per year, Africa remains well behind the consumption levels in industrialised countries within North America and Western Europe, which is estimated at around 100kg per capita per year. Plastics are an important input in many other products such as clothes, toys, furniture, household goods, cars and cell phones, and are therefore important for industrialisation. Moreover, the need for plastics is driven by packaging, which accounts for about 36 per cent of this demand, mostly for use in food retail and food systems. Increasing urbanisation is associated with changes in consumption patterns, including food systems, so the

consumption and processing of plastics in Africa is likely to increase significantly over the next decade, as demonstrated by the example of industrialised nations. For instance, according to the IEA, the global production of plastics has increased more than tenfold since 1970, faster than steel and cement. [11]

Sub-Saharan African countries consume about 2.9 per cent of world fertilisers; however, the demand for these products has been steadily growing, with average annual growth of 4.8 per cent since 2015 [12]. This is highly likely to increase, especially as the continent has 65 per cent of the world's uncultivated arable land. As African countries transform their agricultural sectors and develop their manufacturing capabilities, the local production of chemical products will likely need to increase, especially in resource-rich countries aiming to diversify their economies and invest in adjacent opportunities.

The **electrical and electronic equipment** (EEE) industry also contributes to the climate and pollution crisis, mainly through the level of electrical waste (e-waste) that it generates. EEE is one of the fastest growing and largest manufacturing industries today due to the importance of electronic goods in everyday life. Electronic goods vary from solar mini-grids to smartphones and car components, and constitute necessary tools in digitalisation and the use of cutting-edge technologies to improve daily human life. However, according to the United Nations Environment Programme and World Economic Forum, approximately 50 million tonnes of electronic and e-waste are produced yearly, and only 20 per cent is formally recycled. E-waste accumulates nearly three times faster than other waste. The material value of e-waste alone is estimated at $62.5 billion, higher than the GDP of many African countries. E-waste is not biodegradable and contributes to the contamination of groundwater, soil and air. Moreover, e-waste can contaminate the soil and water if not properly recycled, as it contains approximately 1,000 chemicals, of which some are dangerous to human health. Moreover, e-waste can lead to water contamination if not properly recycled. Currently, Africa generates 2.9 million tonnes of e-waste, much lower than Asia and Europe at 24.9 million tonnes and 12 million tonnes respectively.

Despite this, these sectors are important to economic transformation, and African countries will need to invest in their expansion. Food and beverage (F&B), textiles and apparel, and primary chemical products such as fertilisers and plastics, play a critical role in the early stages of development and industrialisation. F&B offers a strong case in fulfilling African countries' strategic objectives by increasing agriculture productivity and developing the manufacturing sector. During early stages of development, this is a sector that can provide beneficial connections with agriculture and because it can be highly labour-intensive, create jobs at scale while contributing more value-added to a country than agriculture alone. An agricultural revolution preceded the European, American and Asian industrial revolutions for this reason.

Similarly, the textiles and apparel (T&A) industry is critical and strategic for African countries aiming to build their manufacturing capabilities and create jobs on a large scale. Textiles and apparel kickstarted the original European industrial revolution. It is highly labour-intensive and is generally a target for countries in their early stages of development. Among others, the experience of East Asian countries highlights

the importance of this industry in terms of job creation, exports, revenue generation and building local production capabilities. Bangladesh, Vietnam and India represent about 15 per cent of total exports in the industry, with Bangladesh being the second exporter globally after China. In Bangladesh, T&A exports represent about 14 per cent of the country's GDP and the industry employs about 4.5 million workers. The industry has expanded in Africa in the past decade, with the most remarkable recent development in Ethiopia: in 2019, the country exported more than $332 million in T&A products compared to $50 million in 2009. This growth has been facilitated by heavy public investment in industrial infrastructure (industrial parks, in particular), and by increasing levels of foreign investment. Exports of T&A from Africa have increased from $16 billion in 2009 to more than $19 billion in 2019. [13] A growing number of African countries are developing and expanding their T&A industries to create jobs for low-skilled workers and to integrate their economies into the global one. This will inevitably increase GHG emissions and pollution on the continent if the industry follows a business-as-usual path.

These sectors increase labour productivity, create jobs at scale, especially for low-skilled labour forces, and increase value addition, compared to agricultural products. Engaging in them in the early stages of development allows low-income countries to: produce manufacturing goods with relatively low complexity; progressively accumulate technical know-how; develop their local production capabilities; and potentially diversify their manufacturing goods, engaging in more complex products and manufacturing activities, such as the chemical and EEE industries. This is demonstrated by the Product Complexity Index (PCI) shown below. Supporting early industrialisation is key because if countries cannot grow their food and textiles industries, it becomes much harder to move up the value chain and create formal and decent jobs, which leaves people in poverty. This could also lead to informal urbanisation, highly dependent on polluting energy sources with no capacity to manage pollution and waste.

Figure 5 – Product Complexity Index per sector, 2019

Sector	Product Complexity Index - 2019		
	Min	Max	Average
Machines, including EEE	-1.24	2.42	0.93

Chemical products	-1.37	2.76	0.42
Plastics and rubbers	-2.31	1.62	0.52
Textiles and apparel	-2.81	1.31	-0.59
Food and beverage	-2.46	0.46	-0.70

Source: Observatory of Economic Complexity and TBI; the PCI is available at HS4 level; for sectors, we calculated the averages based on PCI at HS4 level for all products under each section/sector level (Note: The Product Complexity Index indicates to what extent products require a high level of knowledge to be produced.)

The chemical industry represents a strategic industry in the African continent for at least two reasons. First, it is high value-added with potential for technological capital accumulation and productivity improvements. For instance, the United Nations Conference on Trade and Development (UNCTAD) classifies chemical products as high skill and technology-intensive manufacturing groups. Therefore, the industry provides an opportunity for African countries to upgrade their technological capabilities and diversify their exported products while increasing the sophistication of exports. Second, the production of agro-chemicals and fertilisers is a crucial focus of the chemical industry, considering the role that fertilisers can play in improving crop yields. Increasing agricultural productivity is a key strategic objective for most African economies where agriculture still forms the backbone.

