Green Industrial Policy and Industrialisation in Africa

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Abstract

The paper examines Africa's challenges and prospects of green industrial policy and industrialisation. Green growth and carbon-neutral industrialisation are vital for African economic transformation, and a sustainable industrial policy is central to achieving these goals. Yet African countries have to accelerate economic transformation and pursue a green transformation path with limited resources and a low base of technological capability. Furthermore, the design and practice of green industrial policy and decarbonisation pathways are more complex than often thought. This paper first sets out conceptual perspectives on green industrial policy. It examines the evidence for and lived experience of progress and challenges in greening African economic development through selected comparative case studies of industrial policy practices. Second, the paper focuses on three strategic complementary priorities for green industrialisation: (a) developing low-carbon industrial hubs to accelerate decarbonisation and the building of green manufacturing, (b) prioritising the expansion of diverse forms of renewable energy, including hydropower, which has strong spillovers and is a significant African endowment, and (c) investing in research and innovation capability from the early stage of development. Third, it argues that carbon-neutral industrialisation is a protracted and the only prospective path to achieving the dual goals of accelerating structural change and achieving its ambition of net zero emissions. Nonetheless, green growth has a broader scope and necessitates more decisive developmental roles of the state in an increasingly complex and competitive landscape. Policy learning from the continent's experiences, and from those emerging economies that pursue green growth, could provide valuable lessons to accelerate the process.

Keywords: Green industrial policy, structural transformation, low-carbon industrial hubs, renewable energy, innovation, productive capability, state, Africa

JEL codes: Q01 (Sustainable development), F0 (International economics), O1 (Economic development), Q02 (Renewable resources and conservation)

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List of abbreviations

AfCFTA	African Continental Free Trade Area
AfDB	African Development Bank
EIB	Ethiopian Investment Board
EU	European Union
FDRE	Federal Democratic Republic of Ethiopia
IEA	International Energy Agency
IPCC	International Panel on Climate Change
IRENA	International Renewable Energy Agency
MoFED	Ministry of Finance and Economic Development
NPC	National Plan Commission
RSA	Republic of South Africa
UNCTA	United Nations Conference on Trade and Development
WHO	World Health Organization

1. Introduction

The greening of African economic development is urgent, but there needs to be consensus on how best to promote it and it is not at the centre of policymaking. There must be more evidence of national experiences of pathways to lower carbon industrialisation in Africa and green industrial policy. Green growth and carbon-neutral industrialisation are vital for African economic transformation, and green industrial policy is central to achieving these goals. Nonetheless, the design and practice of green industrial policy and decarbonisation pathways are more complex than often thought. Africa is the most minor contributor to climate change and the most vulnerable continent, and has to accelerate economic transformation and pursue a green path with limited resources and low technological capability.[1] Several African countries have pronounced their nationally determined commitments to the zero-emission goals.

Many African governments pursue proactive green growth and transformation pathways. There is a strong rationale and urgency for Africa to pursue a green industrial policy to advance industrialisation and broader economic transformation. The global competitive landscape is changing. OECD countries, spearheaded by the United States of America (USA) are investing in frontier green technologies, with a first-mover advantage in play. Emerging economies, like China and India, are pursuing active green industrial policies, opening the possibility of leapfrogging into frontier technologies, with new industries building on latecomer advantage and increasing scale, and shaping the learning and experience curve. However, African countries need to catch up in innovation and investment in new sectors.[2]

Neither the fossil fuel-driven pathway, nor a ‘growing now and cleaning later’ approach, is a viable development route for African countries.[3] Accelerated advances in green technologies, new green industries, and the changing global competitive landscape as advanced countries and emerging economies invest in greening will likely affect African countries’ positioning and prospects.[4] The greening pathway opens windows of economic and technological opportunity for new industries, driving economic development and accelerating the displacement of existing industries to obsolescence. Various studies show that the accelerated transition to a

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[1] See Synthesis Report VI of the Intergovernmental Panel on Climate Change (IPCC 2023). Africa accounts for below 4% of global greenhouse emissions, and Sub-Saharan Africa’s cumulative greenhouse emissions per capita is below 0.5%.

[2] The latest IPCC report (2023) underlines the link between human activity and climate change and shows that the opportunity to respond to climate change and global warming is narrowing down. The considerable gap between Africa and Europe/USA doubled between 2015 and 2021 (International Renewable Energy Agency [IRENA] 2023a).

[3] The Carbon Border Adjustment Mechanism (CBAM) of the European Commission Taxation and Customs Union (2023) and the European Investment Bank ended financing for coal-fired thermal power.

[4] China, which was not much of a player in the automotive and energy industries, has dominated the manufacturing of electric vehicles (EVs) and battery technology, and solar and wind renewable energy. The USA’s Inflation Reduction Act (IRA) focuses on investing in green technologies and industries to an amount of US$ 1 trillion (https://www.whitehouse.gov/cleanenergy/inflation-reduction-act-guidebook/).

carbon-neutral economy potentially generates better benefits than a delayed transition by developing or developed economies (see Way et al. 2022).

The paper contributes to a better understanding of the prospects and challenges of green industrial policy and carbon-neutral industrialisation in Africa and the extent to which green growth and environmental sustainability are integrated into a coherent and synergetic green industrial policy to achieve structural transformation and economic catch-up in African countries. The paper highlights three perspectives. First, the paper highlights that green industrial policy is essential to accelerate green transformation. It illustrates that green industrial policy is possible using selected cases, but underscores the challenges, complexity, imbalances and tensions that accompany policymaking. Second, Africa's green transformation has dual goals: accelerating the already lagging productive transformation, promoting a carbon-neutral path, and an underlining perspective is that green transformation is economical from a longer-term perspective but requires pursuing different paths. Third, the paper suggests that green transformation requires reimagining the role of the state and industrial policy, including an exceptional role for innovation and technological capabilities, and rethinking governance for a green transition.

This study has relevance, given that many African governments must focus on designing strategies and practising appropriate policies. The paper aims to contribute to the debate on this emerging theme by reviewing the existing literature and undertaking an in-depth study of selected cases to demonstrate green industrial policy. Green industrial policy is the pursuit of carbon-neutral industrialisation and green transformation. The paper also highlights that green industrial policy necessitates rethinking the purpose, design and implementation of industrial policy. It also puts new demands on the policymaking process and the developmental role of the state and governance of green transition, the reimagining of the purpose, policy strategies and instruments, and the scale and urgency. This paper explores the green industrialisation that has started in Africa and extracts lessons from multiple case studies.[5]

The paper uses comparative case studies and an explanatory research methodology, relying primarily on a qualitative research design to analyse the various aspects of green industrial policy and explore the dynamics of green industrialisation. It uses a mixed-methods approach comprising interviews, surveys, document review, focus groups and site observations. The paper draws from direct experience of the challenges and dilemmas in policymaking. The cases include low-carbon industrial hubs and clusters that are vital in productive transformation and the pursuit of decarbonisation, given that shifting from a fossil-fuel economy to a low-carbon economy necessitates green energy transition, building productive capacity in the manufacturing sector, and technological capability.

[5] On just energy transition, see the Presidential Climate Commission (2022) and The Presidency, Republic of South Africa (2022).

Ethiopia presents an excellent case to understand the journey towards a carbon-neutral economy, the related challenges and what is possible in green industrial policy. Ethiopia has been widely considered as one of the African countries that has experimented with active industrial policy and pursued an ambitious green economy strategy. The state played developmental roles in this process for over two decades, resulting in rapid economic growth between 2004 and 2019, notwithstanding mixed outcomes in various sectors.[6] Ethiopia as a case study provides current experience and evidence on the multiple aspects of executing green industrial policy. The country's green industrial policy has prioritised green energy, made considerable investments, and relies on 100% renewable energy at an affordable cost, stimulating the manufacturing sector.[7] Moreover, the Ethiopian government's experiment with a new generation of low-carbon industrial hubs and various initiatives to develop productive and technological capacity provide current experience that shows the complexity of and tensions in green industrial policy. This paper draws lessons from Morocco's industrial policy, which has led to a globally competitive automotive industry, world-class industrial hubs, and experiments in renewable energy, primarily solar and green hydrogen. It also includes cases from other African countries.

The paper is organised into five sections. The second section presents a literature review on green industrial policy and industrialisation following this introduction. The third section offers selected case studies: the transition to renewable and green energy, developing low-carbon industrial hubs, and building productive and technological capability. Section four presents a discussion of the case studies and comparative insights. The final section offers conclusions and implications for policymaking and research.

2. Literature Review: Green Industrial Policy and Economic Development

2.1 The Concept of Green Industrial Policy

Africa's carbon-neutral industrialisation and green industrial policy underpin three conceptual perspectives: the green growth perspective, technological revolution and the accompanying techno-paradigm shifts, and developmental environmentalism. Green industrial policy should be based not only on a solid foundation of green growth, but also on understanding the long-term direction of the technological revolution. Green industrial policy demands strong political will and the strategic role of the state in a new context.

From a structuralist perspective of development economics, an industrial policy is the government's intervention to accelerate and shape structural change and productive transformation from low to high productivity and from low to high technology.[8] Green

[6] The annual economic growth in Ethiopia between 2004 and 2019 was 10.5%. See Cramer et al. (2020); Oqubay (2015).

[7] The Grand Ethiopian Renaissance Dam (GERD), a mega-project, is Africa's largest hydroelectric power provider and will generate 6 600 MW when fully operational after 2025, entirely financed from domestic resources.

[8] See Amsden (1989); Gershenkron (1962); Hirschman (1958).

industrial policy is a relatively new but rapidly expanding research sphere. This paper defines green industrial policy as government intervention to build a carbon-neutral economy and accelerate structural transformation and economic catch-up.[9] This definition emphasises three aspects. First, *structural transformation* is at the heart of green industrial policy. Second, the concept underlines that green industrial policy essentially comprises *government intervention* and policies. Third, green industrial policy is about building a *carbon-neutral economy* for sustainable resource utilisation. Both the OECD and emerging economies have embraced the green industrial policy, particularly since gaining momentum after the 2009 global financial crisis, the COVID-19 crisis, geopolitical conflicts such as the Ukraine war, and the China-USA rivalry.[10]

Policy interventions for accelerating growth and decarbonisation could add complexity to the design and implementation of green industrial policy. Climate change and global warming are externalities that are not restricted to local or national boundaries, and they necessitate coordination and collaboration at the international, national, and local levels. The increased complexity and broader scope of the state and industrial policies necessitate the reimagination of the developmental roles of the state, which Kim and Thurbon (2016) call developmental environmentalism.[11] This entails, first, an industrial policy framework in which the state plays an active strategic role in accelerating structural transformation and economic catch-up. Second, the government embraces a green growth perspective, putting environmental sustainability and carbon neutrality as strategic direction and goals, which reject 'degrowth' and 'moral imperative' as unrealistic paths for developing countries. Green industrial policy is viewed as having a much broader scope to incorporate green energy, resource use, manufacturing capacity, green technology, and green investment and finance, which require intervention across industries, on the production and demand side, and synergy at the national, regional and international levels.[12] Lastly, green industrial policy should be

[9] Rodrik and Altenburg (2017:11) define green industrial policy as "any government measure aimed to accelerate the structural transformation towards a low-carbon resource-efficient economy in ways that also enable productivity enhancements in the economy". See Pegels and Altenburg (2020).

