HKUST(GZ) Report 2026

Flying to the Sky

Energy and Economic Transition Pathway With Carbon Neutrality Target in Africa by 2050

Carbon Neutrality and Climate Change Thrust, Society Hub
& Center for Global Climate Strategies
THE HONG KONG UNIVERSITY OF SCIENCE AND TECHNOLOGY (GUANGZHOU)

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Energy and Economic Transition Pathway With Carbon Neutrality Target in Africa by 2050

The Hong Kong University of Science and Technology (Guangzhou)

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Abbreviations

Abbreviation	Full Name
AA-CAES	Advanced Adiabatic Compressed Air Energy Storage
ACMI	Africa Carbon Markets Initiative
ACP100	CNNC multipurpose modular small pressurised water reactor (ACP100)
AfCFTA	African Continental Free Trade Area
AfDB	African Development Bank
AFR100	African Forest Landscape Restoration Initiative
AfSEM	African Single Electricity Market
AGN	African Group of Negotiators
AIM	Asia-Pacific Integrated Model
ALK	Alkaline Water Electrolyser
AMCEN	African Ministerial Conference on the Environment
AP1000	Westinghouse AP1000 advanced passive pressurised water reactor
APR-1400	Advanced Power Reactor 1400
AR6	IPCC Sixth Assessment Report
AU	African Union
BAM	Bundesanstalt für Materialforschung und -prüfung
BAU	Business as Usual
BC	Back Contact (solar cell)
BECCS	Bioenergy with Carbon Capture and Storage
BMWK	Bundesministerium für Wirtschaft und Klimaschutz (German Federal Ministry for Economic Affairs and Climate Action)
CAES	Compressed Air Energy Storage
CCS	Carbon Capture and Storage
CDR	Carbon Dioxide Removal
CFR600	China Fast Reactor 600
CMA	Conference of the Parties serving as the meeting of the Parties to the Paris Agreement
CNNC	China National Nuclear Corporation
COP	Conference of the Parties (UNFCCC)
COP	Coefficient of Performance
CO_2e	Carbon dioxide equivalent
CPI	Climate Policy Initiative
CPIA	Country Policy and Institutional Assessment
CRI	Carbon Recycling International

Abbreviation	Full Name
CTP	Cell to Pack
DACCS	Direct Air Carbon Capture and Storage
DRI	Direct Reduced Iron
DTIC	Department of Trade, Industry and Competition (South Africa)
EAPP	Eastern Africa Power Pool
EEAS	European External Action Service
EEHC	Egyptian Electricity Holding Company
EEP	Ethiopian Electric Power
EgyptERA	Egyptian Electric Utility and Consumer Protection Regulatory Agency
EPC	Engineering, Procurement and Construction
EPR	European Pressurized Reactor
EPRA	Energy and Petroleum Regulatory Authority (Kenya)
ERM	Environmental Resources Management (consultancy)
ESIA	Environmental and Social Impact Assessment
FEED	Front-End Engineering Design
FID	Final Investment Decision
FOAK	First-of-a-Kind
FOCAC	Forum on China-Africa Cooperation
GDP	Gross Domestic Product
GEM	Global Energy Monitor
GHG	Greenhouse Gas
GIF	Generation IV International Forum
H-DRI	Hydrogen-based Direct Reduced Iron
HDI	Human Development Index
HJT	Heterojunction Technology (solar cell)
HTR-10 / HTR-PM	High Temperature gas-cooled Reactor (10 MWt test reactor / Pebble-bed Module)
IAEA	International Atomic Energy Agency
IDA	International Development Association
IDZ	Industrial Development Zone
IEA	International Energy Agency
IFC	International Finance Corporation
ILO	International Labour Organization
INET	Institute of Nuclear and New Energy Technology, Tsinghua University
IPAC	Integrated Policy Assessment Model for China
IPCC	Intergovernmental Panel on Climate Change

Abbreviation	Full Name
IPG	International Partners Group
IRENA	International Renewable Energy Agency
IRP	Integrated Resource Plan
ITER	International Thermonuclear Experimental Reactor
JETP	Just Energy Transition Partnership
KenGen	Kenya Electricity Generating Company
KfW	Kreditanstalt für Wiederaufbau (KfW Development Bank)
LAES	Liquid Air Energy Storage
LCOE	Levelised Cost of Electricity
LCOS	Levelised Cost of Storage
LiDAR	Light Detection and Ranging
LIF	Laser-Induced Firing
LSTM	Long Short-Term Memory (neural network)
LT-LEDS	Long-Term Low Greenhouse Gas Emission Development Strategy
MOX	Mixed Oxide fuel
MPPT	Maximum Power Point Tracking
MVA	Manufacturing Value Added
NDC	Nationally Determined Contribution
NOAA	National Oceanic and Atmospheric Administration (United States)
NOAK	Nth-of-a-Kind
OCP	OCP Group (formerly Office Chérifien des Phosphates)
OECD	Organisation for Economic Co-operation and Development
ONEE	Office National de l'Électricité et de l'Eau Potable (Morocco)
PEM	Proton Exchange Membrane
PERC	Passivated Emitter and Rear Cell
PIF	Public Investment Fund (Saudi Arabia)
$PM_{2.5}$	Fine particulate matter (≤ 2.5 μm)
PRIS	Power Reactor Information System (IAEA)
PUE	Power Usage Effectiveness
PURC	Public Utilities Regulatory Commission (Ghana)
RCP	Representative Concentration Pathway
RCS	Reactor Coolant System
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
RPV	Reactor Pressure Vessel
SAPP	Southern African Power Pool

Abbreviation	Full Name
SC-CAES	Supercritical Compressed Air Energy Storage
SCZONE	Suez Canal Economic Zone
SDG / SDGs	Sustainable Development Goal(s)
SEZ	Special Economic Zone
SFR	Sodium-cooled Fast Reactor
SIDS	Small Island Developing States
SMR	Small Modular Reactor
SOC / SOH	State of Charge / State of Health
SOEC	Solid Oxide Electrolysis Cell
SR1.5	IPCC Special Report on Global Warming of 1.5°C
SSP	Shared Socioeconomic Pathway
STEP	station de transfert d'énergie par pompage (French)
TEDA	Tianjin Economic-Technological Development Area
TIC	Tanzania Investment Centre
Toe	Ton Oil Equivalent
TOPCon	Tunnel Oxide Passivated Contact (solar cell)
UN DESA	United Nations Department of Economic and Social Affairs
UNCTAD	United Nations Conference on Trade and Development
UNDP	United Nations Development Programme
UNECA	United Nations Economic Commission for Africa
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change
UNFCCC LEG	UNFCCC Least Developed Countries Expert Group
UNIDO	United Nations Industrial Development Organization
VOC	Volatile Organic Compounds
VVER	Vodo-Vodyanoi Energetichesky Reaktor (Russian pressurised water reactor)
WACC	Weighted Average Cost of Capital
WAPP	West African Power Pool
WMO	World Meteorological Organization
ZLD	Zero Liquid Discharge

Note: Listed in alphabetical order.

Units, Symbols, and Currency

Unit/Symbol	Meaning
%	Percentage
°C	Degrees Celsius
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent
CH_4	Methane
NO_x	Nitrogen oxides
SO_2	Sulphur dioxide
NH_3	Ammonia
CH_3OH	Methanol
$PM_{2.5}$	Fine particulate matter (diameter ≤ 2.5 μm)
VOC	Volatile organic compounds
t	Ton
10,000 tons / 100 million tons	10^4 tons / 10^8 tons
Mt	Million tons (10^6 t)
Gt	Billion tons (10^9 t)
Mtoe	Million tons of oil equivalent
Mtce	Million tons of standard coal equivalent
tons of standard coal	Ton of standard coal equivalent (tce)
W / kW / MW / GW / TW	Watt / Kilowatt / Megawatt / Gigawatt (million kilowatts) / Terawatt
10,000 kilowatts	10 MW (as used in Figure 4-3-4)
MWe / GWe	Megawatt electric / Gigawatt electric
MWt	Megawatt thermal
MWp	Megawatt-peak (solar PV DC power rating)
MWac	Megawatt (AC power rating)
kWh / MWh / GWh / TWh	Kilowatt-hour / Megawatt-hour / Gigawatt-hour / Terawatt-hour (billion kilowatt-hours)
Wh/kg	Watt-hours per kilogram (battery energy density)
mAh/g	Milliampere-hours per gram (electrode specific capacity)
MVA	Megavolt-ampere (as used in Chapter 4; MVA in the List of Abbreviations refers to Manufacturing Value Added)
MPa	Megapascal
GJ	Gigajoule (10^9 joules)
ha	Hectare

Unit/Symbol	Meaning
m^2 / m^3	Square metre / Cubic metre
mm	Millimetre
$	United States dollar
cents	US cent (1/100 of a US dollar)
yuan	Chinese yuan (Renminbi)
euros	Euro

Flying to the Sky: Energy and Economic Transition Pathway With Carbon Neutrality Target in Africa by 2050

Foreword

By the first half of 2026, zero-carbon energy technologies had sustained their rapid development, with many countries experiencing strong growth in their deployment with almost no reliance on policy support.

The price of photovoltaic (PV) modules had fallen below US$0.10/W, while large-scale onshore wind turbines were priced at US$ 280–300/kW and alkaline water electrolysers at approximately US$180/kW. Electric vehicles equipped with Level 2 automated driving capabilities, LiDAR and a driving range of 510 km were available for US$14,000, while electric two-wheelers cost around US$290, agricultural electric three-wheelers US$525 and home EV chargers US$120. Zero-carbon industrial parks and other emerging industrial platforms have also developed rapidly, with some already able to offer electricity at lower prices than conventional industrial parks.

These technological advances have substantially reduced the cost of emissions reduction in many countries, even eliminating additional costs altogether. Several developing countries have achieved rapid adoption of zero-carbon technologies, outpacing many developed countries.

Africa possesses the world's most abundant solar energy resources and highest levels of solar irradiation, particularly in the Sahara region of North Africa. By 2026, solar PV power generation costs in North Africa's most solar-rich areas had already fallen to 0.7 US cents/kWh. Looking ahead, North Africa could potentially develop more than 10 TW of low-cost solar PV capacity, enabling the production of hydrogen through water electrolysis at a cost of around US$1,000/ton. This would allow the production cost of green hydrogen-based ammonia to fall below that of ammonia

currently produced through petrochemical and coal-based processes. According to our research, the cost of direct air capture (DAC) of CO_2 could fall below US$60/ton in the future. At this cost level, methanol, ethylene and other olefins produced using captured CO_2 could become cheaper than their counterparts manufactured through conventional petrochemical and coal-chemical processes. Even after accounting for transportation costs, these products manufactured in North Africa could be delivered to markets in the United States and China at prices below those of locally produced alternatives.

Africa is also rich in natural resources, including substantial reserves of iron ore, bauxite, copper and lithium, which could provide a strong foundation for the development of domestic manufacturing industries. The rapid technological advances and structural changes associated with the transition towards carbon neutrality present significant opportunities for Africa's future economic development. Although Africa currently has a relatively limited industrial base, this could, in fact, become an advantage, allowing the continent to move directly into a new stage of industrial development. As many technologies and industries are already becoming commercially viable through market-driven development, financing is no longer a major constraint. Creating a more favourable investment environment and strengthening government services will therefore be particularly important.

Looking ahead, we are highly optimistic about Africa's development prospects. By 2050, if the necessary conditions are in place, Africa could become one of the most dynamic regions in the global economy, with its industrial sectors playing an important role worldwide. GDP per capita across Africa could reach the World Bank's current upper-middle-income threshold, while some African countries could attain high-income status.

This report builds on current and previous research conducted by the Integrated Policy Assessment Model for China (IPAC) team at the Hong Kong University of Science and Technology (Guangzhou), using the IPAC model as a quantitative analytical tool to illustrate potential pathways for Africa's development and transition towards 2050. The IPAC modelling team is committed to supporting the global temperature goals of the Paris Agreement, particularly the goal of limiting global warming to 1.5°C. Recent advances in zero-carbon technologies, including their increasing commercial viability without policy-driven incentives, have opened up new possibilities for achieving rapid global emissions reductions in the near term. We need to work together to build a better and more prosperous world. This report aims to

illustrate the regional development prospects of emerging economies.

Following this report, the IPAC modelling team will collaborate with other Asian modelling teams to begin preparing an assessment report on Asia, and subsequently reports on Europe and the United States, with publication planned for 2027 and 2028.

1. Today's Africa

Africa continues to face significant socioeconomic development challenges, with substantial disparities across countries in income levels, industrial structures and access to basic services. Economic development, job creation and improvements in basic services remain essential priorities for advancing inclusive development across the continent. Both the United Nations' 2030 Agenda for Sustainable Development and the African Union's Agenda 2063 identify poverty reduction, social well-being, economic transformation and environmental sustainability as key development priorities (United Nations, 2015; AU, 2015). This report focuses primarily on 2050, exploring potential pathways for Africa's energy and economic transition under explicitly defined development assumptions.