Overall, the industry is economically important in several African countries, especially middle-income ones, and contributes up to 4.1 per cent of the continent's exports. [14] Chemical imports and exports grew at an annual average of 4.2 per cent and 4.7 per cent respectively between 2009 and 2019. [15] Africa's most advanced chemical industries are found in the northern (Egypt, Morocco and Tunisia) and southern (South Africa) regions. Generally, countries that develop strong chemical industries have a certain level of natural resources. Morocco and Tunisia have significant amounts of phosphate, which has historically driven them to develop the chemical industry, starting with the extractive value chain and then upgrading their capacity towards the production of basic chemicals, fertilisers, consumer care and pharmaceutical products. Today, both countries produce a significant volume of their local consumption of pharmaceutical products, while chemical products represent a considerable share of their exports. [16]

The demand for, and production of, chemical products is likely to increase significantly on the continent, driven by plastics and fertilisers.

The EEE industry remains nascent in most African countries, except for South Africa and North African countries, including Morocco where the sector has been steadily growing in recent years, driven by the thriving car industry. However, as explained above, the industry has a vital role in the continent's structural transformation and industrialisation because it offers African economies the possibility of entering more diverse, sophisticated and complex product markets, which could help in the convergence process and technological catch-up. The four Asian Tigers (Hong Kong, Singapore, South Korea and Taiwan), which have been successful in their industrialisation and structural transformations, have witnessed a gradual diversification and sophistication in their exported products, gradually shifting from labour-intensive manufacturing, such as textiles and agro-processing products, to higher value-added ones, like electronics and sophisticated chemical products.

Solutions and Technologies – A Focus on Industrialisation and Manufacturing

The climate crisis and pollution require a global transition from polluting technologies to clean and green energies, but it is essential to find the right balance between enabling African industrialisation and minimising its climate impact. To support the former, while gradually maximising sustainability and minimising the carbon footprint, it is essential to understand the commercial viability of solutions and technologies that could achieve this in the African context.

Policies to realise a transition to low-carbon/carbon-free and clean industrialising economies would have to fulfil the following objectives:

1. **Rollout viable renewable energy sources** fit for critical industries in heavy and light manufacturing, and improve their production-energy efficiency.
2. Develop and adopt technologies to **reduce process emissions of key industrial products**, including heavy-manufacturing (such as cement, steel and aluminium) and some light-manufacturing products (for example ammonia and plastics).
3. **Increase resource efficiency** to reverse the resource depletion process and reduce industrial waste. This could apply to all the manufacturing sectors listed above, including key light-manufacturing sectors that are important to economic transformation, and help to build the case for investing in a circular economy.
4. **Reduce pollution of air, soil and water** caused by industrial activity and effluent.

Most of the solutions to achieve these objectives are still being prototyped or developed, while zero-carbon solutions remain more expensive than traditional technologies, imposing **green premiums** on countries aiming to transition towards a low-carbon economy.

Realising these objectives requires new technologies and production processes. Below, we explore existing solutions for the three last objectives and their feasibility, including in an African context. In our paper "A Just Transition for Africa", we provide an analysis of pathways for gradually greening the energy sector and explore how African countries can fulfill the first objective, which will be crucial to reducing the carbon emissions of industries on the continent, such as food and beverage, and textiles and apparel.

Transitioning to Green Technologies

Reducing process emissions of the most polluting industrial products requires innovative and substitutive technologies. This is explored through two major cross-cutting technologies to either reduce carbon emissions or transition to zero-emission production, and these are **carbon capture, utilisation and storage (CCUS),** and **green hydrogen.**

CCUS technologies capture and reuse the carbon emitted from fossil-fuel energy or industrial activities using fossil-fuel activities, instead of it being emitted into the atmosphere. These technologies start by capturing the carbon - compressing it, storing it and transmitting it to be used in other applications, including the production of industrial products - or injecting it into deep geological formations. However, CCUS technologies are not widespread and not proven for large-scale use. While there are at least 21 large-scale CCUS applications in use across different sectors, from fertilisers (ammonia) to steel and cement, absorbing more than 40 million tonnes of CO_2 emissions each year, their green premium for key industrial products is high. For example, CCUS technologies for cement and steel (Figure 6) would cost between $12.3 billion and $26.4 billion per year, if adopted in Africa. CCUS technologies are only being explored in relatively well-developed countries such as Australia, Canada, Norway, the US, Brazil, China, Qatar, Saudi Arabia and the UAE.

Figure 6 – Estimated cost of the green premium for CCUS in carbon-intensive industrial products

Industrial product	CCUS's green premium range	The potential cost to African countries
Cement	75 to 140 per cent	$11.2 to 21 billion
Steel	5 to 30 per cent	$1.1 to 6.4 billion

Sources: Green premium for cement, Bill Gates, "How to avoid a Climate disaster?"; Green premium for steel, OECD and European parliament; source for the potential cost to African countries: author's computation using direct emissions only, excludes emissions from electricity production. (Note: The average prices per tonnes used for cement and steel are $137 and $582, based on 2020 averages. Potential cost was calculated based on African countries' current consumption of cement and steel, estimated at 109.5 million tonnes and 36.4 million tonnes respectively.)

Another key technology is **green hydrogen**. This is expected to play a significant role in the net-zero strategies of both developed and developing countries in energy and several industrial products, such as aluminium, ammonia and steel. Green hydrogen [17] is produced through water electrolysis using renewable energy to split the hydrogen and oxygen constituents. Hydrogen can then be used as a fuel and an energy source, emitting only water vapour during the combustion process, and either used directly or stored in fuel cells for electricity on demand. Another possible application of hydrogen is to use it as a substitution technology in the production process of industrial products, such as steel, aluminium and ammonia. At present, pathways towards developing a green-hydrogen system remain unclear because transmission and storage mechanisms for commercial use are yet to be built. In time, CCUS technologies may be able to help.