[10] In the USA, the Inflation Reduction Act (IRA) provides over US$ 400 billion for subsidies to boost domestic investment and establish manufacturing facilities for solar, wind, battery storage, and electric vehicles. The Chips and Science Act has earmarked US$ 280 billion to support research and innovation (Whitehouse 2023). In Europe, the Green Deal Industrial Plan aims to support innovation and the manufacturing of green technologies and reduce dependence on China. The Next Generation European Union (NGEU) supports EU members in sustainable recovery. The Critical Raw Materials Act (CRMA) and the Net Zero Industry Act (NZIA) target 40% of essential materials and, in some items, up to 85% of those made in Europe. China has focused on building green technologies and industries since the early 2000s and accelerated this after the 2010s. China's development plans, Made in China 2025 and Made in China 2035, emphasise catching up and leadership in green technology. The key strategies to build this capability have been subsidies and domestic content restriction. Korea's Green Growth and Japan's Green Transformation are parallels aiming at technological leadership in chips and green technologies.

[11] See also Thurbon and Weiss (2019) and Thurbon et al. (2023).

[12] Anzolin and Lebdioui (2021); Mathews (2014); Mathews (2022); Mathews and Oqubay (forthcoming, 2025).

viewed from the long-term perspective of the direction of the technological revolution and techno-economic paradigm accompanying the green industrial revolution in this century.

2.2 The Greening Perspective as a Pathway to the Future

There are two divergent views on the greening of economic development. At the one end, the highly influential 'degrowth' perspective advocates slowing economic growth and limiting production and consumption to achieve a future of ecological sustainability. However, this perspective ignores the imperative for economic growth in developing countries and the associated improvements in living standards. Proponents of this view argue that increased economic growth will inevitably increase pressure for increased energy and resources, thereby harming ecological sustainability and aggravating climate catastrophe. The degrowth perspective denies the possibility of decoupling between economic growth and the use of energy and resources. This perspective fails to provide a practical solution for ending poverty and creating wealth for people in developing and emerging economies.

In contrast, the green growth perspective argues that economic growth does not necessarily undermine environmental sustainability and is not inevitably incompatible, as scientific breakthroughs, green technologies, and new social values potentially offer sustainable solutions for both the production and consumption sides. In addition, the green growth perspective emphasises that green technologies provide a significant opportunity to pursue a decarbonisation pathway and promote energy security, a considerable concern for both developed and developing economies. The advances in renewable energy offer an alternative to the current fossil fuel-based paradigm and could achieve an efficient and sustainable pathway through commitment to a circular economy. Unlike reliance on finite natural resources, the greening pathway relies on green technology and extensive manufacturing capacity, opening prospects for economic catch-up and structural changes. The most recent advances in solar and wind renewable energy and electric vehicles (EVs) illustrate advances in innovation and manufacturing using green technology, enabling cheaper and more sustainable options.[13] Technological advancements in green hydrogen are evolving, where a suitable and economical solution has yet to develop for greening 'hard-to-abate' industries.[14] Recent empirical evidence suggests that a green transition provides a more economical option in the long term based on empirical research on about fifty technologies by Oxford researchers (Way et al. 2022). These researchers concluded that a rapid decarbonisation scenario and fast green energy transition by 2050 would be more economical than what earlier models projected based on overestimated costs. They state that clean is not

[13] See International Energy Agency ([IEA] 2023); IRENA (2022b, 2022c, 2023b, 2023d); Bianchini, Damioli, and Ghisetti (2023).

[14] Mathews (2022) states that the solar-hydrogen economy provides an immeasurable prospect for economic development at the country, regional and global levels, accelerating innovations and advancing manufacturing capability, thereby offering benefits from increasing returns to scale across industrial sectors.

necessarily expensive, and clean technologies could provide savings of over USD 12 trillion, thereby offering economic incentives for countries and industries.

From a green transformation perspective, developing countries would benefit from pursuing carbon-neutral industrialisation instead of 'grow now and clean later', as this would allow them to build new industrial capacity and ensure environmental sustainability. The imperatives for the low-carbon industrialisation pathway are, first, from a long-term perspective, an economy built on a fossil-fuel foundation will not have a future in tomorrow's world, and earlier transition positions developing countries on the virtuous direction of economic transformation. Evidence suggests that the space for financing fossil-fuel projects is gradually narrowing, as more banks are rejecting lending. Governments like the European Union's Carbon Border Adjustment Mechanism (CBAM) restrict presumed carbon-intensive exports.[15] Second, while there will be displacement in terms of jobs and firms as a result of the green shift, it is likely that the low-carbon pathway will provide broad economic opportunity, generating new jobs and expanding manufacturing capacity.

2.3 Green Industrial Policy, Technological Revolution, and Green Windows of Opportunity

Green industrial policy is underpinned by the dynamics of technological innovation, technological revolution, and techno-economic paradigm (Perez, 2002 [especially Chapter 7], 2010; see also Freeman 2008; Schumpeter 1961). Perez and Leach (2022) argue that the world is witnessing the sixth technological revolution, driven by twin digital and green technologies.[16] Technological revolution occurs through long Kondratiev technological waves, overlapping the old and dominant paradigm and gradually substituting it with new technologies as new industries become economical and widely available. These have broad application across sectors. Understanding the nature and direction of the technological revolution is an essential foundation for policymaking and has implications for the direction and design of green industrial policy. Building on Perez's framework, Lema et al. (2021) propose an analytical approach to green windows of opportunity – involving technologies, markets and institutions – which could be specific to sectors, but with significant economic and technological effects. This approach is critical for government policymaking and firms in identifying the new drivers of the economy and the basis for designing a leapfrogging strategy.

[15] CBAM is part of the EU Green Deal, which was implemented in 2023 and put "a fair price on the carbon emitted during the production of carbon-intensive goods that are entering the EU" (European Commission 2022).

[16] The first technological revolution dates to the late eighteenth century (after the 1770s) and featured the rise of machines, factories and canals, followed by the second industrial revolution (from the 1820s), which led to an increase in coal, steam, iron and railways. The third industrial revolution (which evolved in the 1870s) featured the rise of globalisation and of steel and heavy engineering, such as the chemical and electric industries. The fourth technological revolution (the 1900s) led to the height of the automobile, oil, plastics and mass production, continuing its dominance throughout the twentieth century. The fifth technological revolution (from the 1970s to the present) brought the rise of information technology and communications, opening new industries and the reign of technology giants.

UNCTAD (2023c) identifies 17 technologies that may be considered green windows of opportunity. These tap the potential of digital and connectivity technologies and green technologies that are essential for accelerated decarbonisation. These technologies, which are expected to reach a market value of US$ 10 trillion by 2030, are currently dominated by the USA, China and a few Western European countries. Based on the readiness and response criteria, the UNCTAD (2023c) study provides insights into identifying technologies and strategies compatible with a country's innovation capability, productive capacity and natural resources (such as the availability of water, sun or wind).[17] It states that an ideal pathway could be to "switch to products that are more complex, have greater value added and lower carbon footprints" (UNCTAD 2023:xx). The review shows that African countries are not yet significant players in green technologies. Governments should design strategies and policies that concentrate resources on the targeted frontier technologies by investing in R&D, productive capacity and decarbonisation across various manufacturing sectors. Governments should integrate industrial policies and environmental sustainability directions, prioritise more complex technologies and greener sectors, and further stimulate demand and markets. The perspectives on green windows of technology are insightful and relevant for the design of green industrial policy.

Only a few latecomers have been able to catch up since the 1960s, and these rare events have relied on leapfrogging in emerging industries and the pursuit of export-led industrialisation, with considerable investment in innovation capability and giving a top priority to R&D (Lee 2019). Lee (2019) argues that positioning through the opening of innovative technology and new industries requires an appropriate strategy and matching capabilities, and targeted government policies that support firms in acquiring technological and institutional capabilities. Leapfrogging is a strategy for technological catch-up, and the nature of the short-cycle and long-cycle technologies could offer varied opportunities (Lee 2019). Innovation capability combines radical innovations and the incremental development of technological, managerial and organisational capabilities. The firms' absorptive capacity is essential in internalising new capabilities in specific sectors and activities, with productive capacity, innovation, and R&D capability at the firm, sectoral and national levels (Lundvall 1992; Oqubay and Ohno 2019). In summary, green industrial policy should maximise the exploiting of the full potential of digital and green technologies, and the scope for leapfrogging depends on the size and nature of opportunities, the adequacy of policies, and the positioning of the private sector to take advantage.

[17] The seventeen technologies comprise *Industry 4.0 frontier technologies*: The internet of things, blockchain, big data, 5G, robotics, drone technology, 3D printing, artificial intelligence; *green frontier technologies*: Solar PV, concentrated solar power, wind energy, biofuels, biogas and biomass, green hydrogen, electric vehicles; and *other frontier technologies*: Nanotechnology, gene editing.

2.4 Developmental Environmentalism and Green Industrial Policy

Another dimension of green industrial policy comes from the perspective of development environmentalism and offers insights into the developmental roles of states in green transformation. This perspective, inspired by the long East Asian tradition of developmentalism and the Chinese experience, illustrates the active developmental role of the state in achieving industrial transformation and environmental sustainability (Kim and Thurbon 2015; Thurbon et al. 2023). This perspective maintains that the significant departure of the East Asian green transformation was not driven primarily by beliefs in sustainable development or 'environmental sustainability' per se, but rather by the recognition that growth opportunities can only be met through a green growth pathway and that an economy powered by hydrocarbons is a dead end. This led to robust political commitment, reimagining the relationship between growth and environmental sustainability, and building a new compact with the private sector and society. A singular focus on economic catch-up and industrial transformation has been the foundation for the legitimacy of the state and the pursuit of developmentalism. Given the inevitable geopolitical crises, concerns about energy security and finite resources threaten the grand ambitions of both South Korea and China. Notably, the reconceptualisation of green growth was a combination of political commitment that a fossil fuel-driven economy is a dead end and the recognition that green growth presents a significant opportunity to drive growth through innovations in green technologies and products, new markets and industries. While developmental states in African countries have not been comparable to East Asian economies to a similar degree, developmental environmentalism could contribute by exploring relevant lessons that could be adopted in their pursuit of green industrial policy and strengthen the state's activist role.