Africa is at a critical stage where population expansion, economic growth and rising energy demand are closely intertwined. According to the medium-variant projection in the United Nations' *World Population Prospects 2024*, Africa's total population, including North Africa, is projected to reach approximately 2.467 billion by 2050, accounting for 25.5% of the global population, and approximately 3.814 billion by 2100, representing 37.5% of the global total (UN DESA, 2024; authors' calculations). Much of the housing, transport infrastructure, electricity infrastructure and industrial facilities needed to accommodate this population growth have yet to be built (IEA, 2022). The associated infrastructure investments present significant development opportunities, while the energy and technology choices made today will continue to shape Africa's development for decades to come.

Africa will expand its infrastructure against a backdrop of historically low emissions, existing climate-related losses and largely untapped renewable energy resources. In 2019, Africa accounted for only 3.8% of global CO_2 emissions from fuel combustion, but climate-related losses have already averaged 2–5% of its annual GDP (IEA, 2021; WMO, 2024). Meanwhile, approximately 60% of the land area within the world's top 20% of solar resource regions is located in Africa, but the continent accounted for only 1% of global installed solar PV capacity in 2022 (IEA, 2022). The key question is whether African economies can meet their growing development needs while avoiding the carbon-intensive development pathways followed by industrialised economies.

1.1 Economic Growth, Industrial Structure and Development Finance

Projections for 2026 and 2027 indicate that Africa's economy will continue to grow, but at a relatively moderate pace. The African Development Bank (AfDB) forecasts real GDP growth of 4.2% in 2026 and 4.4% in 2027, while the United Nations Economic Commission for Africa (UNECA) projects growth of 4.0% in 2026 (AfDB, 2026b; UNECA, 2026). However, these growth rates remain insufficient to absorb the continent's expanding labour force. Large-scale job creation requires sustained annual economic growth of approximately 7% or more (AfDB, 2026b). Although 12 of the world's 20 fastest-growing economies in 2025 were in Africa (AfDB, 2026a), the projected growth rates for the continent as a whole remain well below the required 7% threshold.

Continental averages also mask substantial regional disparities. Based on the AfDB's classification of Africa into five regions, East Africa recorded the highest growth rate of 6.6% in 2025, with growth projected at 5.9% in 2026 and 6.4% in 2027. West Africa grew by 4.8% in 2025, with projected growth of 4.7% and 4.5% over the following two years. North Africa recorded growth of 4.4% in 2025, with forecasts of 4.0% and 4.2% for 2026 and 2027, respectively. Central Africa grew by 3.6% in 2025, with projected growth of 3.8% and 4.1% in the subsequent two years (AfDB, 2026b). In contrast, Southern Africa recorded growth of 2.3% in 2025, with forecasts of 2.1% in 2026 and 2.7% in 2027 (AfDB, 2026b) (Figure 1-1-1). These figures reflect differences in economic growth rates rather than differences in per capita income or overall levels of development.

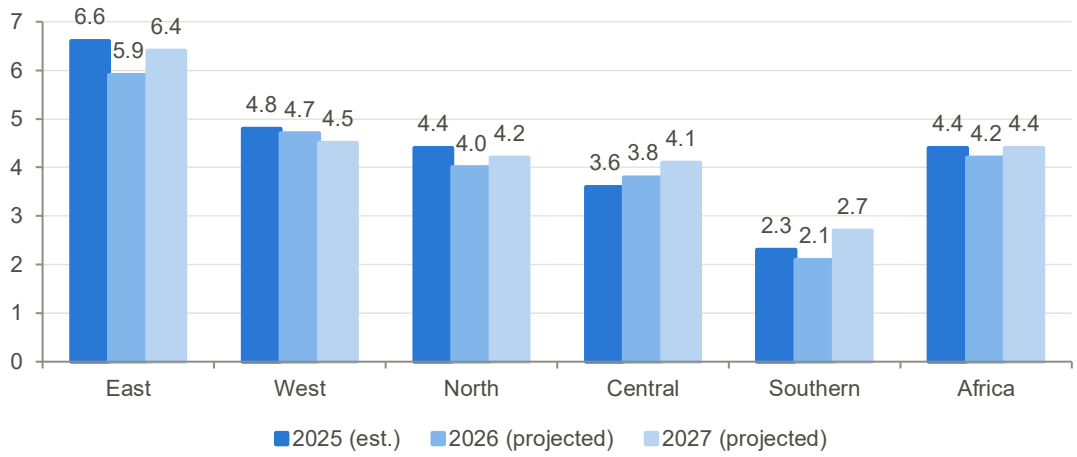


Figure 1-1-1 Real GDP Growth Rates across African Regions, 2025–2027 (%)

Note: Countries are classified into regions according to Annex Table A2.1 in AfDB (2026a).

Source: AfDB (2026b), African Economic Outlook 2026, Figure 1.1, p. 4.

Africa's economic growth in recent years has not been accompanied by an increase in industry's share of GDP. Between 2013 and 2024, the share of industrial value added, including construction, declined from 31.5% to 28.0%, while agriculture's share increased from 13.6% to 16.2%. Services remained the largest economic sector, accounting for approximately half of total output (World Bank, 2026f; authors' calculations). Despite continued economic growth, industry's contribution to Africa's total output has declined, making the expansion of industrial production a development challenge that requires targeted attention (Figure 1-1-2). The concept of "premature deindustrialisation" discussed by Rodrik (2016) refers to the tendency of manufacturing employment or value-added shares in some developing economies to peak and begin declining at relatively low income levels, suggesting that late-industrialising economies may face greater difficulties in absorbing labour through manufacturing expansion. The industrial statistics presented in this section encompass mining, manufacturing, utilities and construction. A decline in the overall industrial share therefore does not necessarily constitute premature deindustrialisation in manufacturing.

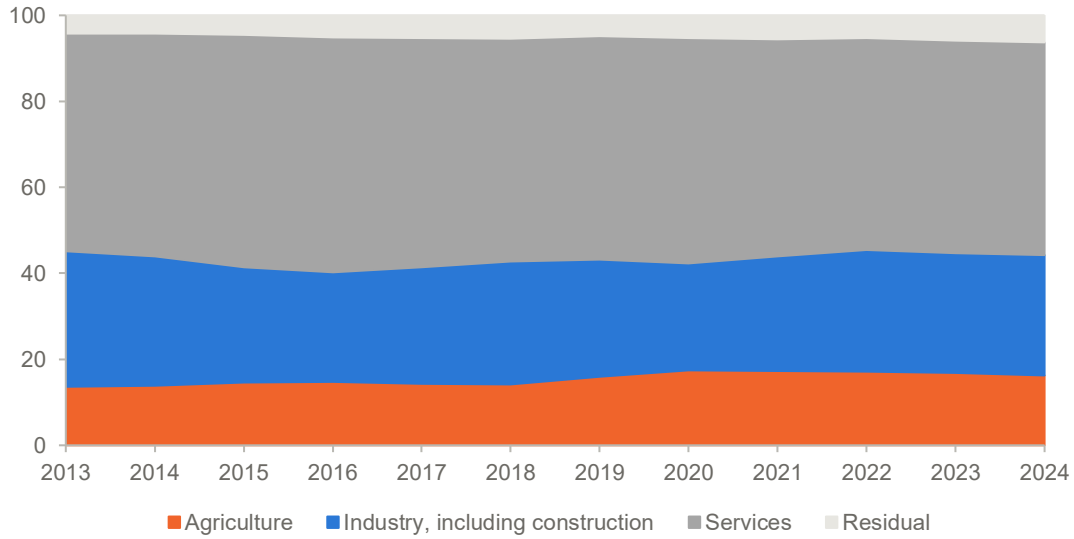


Figure 1-1-2 Sectoral Value Added as a Share of GDP in Africa, 2013–2024 (%)

Note: The analysis covers 54 African economies, with GDP-weighted aggregates calculated using available data. Industry includes construction. The residual represents the difference between 100% and the sum of the shares of the three sectors.

Source: Authors' calculations based on World Bank (2026f), World Development Indicators.

Market fragmentation within Africa has made it more difficult to expand industrial production. In 2022, intra-African trade accounted for 16% of the continent's total merchandise trade, compared with 68% in Europe and 59% in Asia (UNCTAD, 2025). Limited participation of African suppliers in production activities has further exacerbated market fragmentation. Of Africa's 54 countries, only 16 sourced more than 0.5% of their total intermediate inputs from within the continent (UNCTAD, 2025) (Figure 1-1-3)

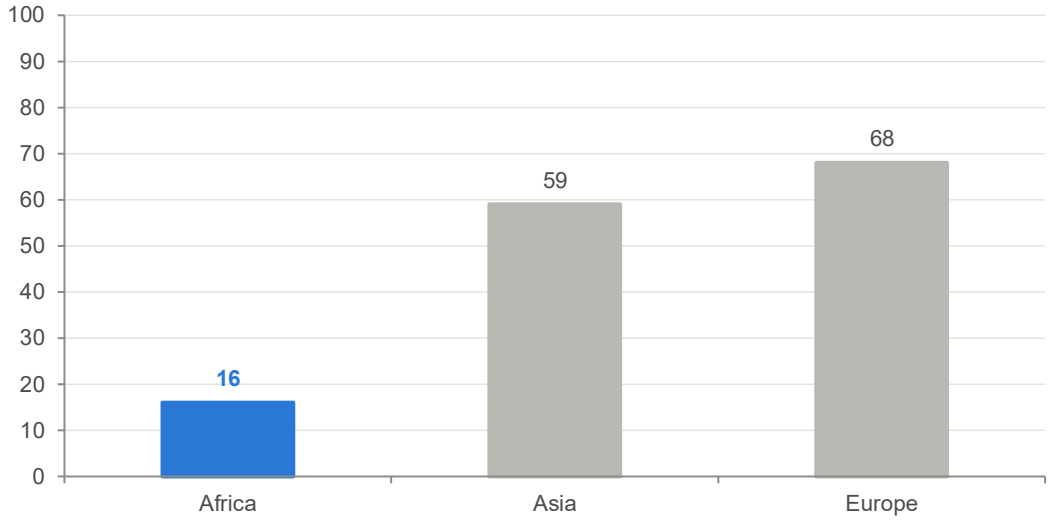


Figure 1-1-3 Share of Intra-regional Trade in Total Trade in Africa, Asia and Europe, 2022 (%)

Source: UNCTAD (2025), Economic Development in Africa Report 2024, p. 46.

Expanding intra-African trade could provide African manufacturers with access to larger markets for their products. Manufactured goods account for 45% of intra-African exports, compared with 23% of Africa's exports to all destinations (UNECA, 2026). Given the relatively low share of intra-African trade in the continent's total trade, the higher proportion of manufactured goods in intra-African exports suggests considerable potential to expand their sales through improved access to neighbouring markets. The African Continental Free Trade Area (AfCFTA) provides an institutional framework for expanding regional trade, but tariff reductions alone cannot eliminate all barriers between producers and customers. The United Nations Conference on Trade and Development (UNCTAD) has highlighted that eliminating non-tariff barriers would generate substantially greater economic benefits than tariff elimination alone (UNCTAD, 2025). Investment in transport and logistics could further increase these benefits. Model estimates indicate that combining trade reforms with transport improvements could increase exports across African countries by an average of 11.5%, compared with 3.4% under trade reforms alone (Fontagné et al., 2023). Therefore, regional industrialisation in Africa could benefit from combining reforms that reduce cross-border barriers with investments that lower the cost of transporting goods.

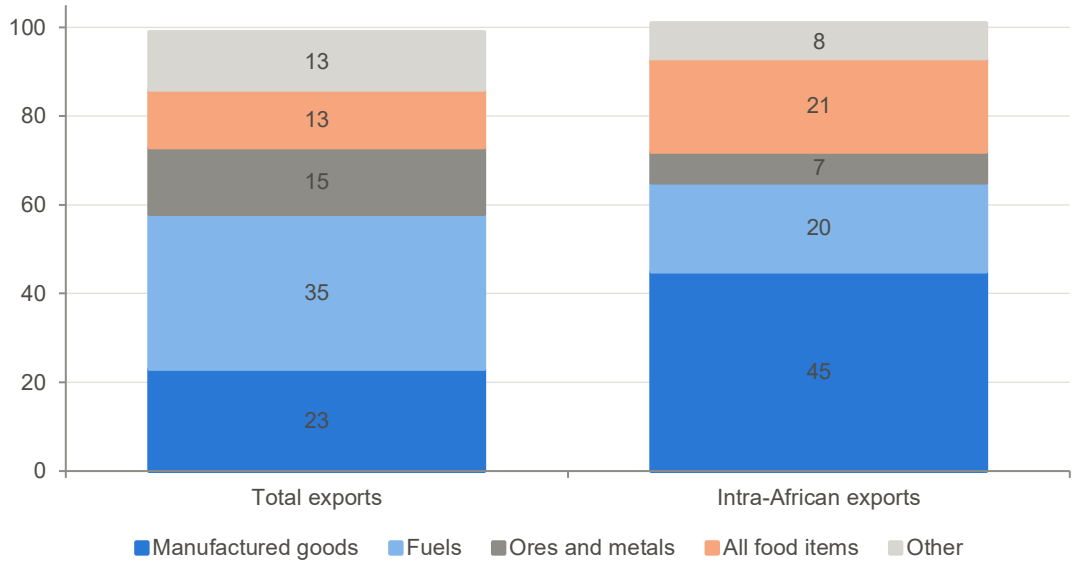


Figure 1-1-4 Sectoral Composition of African Exports: Total Exports versus Intra-African Exports, 2020–2024 Average (%)

Note: Percentages may not sum to 100% due to rounding.