Other technologies to reduce process emissions of industrial products are also being explored. For example, substitutes for the clinker material used to make cement are being studied because clinker is responsible for about 90 per cent of the sector's emissions. Clinker substitute solutions are proving to be effective and do not require significant investment in new infrastructure or equipment. However, several constraints exist for their scale-up, including the availability and cost of the alternative materials.

The two most promising low-carbon technologies in the production of steel are Hydrogen Direct Reduction (H-DRI) and Molten Oxygen Electrolysis (MOE). [18] H-DRI holds the most promise and is based on the production of green hydrogen to replace the use of hydrogen and carbon in steelmaking.

Advanced economies have been investing heavily in carbon-free steel production, with a couple of pilot initiatives launched around the globe. In July 2021, Sweden produced the first fossil-fuel-free steel based on H-DRI technology. This represents an important step towards decarbonising the sector, albeit the production of this new steel at a large scale will only come online in 2026.

In the US, Boston Metal is currently developing MOE technology to produce various products although the technology remains a bit behind H-DRI. Pathways to reducing aluminium-derived process emissions revolve mainly around inert anode technologies to eliminate the formation of CO_2, so that only pure oxygen is created as a by-product of the smelting process. [19] Inert anode technologies remain at the R&D and prototype level, and are not yet commercialised. In June 2021, a Canadian company became the first company worldwide to start constructing commercial-scale inert anode cells and aims to complete the technology demonstration by 2024, before starting to commercialise it. Green hydrogen and CCUS are also being explored for aluminium, however there are no applications yet of CCUS technologies for this product.

Increasing Resource Efficiency – The Role of the Circular Economy

Existing and traditional industrial models are based on the following steps: extract, produce, use and waste. This is not only causing a depletion of natural resources and a huge waste-management issue, but it is also impacting GHG emissions. The continuous production of polluting industrial products leads to more GHG emissions, which could be reduced through the reuse of existing products. As indicated previously, it is estimated that 62 per cent of all global GHGs are emitted during the extraction, processing and production stages, and that only nine per cent of used material is circular. A transition towards zero emissions would need to include a shift toward zero waste, which would require investment in a circular economy.

As an alternative to this traditional model, the circular economy is based on a constant transformation of waste for usage as an input in the manufacturing value chain, and it can also be a solution to increase resource efficiency, reverse resource depletion and reduce industrial waste. The circular economy is built on the principles of reducing, reusing and recycling (3Rs). It aims to cut extraction levels of raw materials (generally a carbon-intensive process), and reduce industrial waste that could contribute to polluting the planet by repairing, recycling and reusing industrial products. The Ellen MacArthur Foundation identifies three principles for the circular economy: designing out waste and pollution; keeping products and materials in use by recycling them; and regenerating natural systems by avoiding non-renewable resources while preserving and enhancing renewable ones.

Circular-economy applications can go from recycling a damaged mobile phone or a plastic bottle, to car-sharing schemes and regenerative agriculture. Recycling is an important part of the circular economy because it provides the opportunity to reuse industrial products and to reduce pressure on extracting

new raw materials. The economic potential for the circular economy is huge. In Europe alone, the circular economy could generate a net economic benefit of €1.8 trillion by 2030. More globally, the circular-economy approach could reduce emissions from the production of key industrial materials by 40 per cent by 2050. Interest from financial institutions has significantly increased over recent years: today there are 13 public-private equity funds dedicated to the circular economy, with $4.6 billion worth of assets under their management, whereas there were only two in 2018. A number of global enterprises are also investing in the circular economy. For instance, in late 2020, Groupe Renault announced the establishment of RE:Factory, the first dedicated circular-economy plant for vehicles and mobility in Europe. It will be fully developed between 2021 and 2024, in collaboration with several partners.

The circular economy in Africa has huge potential to reduce the pollution from industries vital to the continent's economic development. Recycling technologies are significantly improving, and becoming more accessible and effective across many industrial products and sectors, such as aluminium, textiles and apparel, and EEE. For instance, in the case of aluminium, existing technologies are becoming increasingly effective in recycling the metal infinitely without it losing its properties. The recycling of aluminium can reduce the need for primary aluminium by 15 per cent per year. In the textiles and apparel industry, clothing resale is expected to be bigger than fast fashion by 2029 according to the Ellen MacArthur Foundation, supported by more interest in the circular economy.

Circular-economy principles can be applied to all industries and products in Africa. The industries with the highest potential are:

- food systems
- packaging (plastics recycling)
- built environment (construction)
- electronics
- textiles and apparel

The industries have been identified by the African Alliance on Circular Economy (ACEA) [20], using their circularity potential and economic importance as criteria. The ACEA estimates that investing in a systemic and formal circular economy across these sectors could not only help in tackling health pollution and environmental issues, but also create thriving industries that could boost the number of jobs available across the continent.

Interest is increasing in Africa. Although African countries currently recycle only 4 per cent of their waste, several have adopted strategies and national plans to deal with waste management, a key component in the circular economy. There is particular interest in e-waste management with Ghana, Kenya and Rwanda adopting e-waste strategies and guidelines. In 2020, Rwanda established one of the first state-of-the-art e-waste recycling facilities on the continent – EnviroServe Rwanda – financed by

the Rwanda Green Fund (FONERWA), which was established by the Rwandan government in 2012. The facility is aiming to develop a processing capacity of 10,000 tonnes per year. That is more than the annual e-waste generated in the country, estimated at 7,000 tonnes in 2019. EnviroServe is currently processing 4,000 tonnes of e-waste per year and employing more than 600 workers. Under full capacity, the facility could employ more than 1,000 workers. In Nigeria, Africa's most populous country, the E-waste Producer Responsibility Organisation of Nigeria (EPRON) was set up by electrical and electronic producers – including HP, Dell, Philips and Microsoft – to work with consumers and producers to ensure the safe management of e-waste in the country. Moreover, several programmes and targeted initiatives have been relatively successful on the continent, such as Oribags Innovations in Uganda and the Recycling Centre for Used Plastic Bags in Burkina Faso. These projects have been successful in recycling waste into marketable products, while generating jobs in manufacturing and sales.