In summary, these perspectives have significant implications for the greening of industrial policy. First, green industrial policy necessitates a stronger focus on research and development (R&D), innovations and technological advancement – far beyond that bound in conventional industrial policy thinking. Technological innovations in digital and green technologies have a broader scope across all industries and require considerably more funds to boost innovations, necessitating the integration of science and technology policy and national innovation systems as the core of the industrial policy framework.[18] Innovation is not limited to breakthrough technologies but includes a series of incremental improvements and innovations in the decarbonising manufacturing and services sectors.

Second, in emerging and advanced economies, the new industries rely primarily on manufacturing capacity, rather than on extractive mining industries, further magnifying the role played by manufacturing. The Biden administration has enacted bold new initiatives involving enormous resources and significant subsidies to ensure the USA's technological

[18] See Oqubay, Cramer, Chang, and Kozul-Wright (202).

leadership in the face of the perceived Chinese threat in the innovation landscape.[19] The European Union has undertaken various interventions in market mechanisms, such as carbon trading systems and restricting the carbon footprint through CBAM, subsidies for frontier technological innovation, promoting 'made in Europe' and reducing dependence on essential parts imported from China. Macron (2023) underlines that "Europe needs more factories and fewer dependencies. The twin shocks of Covid and the war in Ukraine have taught us lessons about the value of economic sovereignty". He highlights five industrial policy priorities, including green and digital technologies, the European CHIPS Act and the Net Zero Industry Act, supporting European champions, and using reciprocity.

Third, given the global nature of climate change and environmental sustainability, various policy interventions call for coordination and synergy at the national, regional and international levels. Furthermore, the European Union's green industrial policy is a vivid example that shows the increased complexity and the need for regional coordination. Some global initiatives provide direction and facilitate the adoption of coherent policies, as seen in the recent G7 summit in Hiroshima. Fourth, industrial policies require robust collaboration among sector players and public-private dialogue, and public pressure plays a significant role in shaping consumption and putting political pressure on government policies. With new communication tools like social media, the general public and communities are no longer passive players in the transition. Green industrial policies necessitate a broader scope for policy and government intervention, including the energy sector, the circular economy, and links to broader greening strategies encompassing sustainable cities and green transport. Finally, building innovation and industrial hubs nurtures industrial ecosystems and clustering effects for developing green platforms. Developing various specialised industrial hubs is increasingly becoming a relevant policy intervention to build industrial dynamism, production linkages and economies of scale, which are supra-firm benefits. Industrial hubs are critical to promoting greening and circular production, and creating new green platforms such as renewable energy or hydrogen complexes.[20]

3. Low Carbon Industrial Hubs and Green Industrial Policy

3.1 Industrial Hubs and Green Industrial Platforms

Industrial hubs provide an industrial ecosystem, fostering inter-firm learning, promoting domestic linkages, generating supra-firm productive gains and increasing return to scale. Industrial hubs must be specialised and sector-based to promote decarbonisation and achieve these aims. Sector-based industrial hubs provide customised and specialised industrial

[19] The CHIPS and Science Act and the US Inflation Reduction Act of 2022 are the most significant legislation for an industrial policy aimed at a clean energy transition and the development of frontier technologies such as microchips and high-end semiconductors, and high-tech industries.
[20] See Best (2001); Breschi and Malerba (2005); Jacobs (1969); Marshall (1920); and Oqubay and Lin (2020).

infrastructure, shorten investment project execution time, and support the effective execution of targeted government investment incentives and one-stop government services. To keep the green transition, a new generation of industrial parks have been established that focus on building specialised and sector-specific industrial ecosystems, incorporating eco-industrial-enabling green manufacturing, and introducing international sustainability compliance. However, the opportunity for greening across industries is not uniform, and solutions must be adapted to the specific nature of the industry and the respective countries' contexts.[21]

Industrial hubs are essential drivers of green industrial policy and generate benefits through multiple channels. First, industrial hubs can promote a green ecosystem to support the decarbonisation of existing manufacturing firms by introducing stringent environmental standards and adopting technologies and processes in the design and implementation phases. Second, industrial hubs can facilitate introducing and developing new green technologies and systems, such as renewable energy and hydrogen, at an industrial scale, serving as green platforms and powering various industries, thereby making manufacturing competitive and energy-efficient. Third, industrial hubs facilitate industrial symbiosis and the circular economy, offering the sustainable use of resources and improving productivity. Furthermore, in the longer term, industrial hubs can synergise green and sustainable cities, offering additional benefits from greening economic development (Anderson et al. 2022; Mathews 2020).[22]

Eco-industrial parks are broadly defined as industrial hubs that enhance environmental performance, generate productivity and competitiveness gains for firms, and contribute to the decarbonisation of industries. A critical strategy is using green infrastructure, including renewable energy, central waste-treatment facilities, and conducive zoning and land use. Eco-industrial parks promote a circular economy through industrial symbiosis within firms and clusters, and use comprehensive green transformation plans, certification and performance management. In addition, evidence shows that specialised or sector-based hubs facilitate specialised industrial infrastructure, accelerate investment project execution, and support the application of targeted government investment incentives and government services for specific requirements. Several African countries have initiated a new generation of sustainable industrial parks to facilitate carbon-neutral industrialisation, with varied outcomes.

[21] In their research on technology intensity and carbon dioxide emissions, Avenyo and Tregenna (2022) highlight that lower emissions are associated with medium- and high-technology manufacturing. They consider a shift towards more technology-intensive manufacturing as one of the pathways for developing countries.

[22] Singapore provides an excellent example of integrating industrial hubs and sustainable cities to a facilitate green transition.

3.2 Ethiopian Eco-industrial Parks

The Ethiopian government adopted its 'Green Economy and Climate Resilient Strategy' in 2010, laying the foundation for environmental sustainability in manufacturing and the development of green industrial clusters.[23] Ethiopia relies entirely on renewable energy, tapping into its hydroelectric power potential, and the country has made extensive investments in power generation, transmission and distribution. Its new national rail system is electric-powered, including the Addis Ababa-Djibouti import-export corridor.

The development of eco-industrial parks after 2015 became central to Ethiopia's green industrial policy, and its implementation illustrates the complexity and potential role in decarbonisation, environmental sustainability and accelerating productive transformation.[24] In March 2023, a comprehensive guideline for Ethiopian eco-industrial parks was designed to enhance park management and environmental, social and economic performance, thereby facilitating green transformation. The guideline draws from the pioneering experiment at the Hawassa Industrial Park (HIP) in 2015, broader lessons from other industrial parks, and international lessons.[25]

The strategy for eco-industrial parks involved several measures to reduce pollution, improve energy and resource savings, and ensure strict environmental standards. Hawassa Industrial Park built a zero liquid discharge (ZLD) system – a centralised effluent-treatment system to serve more than twenty international apparel and textile firms employing over 35 000 workers, and had a daily capacity of 11 000 m^3 (Industrial Parks Development Corporation [IPDC] 2022). It enables the recycling of over 85% of water and involves a complex chemical and biological treatment process connected to over 50 factory buildings. The technology and equipment were designed and supplied by a specialised Indian environmental technology firm and constructed by an international Chinese company. Such technology is not widely available, and the selection of the technology was made jointly by the IPDC and the firms at HIP, and this was later expanded to other industrial parks (Jensen and Whitfield, 2022).

Various factors influenced the government's commitment to the ZLD policy. First, the Ethiopian government's green economy strategy (FDRE 2011), and new legislation on

[23] See FDRE (2002, 2008a, 2008b, 2011, 2015, 2017), MoFED (2010); National Plan Commission (2016). Also see Okereke et al. (2019).

[24] Ethiopia was new to industrial parks, and the Ethiopian government pursued a bold strategy in its Growth and Transformation Plan of developing a new generation of eco-industrial hubs, mainly after 2013. A Chinese developer built the first industrial park, the Eastern Industrial Zone (EIZ), in 2010. The government's new strategy was based on realising the limits in Ethiopia, the mixed outcomes in other African countries, and extracting lessons from Asia, a white paper discussed in 2014 (FDRE, 2014). The study and policy focused on targeted countries in Asia and Africa, namely Mauritius and Nigeria, South Korea, Singapore, China and Vietnam. The proclamation on industrial parks was endorsed by parliament in April 2015, followed by the pilot development of Hawassa Industrial Park, which was then replicated in other industrial parks. There were 17 government-owned and seven privately-owned industrial parks by 2022.

[25] See *National Eco-Industrial Park Guideline: Ethiopia Eco-Industrial Park Framework Implementation* prepared with technical support from development partners (Korean Green Growth Trust Fund, 2023).

industrial parks in 2015, posited sustainability as the core strategy of industrial parks.[26] In addition, the environmental and social safeguard studies on HIP set out stringent requirements to protect Hawassa Lake (about 2 km from the park) and the biodiversity of Lake Shala and Lake Abiyata (at a distance of approximately 50 km), which made the project politically sensitive. Pressured by consumer uproar and governments after the disaster of Rana Plaza in Bangladesh in 2013, leading buyers and brands have partnered to introduce stricter international compliance, such as the ACCORD on Fire and Building Safety. The IPDC and its consulting firm (a local engineering firm) reviewed and systematically compiled all national and international standards, including a certification programme devised by the US Green Building Council and based on the Leadership in Energy and Environmental Design (LEED) standards. The government's commitment to attracting massive productive investment and leading firms pushed it to single-mindedly pursue eco-industrial parks that fully met international requirements and best practices. The technology allowed the recycling of over 85% of HIP's industrial and sewer water consumption and reduced pollution. Additional measures were taken to improve water efficiency and savings by using water-saving fixtures and rainwater harvesting (see Table 1).

Nevertheless, despite these advances, there were also several challenges and weaknesses. For instance, the conversion of sludge into industrial use and bricks for industrial heating was implemented only partially. The cost of ZLD was higher than the international average (US$2.20), but firms only paid a subsidised rate (US$ 0.80) due to the high cost of imported chemicals and other inefficiencies. Based on the experience at HIP, improvements were made to the design of the ZLD facility, including modular construction, energy efficiency, and additional operational costs.

Significant progress was made in technology and know-how transfer, given that no local expertise existed. Counterpart experts of the company conducted training programmes for Ethiopian workers. Foreign experts were replaced, and some 114 Ethiopians worked in the ZLD facility after comprehensive technical and managerial training and working with their expatriate counterparts, gradually reducing the need for foreign talent. In the other new parks, a commissioning and test period of six months was incorporated as standard procedure.