Source: UNECA (2026), Economic Report on Africa 2026, figure 1.12, p. 19.

1.2 Population Growth and Urbanisation

Population growth will continue to shape Africa's infrastructure needs over the coming decades, extending far beyond the two- to three-year horizon of current macroeconomic forecasts. Beyond continent-wide population trends, demographic changes in sub-Saharan Africa are particularly noteworthy. The global population stood at 8.2 billion in 2024. Using the same year as the baseline, the population of sub-Saharan Africa is projected to increase by 79% to reach 2.2 billion by 2054 (UN DESA, 2024) (Figure 1-2-1). Thirty years is roughly equivalent to the length of a generation's working life, meaning that children currently entering primary school and young people just joining the labour force will experience much of this population expansion. Planning for energy systems, transport corridors and municipal utilities must therefore accommodate demand over the coming decades rather than merely respond to short-term fluctuations in economic output.

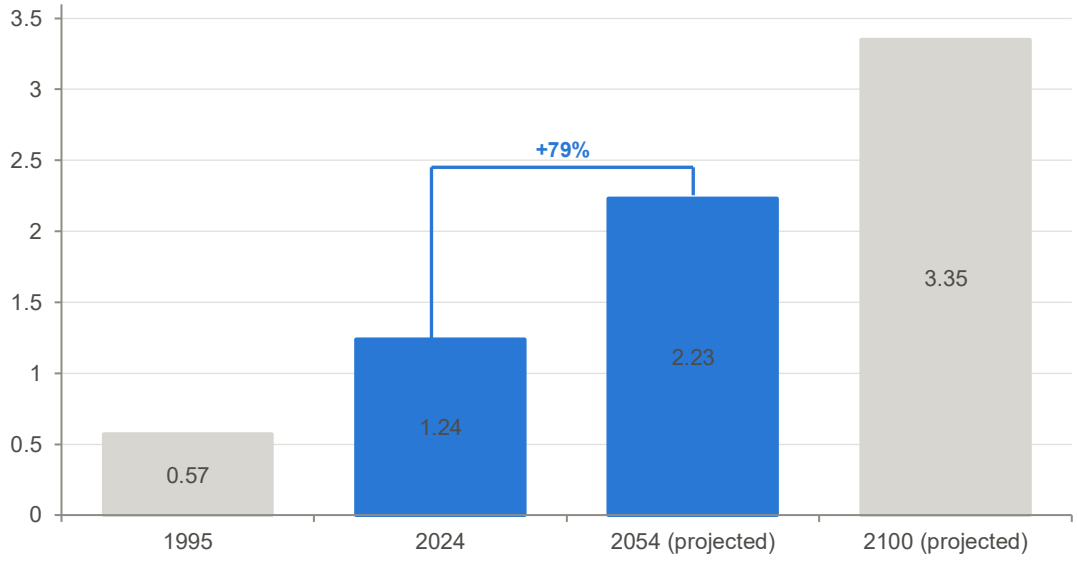


Figure 1-2-1 Population of Sub-Saharan Africa, 1995–2100 (Billions)

Note: The medium-variant projection is used. The 95% prediction interval for 2054 ranges from 2.1 to 2.4 billion people. The bracket indicates the population increase from 2024 to 2054, calculated using data from the United Nations Department of Economic and Social Affairs (UN DESA).

Source: UN DESA (2024), World Population Prospects 2024: Summary of Results, pp. 36, 58; UN DESA (2024), World Population Prospects 2024, Online Edition (Medium Scenario and Probabilistic Forecast Data).

Population growth in Africa is expected to be concentrated in certain countries rather than evenly distributed across the continent. Countries with total fertility rates of four or more children per woman are predominantly located in sub-Saharan Africa, including the Central African Republic, Chad, the Democratic Republic of the Congo, Niger and Somalia (UN DESA, 2024). Countries with both high fertility rates and youthful population structures are expected to experience the most rapid population growth, while other African countries will see slower growth and changes in their age structures. Countries experiencing faster population growth will need to expand access to education, maternal healthcare, housing and employment opportunities more rapidly. Countries with slower population growth, by contrast, will face a more gradual need to expand service provision capacity while adjusting the allocation of services to changes in their population age structures.

In addition to regional disparities, Africa's population growth will become increasingly concentrated in urban areas. The *Nairobi Declaration* projects that Africa's urban population will exceed one billion by 2050 (AU, 2023). Urbanisation is changing the nature of infrastructure demand, as housing, transport and basic services must accommodate larger populations at higher densities. African cities therefore need to

rapidly expand formal housing, high-capacity public transport systems, electricity distribution networks and treated water supply networks.

The construction needs arising from urban population growth extend far beyond housing. The International Energy Agency (IEA) projects that Africa's residential floor area will more than double by 2050, reaching approximately 50 billion m^2. A more immediate challenge is the need to add 70 million new homes by 2030 (IEA, 2022). Road networks, office and industrial buildings, substations and municipal water supply systems will also need to expand alongside housing. Meeting these housing and infrastructure needs will require a sustained supply of cement, steel, reinforcing bars, copper wiring and construction equipment, as well as greater planning and construction capacity. If African producers can secure a substantial share of procurement contracts, the large and predictable demand for construction materials and equipment could support the development of local industries and supply chains within Africa.

1.3 Social Development Progress and Gaps

Population growth and urban development will increase demand for healthcare, education and infrastructure. Despite improvements in human development over recent decades, universal access to basic services has yet to be achieved. The Human Development Index (HDI) in sub-Saharan Africa increased from 0.405 in 1990 to 0.568 in 2023 (UNDP, 2025). Combining measures of health, education and income per capita, the index reflects progress across multiple dimensions amid rapid population growth.

However, human development remains uneven across Africa. Most North African countries fall within the medium or high human development categories, while sub-Saharan Africa continues to rank lowest among the regions compared by the United Nations Development Programme (UNDP, 2025). In 2023, the region's HDI of 0.568 was below South Asia's 0.672 and the global average of 0.756 (UNDP, 2025). In terms of the pace of improvement, sub-Saharan Africa's HDI recorded a compound annual growth rate of 1.03% between 1990 and 2023, lower than South Asia's 1.20% and East Asia and the Pacific's 1.25% (UNDP, 2025, Table 2). Comparisons of both current HDI levels and long-term growth rates indicate that considerable scope remains for improvements in health, education and income across the region (Figure 1-3-1).

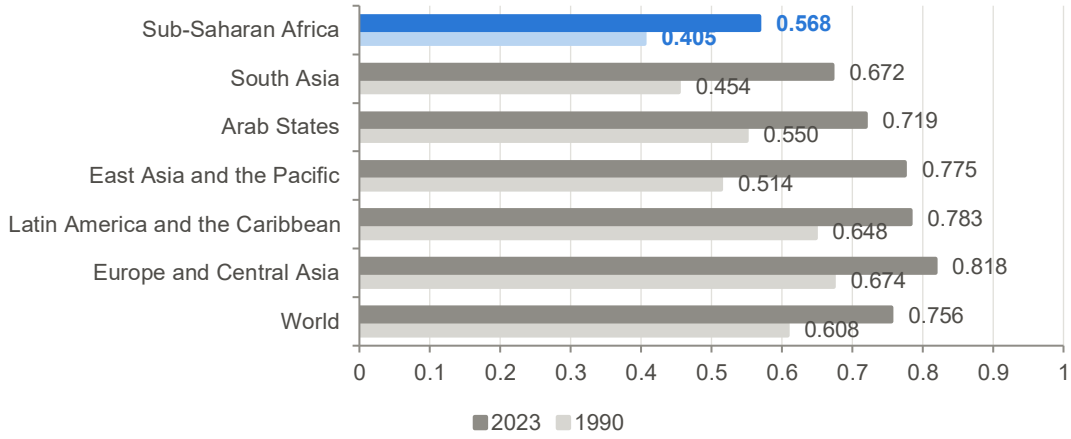


Figure 1-3-1 Human Development Index by Region, 1990 and 2023 (Index, 0–1)

Note: Regional classifications follow those used in the Human Development Report, which does not provide an aggregate value for Africa as a whole. Most North African countries are included in the Arab States group.

Source: UNDP (2025), Human Development Report 2025, tables 1 and 2.

Recent monitoring of the Sustainable Development Goals (SDGs) provides a more direct assessment of whether development progress is keeping pace with existing commitments. The 2025 High-level Political Forum on Sustainable Development reviewed Goals 3, 5, 8, 14 and 17, covering 46 measurable SDG targets in Africa. Of these, only 2 were on track, 30 required accelerated progress and 14 showed regression (UNECA, 2025). Even among the five goals reviewed, the number of targets showing regression was seven times that of those on track, while nearly two-thirds of the measurable targets required faster progress. Advancing these targets therefore requires not only accelerating improvements but also reversing previous setbacks (Figure 1-3-2).

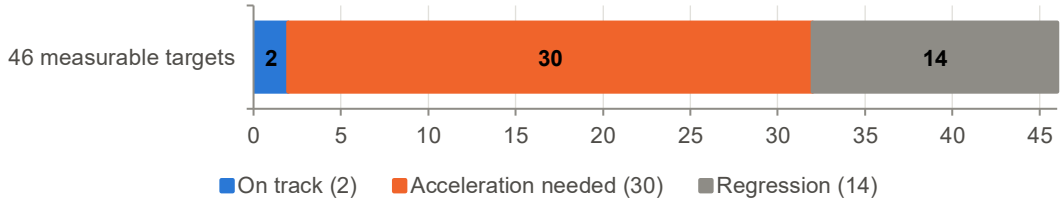


Figure 1-3-2 Progress on Measurable SDG Targets in Africa: Goals 3, 5, 8, 14 and 17 (Number of Targets)

Note: The five goals were reviewed at the 2025 High-level Political Forum on Sustainable Development. Of the 63 targets, 46 were measurable and 17 lacked sufficient data. Targets 14.5 and 17.19 were on track.

Source: UNECA (2025), Africa Sustainable Development Report 2025, pp. 9–10.

Persistent income poverty further limits improvements in living standards. The global distribution of extreme poverty is heavily concentrated in sub-Saharan Africa. In

2024, the region accounted for approximately 16% of the world's population but 67% of the global population living in extreme poverty (World Bank, 2024) (Figure 1-3-3). Fragile and conflict-affected economies also bear a disproportionate burden of extreme poverty (World Bank, 2024). Improvements in average indicators of health, education and income do not necessarily mean that all households have achieved an adequate standard of living. Improving living standards requires both raising the incomes of the poorest households and expanding access to public services.

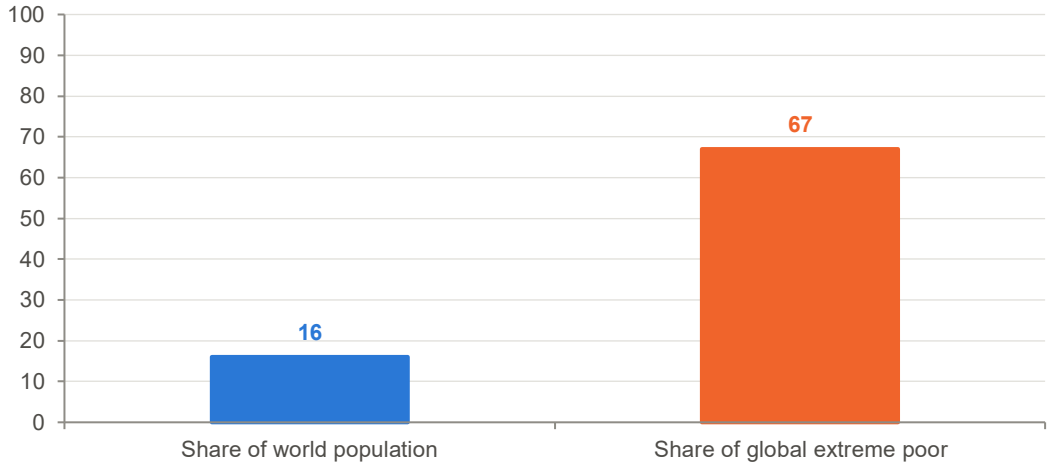


Figure 1-3-3 Share of Sub-Saharan Africa in the Global Population and Population Living in Extreme Poverty, 2024 (%)

Note: Figures for 2024 are estimates. The extreme poverty line is set at US$2.15 per person per day (2017 purchasing power parity, PPP).