However, the circular economy is still far from being the default approach for industries, especially in Africa. Innovation and technologies are needed to minimise waste and develop new business models and recycling processes. For instance, a number of technologies are necessary in the circular economy, including for traceability of supply chains. While advancements have been made, including in satellite-based GPS technology, the "internet of things" (IoT) and low-power wireless technology, these might not yet be affordable and accessible at scale in African countries. Moreover, a shift towards a circular economy will need significant investment in infrastructure for waste-management and recycling, as well as a significant change in industrial processes. These would require financing and upfront investments, which many African countries would struggle to meet alone.

Reducing Pollution Caused by Industrial Activity and Effluent

In parallel to the solutions already explored, there is a need to make value chains and enterprises greener by using the latest technologies in pollution control and reduction. Green-manufacturing practices offer some solutions that could be explored in African countries across different polluting industries. Green manufacturing provides a new paradigm for production based on environmentally friendly principles, which can be defined as producing green products using sustainable inputs, clean processes and clean technologies.

There are two main layers of intervention for green manufacturing: i) **a value-chain layer** that is specific to each industry and will affect the choice of inputs, products, processes and technologies, while constituting the basis for this type of manufacturing; and ii) **a cross-cutting layer** that applies to all industries, from industrial infrastructure to energy supply, transportation of goods and reduction of waste, by adopting the circularity principle throughout. For the cross-cutting layer, we will focus on eco-industrial parks in particular as a central piece of industrial infrastructure.

The Value-Chain Layer – Greening Different Industries

There are different steps and stages to greening value chains within industries, including using green inputs, renewable energy and applying circular-economy principles for waste management. Greening value chains should go further to include reduction in the quantity of harmful substances used in manufacturing. This could be achieved by using alternative approaches to replace toxic chemicals and hazardous substances, implementing innovative processes that increase operational efficiency, reducing water use, and limiting or eliminating the discharge of toxic waste.

Greening value chains should also include investing in effluent treatment plants to remove polluting substances, such as nitrogen and other organics. For some industries, effluent pollution is significant and would require a heavy shift of the means and paradigm of production. This will be particularly important in the context of African countries because significantly polluting industries - such as chemical, textiles and apparel, and food and beverage - will continue to develop.

The Cross-Cutting Layer – Infrastructure and the Eco-Industrial Park

Industrial infrastructure is key to sectoral development, and industrial parks (IPs) have historically been central to industrialisation and the export-promotion strategies of low- and middle-income countries (LMICs). IPs are clusters or geographic agglomerations of interconnected firms and supporting institutions. They can create positive externalities, including knowledge spill-over, better access to markets and suppliers, increased competitiveness, the creation of pools of specialised workers with specific skills, and easier coordination between companies, governments and service providers. IPs aim to realise these benefits while attracting foreign direct investment and promoting exports. They are generally designed under a "plug-and-play" model to attract foreign investments, and are central to investment and export-promotion policies in many LMICs, including an increasing number in Africa. The model includes an extensive set of services such as upgraded infrastructure, streamlined administrative and regulatory frameworks, fiscal and financial incentives, and facilitated access to support services such as logistics and finance.

As IPs represent an important concentration of industrial activities, they are generally responsible for a significant share of waste outflows. For instance, in Vietnam, IPs are responsible for about 70 per cent of the total industrial effluent in the country. Eco-industrial parks (EIPs) can be an alternative tool while reducing the pollution and GHG emissions caused by manufacturing and industry. In EIPs, in addition to the typical services provided in conventional IPs, companies are enabled to collectively address environmental challenges, and adopt the necessary business and manufacturing practices to produce green and environmentally friendly products. These practices aim to reduce GHG emissions and pollution levels, ensure efficient use of resources, including water and energy, notably through reuse and recycling of wastes, and improve the management of chemical and hazardous substances.

EIPs include specific environment-oriented services in addition to those provided by conventional IPs, including:

- Provision of environmentally friendly inputs, including the supply of renewable energy, and green and environmentally compliant raw materials.
- Efficiency in water and energy management.
- At the plant level, using green processes and green manufacturing (including little to no use or production of hazardous material, including in waste).
- Adopting circular-economy practices and facilitating the recycling or reuse of wastes as inputs within enterprises in the EIP (a process also called industrial symbiosis).
- Enabling community cohesion and resilience to various types of risks.

There is some progress in building eco-industrial parks in Africa. In Ethiopia, Hawassa Industrial Park represents a flagship project on the continent, with a supply of hydropower energy and the installation of the Zero Liquid Discharge (ZLD) industrial-effluent treatment plant. However, the development of EIPs can be challenging, especially in the context of African countries, where the newest green technologies are generally either inaccessible or accessible at relatively high costs.

Typically, green plants require high upfront capital costs with long-term returns on investments, limiting implementation and the appetite of investors, especially in African countries. Other challenges include limited financial support for innovative processes and environmental measures, and uncertainty around the adoption of new green technologies. Experiences of implementing EIPs in South Korea indicate some positive results, as it is estimated that EIPs led to a 48 per cent reduction in GHG emissions between 2005 and 2012 within evaluated industries, compared to their pre-establishment in 2004. However, other international experiences, including in China and Vietnam, indicate that several challenges might still be encountered. These include achieving industrial symbiosis, keeping to the commitments for green technology and practices by investors and plants, and effectively supporting their implementation from a policy and regulation perspective.