Several energy-saving measures were taken, such as LED lighting in all production facilities and the use of smart light sensors. In addition to the double-way connection to the national grid system to ensure a reliable power supply, all factories were equipped with energy-saving transformers, which enabled a plug-and-play system. Only a solar lighting system was used in Semera Industrial Park, and electric vehicles were not introduced. Recycling and reducing waste through effective solid waste management was not raised in the industrial parks. Regarding land use, green areas and tree planting were introduced as part of eco-industrial

[26] See also Ethiopian Investment Board (2017).

principles. Greening in land use was compulsory and contributed to a cleaner production system and recreation for workers. Over one million trees were planted in 11 industrial parks, which will contribute to greener clusters and the potential reduction of carbon emissions.[27]

Green industrial policy is not only about the environment, but also about inclusiveness. For instance, the HIP and other industrial parks had to recruit and employ all people who had been displaced from the industrial park's location. Several work opportunities were designed. The fire brigades of industrial parks have to recruit and train from the locality. Factories were obliged to give priority to employing those relocated community members, and support was facilitated for their enterprises, such as cleaning, gardening, landscaping, and security enterprises in the industrial parks[28]. Projects were sponsored jointly with firms, development partners and donors to support the communities surrounding industrial parks. Through such programmes, a sense of ownership was created.

In summary, the Ethiopian experience shows that it is possible to have a green economy strategy combined with industrial hubs, ensuring high level of environmental sustainability. Associated institutional reforms were also implemented. The development of ZLD was challenging in terms of construction, and managing the facilities required expertise. Not all firms were willing to adopt the approach. The government had to provide subsidies and make investments in the infrastructure. A critical aspect of building industrial parks was ensuring that all industrial hubs were integrated into the city plan and contributed positively to the urban system.

The Ethiopian experience furthermore shows that, despite challenges, initiating eco-industrial parks by developing new industrial parks offers significant benefits, including a steep learning curve. Upgrading old industrial parks presents tremendous obstacles. It also shows that the government’s commitment to pursuing eco-industrial parks is critical to ensuring their success despite inter-agency coordination difficulties. The opportunity for continuous improvement of the green performance of firms, eco-industrial parks, and technological and organisational innovation is significant. Policy learning by the government, and the development of technical capabilities, become essential to accelerate low-carbon industrial hubs.

3.3 Morocco’s Industrial Platform

After 2000, Morocco pursued a very ambitious industrial hub strategy aligned with the government’s industrial policy, with strategic priorities in automotive and aeronautics, textile and food processing, renewable energy, pharmaceutical and logistics. Morocco has 149 industrial parks over 12 000 ha, spread across the provinces, but with a concentration in the country's north, such as the Tanger-Med Zones. Morocco’s automotive manufacturing dates back to the 1970s under an import-substitution strategy, using vehicle assembly with little

[27] Over 50,000 trees were planted and greened HIP.

[28] About 500 people were employed in fire brigades and over 2 500 in other outsourced services.

value addition and low economies of scale. The new industrial policy – to build an automotive industry – was guided by different strategies and policies to reflect the nature of the global automotive industry. The rise of the automotive industry was initiated by the Moroccan government and championed by the Renault-Citroen-Peugeot Group, with the prime strategy of building an industrial ecosystem that has led to Morocco's emergence as Africa's major exporter of cars and a flagship of Morocco's industrial transformation.

The Tanger-Med zones incorporate eight industrial zones geared primarily to the automotive industry (Tanger Med 2023).[29] The automotive industrial platform is the largest and has prioritised accelerating domestic value addition and incorporating foreign and local firms of tier 2 and 3 suppliers and sub-suppliers. The specialised industrial ecosystem is dedicated to various automotive subsystems, enabling the fast growth of domestic value addition, reaching approximately 60% in 2022. The specialised sectoral focus has promoted priority industries, domestic value addition, and building an industrial ecosystem comprising over 250 companies. Initiatives to green the industrial hubs have been implemented, with a strong pull from the lead firms and assured international compliance. A key element has been powering renewable energy, reaching 40% of total energy requirements. Strict environmental monitoring and recycling initiatives have been implemented. In sectors like textile, efforts are made to develop green zones and some innovations in green products.

The scale of industrial hubs, and complementarity, have enabled the development of manufacturing capability of significant economies of scale in a relatively short period, along with synergy with the development of the Tanger-Med port as a major port and logistics infrastructure.[30] The proximity to the port and world-class port infrastructure has facilitated the reduction of the carbon footprint linked to transportation. Tanger-Med's strategic location, its proximity to Europe, and the intersection of the Atlantic Ocean and the Mediterranean Sea, provide unique transhipment advantages. Know-how transfer and the localisation of skills have been supported by different specialised industrial institutes for automotive, aeronautics, textile, and renewable energy, led jointly by the chamber of industries and government agencies. This has helped to respond to the specific requirements of each sector and the lead firms, and to implement clear roadmaps. The experience in the Moroccan industrial hubs illustrates the government's strategic prioritisation of and commitment to industrial transformation through large-scale industrial platforms facilitating environmental sustainability and greening, and the viability of manufacturing capacity.

However, there are increasing shifts in the global automotive industry. EVs have grown fast in recent years, driven by technological advancement, government policies, and rapidly

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[29] The Renault Tanger-Med Hub (300 ha), Tanger Automotive City (600 ha), Tanger Free Zone (150 ha) and Tanger Automotive City hosting automotive manufacturers and part suppliers.

[30] The Tanger-Med port was launched in 2002, and the first phase of the port was completed in 2007. The passenger and vehicle port was developed from 2008 to 2010. Tanger-Med's second port was completed in 2019. The first industrial zone in the Tanger-Med Free Zone was initiated in 2000, and Renault's industrial complex was operational in 2012.

decreasing prices. Their share in the worldwide car market jumped from 5% to 15% between 2019 and 2022 (Financial Times 2023; IEA 2023b; IRENA 2023a). China has emerged as a leading player in EV manufacturing and market share. Many European countries aim to restrict vehicles powered by combustion by 2035. The transformation of the future of Morocco's automotive industry is determined by shifting to the production of electric vehicles (EVs) and decarbonisation across the entire production system (The Economist 2023b; IEA 2023b). The growth and sustainability of the automotive industry will be shaped by how the multinational auto manufacturers and the Moroccan government adapt to the new reality of accelerated greening of the industry. Moreover, similar observations can be made in South Africa's automotive industry.

Table 1: Summary matrix of low-carbon energy solutions

Green goals	Strategies
Strategy	A critical industrial policy to ensure production transformation, decarbonisation and energy security The strategic role of the state as the top priority Ensuring economic and sustainable energy solutions Maximising synergy and linkages between energy, manufacturing, job creation and developing technological capabilities
Specialisation	Specialised industrial ecosystem for each industry
Water-use conservation	Conservation of rainwater Recycling of water
Pollution	Waste-treatment systems Improved zero-liquid systems
Energy sources	Continuous upgrading of hydroelectric power projects through best practices Ensuring maintenance and maximum capacity utilisation Promoting complementarities across various energy sources Ensuring affordable and economic systems
Linkage effects	Synergy between manufacturing and energy strategies and instruments Utilising energy for employment creation and production capability Prioritising increasing returns to scale and achieving productivity gains
Incentives	Incentivising energy efficiency and use of clean energy Incentivising power generation from production systems Promoting the production of affordable energy uses Developing infrastructure to enable the end use of renewable energy (such as electric vehicles, public transport, and other sectors) Levying additional costs on the use of non-renewable energy (such as cars with combustion engines or used cars)
Environmental compliance standards	International compliance requirements Improvements in national standards Improvement in industry standards
Environmental safeguard studies	Environmental and social safeguard studies as critical parameters of investment decision and location choice
Shift to renewable energy	A shift to renewable energy and adoption experiments Improving energy efficiency in production process and inputs Upgrading localised and national grid systems Diversifying energy sources National-level performance at sector and intersectoral levels Energy performance at industrial hubs Energy performance of firms Innovative and intelligent solutions through compulsory digital technologies

	Measuring energy impacts on productivity and affected communities, firms, industries
Circular production	Reuse of energy by-products such as sludge in ZLD and ethanol production (sugar cane industry)
Research	Institutions doing research on green energy Studying best practices globally Dissemination and diffusion forums Incorporation into university education systems
Governance systems	Transparency of firms' energy performance
New energy hubs	Green platforms for renewable systems Green platforms for green hydrogen
Regional approach	Cross-border power-sharing Cross-border, sub-regional and regional grids and power exports

The country cases show that developing industrial hubs is a strategic approach that generates maximum benefits for developing priority sectors, economies of scale and production linkages, and learning. However, an equally critical advantage is that industrial hubs provide a perfect opportunity to decarbonise manufacturing and ensure carbon-neutral industrialisation. Green industrial platforms that use new technology and build new manufacturing capacity could be best achieved through eco-industrial hubs generating supra-firm benefits.

4. Research and Innovation Capability

A key focus of green industrial policy and a driver of green transformation is the development of technological capability and innovation as a leapfrogging strategy in emerging industries and the acceleration of decarbonisation for sustained productivity growth. Being the first mover has the advantage of standing ahead of the competition, and, for latecomers, developing on latecomer advantage and leapfrogging are real possibilities. Still, this requires investing in R&D, creating a national innovation system for green and digital technologies, and supporting infrastructure. Many newly industrialising economies (such as Taiwan, Singapore and China) have used innovation hubs to build innovation and research capabilities. Innovation hubs have facilitated infrastructure support and strengthened the links between industry, university, essential government agencies and inter-firm learning. However, such innovation hubs thrive when integrated with government funding for research and development, and within an industrial policy framework. Due to more pressing priorities and an inadequate focus, innovation and research capabilities have yet to be a priority in many African countries (Table 2). South Africa and Mauritius are among the few countries that have invested in R&D on a limited scale.

4.1 R&D Capability and Infrastructure

South Africa has a high concentration of outstanding research universities and significant research capability, nurtured by a national innovation system. Over half of Africa's top 10 universities are South African, and these research universities lead in science, engineering and technology, as well as in the health, computer and environmental sciences. They are also home to many prime technology and engineering research organisations. South Africa leads in the publication of scientific papers, the numbers of which increased from 5 540 in 1996 to 10 669 in 2011, and from 14 706 in 2015 to 21 062 in 2019. Universities dominate in research publications, accounting for nearly 90% of the total, with a lion's share of 60% being produced by five universities. About half of the research papers are co-authored with international partners. In addition, the number of doctoral students has shown growth. South African research institutes contributed significantly to research and technologies related to the COVID-19 pandemic (World Health Organization [WHO] 2020). UNESCO (2021:562) states, "South Africa counts the region's most sophisticated innovation system. Its strengths include dynamic institutional structures, effective policy frameworks and the region's highest research intensity".[31]

Table 2: R&D expenditure share of GDP (2005 to 2020)

Country	R&D expenditure share of GDP in %		R&D expenditure per capita in US$	
	2005	2020	2005	2020
USA	2.5	3.45	1 102	2 183.5
EU27			451.7	984.5
OECD	2.10	2.67	626.7	1 207.5
Israel	4.04	5.44	1 000.7	2 146.7
Germany	2.44	3.13	787.2	1 735.8
Japan	3.13	3.27		
Korea	2.52	4.81	635.4	2 179.7
Sweden	3.36	3.49	1 150.5	1 941.3
China	1.31	2.4	65.9	413.4
South Africa	0.86	0.68	83.6	89.8
Chinese Taipei	2.33	3.63	671.6	2 035.5

Source: OECD dataset

The South African government's research fund has increased steadily to 0.8% of the country's GDP, but it is still far lower than the government's target and the world's average rate of 1.5%.[32] Regarding funding allocation for research and development, South Africa stands at the top on the continent, and its allocation in 2020 was about 0.8% of GDP, comparable to India's 0.7%. Nonetheless, this is half of the government's plan and is below the global

[31] South Africa accounted for over 12.5% of Africa's 744 tech hubs (including incubators and accelerators), the highest share in 2017, followed by Kenya, Egypt and Morocco (UNESCO 2021). There was also a surge in the number of tech hubs, from 314 to 744 between 2015 and 2018.