Source: World Bank (2024), Poverty, Prosperity, and Planet Report 2024.

The concentration of poverty is accompanied by substantial infrastructure gaps. The Tracking SDG 7: The Energy Progress Report, published in 2026, indicates that approximately 563 million people in sub-Saharan Africa still lacked access to electricity in 2024, making it the region with the largest concentration of people without electricity access worldwide (IEA et al., 2026, Chapter 1). This figure covers sub-Saharan Africa only, and access to electricity does not necessarily mean that the supply is reliable or affordable. Closing the electricity access gap while improving service quality remains a major priority for social development and infrastructure provision.

Similar gaps persist in access to clean cooking, drinking water and sanitation. The same report estimates that approximately 970 million people in sub-Saharan Africa lacked access to clean cooking fuels and technologies in 2024 (IEA et al., 2026, Chapter 2). Many households rely on traditional biomass fuels, which contribute to poor indoor air quality and place pressure on local forests (IEA, 2022). Across Africa as a whole,

the *Nairobi Declaration* reported in 2023 that 400 million people lacked access to safe drinking water and 700 million lacked adequate sanitation facilities (AU, 2023). Although these figures differ in geographical coverage and reference year, they all point to substantial gaps in access to basic services. Infrastructure financing must therefore often support first-time access rather than merely upgrading existing networks.

Providing healthcare, education, water supply and clean cooking services to households that currently lack basic services requires reliable energy. Electricity supports the operation of healthcare facilities, schools, municipal water pumps and communication networks, while clean cooking technologies can reduce household exposure to harmful smoke. Expanding electricity supply cannot replace healthcare workers, teachers or water distribution networks, but unreliable or unavailable electricity can limit both the coverage and quality of these services. Closing gaps in access to basic services will increase demand for electricity and modern fuels. The low levels of energy use among households without access to these services indicate substantial unmet demand, making the expansion of modern energy services an essential component of Africa's future energy development.

Energy security also affects the continuity of these services. For countries dependent on imported fuels such as petrol and diesel, increases in international prices, currency depreciation or transport disruptions can raise transport and business operating costs, while increasing household living expenses and pressure on government fuel subsidies (World Bank, 2026g). Abundant natural resources do not automatically translate into a sustainable and affordable energy supply. The specific risks depend on each country's fuel mix, import dependence and energy infrastructure conditions.

1.4 Carbon Emission, Trends and Distribution

1.4.1 CO_2 Emissions

Limited access to electricity and clean cooking, together with a relatively weak industrial base, partly explains Africa's low initial emissions level. In 2024, Africa's fossil CO_2 emissions, including those from cement production, reached 1.50 Gt, accounting for 3.9% of the global total (authors' calculations based on Andrew and Peters, 2025). Per capita fossil CO_2 emissions were approximately 1.0 ton, well below the global average of 4.73 tons (authors' calculations based on Andrew and Peters, 2025;

UN DESA, 2024). Africa's low per capita emissions partly reflect unmet demand for modern energy services rather than the completion of a low-carbon transition.

The fossil CO_2 emissions presented in this section are based on the territorial emissions of 54 African countries reported in the Global Carbon Project's fossil CO_2 emissions dataset (2025v15). The data include emissions from fossil fuel combustion and oxidation, as well as cement production, but exclude land-use change emissions and do not subtract CO_2 uptake through cement carbonation. The global total used as the denominator additionally includes emissions from international aviation and maritime bunker fuels that are not allocated to individual countries. Per capita emissions are calculated using population estimates for 1 July 2024 from the United Nations' *World Population Prospects 2024*, with Africa's population aggregated across the same 54 countries (Andrew and Peters, 2025; UN DESA, 2024; authors' calculations).

Africa's share of current global emissions is relatively small, and its contribution to cumulative emissions since 1850 has also been limited. Between 1850 and 2024, Africa's cumulative fossil CO_2 emissions amounted to 54 Gt, compared with a global total of 1,845 Gt, representing a share of 2.9% (authors' calculations based on Andrew and Peters, 2025). In comparison, Europe accounted for 29.7% of global cumulative emissions, Asia for 29.5% and North America for 26.7%. Africa's share was approximately one-tenth of that of each of these three largest emitting regions (Figure 1-4-1). This historical comparison highlights that Africa's future infrastructure expansion will take place in a different context from that of economies with substantially higher historical fossil CO_2 emissions.

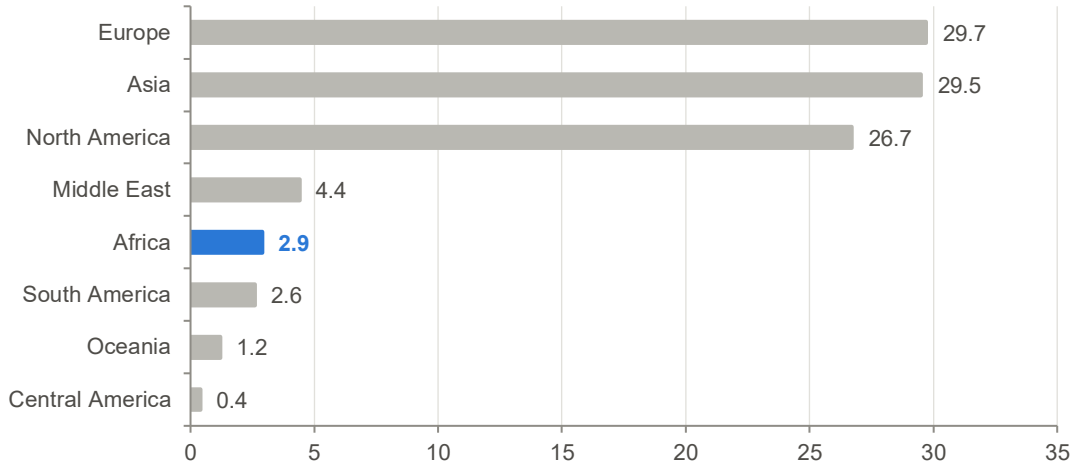


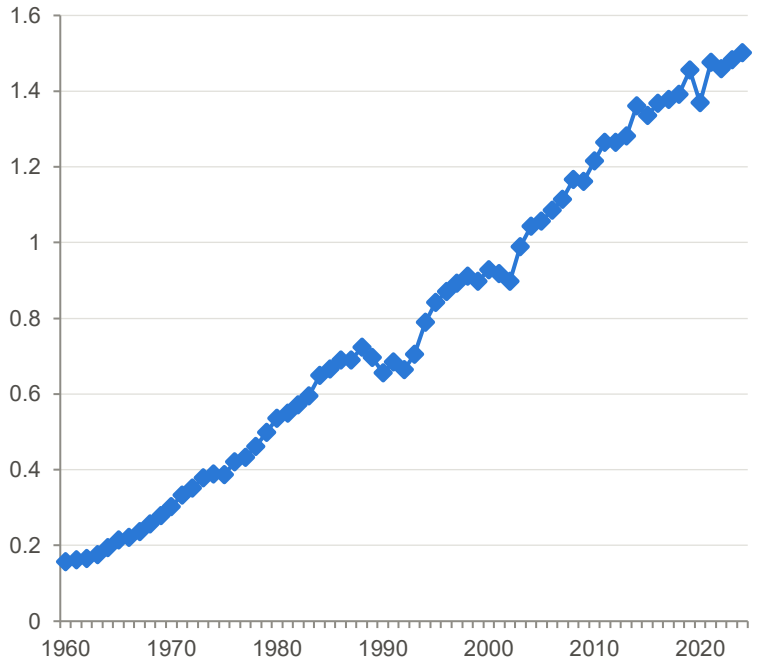
Figure 1-4-1 Regional Shares of Global Cumulative Fossil CO_2 Emissions, 1850–2024 (%)

Note: Regional classifications follow those used in the Global Carbon Budget. Emissions from international aviation and maritime bunker fuels, together with statistical discrepancies, account for approximately 2.5% of the global total and are not allocated to individual regions.

Source: Authors' calculations based on Andrew and Peters (2025), The Global Carbon Project's Fossil CO_2 Emissions Dataset (2025v15).

Despite its relatively small historical contribution, Africa's annual fossil CO_2 emissions have continued to increase, rising from 0.16 Gt in 1960 to 0.66 Gt in 1990 and reaching 1.50 Gt in 2024. Over the same period, Africa's share of global emissions increased from 1.7% to 2.9% and then to 3.9% (authors' calculations based on Andrew and Peters, 2025). Thus, Africa's share of annual global emissions in 2024 was higher than in 1960, although it remained below 4%. Despite its relatively small contribution to cumulative emissions, the continued rise in annual emissions makes the emissions intensity of future economic growth an important consideration (Figure 1-4-2).

a. Annual Fossil CO_2 Emissions in Africa (Gt CO_2)



b. Regional Shares of Global Fossil CO_2 Emissions (%)

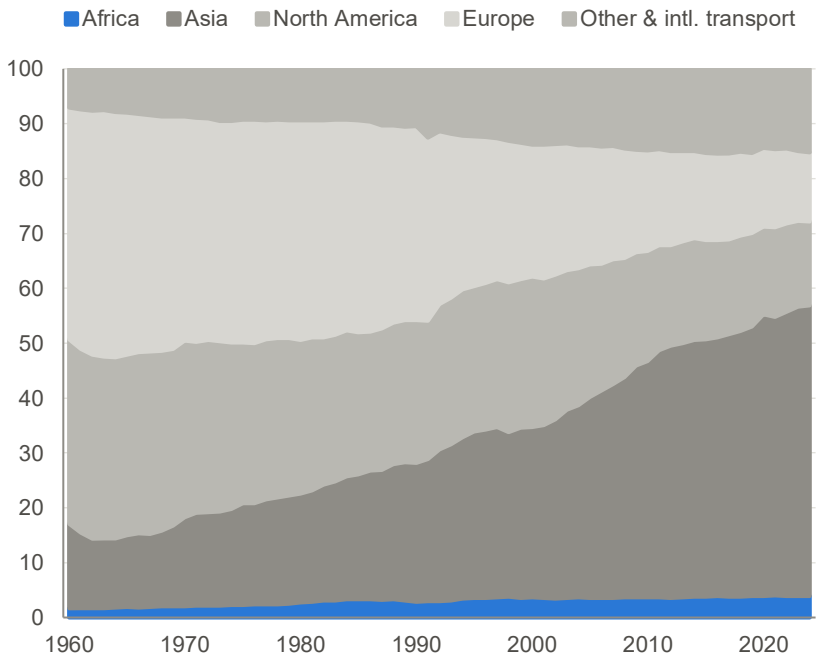


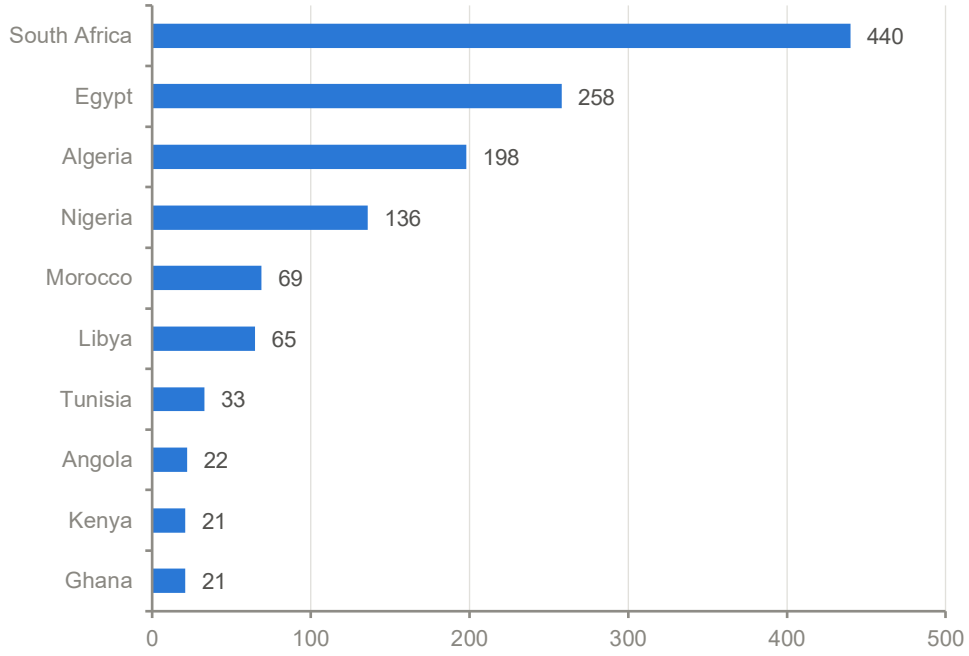
Figure 1-4-2 Africa's Fossil CO_2 Emissions and Share of the Global Total, 1960–2024 (Gt CO_2; %)

Note: The global total includes emissions from international aviation and maritime bunker fuels.