Conclusion

There is a need for further innovation and R&D for green technologies in industrialisation before they become affordable and available at scale. Many challenges remain to make Africa's industrialisation path greener, either caused by the lack of availability of sustainable technologies and solutions, or their comparatively high prices compared with traditional ones. Proving most of the technologies and solutions that have been presented above will be expensive and challenging, with high failure risks and long-term horizons needed.

Even if these technologies were proven in the short term, it would be likely that they would remain expensive in the medium term. The "familiarity" bias of using or adapting existing and current mainstream technologies could cause further lags between the time that greener technologies are introduced and

then adopted. Moreover, these technologies are mainly being developed, tested and used in advanced economies, with little opportunity for most African countries to engage in their R&D. Therefore, high green premiums for these technologies and solutions are expected. And if a drastic transition to green is imposed, this would ultimately impact the development path of African nations.

The Case for Green Industrialisation and Green Industrial Policies

Green industrialisation aims to decouple economic and industrial growth from negative environmental externalities by using clean energy, sustainable inputs and green technologies. Yet most African countries need to achieve important objectives such as infrastructure development, poverty reduction, job creation and improvement of health and education outcomes, with very scarce resources. Therefore, policymakers in Africa might put these objectives above global environmental concerns, especially when a green transition remains uncertain as a development path and represents uncharted territory. Given these urgent development objectives, and the current lack of availability and price of carbon-free and green technologies, any green industrialisation in Africa will need to combine a continuing industrialisation path and the building of local production capabilities with the maximisation of green technologies, as they become available and feasible. This process should be supported by high-income countries (HICs), where most of the technology and capital for a green transition is concentrated.

Maximising green industrialisation could provide certain benefits to African countries including an opportunity to integrate into a global green economy. That transformation is already underway, driven by heavy investment in sustainable and green technologies and the emergence of markets for green products. For instance, between 2013 and 2020, venture-capital investment in climate tech grew five times faster than general funding for start-ups. In 2020 alone, investments in green technologies, in sectors from energy and transport to industry and agriculture, reached more than $500 billion, doubling in just a decade. Maximisation of green industrialisation in Africa might also hold the potential for innovation, productivity gains and job creation through the manufacturing of new products and the development of new industries.

The green economy offers the possibility of manufacturing new products and engaging in new activities to improve innovation and productivity in Africa. Many fast-emerging economies, such as China, India, Morocco and Brazil, are increasing their engagement in green technologies and have successfully developed new export opportunities in the green economy. For example, China has invested heavily in electric vehicles (EVs) and is on the path to playing a major role in this fast-growing market. The country has invested at least $60 billion in the sector and is implementing an ambitious plan to increase its EV share to 40 per cent of sold cars by 2030. The market in China is expected to grow at 24 per cent per year until 2030, driven by public and private investments, including from key players such as Tesla. Morocco is also investing in green hydrogen production as part of a broader plan to transition to a 52 per cent renewable-energy mix by 2030, up from 15 per cent in 2018 – and to a full renewable energy supply by 2050.

Such transitions require intensive intervention to direct efforts towards producing affordable and green technologies and products. Governments and policymakers in African countries can play an important role in shaping the markets and the production factors for a green transition, while investing in industrialisation and job creation on the continent.

Maximising Green Industrialisation – Possible Features of Green Industrial Policies in Africa

For green industrialisation to succeed, climate efforts need to adopt an industrial-policy approach. The main objective is to anticipate the future needs of economies, and to adapt and coordinate by aligning the necessary resources and policies, including adequate soft and hard infrastructure. Adaptation to future trends is vital to ensure relevance in the global economy and pave the way towards economic development. This can be achieved through a set of government interventions to influence the economic structure for meeting development objectives. As green technologies, products and markets are increasingly shaping the global economy, African countries need to anticipate and prepare for them, making a case for green industrial policies. Altenburg and Rodrik (2017) [21] defined green industrial policies as "any government measure aimed to accelerate the structural transformation towards a low-carbon and resource-efficient economy in ways that also enable productivity enhancements in the economy."

Green industrial policies aim to foster growth by following the hypothesis that economic growth and environmental sustainability can go hand-in-hand through a decoupling of growth and environmental pollution. As in conventional industrial policies, information and coordination failures provide a rationale for government interventions. But there are differences between green and traditional industrial policies. In the former, there is a clear distinction between desirable and non-desirable technologies (in other words, polluting and clean ones). Therefore, the focus is not only on building local production capabilities, but also on reducing the environmental externalities of economic activities through the development and adoption of clean and green technologies. In addition, green policies require coordinated and aligned interventions at the global level to tackle the collective threat of climate change. This is highly challenging, especially considering the difference in responsibilities for pollution, and the divergent needs of African countries and HICs. Despite this, such coordination is particularly important because most green-tech innovation is concentrated in advanced economies, and this could actually represent an opportunity for technological catch-up and upgrades for African countries.

Realising the four objectives for a green transition and industrialisation – as presented previously – will be challenging and more likely realised in the long rather than the short term. In African countries, green industrialisation is not straightforward and will need to be supported by HICs, not only because they must shoulder the greatest responsibility for the world's pollution and climate crisis, but also since green technologies and innovation are mostly based in these advanced economies. While industrialisation will

necessitate an increase in GHG emissions in Africa, policymakers on the continent should start adopting policies to maximise the potential for more sustainable industrialisation. This will pave the way to a green structural transformation and "carve out a role for African economies in a rapidly greening world economy," according to Harvard's Ricardo Hausmann.

The tools and instruments that policymakers could use are similar to those typically used in traditional industrial policies, but which add green filters. These filters do not suggest an exclusive prioritisation of green sectors and activities but rather a maximisation of investment in feasible and affordable green activities. African countries will need to focus on developing key industries such as chemical, food and beverage, textiles and apparel, and EEE, plus other significant industrial products such as cement, steel and aluminium, while also greening enterprises in these industries, and engaging in new green technologies and activities as much as possible.