[32] Africa is lagging far behind in terms of investment in innovation capability. For instance, South Africa, which accounts for the highest R&D expenditure in Africa, allocated 0.8% of GDP and US$ 84 to 90 GDP per capita, and the amount remained flat between 2005 and 2020. In the same period, China's R&D GDP per capita surged six times, from US$ 65.9 to US$ 413.4, while the OECD and EU27's average only doubled – from US$ 623 to US$ 1 207 and US$ 452 to US$ 985, respectively. China's R&D expenditure grew from 1.31% to 2.4% of GDP between 2005 and 2020. The front runners with the highest R&D GDP per capita in 2020 were the USA, Korea, Israel and Chinese Taipei, which allocated over US$ 2 000, accounting for 3.5% to 5% of their GDP.

average R&D expenditure. South Africa's sophisticated research network includes the Council for Scientific and Industrial Research (CSIR), the continent's leading research and scientific organisation, focusing on advanced manufacturing, energy, health and defence. It also includes the Agricultural Research Council (ARC), the South African Medical Research Council (SAMRC), and the Human Sciences Research Council (HSRC).[33] Some state-owned enterprises (SOEs), such as Eskom, Denel and Transnet, have in-house research capabilities. The Industrial Development Corporation (IDC) plays a critical role by providing development financing for green industries and renewable energy. SASOL (in which the South African government holds shares) has expertise in energy and chemical companies, leading in gas-to-liquids technology, coal-to-liquids technology, catalysis and green hydrogen. Anglo-American, Naspers (a global internet and media company) and Standard Bank have prioritised the financing of green energy.

The Department of Science and Technology (DST) is the core institution of South Africa's national innovation system, and has the mandate of leading and developing South Africa's innovation capability and developing national policies and strategies for science, technology and innovation. It also invests in research and development in priority areas, such as developing human capital and the diffusion of knowledge and technology. The Department of Education, the Department of Trade and Industry and the Department of Environmental Affairs are critical players in technological advancement.

South Africa's national innovation system provides the institutional and policy framework for science, technology, innovation systems, knowledge and human capabilities, innovation performance, and research financing. However, South Africa's White Paper on Science, Technology and Innovation (Department of Science and Technology 2019) highlights the fundamental weaknesses of the national innovation system and innovation performance: *slow output in patents and transforming into commercialised products*, inadequate high-level science, engineering and technology (SET) and technical skills, poor environment for innovation, lack of policy coherence, weak coordination and collaboration between actors, particularly businesses and civil society, and inadequate monitoring and evaluation systems (Department of Science and Technology 2021). The White Paper states that priority areas support emerging industries, greening the economy, and ICT (Department of Science and Technology 2014, 2019).

However, the White Paper does not specify the ambitions and policies of specific industries, the required research and development, and the required technology in the context of the technological race for emerging or advanced economies. Furthermore, the innovation system faces several challenges, with mixed outcomes. Inter-agency coordination has not been satisfactory, and the links between government agencies and the private sector across

[33] The National Institute for Communicable Diseases (NICD), the South African National Energy Development Institute (SANEDI), the National Cleaner Production Centre South Africa (NCPC-SA), and the South African National Biodiversity Institute (SANBI).

industries have been inadequate. Also, specific policies to attract international talent and retain local talent have been coherent and consistent. Despite its manufacturing infrastructure and research lead, South Africa missed a leapfrogging opportunity to become Africa's manufacturing leader in renewable energy, decarbonise its carbon-intensive economy and transform its production in the last two decades.[34]

4.2 Research Universities and Higher Education

In addition to the situation in South Africa, countries such as Morocco, Ethiopia, and Côte d'Ivoire have taken several initiatives to transform their higher education sector and promote innovation. Morocco has over 700,000 university students, who are concentrated in large universities. However, the proportion of students in natural sciences, engineering and technology is limited to about 30%. Morocco's ambitious industrialisation strategy and economic transformation demanded building a research university that focused on sciences, technology, and engineering. The government's bold and ambitious response was to create a technology-focused greenfield university, the King Mohammed VI Polytechnic University (UM6P) in Benguerir, supported by Morocco's largest state-owned enterprise, the OCP. This is a similar approach to South Korea building its first science and technology university in the 1980s, inspired by world-class universities in the USA, such as MIT and Stanford. UM6P has prioritised four schools, namely the schools of engineering and computer science, agriculture and environmental sciences, health sciences, and business and management. It also focuses on technological frontiers in renewable energy, material science, biotechnology and water management research institutes. UM6P has been championed by the government and King Mohammed VI, opening considerable prospects.[35]

The Ethiopian government's approach to building research universities focused on developing engineering and technological capabilities incorporated in diverse strategies. First, the government committed to expanding universities by providing extended graduate and research degrees. Between the 1990s and late 2010s, the government increased the number of universities nationwide ten-fold – from five to fifty universities – presenting significant execution challenges in content development, preparing teaching and research staff, and constructing and equipping then with facilities. The student population increased from below 10 000 to about 450 000. The university expansion programme was combined with reforming the academic programmes, with a shift from the dominant social sciences and humanities (about 80%) to courses in science, engineering and technology, which then accounted for 70%, of which 40% were in engineering.

[34] See Andreoni et al. (2021); Baigrie (2022); Oqubay et al. (2021); Tooze (2023).

[35] In a way, the vision is similar to the initiative of the government of Côte d'Ivoire's to build a polytechnic university with the ambition to be a leading university in Western Africa. The INS-HB (Institut National Polytechnique HB) in Yamoussoukro in the late 1980s and early 1990s focused in building capabilities in sciences, engineering and technology.

Furthermore, reforming the technical education and vocational training (TVET) system was part of this reform, expanding to over 1 200 technical schools nationwide. German technical support was a significant part of the programme, and the Ethiopian government brought 400 German professionals financed by its treasury. Two science and technology universities were founded in Adama and Addis Ababa, emulating the South Korean model. There also was significant reform to ensure that technical schools were expanded with links to industries. Universities were restructured to achieve this aim, and expatriate staff were brought in to assist in this transformation.[36] While this transformation took place with the highest political commitment by the government, the quality of education, research links to industry and the governance system of the universities remained a significant weakness. Arguably, the bold university and TVET system reform was Africa's first in scale and scope. Investors state that the availability of these university graduates has facilitated skill development and know-how transfer in firms.[37]

4.3 Innovation Hubs

Innovation hubs and technological parks have played a technological catch-up role by providing an effective innovation ecosystem conducive to research and innovation, pulling the synergy of institutional networks – firms and industrial associations, research institutions, and government institutions. Silicon Valley has attracted research as the world's leading innovation hub, which was initially developed at Stanford University in the 1960s, nurturing new start-ups and capturing leadership in the digital and ICT revolution. It has become the home for the world's leading tech companies. Learning from Silicon Valley, East Asian economies emulated the development of similar science and technology parks and innovation hubs in the late 1970s. Inspired by Silicon Valley, Taiwan developed Hsinchu Science Park in 1976, which became operational in 1980 after targeted learning from the USA, Europe and Japan.[38] Singapore made a concerted effort in the 1980s and 1990s to build similar innovation hubs and target multinational corporations to locate their R&D facilities and attract international talent using comprehensive support schemes. China has followed a similar path in developing science and technology parks (in Shenzhen, Beijing, Shanghai, and other cities). The presence of leading research universities and public research institutions, collaborative research with industries and corporate entities, and a targeted policy for 'brain gain' or talent attraction have been critical drivers in developing innovation hubs.

[36] This included 400 expatriates who were hired from Germany to assist in the university and TVET reforms.
[37] See Oqubay (2015); Oqubay and Tesfachew (2019).
[38] Hsinchu hosts over 400 technology companies, accounting for over 10% of Taiwan's GDP. The park focuses on information technology, biotechnology, semiconductor industry and renewable energy.

Three innovation hubs founded in the 2000s, namely VITIB in Cote d'Ivoire, the ICT Village in Ethiopia, and Cyber City in Mauritius, are a few cases that can illustrate what has happened and the challenges faced.[39]

The Cyber City of Mauritius, or Ebene Cyber City, was initiated in 2002 to diversify the economy from labour-intensive industries and build a knowledge-based economy. The targeted sectors included information technology, the high-tech industry, business process outsourcing (BPO), and international financial services. It was a government flagship project implemented in phases on 200 ha of land. It currently hosts over 900 firms employing 32 000 professionals, and the industries contributed 5% of exports and 6.9% to GDP in 2022. The Cyber City has emerged as Africa's leading ICT and BPO hub and contributed to the Mauritian economy's economic diversification. The public-private dialogue has been effective, and the private sector plays an active role. The government of Mauritius has placed the development of the hub as a strategic priority and followed policies that are attractive to talent, including relaxed visa provision, banking services, and amenities. The Economic Development Board (EDB Mauritius) regards attracting and supporting investors and firms as a critical priority. ICT has been the primary targeted industry, and new high-value activities have been added, such as biotechnology and research laboratories in life sciences, renewable energy technologies, and marine biotechnologies.

In Côte d'Ivoire, the initial vision was to develop Africa's leading technology park. The government's vision to establish VITIB through a joint venture arrangement in 2004 was a pioneering initiative with strategic significance for developing technological capabilities. The location is appropriate, given its proximity to Abidjan, the airport, and beaches. The land size is ideal for full expansion, but the soil is unstable. The design and execution of the project have taken a very long time, and it has not been able to create critical mass in terms of export value, innovation and talent. Shared facilities, commercial zones and production facilities have not expanded. The priority on ICT and biotechnology was appropriate, but innovation and high-tech in related industries have evolved rapidly since then. The links between Abidjan University and industries are weak. Targeted investment promotions have been inadequate, and VITIB did not emerge as a flagship project. VITIB's incentives concerning corporate tax and customs were inconsistent and complicated to implement. By 2022, VITIB had only created a few hundreds jobs, and its technological and economic benefits were meagre. Moreover, VITIB did not provide an ecosystem comparable to international benchmarks and was not at the heart of the country's industrial and innovation policy. The government plans a second technology park in the vicinity of the technical university, which is a perfect match and a plausible policy decision.