Source: Authors' calculations based on Andrew and Peters (2025), The Global Carbon Project's Fossil CO_2 Emissions Dataset (2025v15).

Although Africa accounts for only a small share of global annual emissions, its emissions are concentrated in a few countries. In 2024, South Africa, Egypt, Algeria, Nigeria and Morocco together accounted for 73.3% of Africa's fossil CO_2 emissions, with South Africa alone contributing 29.3%, equivalent to 440 Mt (authors' calculations based on Andrew and Peters, 2025). Changes in energy supply and industrial production in these five countries therefore have a disproportionately large impact on Africa's total emissions. As other African countries expand access to electricity and industrial production, their development pathways will also become increasingly important in shaping future emissions (Figure 1-4-3).

a. Top 10 Emitting Countries (Mt CO_2)



b. Share of Africa's Fossil CO_2 Emissions by Country (%)

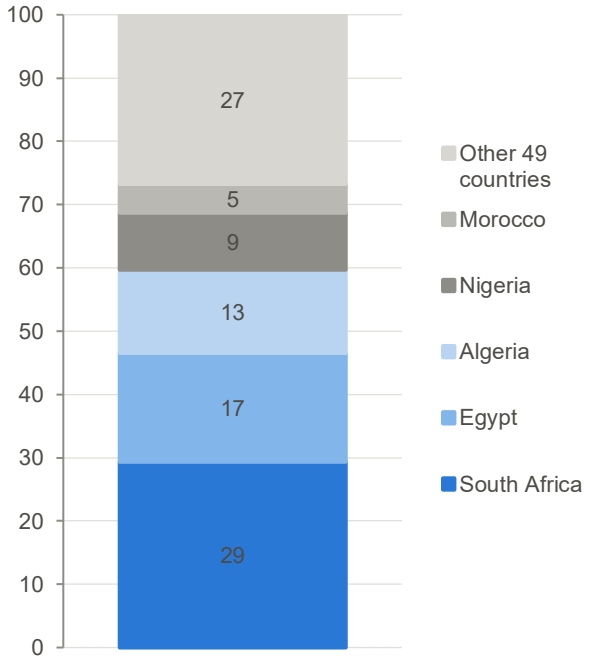


Figure 1-4-3 Fossil CO_2 Emissions from Africa's Major Emitting Countries, 2024 (Mt CO_2; %)

Note: Total fossil CO_2 emissions from Africa's 54 countries amounted to 1,502 Mt CO_2 in 2024, including emissions from cement production without subtracting CO_2 uptake through cement carbonation. Emissions from land-use change and international aviation and maritime bunker fuels are excluded.

Source: Authors' calculations based on Andrew and Peters (2025), The Global Carbon Project's Fossil CO_2 Emissions Dataset (2025v15).

Africa's fossil CO_2 emissions remain relatively low in terms of current, historical and per capita levels. However, population growth, urbanisation and industrial development will increase demand for energy and materials. The technologies adopted in new electricity grids, factories, buildings and transport systems will determine the emissions generated as Africa addresses its infrastructure and basic service gaps. Africa's limited historical responsibility for emissions does not diminish the importance of supporting its next stage of development with lower emissions.

1.4.2 Methane Emissions

Anthropogenic methane emissions in Africa originate from sources including livestock farming, rice cultivation, fossil fuel production and transportation, as well as solid waste and wastewater management. Assessing mitigation potential requires distinguishing these anthropogenic sources from natural wetland emissions and recognising the difference between methane (CH_4) mass and CO_2-equivalent emissions as measurement metrics (Saunois et al., 2025).

Methane emissions from livestock primarily arise from enteric fermentation in ruminants and manure management. A satellite-based inversion study of methane emissions in Africa during 2019–2024 found that both livestock emissions and changes in wetland emissions contributed to the increase in regional methane emissions. However, the spatial overlap between these two sources introduces uncertainty in their respective contributions (Balasus et al., 2026).

Methane emissions from the energy sector vary according to countries' energy resource profiles. Regional analysis by the International Energy Agency (IEA) indicates that fossil fuel-related methane emissions in sub-Saharan Africa primarily originate from oil and gas operations and coal mining, with coal-related emissions concentrated mainly in South Africa. Facility-level observations in Algeria and Egypt have also identified emissions associated with incomplete combustion and venting. Mitigation measures therefore need to be tailored to individual countries and facilities (IEA, 2026c).

Future anthropogenic methane emissions will depend on the scale of agricultural and energy activities, waste management practices and the implementation of mitigation measures. Nigeria has already introduced regulatory requirements covering

leak detection and repair, emissions measurement and reporting (IEA, 2026c). Section 4.3.2 of Chapter 4 examines emissions pathways under modelled scenarios, and the corresponding estimates should be interpreted in the context of their scenario assumptions and accounting boundaries.

1.5 Environment Conditions: Climate Impacts and Natural Resource Endowments

Africa's relatively low emissions do not shield the continent from the growing impacts of climate change. Since 1991, Africa has warmed at a faster rate than during any previous 30-year period. In 2025, Africa's average temperature was 0.51°C above the 1991–2020 average, making it the third to seventh warmest year on record, depending on the dataset used (WMO, 2026a). North Africa has experienced the fastest warming on the continent, with temperatures increasing by 0.43°C per decade between 1991 and 2025 (WMO, 2026a). Rising temperatures have also been accompanied by rapid sea-level rise. Between 1999 and 2025, mean sea levels along Africa's Atlantic Ocean, Indian Ocean and Red Sea coasts rose by 4.2–5.6 mm per year, exceeding the global average of 3.6 mm per year (WMO, 2026a).

Changes in climate and sea levels have already caused measurable human and economic losses. Climate-related losses average 2–5% of annual GDP, while the World Meteorological Organization (WMO) has also reported that some African countries allocate up to 9% of their national budgets to responding to climate-related disasters (WMO, 2024). In 2025, extreme weather and climate events affected at least 13 million people across Africa, with more than 3,000 reported deaths (WMO, 2026a). Flooding in the Democratic Republic of the Congo and Nigeria, together with Tropical Cyclone Jude in Mozambique, illustrates how recurring disasters can cause loss of life, displacement and fiscal pressures (WMO, 2026a). In 2024, the WMO estimated that adaptation financing needs in sub-Saharan Africa alone would reach US$30–50 billion annually over the following decade, equivalent to 2–3% of the region's GDP (WMO, 2024). Economic losses, emergency expenditures and adaptation needs collectively place pressure on public resources available for other development priorities.

While facing the impacts of climate change, Africa also possesses abundant renewable energy resources and critical mineral reserves that could support the development of low-carbon energy and related industries. Approximately 60% of the

land area within the world's top 20% of solar resource regions is located in Africa. However, according to the IEA's 2022 report, Africa accounted for only around 1% of global installed solar PV capacity at that time (IEA, 2022) (Figure 1-5-1). Beyond solar energy, hydropower, wind and geothermal resources also provide a foundation for renewable energy development across Africa, although development conditions vary by region (IEA, 2022). Africa also holds substantial critical mineral resources, with the United Nations Economic Commission for Africa estimating that approximately 30% of global critical mineral reserves are located on the continent (UNECA, 2026). The contrast between solar energy potential and installed capacity highlights the distinction between natural resource endowments and actual energy development. Converting solar potential into electricity generation and mineral reserves into domestic industrial production requires financing, electricity grid infrastructure, transport connectivity and effective institutional arrangements.

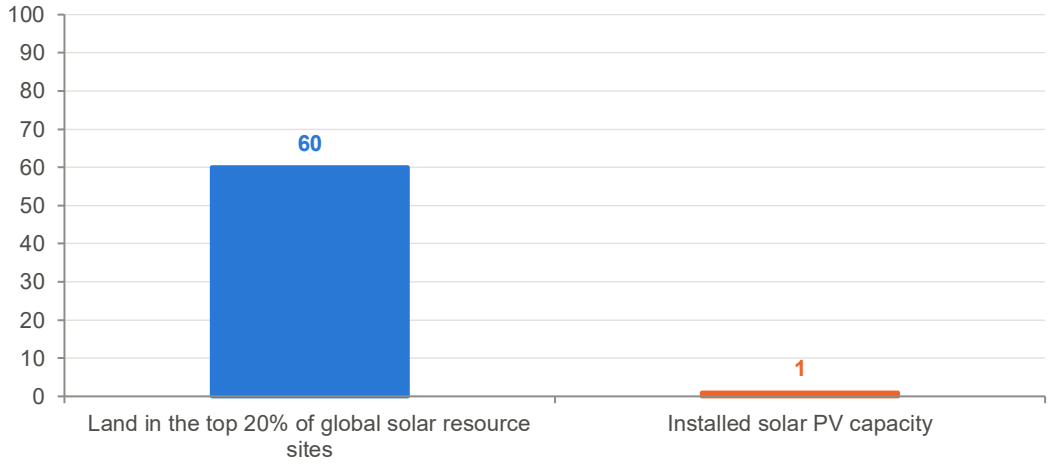


Figure 1-5-1 Africa's Share of Land Area in the World's Top 20% Solar Resource Regions and Global Installed Solar PV Capacity (%)

Note: The 60% figure refers to Africa's share of the total land area within the world's top 20% of regions with the most favourable solar resources.

Source: IEA (2022), Africa Energy Outlook 2022, pp. 17 and 92.

Africa's natural wealth also includes forests that store carbon and support local livelihoods. Peatlands beneath the swamp forests of the central Congo Basin store approximately 29 billion tons of carbon (Crezee et al., 2022). Forests across the basin also help regulate regional rainfall, maintain soil conditions and support local livelihoods by providing food and other forest products (World Bank, 2025a). However, agricultural expansion and increasing pressure on land are threatening forest ecosystems and the services they provide (World Bank, 2025a). Protecting forests and peatlands can both safeguard existing carbon stocks and preserve the environmental

functions that support local communities and economic activities. As infrastructure and production expand, land-use decisions must balance the value of conserving existing ecosystems against the benefits of new development.

Development planning must meet growing energy demand while protecting communities from climate-related disasters and preserving the ecosystems that support local livelihoods. Climate-resilient infrastructure can reduce disruptions to communities and economic assets, while lower-emission energy systems can meet rising demand without reproducing the emissions intensity of existing industrial systems. Forest conservation helps maintain the environmental functions on which local livelihoods depend. Energy and industrial projects need to consider climate risks, as well as the impacts of their construction and operation on environmental functions (WMO, 2024, 2026a; IEA, 2022; World Bank, 2025a).

1.6 Africa's Industrial Sector

1.6.1 Industrial Structure and Manufacturing Infrastructure

African industrial systems differ substantially in scale, manufacturing intensity, employment structure and the infrastructure on which production depends. These differences shape both the feasible pace and the appropriate form of low-carbon industrial upgrading. This section draws on seven countries, Egypt, Morocco, Nigeria, Ghana, Ethiopia, Kenya and South Africa, to capture major regional and structural differences in industrial development across the continent.

One indication of these differences is the scale and trajectory of manufacturing activity. In 2024, manufacturing value added (MVA), measured in constant 2015 US dollars, was about US$57.9 billion in Egypt, US$43.0 billion in Nigeria and US$41.0 billion in South Africa. Morocco recorded US$20.2 billion, while Kenya, Ghana and Ethiopia recorded US$8.8 billion, US$8.1 billion and US$6.6 billion, respectively. Trajectories since 2015 also diverged: MVA rose by 142.0% in Ethiopia, 47.9% in Ghana, 25.9% in Kenya, 22.3% in Morocco and 5.3% in Egypt, but fell by 7.5% in Nigeria and 5.5% in South Africa (World Bank, 2026a) (Figure 1-6-1).

Manufacturing intensity varies independently of absolute scale. Manufacturing accounted for 15.3% of GDP in Morocco in 2024, 13.9% in Egypt and 12.8% in South Africa, compared with 10.6% in Ghana, 8.7% in Nigeria, 7.3% in Kenya and 4.4% in

Ethiopia (World Bank, 2026b). The ordering differs from the scale comparison: Morocco's manufacturing base was smaller than those of Egypt, Nigeria and South Africa, yet manufacturing represented the largest share of GDP among the seven economies. In contrast, although Ethiopia has experienced rapid manufacturing growth, manufacturing still accounts for a relatively small share of its overall economy. The absolute scale of manufacturing, its growth rate and its contribution to the economy therefore need to be considered together.