African nations will take different paths towards green industrialisation with varying timeframes. The exact transition of each country, and precise list of interventions that could be implemented, will depend heavily on the local context, including fiscal and macroeconomic circumstances, the resource base, the role of fossil fuels in the economy, local industrial and manufacturing capabilities, and the energy mix. However, we provide a list of features of green industrial policies that could be explored and adapted to each country's context.

Eight Key Steps for Rolling Out Green Industrial Policies in Africa

1. Sector development: In collaboration with the private sector, governments, backed by their international partners, should actively and strategically identify emerging green activities and sectors as well as green frontier technologies that local industries could engage in. They should also design and implement policies and programmes to facilitate the development of these identified activities. Green technologies and activities are rapidly evolving, with increasing space for the involvement of LMICs. There are several activities that could facilitate a greener industrialisation, and which African countries could engage in. In manufacturing, Altenburg and Rodrick (2017) [22] have identified a list of such activities and products that represent an opportunity for LMICs, including those in Africa. These encompass the manufacturing of renewable energy equipment, activities in the circular economy including material recovery and recycling, and waste treatment and management. In services, African countries could engage in new activities linked to sustainable electrification, to the circular economy such as the internet of things and other technologies required for traceability within supply chains, and to recycling, repair and waste management. Investing in these opportunities would help African countries tap into the growing market of environmentally friendly and conscious customers in HICs.

The exact list will evolve depending on global and local innovation, affordability of technology and the development of local industrial capabilities in African countries. Adopting a "self-discovery" approach to

identifying these green sectors and activities is critical in order to channel resources and policies effectively. The self-discovery approach is a concept defined by economist Dani Rodrik as a process by which public and private actors strategically coordinate, learn from each other and find solutions together. [23] This process, originally defined for traditional industrial policies to identify target sectors, can be applied to an approach of incremental engagement in green industrialisation. Collaboration with the private sector is key to ensuring that the information gaps that governments typically have are addressed. The perspective of markets is integrated into the selection of these sectors and the interventions that would help in their development.

For example, Morocco started producing renewable-energy equipment in parallel with the country's plan to transition to clean energy. In 2009, the government adopted an ambitious national energy strategy called "Horizon 2030" to focus on developing the production of renewables (wind, solar and hydroenergy). The authorities seized this opportunity to develop local manufacturing capabilities in renewables' equipment, including turbine blades, through partnerships with foreign investors and international companies such as Siemens, which paved the way towards supplying the needs of a growing industry locally.

African governments could focus on identifying and adapting green frontier technologies. While it is highly likely that R&D and innovation for green structural transformation will be concentrated in advanced economies, some middle-income countries that have relatively developed local manufacturing capabilities, such as China, Brazil and India, are engaging in green R&D programmes. For instance, China has heavily invested in R&D subsidies in the production of solar photovoltaic (PV) panels since the early 2010s, which has led to a significant drop in their prices and better efficiency. Similarly, Brazil is investing in the development of green hydrogen, which could revolutionise the energy sector. Outside these fast-emerging economies, it may be difficult for low-income countries, including those in Africa, to develop R&D in completely unproven technologies. However, there is a space to support firms and entrepreneurs to adapt and commercialise early technologies that remain not fully commercialised. They could be defined as new-frontier technologies, supported through direct and indirect financing mechanisms (grants, subsidies or concessional loans). This could be applied to CCUS technologies, recycling of plastics, and other technologies in the circular economy across sectors such as textiles and apparel and EEE. As discussed earlier, Rwanda has started engaging in e-waste recycling by developing a state-of-the-art plant. These technologies should be aligned with the green activities and sectors identified in order to maximise the potential for green structural transformation driven by local capabilities.

2. Alignment of trade and investment policies: Use trade and investment policies as an instrument to promote the adoption of green frontier technologies, and to support the development of green activities and sectors in African countries. Trade and investment policies can be used by African policymakers as a critical instrument for green industrial policies, especially in the context where collaboration and

alignment are necessary to ensure a global path towards net-zero emissions. This necessary collaboration, the significant role that HICs have played in the climate crisis, and the concentration of green tech R&D and innovation in advanced economies all provide significant leverage for African countries to include local-content requirements and technology-transfer measures in their trade and investment policies. Traditionally, local-content requirements have been used to foster domestic connections with foreign companies through regulations that oblige foreign investors to procure and consume a minimum of services and goods locally. These local-content requirements can be adapted to green activities and sectors identified by African countries as feasible in their local economies. Technology-transfer requirements could also be included in trade and investment policies to facilitate green technology dissemination and adoption.

3. Optimising green in fiscal policies: Fiscal policy needs to be aligned to accelerate the transition to renewable energy, to adopt clean technologies like CCUS and improved waste management, and to provide incentives for the private sector to engage in green industries and activities. Fiscal policies are an important tool that African countries could leverage to foster their green structural transformation, particularly in the case of energy, since the the sector typically benefits from huge public investment, notably through subsidies. For instance, African countries should analyse the feasibility of a reduction in public subsidies for fossil fuels. This could be a phased approach: starting by retaining subsidies only for the vulnerable populations instead of keeping the universal subsidy schemes that exist in many countries, while phasing out subsidies for polluting activities until the energy mix allows for access to affordable, clean energy. Policymakers should also increase investment in renewables, notably by using the saved fiscal resources from reform of public subsidies in fossil fuels. This would enable the development of renewable energy solutions and support the shift to a 100 per cent renewable-energy mix. Fiscal policies can also be used to provide tax incentives to encourage the greening of industries and enterprises across the most strategic value chains for African countries.