[39] VITIB is an acronym for Village of ICT & Biotechnology of Côte d'Ivoire (Village des Technologies de l'Information et de la Biotechnologie).

5. Renewable Energy and Green Industrial Policy

Energy is central to Africa's green transformation for a number of reasons. First, energy accounts for the lion's share (about 75%) of the global fossil oil-based economy and is the primary contributor to climate change. Second, Africa lacks universal access to electrification and cooking, a critical aspect of poverty and poor living conditions. The continent has about 600 million people without access to electricity – over half the population in many countries.[40] This demand will potentially drive productive capability and manufacturing growth. Third, Africa lags in new investments in renewable energy and innovation capability. Lastly, some African countries have carbon-intensive economies (like South Africa), while others, like Nigeria and Angola, are oil-rich, showing the magnitude of the challenge.[41] It is not possible to think of sustainable urbanisation – given that 60% of Africans will live in cities by 2050, and transportation and manufacturing depend on energy. Hence, green energy becomes a critical aspect of greening African economic development.

Electricity demand in Ethiopia has been growing by 19% per year on average between 2004 and 2019. Ethiopia's hydroelectric power generation is estimated at 45 000 MW hydro, 10 000 MW geothermal energy, a wind energy potential of 100 000 MW, and unlimited solar energy. Nineteen power stations have been developed, comprising 14 hydroelectric power, three wind farms, one geothermal, and one waste-to-energy plant. The capacity of hydroelectric power stations increased from below 100 MW to over 6 600 MW, benefitting the economies of scale.[42]

The imperative for governments to put the greening of energy at the centre of their green industrial policies is: first, the shift to renewable energy provides an opportunity to develop manufacturing capability and industrial capacity, which has spillover effects on the economy. Second, decarbonisation of manufacturing and other sectors, and moving away from the fossil fuel economy are the only viable options to remain a competitive economy and be positioned for the future. Decarbonisation maximises energy efficiency in inputs, production processes and products. Third, for economies pursuing economic catch-up, developing renewable energy could provide a window of opportunity for leapfrogging frontier technologies and innovations throughout all industries' production and supply chains. In addition, given the geopolitical and related crises in dependence on fossil fuel energy, the renewable energy pathway relying on the infinite resources of water, wind and sun strengthens energy security. The revolution in green energy has focused primarily on

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[40] UNCTAD (2023a, 2023b); IRENA and African Development Bank (2022). Also see African Union (2023).

[41] See Department of Minerals and Energy (1998); Department of Public Enterprises (2019); Lema et al. (2018); REN21 (2022); The Economist (2023a); Wiatros-Motyka (2023).

[42] Five projects included the Beles project 460 MW, Gibe I 183 MW, Gibe II 420 MW, and Gibe II 1870 MW. Leading European and Chinese contractors and specialists participated through competitive bids. Salinni Contractor in civil construction, Siemens/Isolux (Germany and Spain), Alsthom and CYMI France and Spain,), ABB (Switzerland), JV of ELC Electroconsult and ENEL, ELC Electroconsult and Tractbel. Vergnet (France) and Chinese companies were contracted in wind farm projects.

renewable energy, electric vehicles and battery storage, green hydrogen, and improving energy efficiency.[43]

Furthermore, investment in renewable energy in Africa has been marginal. North America and Europe's investment in renewable energy was 22 times that of Africa in 2015. This disparity increased 43 times in relation to Europe, and 57 times to North America, in 2021 (IRENA 2023a). This pattern has been aggravated in 2022 and 2023.

This paper focuses on renewable energy, particularly in Ethiopia, which is 100% powered by renewable energy and produces at the least cost, and in Morocco and South Africa, which are developing green hydrogen platforms and products.

5.1 Green Industrial Policy and Hydroelectric Power

Many African countries have adopted various strategies to develop renewable energy that match their comparative advantages, and the outcomes have been varied. Ethiopia, an importer of fossil oil, pursued a strategy of building renewable energy, primarily hydroelectric power, supplemented by wind and solar power, with an installed capacity of 5 000 MW. The government's Grand Renaissance Dam will generate an additional 6 500 MW when completed in 2025. It is Africa's largest hydroelectric power project financed by domestic sources. With forthcoming projects in the pipeline, such as Koysha (Gibe IV and V, which will provide more than 2 100 MW), the total power generation is expected to reach 17 000 MW by the end of the five-year plan. The government's industrial policy stipulates energy provision to the manufacturing sector at a subsidised low price, making it the cheapest rate in Africa.[44] For over two decades, the government has invested heavily in power generation, transmission, and distribution networks as national priorities.

Hydroelectric power offers considerable prospects for clean and renewable energy and accounts for the most significant contribution worldwide, with a lion's share in China, Brazil and Norway. Firstly, hydroelectric power continues to be the cheapest renewable source and can be complemented with other renewable energy sources (IEA 2021; IRENA 2023e; Bairol 2023). Hydroelectric power projects have a longer lifespan of up to 80 years. Technologies such as floating solar systems can reduce water evaporation from reservoirs, and solar farms in the vicinity can be integrated into the existing grid system. In the same way, wind energy can be expanded around the hydroelectric power project where wind potential is available. Second, existing technologies allow for increased energy generation by using alternative technologies such as pumped storage. In addition, existing hydroelectric power can be used to develop green hydrogen hubs, allowing the use of cheap renewable sources from existing

[43] In 2022, more than 10 million EVs were produced worldwide, growing over 55% from the previous year. And China has emerged as one of the world's leading EV manufacturing powerhouses. The EV market is growing rapidly, as technology advances (such as batteries) and car costs have decreased significantly, stimulated by government incentives and regulatory pressure.

[44] The rate was 3 US cents per kWh until 2018, and currently is 4.5 US cents per kWh.

alternative investments. Third, hydroelectric power allows a high domestic value added (in many cases over two-thirds of the total cost), contributing to the expansion of the manufacturing of building materials, industrial engineering and the metallurgy industry, and job creation during construction. Fourth, it contributes to the conservation of nature, the development of agroforestry and fisheries, food security alternatives, and eco-friendly tourism. The potential for afforestation could provide opportunities in the manufacturing sector and create jobs. The hydroelectric power sustainability standard, a global certification scheme, was initiated in 2022, contributing to better environmental and productive performance.

Ethiopia's state-led energy policy comprises economic and sustainable energy development, linkages with the manufacturing and construction sector, technological capability, and the active role of the state. Ethiopia's energy sector, while entirely dependent on renewable energy, faces a significant challenge in achieving universal access to electricity for over 50% of its rapidly growing population. The national grid requires upgrading to reduce wastage and improve energy efficiency. Solar and wind energy account for an insignificant share, and diversification in renewable energy sources has become crucial.[45]

5.2 Green Energy: Economic and Sustainable Solutions

Developing the energy sector has been one of the top strategic priorities for over 25 years, involving investment in power generation, transmission and distribution. Estimates show that the Ethiopian government invested more than US$ 20 billion in power.[46] Hydroelectric power has been the primary source, building on its comparative advantage and further diversification into other sources after 2010, such as wind energy generation at the lowest cost. Hydroelectricity offers benefits in having an extended lifetime (over 50 years), linkages to large-scale irrigation, and enriching biodiversity. Hydroelectric power has been the leading source of renewable energy worldwide, dominated by emerging and developing economies: 62% from 1991 to 2000, growing to 86% from 2001 to 2020, a trend expected to continue until 2030. Between 1930 and 1990, three small-scale hydropower projects were built: Aba Samuel in 1932 (6.6 MW), Tis Abay (11 MW) in 1953, and Koka in 1960 (43 MW), providing a total of 60 MW.

Between 2000 and 2002, over a dozen projects were built, generating over 10 000 MW, which is an enormous amount. As the project scale increased, the cost per unit decreased drastically, and benefits from advanced technology, especially in wind energy (see Table 3) – investment in power generation, transmission and distribution. The Ethiopian government pursued a policy of using low-cost financing to ensure affordability, including various financing sources: state-guaranteed domestic and foreign loans; concessional loans from multilateral and

[45] See Shen et al. (2023); Yalew (2022); Zenawi (2011).

[46] According to IRENA (2023a; IEA, 2021), large-scale hydroelectric projects generate at a lower cost (0.02 cents to 0.19 cents/kWh), while medium-size projects generate at 0.02 cents to 0.29 cents/kWh.

bilateral banks such as the World Bank, European Investment Bank and Exim Bank; and financing from the Commercial Bank of Ethiopia supported by an extensive mobilisation of savings. While the policy was open to private sector investment in power generation, it was unsuccessful, as the low tariff was unattractive. The government used green bonds in the form of the Grand Ethiopian Renaissance Dam (GERD) Bond, which raised over 25% of the financing for the mega-project. The investment requirement and power generation capability showed significant growth to ensure economies of scale, dependability, and decreased costs.

Table 3: Cost comparison of renewable energy

	Hydroelectric power	Wind	Solar	Geothermal	Waste to energy
Investment requirement	High	High	High		
Scale	Micro to mega	Scalable	Scalable		
Foreign exchange requirement	Moderate				
	Significant local value addition				
Cost kWh (US cents)	0.3 to 0.5 cents				
Gestation period	4 to 12 years				
Lifetime (years)	40 to 80	20	20		
Production linkages to manufacturing	Strong	Strong	Strong		
Employment	significant	Limited	Limited		
Biodiversity	Direct positive	Limited	Limited		
Land requirement	Limited	Limited	Significant		

5.3 Technological and Organisational Capability

Green and clean energy is essential for environmental sustainability and carbon-neutral industrialisation, and is at the core of green industrial policy. Developing a high-growth energy sector and relying 100% on renewable energy has been a vital aspect of the Ethiopian government's industrial policy and has driven productive transformation and productive capability.

The literature on industrial policy and latecomer development has emphasised the indispensable role of learning by doing, the need for skills and know-how transfer, and various dimensions of innovations and technological learning. For instance, Amsden (1989:172) and Amsten and Hikino (1994) present a broader framework of technological capability, including three elements: production capability, investment capability, and innovation capability.[47]

Amsden's (1989:189) broad definition of technological capability includes productive capability, investment capability, and innovation capability. Several policy measures were followed to ensure organisational and technological capability building, although the outcomes never matched the government's ambitions. The first shift was from the Ethiopian

[47] See Agarwal et al. (2022); Lema, Fu, and Rabellotti (2020).