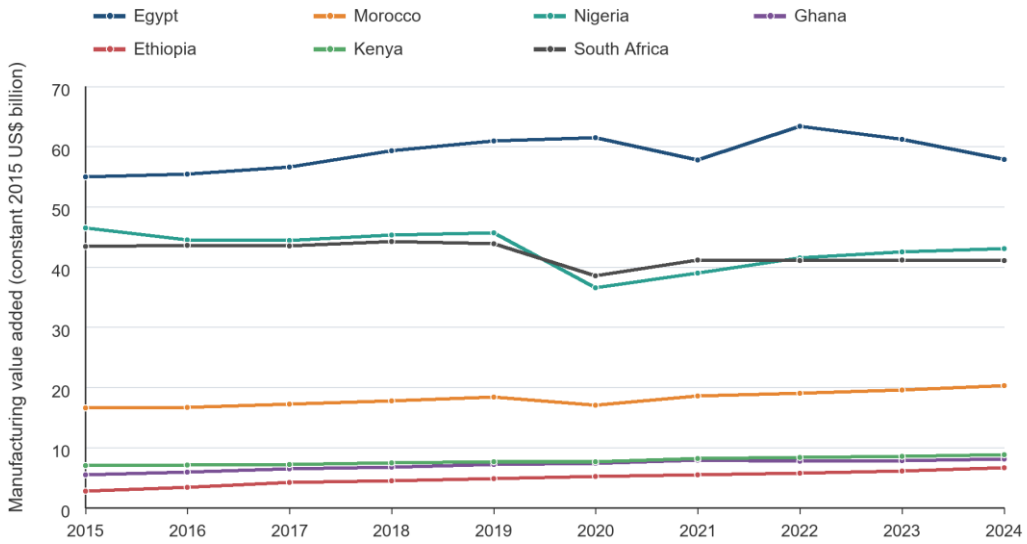


Figure 1-6-1 Manufacturing Value Added in Seven African Economies, 2015–2024 (Constant 2015 US$, Billion)

Source: World Bank, World Development Indicators, indicator NV.IND.MANF.KD (World Bank, 2026a).

Employment patterns further illustrate these structural differences. UNIDO reported manufacturing employment shares of 12.5% in Egypt, 11.5% in Ghana, 10.8% in Morocco, 10.7% in Nigeria, 8.8% in South Africa, 6.8% in Kenya and 3.2% in Ethiopia in 2022. Broader industry-employment shares, which include mining, construction and utilities in addition to manufacturing, were higher in every country: 29.2% in Egypt, 23.6% in Morocco, 20.8% in South Africa, 17.9% in Ghana, 16.8% in Nigeria, 12.3% in Kenya and 6.4% in Ethiopia in 2024 (UNIDO, 2023; World Bank, 2026c) (Table 1-6-1). The difference between industrial and manufacturing employment indicates that a higher share of industrial employment does not necessarily imply a larger manufacturing workforce, as some employment may be concentrated in sectors such as construction, mining and utilities. Therefore, comparisons of employment structures across countries need to distinguish manufacturing from the broader industrial sector.

Table 1-6-1 Selected Indicators of Manufacturing and Industrial Structure

Country	MVA 2024, constant 2015 US$ bn	MVA change, 2015–2024 (%)	MVA share of GDP, 2024 (%)	Manufacturing employment, 2022 (%)	Industry employment, 2024 (%)	Firms reporting outages, latest survey (%)
Egypt	57.9	+5.3	13.9	12.5	29.2	35.6 (2025)
Morocco	20.2	+22.3	15.3	10.8	23.6	10.9 (2023)
Nigeria	43.0	−7.5	8.7	10.7	16.8	82.5 (2025)
Ghana	8.1	+47.9	10.6	11.5	17.9	73.8 (2023)
Ethiopia	6.6	+142.0	4.4	3.2	6.4	85.9 (2025)
Kenya	8.8	+25.9	7.3	6.8	12.3	74.6 (2025)
South Africa	41.0	−5.5	12.8	8.8	20.8	92.0 (2020)

Note: MVA denotes manufacturing value added. Manufacturing employment and industry employment use different sector boundaries. The outage indicator is the share of surveyed firms reporting an electrical outage; it does not reflect the frequency or duration of outages or the amount of electricity lost. Survey years vary across countries, and the results should not be used for strict year-by-year rankings.

Source: World Bank (2026a, 2026b, 2026c, 2026d); UNIDO (2023).

Differences in manufacturing scale and employment structure are closely related to the existing industrial base of each country. Morocco has developed a manufacturing system centred on automotive production, aerospace, electrical equipment and phosphate processing, with connections to international supply chains through export markets and industrial parks. Egypt and South Africa have relatively diversified industrial sectors, covering food processing, chemicals, metals, machinery and transport equipment. Egypt is developing new clean technology manufacturing and port-related industrial projects in the Suez Canal Economic Zone, while South Africa has relatively well-established mining, metal processing and equipment manufacturing industries. Manufacturing in Nigeria and Ghana is closely linked to domestic consumer markets and resource processing, with food products, cement, chemicals and other consumer goods accounting for important areas of production. Ethiopia and Kenya have relatively smaller manufacturing sectors, with food processing, textiles and apparel, cement and chemicals forming the main components of their industrial bases.

Industrial production also depends on adequate electricity supply, water supply, wastewater treatment and transport infrastructure. The Hawassa Industrial Park in Ethiopia has established garment manufacturing operations and is equipped with a

dedicated 75 MW hydropower supply line and centralised wastewater treatment facilities. The planned Olkaria Green Energy Park in Kenya aims to attract energy-intensive industrial projects by utilising local geothermal power resources. These cases demonstrate how industrial parks can reduce the costs of infrastructure construction and operation for individual firms through the centralised provision of shared facilities. However, while Hawassa has already established industrial production activities, Olkaria remains at the project development stage, representing different levels of development progress (UNIDO, 2025, 2026; Zhang et al., 2018; SCZONE, 2020; KenGen, 2023; DTIC, 2025).

The comparison of the seven countries shows that Africa's manufacturing sector includes both economies with relatively large and diversified industrial bases and countries expanding industrial production from a lower starting point. There is no fixed relationship between the scale of manufacturing, its share of the economy and its contribution to employment. Existing industrial sectors and infrastructure conditions further influence the types of new industrial activities that each country can develop.

1.6.2 Electricity Conditions and Industrial Competitiveness

Electricity supply is an essential requirement for industrial production, and its importance extends beyond electricity prices to the reliability of supply and the availability of sufficient power for industrial operations. Power outages, voltage fluctuations and insufficient grid capacity can disrupt production, reduce equipment utilisation and increase the costs of backup power generation and inventory management. Reliable electricity supply is particularly important for industries requiring continuous operation, such as chemicals, metal processing and other energy-intensive industries. Electricity tariff structures vary across countries in terms of supply voltage, maximum demand, seasonal variations, time-of-use pricing, customer categories, fixed charges and subsidy arrangements. The available data are therefore insufficient to support a reliable cross-country ranking of industrial electricity tariffs. Residential or general electricity tariffs should not be used as substitutes for missing industrial tariff data.

Available industrial electricity consumption data indicate substantial electricity demand from industrial and commercial activities in some African countries, although statistical coverage varies. In Ghana, industrial electricity consumption increased from 3,990 GWh in 2015 to 8,250 GWh in 2023 (Energy Commission of Ghana, 2024). In

Egypt, total electricity sales reached 169.579 billion kWh in the 2022/23 financial year, of which industrial customers accounted for 27.4% (EEHC, 2023, p. 92). However, these figures should not be used to estimate total national industrial electricity consumption without further verification of the report's statistical coverage. In Kenya, electricity sales to large commercial and industrial customers reached 5,431.74 GWh in the 2023/24 financial year, accounting for 51.86% of total national electricity sales. However, this category includes not only factories but also commercial buildings, warehouses, airports, ports and railway facilities (EPRA, 2024). In South Africa, Eskom sold 44,231 GWh of electricity to industrial customers and 28,072 GWh to mining customers in the 2023/24 financial year. These figures cover only Eskom's electricity sales and do not represent total national industrial electricity consumption (Eskom, 2024). Given differences in statistical definitions and coverage across countries, these data are useful for illustrating the scale of electricity demand from industrial and related economic activities but should not be used for strict cross-country comparisons.

Enterprise surveys provide further evidence of electricity supply disruptions affecting industrial operations. According to the World Bank Enterprise Surveys, 82.5% of surveyed firms in Nigeria, 85.9% in Ethiopia and 74.6% in Kenya reported experiencing power outages in 2025. The corresponding figures were 73.8% for Ghana in 2023 and 92.0% for South Africa in 2020. In contrast, the shares were 10.9% in Morocco in 2023 and 35.6% in Egypt in 2025 (World Bank, 2026d). These findings indicate that power outages are common among businesses in some African countries. However, this indicator only measures whether firms have experienced power outages. It does not capture their frequency or duration, nor does it directly measure the resulting economic losses.

A gap also exists between electricity access rates and the actual reliability of electricity supply. In 2024, electricity access rates in Ghana and South Africa reached 91.9% and 90.2%, respectively, yet enterprise surveys continued to indicate high proportions of firms experiencing power outages. Eskom reported approximately 13.2 TWh of load shedding and electricity curtailment during the 2023/24 financial year, equivalent to around 7% of its electricity sales. Meanwhile, South Africa still requires substantial expansion of its transmission network (World Bank, 2026e; Eskom, 2024). In Nigeria and Ethiopia, electricity access rates were 62.5% and 56.6%, respectively, while firms also reported high levels of exposure to power outages. These findings indicate that electricity access rates primarily reflect whether people have access to electricity services, but do not adequately capture the quality and available capacity of

electricity supply required by industrial enterprises. Expanding grid coverage, increasing generation capacity and improving transmission and distribution networks are therefore priorities of varying importance across countries.

Industrial electricity tariffs further affect firms' production costs, but the available tariff data do not provide a consistent basis for cross-country comparisons. Countries apply different tariff structures depending on factors such as supply voltage, customer category, maximum demand and time of use. For example, Egypt's published 2024 electricity tariff schedule specified energy charges of 160–194 piastres per kWh for "other customers" supplied at voltage levels ranging from extra-high to medium voltage. In Ethiopia, published energy charges for certain industrial customers ranged from 0.9280 to 1.5310 birr per kWh, with additional demand charges applied. In Ghana, energy charges for certain non-mining special load customers in 2024 ranged from 107.5529 to 206.5170 pesewas per kWh, while high-voltage mining customers were subject to a different tariff structure. In Morocco, electricity charges for large customers also depend on supply voltage, time of use and capacity charges (EgyptERA, 2024; Ethiopian Electric Utility, 2023; PURC, 2024; ONEE, n.d.).

These electricity tariffs not only use different currencies but also apply to different customer categories and billing conditions. Direct comparisons of prices per kWh may therefore fail to reflect the actual electricity costs borne by industrial enterprises. A more meaningful approach is to examine how energy charges, demand charges, supply reliability and backup power generation costs jointly affect industrial production.

Overall, differences in industrial electricity supply conditions across Africa extend beyond grid access to include the reliability of electricity supply, the capacity of existing networks to support additional production and the actual electricity costs faced by enterprises. To support future industrial expansion, additional power generation capacity must be accompanied by investments in transmission and distribution networks and improvements in supply quality, ensuring that new generating capacity translates into a reliable electricity supply for sustained industrial operations.

1.6.3 Diverging Industrialisation Pathways across Africa

Comparisons of manufacturing scale, industrial structure and electricity supply conditions indicate that there is no single pathway for industrialisation across Africa. Some countries have developed diversified industrial systems, while others rely on resource processing, consumer goods manufacturing or industrial parks to expand

production. These differences in existing development conditions shape each country's priorities for industrial expansion and influence which industries and production processes can adopt low-carbon technologies.

Egypt and Morocco in North Africa have established relatively mature manufacturing systems, although their industrial structures and organisation differ. Egypt has a large domestic market and an industrial base covering food processing, chemicals, metals and engineering manufacturing. The Suez Canal Economic Zone and surrounding port-related industrial developments offer opportunities to connect new manufacturing and energy projects with logistics networks, ports and existing industrial facilities. Morocco's manufacturing sector, by contrast, is more export-oriented, with automotive production, aerospace, electrical equipment and phosphate processing playing important roles in its industrial structure. The Jorf Lasfar industrial complex, supported by established chemical, fertiliser and logistics facilities, provides an industrial foundation for developing new low-carbon chemical and green ammonia projects. These two models demonstrate that new investments in low-carbon industries can be integrated with existing production systems and supply chains, rather than relying entirely on newly established, standalone industrial projects.

In West Africa, Nigeria and Ghana rely heavily on domestic markets, resource processing and consumer goods manufacturing as key foundations for industrial development. Nigeria has a large domestic market and manufacturing industries covering food products, cement, petrochemicals and consumer goods. However, manufacturing accounts for a relatively small share of its GDP, and its manufacturing value added declined between 2015 and 2024. This indicates that a large domestic market alone is insufficient to ensure sustained industrial development. Ghana has a smaller manufacturing sector, but it has grown relatively rapidly over the past decade, supported by food and cocoa processing, cement, chemicals, pharmaceuticals and mining-related manufacturing. However, firms in both countries report high levels of exposure to power outages, suggesting that electricity supply conditions may continue to constrain the expansion of existing industries and the development of more advanced processing activities.