4. Access to finance: Governments, with substantial support from the international community, should facilitate the development of financing mechanisms for green industrialisation by designing and implementing a set of incentives to encourage firms to engage in green activities and practices. The development of green activities, the adoption of green frontier technologies and the greening of enterprises in existing industries will require significant investment as well as a set of incentives (whether financial or fiscal) to shift productivity factors (such as labour and capital) towards green activities and practices. The financing mechanisms can be through green funds, established via public-private partnerships and financed by the public sector, with contributions from private actors and development partners. This is the case in Rwanda where, in 2011, the authorities established the National Fund for Environment (FONERWA) to support the financing of the green transition. FONERWA is financed by public and private contributions as well as through donor contributions, and it has invested in a number of successful initiatives, including an e-waste recycling facility. The financing mechanisms offered include innovation and credit lines for private actors involved in novel green activities.

Governments in Africa should facilitate the development of risk-capital financing to complement public-backed mechanisms. Engaging in green sectors and activities, especially in the context of African countries, can be considered high risk because these activities will likely be involved in either the commercialisation of new technologies or development of new markets. These high-risk activities can be adequately supplied by capital-risk financing, including seed and venture-capital investment funds.

The financing mechanisms involving the public sector, as well as incentives, should be aligned with the green activities and technologies identified as strategically important and feasible as part of a gradual, green structural transformation on the continent. These mechanisms should be used to support the greening of enterprises engaged in strategic industries such as chemicals, food and beverage, textiles and apparel, and EEE, plus other sectors prioritised for structural transformation. As with traditional industrial policies, the support provided should be conditional on performance, accompanied by a clear set of requirements and criteria to avoid rent-seeking approaches and to ensure that resources are efficiently channelled towards the fulfilment of development objectives.

5. R&D, incubators and accelerators: There is also a need to scale up support for the development of small and medium enterprises – both green SMEs and SMEs that can drive transformation – as well as to assist them minimise their carbon footprint. SMEs are key to ensuring that global solutions are adapted to the local context. This can be done through investment in business-oriented R&D, and through support for incubators and accelerators dedicated to the green transition. This will help African countries to learn by doing, which is fundamental to innovation on the continent.

6. Green industrial infrastructure: Investment in green infrastructure is key to helping green industries and enterprises, and achieving other development objectives such as diversification and improved export sophistication, technological capabilities and competitiveness in general. Eco-industrial parks (EIPs) can be central to green industrialisation strategies by providing the same advantages as traditional industrial parks, while reducing the pollution and GHG emissions caused by manufacturing and industry.

7. Public procurement to stimulate the economy: Governments could use public procurement to create markets for carbon-free and green technologies and products, with eco-labelling and certification programmes as a prerequisite to differentiate “good” from “bad” products, and to provide information to consumers. Public procurement plays a significant role in several African economies and can be used as a strategic tool to stimulate demand in a number of sectors. Public procurement is generally used as a tool to promote SMEs either by setting a minimum threshold for procurement, or by giving them preferential treatment when processing bids. In the case of green industrial policies, authorities can use public procurement as a way to encourage the development of new sustainable activities or the adoption of green practices by enterprises. In China, green public procurement has been implemented since 2006, with the publishing of "Recommendations on the Implementation of Environmental Labelling Products in Government Procurement" and the first government procurement "List for Environmental Labelling Products." The selection of products is updated regularly and includes a wide range from

electronics and electrical repairs (computer equipment and software, printers and household appliances) to vehicles (buses and cars). As a result of these policies, more than 93,000 products in 44 categories have been certified and labelled. Green public procurement facilitated the purchase of $28 billion worth of products with environmental labelling in 2014 and $17 billion on products with "energy conservation" labelling in 2012.

The implementation of green public procurement requires differentiation between polluting and clean products and enterprises. Eco-labelling and certification programmes are useful tools to achieve this, and can also be used to target government support towards green enterprises to send a market signal to consumers. In turn, this could help in changing consumer behaviour towards green products.

8. Green guidelines and standards: Governments and their partners could provide guidelines and standards on green practices in manufacturing and services. The gradual move towards green products and enterprises will need to be accompanied by a set of guidelines and standards to help existing firms adapt their business models, change their current production practices and adjust to the new green economy. Some countries have developed regulations to forbid the development and commercialisation of polluting products. However, in the case of most African countries, these measures may be too prohibitive, especially under a gradual, green structural transformation. Such an evolution of guidelines will need cooperation from the private sector and its associations to ensure broad and effective access to information among enterprises. It is essential that any standards applied are proportionate and do not cause firms to go out of business. The cost of meeting standards by firms, especially SMEs, is typically high, and without proper assistance for these firms and even larger ones, there needs to be extreme caution applied when implementing new green standards. They should only come once proper support systems are in place, particularly for companies that are key to Africa's industrial and economic transformation.

How to Maximise Green Industrialisation: Four Basic Steps

Green industrial policies will require a long-term commitment, and an entrepreneurial approach to identify technologies and solutions that African countries can adopt. The following steps and institutional arrangements will be required for successful implementation:

1. **Define a green roadmap that is aligned with existing industrial policies and industrialisation strategies.** Such a roadmap could assess potential viable green industries and technologies that African countries could enter, which would maximise their environmental credentials in strategic sectors important for structural transformation, and serve as priorities in national development plans. The next step would be to assess the political economy of these activities and identify sectors that could succeed economically, politically and environmentally. Bottlenecks would then need to be identified from technological, financial and ecosystem perspectives to engage local capabilities in

these activities. Finally, the roadmap would entail addressing and tackling the bottlenecks by using the instruments and tools proposed above.

2. **Engage in strong and effective public-private partnerships.** Public-private partnerships will be necessary in several stages of green industrial policies, from identifying new technologies and activities, to effectively monitoring the development of local capabilities and assessing market needs. Public-private dialogue should be institutionalised and formalised, with clear objectives and governance mechanisms. These formal platforms should have periodic and openly published deliberations.
3. **Build strategic relationships with the development and international community**. As discussed above, HICs must be key partners with African governments to implement green industrial policies, including technology transfer and capacity building to enable the identification of frontier technologies and new green activities. It is essential for African governments to strategically and clearly communicate their roadmap and their green maximisation plans, and to determine relationship priorities with different development partners and donors.
4. **Set up the necessary institutional arrangements**. Strong political support and coordinated government action are key to ensuring the alignment and coherence of all policies, including environmental and economic ones. For green industrial policies, learning and adaptability will be necessary to adjust policies and interventions to new technologies and pathways. This calls for strong leadership, technical expertise and coordination, with the right delivery structures. Ideally the economic or trade and industry ministries should be empowered to implement and monitor these policies to ensure complete alignment with development plans. Adequate delivery structures should be put in place, populated with the right skillsets, including a chief scientist responsible for identifying green frontier technologies and activities.