Electric Light and Power Authority (EELPA) into two separate organisations—a separation of the regulatory agency and the state-owned utility operator in 1997, reforming into two agencies—the Ethiopian Electric Agency to regulate the power sector and the commercial utility provider Ethiopian Electricity Power Corporation (EEPCO) to operate as the into a commercial entity. A second shift was the restructuring of the EEPCO into two specialised corporations – Ethiopian Electric Power (EEP), responsible for power generation and transformation, and Ethiopian Electric Utility (EEU), responsible for operating, maintaining and developing distribution (FDRE 2013, 2014). This unbundling of the utility was a landmark strategic move based on the international best practice of unbundling to ensure specialisation and scale. EEU buys bulk power from EEP for distribution and retail. EEP manages not only existing power plants but also expands new ones. Further decentralisation measures were implemented to give more responsibility to branches and subsidiaries. In addition, an international contract management company was hired to improve the efficiency and service of EEU, and new laws on private power providers and public-private partnerships (PPPs) were introduced in 2018 and 2019.[48]

Furthermore, EEPCO had its specialised school to train technicians, and it relied on a few universities for scarce engineering professionals. The shortage of professionals and technicians was solved by the expansion to 50 public universities, producing large numbers of engineering professionals and graduates from over 1 200 technical schools. Moreover, the capability to design and manage hydroelectric power projects increased as the complexity and size of projects increased. Project management involves managing feasibility and technical studies, procurement, mobilising resources, construction, commissioning and post-project operation. Each project lasts over a decade (see Table 4).[49] METEC, an SOE industrial engineering company, was assigned to significant projects such as the mega-project GERD, which had security sensitivity. Selected universities were involved in several projects for capacity-building purposes. Local consultants and subcontractors participated with international contracting companies.

Table 4: Total renewable energy strategy

	Capacity (MW)	Investment (US$)	Investment cost per MW (millions)	Project period	Financing source	Technological and investment complexity
Hydroelectric power projects						
Gilgel Gibe I	184 MW	356			Mixed	
Tekeze	310 MW	US$360		1999-2008	Domestic	Double curvature, arch

[48] Proclamation No 1076/2018 and Regulation No. 447/2019. The law was amended in 2023. The licence for power generation: hydro and geothermal power generation up to 25 years, renewal up to 12.5 years.
[49] Micro (5 KW to 100 KW), mini-hydro (100 KW to 1 MW), small (1 to 20 MW), medium (20 to 100 MW), large (> 100 MW).

						dam, height 210 m Joint venture of a local and international company
Tana Beles	460 MW	US$500			Domestic	
Gibe II	420 MW	Euro 490			Mixed	
Gibe III	1 870 MW	US$ 1 800			Mixed	
Gibe IV and V (Koysha)	2010 MW (1450 + 560)				Mixed	
GERD	6 600 MW	US$5 000	0.75		Domestic	
Wind energy	Sub-total 324 MW				Mixed	
Ashegoda	120 MW	Euro 210	2.42		Mixed	Vegnet (France) 1 MW turbine, two blades
Adama I	53 MW	US$118	2.2		Mixed	1.5 MW turbine, three blades
Adama II	151 MW	US345	2.2		Mixed	2.5 Aysha, three blades
Aysha I	390 MW	570	1.46		Mixed	
Geothermal						
Geothermal (Aleta Wondo)	5 MW				Foreign	
Corbette and Tulu Moye Geothermal (Private)	1 000 MW				Foreign	
Solar energy						
Solar PV (Photovoltaic)	350 MW (Metehara 100, Dicheto 125, Gaad 125)				Mixed	
Others						
Biofuel-ethanol						
Waste to energy Koshe/Rappie Addis Ababa	50 MW (incinerates 1 400 tons of waste/day)				Mixed	

5.4 Manufacturing and Energy Complementarity

An essential feature of building a green energy and hydroelectric power-centric system is the sustained complementarity and linkage effects with the manufacturing and construction sector, contributing to building domestic productive capacity, creating employment and reducing foreign exchange requirements. First, the expansion and demand from hydroelectric projects drove the growth of the cement industry and other building materials manufacturing, particularly between 1998 and 2015. Second, power generation enabled the expansion of the manufacturing sector and facilitated urbanisation, which was targeted by government policy to give priority to manufacturing industries. Priority was given to industrial parks, industrial projects, an electric-powered railway (Addis Djibouti export-import corridor) and the Addis Ababa light rail system. The government pursued a targeted subsidy for the manufacturing sector, providing under 3 US cents per kWh for over two decades and an incremental increase to about 4 cents after 2018. Providing low and clean electricity became an advantage to attract manufacturing foreign direct investment (FDI) and Western brands as part of the investment incentives (Oqubay 2015, 2019a, 2019b). However, manufacturing also puts pressure on utility providers – such as industrial parks and the cement industry – through a significant expansion in demand and the push for improved quality and reliability. Industrial parks played a critical role in streamlining the provision of power in concentrated hubs, supported by the construction of dedicated substations. This process was characterised by tensions and challenges, given shortages and delays in projects, which induced positive responses and improvements.

In addition, the government followed a policy to promote regional integration in East Africa, contributing positively to infrastructure connectivity by exporting energy at a lower price. Transmission lines were built to Kenya, Djibouti and Sudan, and agreements were reached to supply about 1 000 MW to Djibouti (200 MW), Kenya (500 MW) and Sudan (200 MW). Nonetheless, the affordability of solar and wind energy allowed neighbouring countries to rely on their domestic sources.

5.5 State-led Development and Politics

Ethiopian state-led policy was characterised by a high political commitment, enabling a sustainable energy system and accelerating structural transformation. The strategic priority of the energy sector is reflected in resource allocation and investment, as well as the development of SOEs to spearhead the industry. The entire investment made by the government and private sector made the sector less attractive, given the risks from the long gestation period and scale of the required investment in hydroelectricity power projects. The government's policy determined that the private sector can participate in power generation, but transformation and distribution are under government ownership to ensure access to affordable energy. In contrast to many African countries that have privatised the utility, giving rise to high tariffs, the government made it sustainable and economically facilitated rapid economic growth. Given the political and geopolitical tensions surrounding hydropower projects, the state's role was vital, most notably GERD and other plants. The government improved coordination among the various ministries and agencies, between federal and regional governments, with hands-on robust leadership from the Office of the Prime Minister, using different taskforces and appointing senior board members. The government's leadership was necessary to mobilise domestic resources for hydroelectric dam construction and prioritise access to foreign finance.

The execution of policy faced immense challenges and tensions, which became an inherent part of the process – the imbalance between demand and supply, linkage effects demanding timely interventions, and the political nature of the programme. The sector has various weaknesses: the national grid and distribution networks are inefficient, requiring major upgrading, and Ethiopia has achieved universal access to only 55% of its growing population. Diversifying energy sources is necessary to ensure more reliable sources of energy. Given the constraints in expanding public funds and the high-interest rate for further expansion, an innovative policy is required to attract the private sector into the sector.

Given these considerations, building research capability, strategies and benefits and maximising learning from international benchmarks have become essential. Many African countries can benefit from hydroelectric power, as the continent has significant potential. However, reviewing energy policies and roadmaps and integrating them into the green industrial policy framework is essential for achieving green growth.

5.6 Green Hydrogen Platform

A total substitution for the solar-hydrogen economy necessitates developing a green solution for heavy and other industries such as cement, steel, chemical and aviation, which consume vast amounts of energy and require a specialised delivery system.[50] However, green hydrogen, powered by renewable energy, which is a clean and complete solution, requires innovations and technologies to produce at a cheaper cost, to develop an appropriate delivery system or pipeline solution, and to ensure that demand shifts to this technology; also that there is a regulatory framework for green hydrogen that is applicable across various sectors. While the debate on the multiple pathways continues, the race for technological breakthroughs and infrastructure development has intensified. The European Union has targeted 20 million tons of green hydrogen by 2030, half produced in the EU and half imported. France, Germany, Spain and Portugal have agreed to build a pipeline for green hydrogen by 2030. Spain is among the European countries that have raised its ambition to become the European leader in green hydrogen.[51] Similarly, other OECD countries (such as Australia, Japan and South Korea) and China are investing heavily in green hydrogen. Leading companies have targeted green steel, green fertiliser, and green cement to be achieved by 2050.[52]

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[50] Existing hydrogen technology is based on grey, blue or pink hydrogen, which are not entirely clear solutions. In grey hydrogen, electrolysis is powered by fossil fuels (currently 90% of the hydrogen market), blue hydrogen is from natural gas and supported by carbon capture and storage, and pink hydrogen is powered by nuclear energy.

[51] See O'Mahony (2023). In an article, 'Spanish industry kicks off EU green hydrogen race', she points out that Spain wants to use its plentiful sunshine and wind to be a world leader in the production of 'green' hydrogen created exclusively from renewable energy.

[52] See Andreoni and Roberts (2022); Avenyo and Tregenna (2022); Civillini (2023); OCP (2022); O'Mahoney (2023). See also Lee and Mathews (2023).

Green hydrogen is new to Africa, and the current production of hydrogen in South Africa and Morocco is based primarily on natural gas and coal. However, various investment initiatives have been announced since 2021, mainly to supply to the European market. South Africa and Namibia have also been at the forefront of investment in green hydrogen and hydrogen-based fuels. Projects at the implementation stage are sponsored by Anglo-Americans, Sasol in South Africa, and OCP in Morocco. In May 2022, the African Green Hydrogen Alliance was founded by six African countries: Egypt, Kenya, Mauritania, Morocco, Namibia and South Africa (Table 5). There are other potential players in the production and export of green hydrogen across the Eastern, Northern, Western and Southern regions. However, most of these projects are at the early stage of feasibility studies or announcements, showing uncertainty in the direction and scope of green hydrogen. The available technologies for green hydrogen still need to be economical, but the technology will likely advance in the coming decades.

There are real concerns about recent agreements (between Egypt, Morocco and Namibia) on green hydrogen because it could pose a risk of 'cannibalisation', with countries neglecting their energy needs, generating benefits for Europe, and diminishing the scope of Africa's manufacturing capability. There is inadequate evidence suggesting a commitment to developing an integrated manufacturing capacity and supply chains. This message reinforces the need for a proactive green industrial policy that focuses on expanding the domestic manufacturing sector and capitalising on the value-added benefits of the green hydrogen platform.

The green hydrogen initiatives by Morocco's OCP and South Africa's Sasol could provide an alternative approach linked with the production of green ammonia. The OCP Group, the largest employer in Morocco, has launched an ambitious five-year green investment plan amounting to US$ 13 billion to develop its mining and fertiliser production capacity from 12 to 20 million tons between 2023 and 2027, a shift to fully renewable energy and green ammonia, and to achieve carbon neutrality by 2040. An ambitious plan includes producing one million tons and three million tons of green ammonia by 2027 and 2032, respectively. OCP also targeted producing 5 GW and 13 GW by 2027 and 2032, respectively.

In Morocco, the Institute for Solar Energy and New Energies (IRESEN) was founded in 2011 to support the national energy strategy through applied research and innovation in green technologies (IRESEN 2023). IRESEN has over 800 researchers, has produced more than 400 scientific publications and has 22 university partners. Green Energy Park focused on solar energy in 2017, along with green hydrogen, intelligent electricity grids, and green mobility and buildings. IRESEN's nine board of directors comprise executives of the Ministry of Economy and Finance, the Ministry of Energy Transition and Sustainable Development, the Ministry of Science and Technology, the OCP Group, Enegie Agencies, and various federations of industries. The Scientific Council comprises prominent Moroccan and international researchers on green technologies from partner institutions.