In East Africa, Ethiopia and Kenya demonstrate different approaches to expanding industrial production from relatively small manufacturing bases. Ethiopia experienced rapid growth in manufacturing value added between 2015 and 2024, although manufacturing still accounts for relatively small shares of GDP and employment. The

Hawassa Industrial Park supports the development of export-oriented manufacturing industries, including textiles and apparel, through the centralised provision of electricity, wastewater treatment and other supporting services. Kenya has a relatively diversified industrial structure, with food processing, chemicals, cement and other manufacturing activities forming an important production base, alongside substantial commercial and industrial electricity demand. The country's geothermal resources offer potential for a stable supply of renewable electricity to support industrial activities. The planned Olkaria Green Energy Park aims to attract industrial enterprises by taking advantage of these resources, although project development and investment plans should not be equated with industrial output that has already been realised.

South Africa has an industrial base that differs from those of the countries discussed above. Its long-established mining, metal processing, automotive, chemical and engineering manufacturing industries have provided the country with relatively mature supplier networks, technical capabilities and industrial facilities. However, South Africa's manufacturing value added declined by 5.5% between 2015 and 2024, while its electricity supply has also come under severe pressure. Load shedding, insufficient transmission capacity and other grid-related problems may reduce the utilisation of existing equipment and affect investment in new projects. South Africa's experience demonstrates that even countries with relatively well-developed manufacturing systems may face constraints on industrial growth due to infrastructure deficiencies.

The countries discussed above represent different conditions for industrial development across Africa. Some North African economies build on relatively mature manufacturing industries and export networks, while some West African economies combine domestic markets with resource processing to expand production. In East Africa, some economies are developing new manufacturing capabilities through industrial parks and energy resource development, while South Africa needs to improve electricity supply and restore production growth within its existing industrial system. These differences do not imply that each region must follow a single industrialisation pathway, as industries, firms and industrial parks within the same country may also be at different stages of development. More importantly, existing production capacities and infrastructure conditions determine the starting points for each country's next stage of industrial investment.

1.6.4 Implications for Low-Carbon Industrial Upgrading

Differences in industrial bases and electricity supply conditions across African countries require different combinations of technologies and investments for low-carbon industrial development. For countries with large and diversified manufacturing systems, renewable electricity and grid infrastructure development must both meet the needs of existing industrial production and support new clean technology, chemical and materials manufacturing activities. For export-oriented manufacturing industries, low-carbon energy supply also needs to be integrated with reliable electricity, logistics infrastructure and product certification systems. In countries with less developed manufacturing bases, reliable electricity, transport connectivity, water supply and supporting industrial services are often prerequisites for expanding production. Low-carbon industrial investment must therefore consider not only the availability of renewable energy resources, but also whether existing industries can utilise these resources and whether the necessary infrastructure can support long-term project operations.

Electricity system development is a critical component of this process. Solar, wind and other renewable energy sources can increase electricity supply and reduce emissions from power generation, but additional installed capacity does not necessarily translate directly into a reliable electricity supply for industrial use. In countries with highly variable renewable electricity generation, weak grids or transmission congestion, expanding renewable power generation needs to be accompanied by investments in energy storage, grid reinforcement and system flexibility. Electricity systems face different challenges, requiring technology combinations tailored to existing supply conditions. In countries such as South Africa, where industrial electricity demand is already substantial, improving grid operations and transmission capacity can also help increase the utilisation of existing industrial facilities. Given the different challenges facing electricity systems, investments in additional generation capacity and grid infrastructure need to be planned together.

Industrial parks and port-based industrial platforms can provide a basis for the centralised development of infrastructure to support new low-carbon industries. By sharing electricity supply, water supply, wastewater treatment, logistics and other services, these platforms can reduce the need for individual firms to develop their own supporting facilities. The Hawassa Industrial Park demonstrates the role of shared infrastructure in supporting manufacturing production, while the Olkaria Green Energy

Park illustrates a planned approach to attracting new industrial projects by utilising local renewable energy resources. For countries with relatively weak infrastructure, industrial parks may offer an important means of improving production conditions through concentrated infrastructure investment. However, whether these parks achieve their intended outcomes depends on the actual completion of infrastructure, the establishment of industrial enterprises within the parks and their ability to sustain production.

Different low-carbon industrial technologies also need to be integrated with appropriate existing industrial capabilities. The development of green hydrogen and low-carbon ammonia requires a stable supply of clean electricity, water resources, and chemical production and transport infrastructure. Where new projects can be connected to existing fertiliser, chemical and port facilities, they may benefit from established infrastructure and market channels. Green steel and other low-carbon metal industries require reliable, large-scale energy supplies, suitable mineral feedstocks, transport infrastructure and downstream demand. The development of electric vehicles and related manufacturing industries depends not only on electricity supply but also on vehicle assembly, component manufacturing, charging infrastructure and consumer markets. These technologies have different production requirements, and their development prospects cannot be assessed solely on the basis of local renewable energy resources.

For economies dependent on minerals and other natural resources, low-carbon industrial development needs to combine renewable energy supply with domestic resource processing and the development of local suppliers, rather than directing new investment solely towards the export of unprocessed raw materials. By strengthening the links between energy development, domestic processing activities and industrial supply chains, resource advantages are more likely to translate into sustained industrial production capacity.

These considerations indicate that the key to low-carbon industrial development in Africa lies not only in introducing new energy and production technologies, but also in aligning these technologies with existing industrial capabilities, electricity systems and infrastructure conditions. The following chapters further examine development opportunities in renewable electricity generation, energy storage, power grids, industrial parks, hydrogen-based industries, low-carbon chemicals, green metals and electric transport. These sectors have the potential both to reduce emissions from

industrial production and to support new manufacturing activities. However, their actual contributions depend on whether resource potential and project plans can be translated into reliable production and sustained industrial development. African countries will not enter the low-carbon transition from the same industrial starting point and therefore need to identify investment priorities according to their existing industrial bases and development conditions.

1.7 Industrial Park Development in Africa

1.7.1 From Conventional Industrial Estates to Integrated Industrial Platforms

Industrial parks reduce the costs of infrastructure construction and operation for individual firms by concentrating industrial enterprises in designated areas and providing shared facilities and services, including industrial land, electricity, water supply, wastewater treatment, internal roads and administrative services. In Africa, some industrial enterprises continue to face challenges such as unreliable electricity supply, insufficient industrial water supply, poor transport connectivity and complex trade procedures. The centralised provision of these services can improve production conditions and reduce infrastructure constraints and operational risks that individual firms may struggle to address independently (UNIDO, 2019; Zhang et al., 2018).

As industrial production and trade demand expand, some industrial parks are evolving beyond traditional clusters of industrial land into more comprehensive industrial platforms covering wider geographical areas. These platforms include special economic zones connected to customs and logistics facilities, port-based industrial complexes, and industrial corridors linking resource extraction sites, production centres, urban areas and export ports. The growing interconnections between different types of infrastructure are an important driver of this development. Industrial production requires not only reliable electricity and water supply but also roads, railways, warehouses, ports and customs services to transport raw materials and equipment to production sites and deliver finished products to markets. The role of industrial parks is therefore gradually expanding from providing land for factory construction to coordinating the infrastructure required for production, logistics and trade.

The Hawassa Industrial Park in Ethiopia demonstrates a model of centralised

service provision within a single industrial park. Primarily focused on textile and garment manufacturing, the park is equipped with a dedicated 75 MW hydropower supply line, one-stop administrative services and centralised wastewater treatment facilities. Its zero liquid discharge (ZLD) wastewater treatment system is designed to recover and reuse 90% of treated water (Zhang et al., 2018). These facilities provide more than factory buildings and industrial land by integrating energy supply, environmental management and administrative services within the same industrial park, reducing the need for individual firms to construct and manage their own supporting infrastructure.

The Sokhna Integrated Zone in Egypt and the Coega Special Economic Zone in South Africa illustrate how industrial parks can be integrated with port logistics. Sokhna connects industrial land with Sokhna Port, Adabiya Port, road networks, utilities and import-export services, providing manufacturing and processing enterprises with infrastructure for production and trade (SCZONE, 2020). The Coega Special Economic Zone, supported by the deep-water Port of Ngqura, integrates different industrial clusters with road and rail networks, customs facilities, warehousing and investor services (Coega Development Corporation, 2024). Within these platforms, ports serve not only as gateways for product exports but also facilitate the import of equipment and intermediate goods, cargo storage, customs clearance and inland transport, becoming an integral part of the industrial production system.

Namibia's Southern Corridor Development Initiative proposes an industrial development model covering a much wider geographical area. The initiative plans to connect potential production sites in the Tsau //Khaeb area with towns such as Lüderitz and Aus, while coordinating the development of electricity transmission, water supply, transport and port infrastructure (ERM, 2025). Unlike industrial parks where production activities are already underway, the infrastructure associated with the Southern Corridor remains at the planning and assessment stage and cannot yet be regarded as established industrial production capacity. A distinctive feature of this initiative is its approach to integrating geographically dispersed resource extraction sites, processing locations, towns and export ports within a coordinated infrastructure system, providing a spatial framework for future resource processing and industrial development.

The cases discussed above illustrate two main approaches to organising industrial park infrastructure. The first is spatial concentration, which involves providing

industrial land, utilities and shared services within a single industrial park, as demonstrated by the Hawassa Industrial Park. The second is regional connectivity, which coordinates industrial activities across different locations through connections between ports, transport corridors, energy networks and resource extraction sites, as illustrated by Namibia's Southern Corridor. Sokhna and Coega combine elements of both spatial concentration and port connectivity. As these approaches develop, industrial parks in Africa are gradually evolving into industrial platforms with wider geographical coverage and more diverse functions, although substantial differences remain in their construction progress and operational status.

1.7.2 Emerging Development Models of African Industrial Parks

Industrial parks in Africa have developed different models in terms of infrastructure provision, industrial orientation and spatial organisation. Based on their primary functions, representative platforms can be classified into three categories: manufacturing-oriented industrial parks and special economic zones, port-connected industrial platforms, and resource-processing and corridor-connected industrial platforms. These models are not mutually exclusive, as some platforms perform multiple functions. Nevertheless, this classification helps compare how infrastructure is organised under different conditions for industrial development.

The first category comprises **manufacturing-oriented industrial parks and special economic zones**. These platforms primarily support manufacturing development through the centralised provision of industrial land, infrastructure and business services, although their industrial priorities vary. Ethiopia's Hawassa Industrial Park focuses on textile and garment manufacturing, supporting production through shared electricity supply, wastewater treatment and administrative services (Zhang et al., 2018). South Africa's Atlantis Special Economic Zone (Atlantis SEZ) focuses on technology-oriented manufacturing and provides supporting infrastructure and services (DTIC, 2025). The East London Industrial Development Zone (East London IDZ) has established a science and technology park in addition to providing industrial land and customs services, offering technological and innovation support to enterprises (East London Industrial Development Zone, 2022). Kenya's Olkaria Green Energy Park, meanwhile, plans to attract industrial enterprises by utilising the area's stable geothermal electricity supply, although it remains at the development and investment promotion stage (KenGen, 2023).

These cases demonstrate that manufacturing-oriented industrial parks can develop around specific industries, technological capabilities, energy resources or shared infrastructure. Hawassa focuses on garment manufacturing, while Atlantis and East London place greater emphasis on technological and industrial capabilities. Olkaria seeks to translate its energy supply advantages into advantages for industrial location. These different industrial orientations can be combined and do not imply that all industrial parks follow a fixed development model.

The second category comprises **port-connected industrial platforms**. These platforms integrate industrial production with ports, warehousing, transport and trade services, reducing the logistical barriers between production sites and international transport networks. Egypt's Sokhna Integrated Zone connects manufacturing and processing sites, utilities and customs-related services with Sokhna Port and Adabiya Port, allowing raw material imports, industrial processing and product exports to operate within an integrated port-industrial system (SCZONE, 2020). South Africa's Coega Special Economic Zone organises industrial clusters around the deep-water Port of Ngqura while providing warehousing, customs facilities, road and rail transport, and investor services (Coega Development Corporation, 2024).

The two platforms differ in their spatial organisation. Sokhna connects industrial areas with multiple ports through roads and supporting infrastructure, while Coega integrates industrial clusters with a nearby deep-water port logistics hub. Despite these differences in physical layout, both incorporate cargo handling, warehousing, customs services and inland transport into their industrial platform functions. Industrial parks therefore serve not only as production sites but also as important nodes connecting raw material supply, processing and product trade.

The third category comprises **resource-processing and corridor-connected industrial platforms**. These platforms integrate industrial processing with resource extraction sites, energy supply, logistics facilities and export routes. They mainly take two forms: concentrated resource-processing platforms and cross-regional industrial corridors.