The Role of High-Income Countries in Africa's Green Transition

The implementation of green industrial policies and the gradual green transition in Africa will need support from high-income countries (HICs), without jeopardising the continent's industrialisation and development process.

As discussed in our paper, "A Just Transition for Africa", HICs must bear the greatest responsibility for cutting emissions and financing measures across the globe to adapt to the inevitable impacts of climate change. Investment in innovation for greener industrialisation is therefore incumbent on HICS. They must also take responsibility for supporting African countries to identify clear and realistic pathways to maximise their green industrialisation path.

The role of HICs in the gradual green transition of African countries will be critical. HICs must be strategic and long-term partners to African countries to facilitate a realistic and pragmatic green transition, while aligning with the long-term development goals of these nations. HICs also need to

provide technology transfer and capacity development for new green technologies, and bear the green premiums for critical industrial products and clean energy, until affordable technologies are available at scale in Africa. The current concentration of green R&D and technologies in advanced economies and their high costs also serve to highlight the role that these countries should play in Africa's green transition.

This rationale does not stem from a philanthropic approach, but rather from the collaboration and alignment that will be needed to ensure a global path towards net-zero emissions. Moreover, the green premiums for these technologies cannot be shouldered by African countries alone, as they are currently polluting less globally while needing economic development the most. Overall, HICs must help African nations bear the cost until a full transition towards green energy and economy is affordable, which does not compromise their development path.

Through the Paris Agreement, HICs have committed to $100 billion of support per year to help fund climate resilience and adaptation in low-income countries. As argued in our previous paper "Mind the Gap: Success at COP26", despite this important step, there is still a need to thoughtfully and effectively support African countries in designing and implementing pathways towards decarbonisation, while also supporting them on their road to industrialisation.

Charts created with Highcharts unless otherwise credited.

Footnotes

1. ^ https://drodrik.scholar.harvard.edu/files/dani-rodrik/files/altenburg_rodrik_green_industrial_policy_webversion.pdf
2. ^ https://www.energyforgrowth.org/blog/infographic-what-is-sub-saharan-africas-contribution-to-global-co2-emissions/
3. ^ World Steel Factbook 2020
4. ^ Source: Statistica
5. ^ Consumption in 2005: 29.1 M tonnes and consumption in 2019: 90 M tonnes
6. ^ Figures for exports of goods and services expressed in current $. Source: WDI
7. ^ https://www.iea.org/reports/transforming-industry-through-ccus
8. ^ Ammonia was discovered by Haber and Bosch in Germany at the beginning of the 20th century and is produced by synthesising hydrogen and nitrogen using a catalyst at a high temperature and pressure.
9. ^ Algal and plant growth due to excess nutrients, potentially leading to water deprived of oxygen.
10. ^ About 172 million tonnes of polymers and plastics valued at $285 billion were imported and used on the continent between 1990 and 2017: https://enveurope.springeropen.com/track/pdf/10.1186/s12302-019-0254-5.pdf
11. ^ The global production of plastics is currently estimated at between 350 and 400 million tonnes per year (compared to only two million tonnes in 1950): https://ourworldindata.org/plastic-pollution
12. ^ http://www.fao.org/3/i6895e/i6895e.pdf and author's computation
13. ^ Source for all exports number: Observatory of Economic Complexity and author's computation.
14. ^ Sources: https://oec.world/en and author's computation
15. ^ Sources: https://oec.world/en and author's computation
16. ^ For instance, Morocco is the only net exporter of chemical products in the continent (with a trade surplice of $1.6 billion in 2019) and is the main exporter of fertilisers in the continent through the OCP Group, representing about 47 per cent of the total fertilisers' exports in the continent.

17. ^ It is also possible to produce grey and blue hydrogen. Grey hydrogen – high-emission hydrogen – is produced from natural gas reforming or coal gasification from fossil fuels (such as natural gas) or biomass, whose CO2 emitted during production is not abated using carbon capture and storage. Blue hydrogen – low-emission hydrogen – is also produced from natural gas reforming or coal gasification from fossil fuels or biomass whose CO2 emitted is mostly (~95 per cent) abated using carbon capture and storage.

18. ^ The H-DRI is based on the production of green hydrogen and using it as a substitute to a mix of carbon and hydrogen in the process of making steel. The MOE is also an electrolysis process used to break down iron oxide into its metal form and release oxygen.

19. ^ Extracting aluminium from its oxide, alumina

20. ^ Following COP23 in 2017, the governments in Rwanda, Nigeria and South Africa launched the African Alliance on Circular Economy (ACEA), which aims to support the transition to a circular economy on the continent and help in finding an alternative strategy for industrial development and job creation that combines industrialisation and sustainability objectives. Ghana and Cote d'Ivoire joined the alliance in 2019, and the five members signed a charter during the 2019 African Ministerial Conference on the Environment (AMCEN) in South Africa.

21. ^ https://drodrik.scholar.harvard.edu/files/dani-rodrik/files/altenburg_rodrik_green_industrial_policy_webversion.pdf

22. ^ https://drodrik.scholar.harvard.edu/files/dani-rodrik/files/altenburg_rodrik_green_industrial_policy_webversion.pdf

23. ^ In his own words, Rodrik defined the self-discovery process as "the right way of thinking of industrial policy is as a discovery process – one where firms and the government learn about underlying costs and opportunities and engage in strategic coordination."

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