The South African government has developed a road map and strategy to develop South Africa as the leading producer and exporter of green hydrogen, and its existing manufacturing experience and infrastructure could serve as the basis to achieve this ambition. However, there is a need to review the required strategies and policies, given the rapid advances in the sector – in technological, industrial and market aspects.

Table 5: New hydrogen production projects in Africa

Project	Lead developer	Year	Capacity	Use	Status
Morocco					
OCP Group demonstration	OCP Group	2022	260 t H_2/year	Fertiliser	Under construction
Masen green hydrogen	Masen	2025	100 MW electrolysis	Exports	Feasibility studies
HEVO-Morocco	Fusion fuel	2026	31 kt H_2/year	Ammonia fuel exports	Feasibility studies
South Africa					
Anglo-American Mogalakwena Mine	Anglo-American	2022	3.5 MW electrolysis	Mining trucks	Under construction
Sasolburg green hydrogen	Sasol	2023	2kt H_2/year	Chemicals, steel, transport, power	Feasibility studies
Nelson Mandela Bay green ammonia	Hive hydrogen	2026	140 kt H_2/year	Ammonia fuel, fertilisers, exports	Feasibility studies
Secunda SAF - Phase 1	Sasol	n.a.	8 kt H_2/year	Synfuels	Feasibility studies
Secunda SAF - Phase II	Sasol	2040	1.3 Mt H_2/year	Synfuels	Announced
Boegoebaal green hydrogen	Sasol	n.a.	400 kt H_2/year	Chemicals, synfuels, exports	Feasibility studies
Egypt					
EBIC Ammonia	Fertiglobe	2024	100 MW electrolysis	Ammonia production	Feasibility studies
EEHC-Siemens MOU	EEHC Siemens	n.a.	100 to 200 MW electrolysis	Unspecified	Announced
Mauritania					
Aman green hydrogen	CWP Global	2030	1.8 Mt H_2/year	Ammonia fuel, fertiliser, exports	Announced
Project Nour	Chariot	n.a.	10 GW electrolysis	Exports	Announced
Namibia					
O&L Group - CMB.TECH hydrogen hub	O&L group CMB.TECH	2023	4 MW electrolysis	Transport	Under construction
Renewstable Swakopmund	HDF Energy Namibia	2025	24 MW	Electricity generation	Feasibility studies
Hyphen Hydrogen Energy - Phase I	Hyphen-Hydrogen	2026	120 kt H_2	Exports	Feasibility studies
Hyphen Hydrogen Energy - Phase II	Hyphen-Hydrogen	n.a.	3 GW electrolysis	Exports	Announced

Source: IEA (2023a). Note: H_2 = hydrogen; MW = megawatt; GW = gigawatt; Mt = million tonnes; t = tonnes; kt = thousand tonnes; n.a. = not available; MoU = memorandum of understanding.

6. Synthesis of Green Industrial Policy: Discussion and Conclusions

This paper has focused on green industrial policy and industrialisation in Africa, drawing from structuralist development economics and lived experience to show that carbon-neutral industrialisation is the only viable path. It underlines that degrowth, or 'brown growth', is a dead end. Africa is a latecomer, with limited investment in industrialisation, and developing its new carbon-neutral capability is economical and sustainable, and necessitates a green industrial policy. Such green industrial policy should generate high growth, and accelerate economic transformation, and be embedded in economic diversification and productive transformation. Furthermore, it is less likely that green industrial policy will accelerate economic transformation, as it is not driven by exports, allowing more extensive market access and enabling international learning and productivity gains. Africa will go through massive urbanisation and demographic growth in the next three decades, with significant implications for green industrial policy and the creation of huge markets, productive capacity, and employment as primary aims. Hence, green industrial policy has twin goals: ensuring economic transformation and building a carbon-neutral economy. An earlier pursuit of green growth is obviously more economical, given the urgency of achieving the net-zero targets.

However, for a successful green industrial policy, a longer-term perspective is essential, particularly regarding the dynamics of technological change, to guide the deliberate selection of technologies, invest in winning and new industries, and not invest in obsolescence. Understanding technological directions is essential to pursuing a green growth strategy involving leapfrogging into new green industries. However, this leapfrogging opportunity will be more likely for the few countries that have invested in innovation and industrial capacity. The green industrial policy must also be based on decarbonising existing and mature industries to ensure that such sectors are gradually transformed into green ones. Hence, combining the decarbonisation of existing industries and leapfrogging strategies go hand in hand. A "production-centric" green industrial policy focusing on building industrial capacity and embedded in innovation is effective in accelerating economic transformation, rather than policies based on the exchange of market mechanisms or carbon trade.

National economies in Africa have divergent economic structures requiring different strategies and policies. For instance, as a generalisation, we could identify four major economies – oil-based, resource-rich, carbon-intensive and resource-poor economies – that face different challenges and prospects. Industrial structure, political economy, and the potential for linkage effects make national economic strategy divergent, although there is a significant opportunity for policy learning (Cramer et al. 2020; Oqubay 2015). Different sectors require different industrial policy designs. Furthermore, ending the subsidies to fossil fuel industries is an important policy instrument that will clear the way for clean and new energy and green industries (Table 6).

Table 6: Matrix of green growth strategies

Typologies	Country cases	Strategic issues
Carbon-intensive economies	South Africa	Just energy transition A bold policy approach to reverse incumbent vested interests Industry-specific and locally-focused policies The need to ensure that new initiatives are developed outside the incumbent institutions Development of the national and localised grids
Oil-rich economies	Nigeria, Angola, Equatorial Guinea	Diversifying the economy away from fossil fuels Decarbonisation across sectors Value addition and innovation in the energy sector
Resource-rich economies	South Africa, Democratic Republic of Congo, Botswana	Value addition to extractive industries Developing industrial capacity Diversifying economies and exports
Resource-poor economies	Ethiopia, Rwanda, Côte d'Ivoire Mauritius	Focus on job creation, exports, and production linkages Focus on service tradables and service exports Focus on light manufacturing with strong linkages to agriculture Building carbon-neutral economy and total renewable capacity

Source: own compilation. It should be noted that there is no rigid classification of countries.

The paper's focus on three cases is based on the imperative that green industrial policy requires a broader scope for intervention. Unlike the conventional industrial policy, green energy is central to carbon-neutral industrialisation and energy security, as shown in the Ethiopian and Moroccan cases. Universal access to electricity should not be seen solely from the perspectives of poverty reduction and the SDGs, but also in terms of how it serves as a demand to develop productive capacity. Having energy as a national strategy is vital for the growth and competitiveness of the manufacturing sector. However, the energy paths selected will be different for different African countries. Developing new energy hubs and green hydrogen should be guided primarily from the perspective of developing industrial capacity and innovation capability, and not for 'procuring' energy. South Africa's case is an example of such an outstanding opportunity that could be lost despite enormous demand, industrial capacity, and investment in R&D over the last twenty years. As the cases show, this is a work in progress requiring significant policy focus to ensure the strategy is successful.

International best practice shows that low-carbon industrial hubs are one of the critical elements of green industrial policy, providing an industrial ecosystem but pulling the decarbonisation process. The initiatives taken in Morocco and Ethiopia indicate the potential of green industrial policy, although it requires additional investment and policy instruments. However, low-carbon industrial hubs must ensure the growth of linkage effects, verticality, domestic capability, and economies of scale. It is essential to ensure that industrial parks are designed to ensure productivity gains, inter-firm learning, and linkages. Decarbonisation and performance improvements must be strengthened at the industry, industrial hub and firm level.

Technological advancements and innovation have accelerated increasingly in the last few decades. Experiences in emerging economies, such as China, show that investing in R&D

should start early, and R&D expenditure must grow over time. South Africa's commitment to scientific R&D is a positive lesson for all African countries. The research should focus on strategic priority sectors and commercialisation and attracting international talent, while containing the brain drain is critical. R&D capacity is likely to have a limited effect if it is not integrated tightly with the development of the manufacturing sector. In this process, innovation hubs facilitate the boost of innovation capability, and transforming the university and technical school system is possible in many African countries. These complementary policies are conducive to attracting productive investment.

The reviewed cases clearly show that carbon-neutral industrialisation and green industrial policy have significant benefits and are attainable in African countries. It also shows that government interventions and the development state have the opportunity for policy learning, focusing on emerging economies that could be considered close to African countries as comparators and benchmarks. However, designing and implementing a successful green industrial policy is more challenging than applying conventional policy, as it requires dealing with urgency and uncertainties, policy interfaces, and readiness to experiment and change policy as needed. Research that assists policy learning and the quality and performance of green industrial policy are essential (Table 7).

Table 7: A matrix of green industrial policy

	Green industrial policy	Conventional industrial policy
	The urgency of Net Zero Goals and uncertainty magnified.	Fossil fuels was the norm and green purpose was not central. Promoting both green growth and productive transformation is challenging
Pathways	Diverse pathways: stage of development, national, sectoral,	Carbon intensity and fossil fuel dependency was not a major determinant. There is no single path and uniform approach to green transformation. It requires a new perspective.
Scope	Broader scope, policy interfaces and synergy, complementarity. Energy, sustainable urban development, mobility etc., are integrated into green industrial policy	Energy and other sectors such as energy, urban, mobility, and consumers were not critical component
Aim	Green industries and technologies Decarbonisation of industries Ending reliance on hydro-carbon	Productive transformation to ensure structural transformation and catch-up was the aim
Orientation	Production centric and innovation are central. Carbon trade and market mechanisms are supplementary	Productive centric is central, and the focus is not on fixing market failure
Agglomeration/ecosystem	Low-carbon industrial hubs and platforms are central	Greening was not essential requirement in industrial ecosystems.

Technological capability and innovation	Innovation and technology focus on green and digital technologies, and decarbonization is critical to production transformation.	Technological capability and innovation have been central but the greening technologies were peripheral.
Development financing	Innovations in financing, such as green bonds, have emerged since the mid-2010s. Sustainability and decarbonisation are essential criteria for development financing.	Environment sustainability and decarbonisation were not essential parameters.
Politics of fossil fuel economy	New pressures to reduce subsidies to the fossil fuel industry (such as coal-fired), and massive incentives to new technologies and manufacturing investment to support green growth.	The political economy has been favourable to fossil fuels. Subsidy to fossil fuels is significant. Fossil fuel multinational corporations earn excessive super profits.
Industrial revolution	Industrial Revolution 6- Green Industrial Revolution	Industrial Revolution 1 (machinery, iron, textile industry) Industrial Revolution 2 (steam engine & railways) Industrial Revolution 3 (steel, electricity, heavy engineering) Industrial Revolution 4 (automotive and mass production) Industrial Revolution 5 (ICT)

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