Concentrated resource-processing platforms typically build on existing industrial facilities and transport networks. Morocco's Jorf Lasfar Industrial Park provides industrial land and logistics facilities for chemical, metallurgical and other energy-intensive industries, with railways, motorways and nearby ports connecting raw material transport with product markets (MEDZ, n.d.). These facilities enable resource-

processing activities to be integrated with existing industrial infrastructure and mineral logistics networks.

Cross-regional industrial corridors, by contrast, require infrastructure coordination across wider geographical areas. Namibia's Southern Corridor plans to connect resource extraction sites, potential processing facilities, towns, electricity transmission networks, water supply infrastructure, transport routes and export ports (ERM, 2025). This model could organise geographically dispersed resource development and processing activities into an interconnected industrial system. However, the associated projects remain at the planning and assessment stage, and actual industrial production capacity has yet to be established.

These two forms demonstrate that resource-based industrial activities can either be concentrated in existing processing and logistics centres or connected across multiple production sites through regional infrastructure networks. The choice between these approaches depends on resource distribution, energy and water supply conditions, transport distances and the locations of existing industrial facilities.

Table 1-7-1 Representative African Industrial Platforms and Development Stage

Country	Platform	Development model	Main industrial function	Key infrastructure / connectivity	Development maturity
Ethiopia	Hawassa Industrial Park	Manufacturing-oriented	Textiles and garments	Power; sheds; ZLD; one-stop services	Operational (Zhang et al., 2018)
South Africa	Atlantis SEZ	Manufacturing-oriented / specialised	Technology-oriented manufacturing	Water; sewerage; roads; smart grid	Operational/expanding (DTIC, 2025)
Egypt	Sokhna Integrated Area	Port-linked	Manufacturing, processing and trade	Land; utilities; roads; ports; import-export	Operating/developing (SCZONE, 2020)
South Africa	Coega SEZ / Port of Ngqura	Port-linked	Industrial clusters, logistics and export production	Port; road; rail; customs; warehousing	Operational/expanding (Coega Development Corporation, 2024)
Morocco	Jorf Lasfar Industrial Park	Resource-processing / port-linked	Heavy industry and logistics	Land; logistics; rail; motorway; port	Operational (MEDZ, n.d.)

Country	Platform	Development model	Main industrial function	Key infrastructure / connectivity	Development maturity
Namibia	Southern Corridor	Corridor-linked	Prospective conversion and export	Sites; towns; power; water; transport; gateway	Planned/assessment (ERM, 2025)

Note: Development stages primarily reflect the construction and operational status of industrial platform infrastructure and do not imply that all enterprises or associated projects within the parks have commenced operations. Some operational platforms are still undergoing further expansion.

Source: Zhang et al. (2018); DTIC (2025); SCZONE (2020); Coega Development Corporation (2024); MEDZ (n.d.); ERM (2025).

1.7.3 Key Trends in Industrial Platform Development

The development of representative industrial platforms in Africa reveals three main characteristics: infrastructure provision is gradually shifting from fragmented development towards centralised coordination, different platforms perform distinct functions within industrial value chains, and the degree of infrastructure integration does not necessarily correspond to actual project maturity.

First, industrial parks are increasingly coordinating the various types of infrastructure required for industrial production through centralised development and cross-regional connectivity. Traditional industrial parks primarily provide land and basic supporting facilities, while some integrated industrial platforms go further by incorporating energy supply, water supply, wastewater treatment, logistics, customs and administrative services into coordinated development and management systems. Their role is not simply to increase the availability of infrastructure, but also to reduce coordination problems between different stages of production. For example, insufficient electricity or water supply may constrain factory operations, while inadequate transport and port capacity can increase the costs of raw material transportation and product exports, even where production facilities are well developed. Hawassa primarily addresses these challenges through the concentration of infrastructure within the park, while Sokhna and Coega combine internal facilities with port connectivity. Namibia's Southern Corridor, meanwhile, plans to coordinate production sites and infrastructure across a wider geographical area (UNIDO, 2019; SCZONE, 2020; ERM, 2025).

Second, different industrial platforms perform distinct functions within industrial

value chains. Hawassa focuses on textile and garment manufacturing, while Atlantis and East London emphasise technology-oriented production and innovation capabilities. Sokhna and Coega integrate industrial manufacturing with trade and logistics, Jorf Lasfar provides supporting infrastructure for resource processing and energy-intensive industries, and the Southern Corridor plans to connect resource processing activities with export facilities. Rather than performing identical industrial functions, these platforms provide different forms of production support according to existing industries, resource distribution and transport conditions. In several cases, governments or development agencies with public responsibilities undertake land development, shared infrastructure provision, customs arrangements and business services, while enterprises make investments in specific production activities. This division of responsibilities allows industrial park development to be integrated with the production activities of different enterprises (SCZONE, 2020; Coega Development Corporation, 2024; DTIC, 2025; East London Industrial Development Zone, 2022).

Third, the degree of spatial integration of infrastructure does not necessarily correspond to the actual maturity of industrial projects. Hawassa, Atlantis, East London, Sokhna, Coega and Jorf Lasfar already have operational industrial platform infrastructure, although some parks continue to expand and newly established projects within them may be at different stages of development (Zhang et al., 2018; DTIC, 2025; SCZONE, 2020; Coega Development Corporation, 2024; MEDZ, n.d.). In contrast, Olkaria remains at the park development and investment promotion stage, while Namibia's Southern Corridor is still undergoing planning and assessment (KenGen, 2023; ERM, 2025). Although the Southern Corridor covers a wider area in its development plans, this does not mean that its industrial infrastructure and production capacity are more mature than those of operational industrial parks. Assessing the development of industrial platforms therefore requires distinguishing completed facilities, projects under construction and future plans, rather than judging actual industrial capacity solely by the scale of planned development.

Overall, industrial parks in Africa are developing through a variety of approaches. Some improve production conditions by concentrating enterprises and infrastructure within designated areas, while others rely on ports and transport networks to connect regional and international markets. Other initiatives seek to integrate resource extraction sites, energy supply and processing facilities into industrial systems covering wider geographical areas. Substantial differences remain in the construction progress and operational status of these models, but the increasingly close connections between

industrial land, energy, water resources, transport and trade infrastructure are expanding the role of industrial platforms in Africa's industrial development. These platforms also provide different infrastructure and industrial conditions for the subsequent deployment of low-carbon industrial technologies.

Africa's growth requires infrastructure that can both serve an expanding population and address longstanding gaps in access to basic services. Housing, electricity grids, transport networks and industrial facilities all require sustained investment, while high debt levels and limited fiscal space constrain available financing. Africa's contribution to historical fossil CO_2 emissions has been relatively small, yet climate-related losses have already increased pressure on public resources. At the same time, much of the required infrastructure has yet to be built, providing opportunities to adopt more energy-efficient buildings and lower-emission energy systems. Solar energy and mineral resources expand the options for new power generation and industrial development, but harnessing these resources requires investment not only in electricity generation and mining but also in supporting grid infrastructure and transport connectivity. Development must also preserve the role of forests in supporting livelihoods and regulating the climate. Investment and land-use decisions over the coming decades will influence whether efforts to meet basic needs can also support Africa's industrial development while avoiding increased vulnerability and lock-in to high-emission pathways.

2. Global Temperature Goals, Emissions and Emissions Reduction

2.1 Global Temperature Goals

The 2015 Paris Agreement established the global temperature goal of holding the increase in global average temperature to well below 2°C above pre-industrial levels by the end of this century, while pursuing efforts to limit warming to 1.5°C.

Since then, the international community has placed this goal at the centre of global emissions reduction efforts. Following the adoption of the Paris Agreement, the Intergovernmental Panel on Climate Change (IPCC) began preparing its Special Report on Global Warming of 1.5°C in 2017 to assess the feasibility of achieving the 1.5°C target. The report was published in October 2018. In December 2019, the European Union announced its goal of achieving climate neutrality by 2050. In September 2020, China announced its targets of peaking carbon emissions before 2030 and achieving carbon neutrality before 2060. Subsequently, major countries and regions also announced carbon neutrality targets, many aiming to achieve them by 2050. To date, nearly 160 countries have committed to or announced carbon neutrality targets for 2050 or before 2060, collectively accounting for the vast majority of global CO_2 emissions.

2.2 Global Emissions Reduction Pathways

The IPCC Special Report on Global Warming of 1.5°C, published in October 2018, was a dedicated assessment undertaken in response to the request from the United Nations Framework Convention on Climate Change (UNFCCC) following the adoption of the Paris Agreement, with a particular focus on the Agreement's 1.5°C temperature goal. The preparation of the report began in early 2017 and was completed in October 2018, taking less than two years. It assessed the research findings available up to 2018 on pathways towards limiting global warming to 1.5°C.

At the time, there were already considerable doubts about the feasibility of achieving the 2°C target, while limiting warming to 1.5°C was widely regarded as virtually impossible. Research on the 1.5°C target was still relatively limited during the preparation of the report. Nevertheless, the IPCC Special Report sought to assess the

feasibility of emissions reduction pathways consistent with the 1.5°C goal. It introduced six dimensions of feasibility assessment and attempted to evaluate these pathways against the six criteria.

Figure 2-2-1 presents the CO_2 emissions scenarios assessed in the IPCC Special Report on Global Warming of 1.5°C. A key characteristic of these scenarios is that global CO_2 emissions reach net zero around 2050. Most 1.5°C pathways involve a temporary temperature overshoot, meaning that global warming exceeds 1.5°C around 2050, reaching more than 1.6°C, before net-negative CO_2 emissions bring warming back to approximately 1.5°C by 2100.

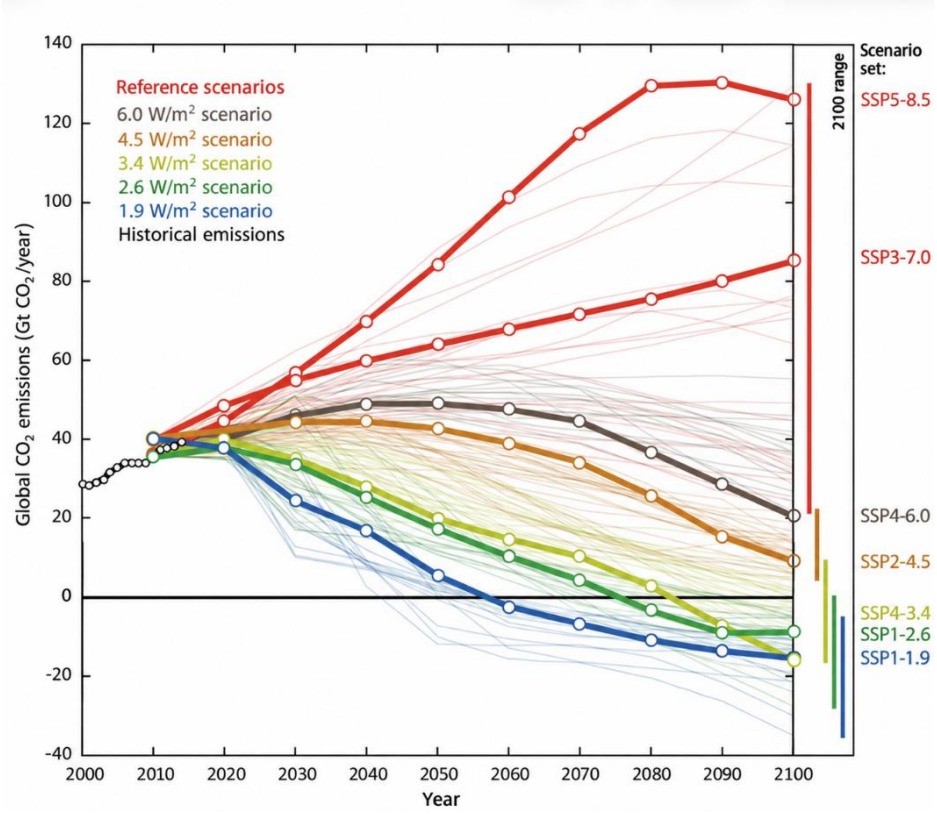


Figure 2-2-1 Global CO_2 Emissions Scenarios, 2000–2100 (Gt CO_2/year)

Source: IPCC (2018).

Correspondingly, under the 2°C warming emissions pathway, global net-zero emissions would be achieved between 2070 and 2080, followed by a transition to negative emissions.

Figure 2-2-2 illustrates the characteristics of various 1.5°C scenarios. In the IPCC scenario database, “no-overshoot” scenarios (Scenario S1 in the figure) are rare, and most model analyses conclude that achieving a “no-overshoot” scenario is difficult. In low-transcendence scenarios (see Scenario S2 in the figure), global net-zero emissions

are generally achieved between 2050 and 2060; emissions must peak immediately and enter a phase of rapid reduction, with emissions reduced by more than 40% by 2030. The S2 scenario achieves net-zero emissions between 2045 and 2055. The high-transcendence scenario, S5, also reaches net-zero emissions between 2049 and 2059, but requires a 10–15% reduction in emissions by 2030 compared to current levels.

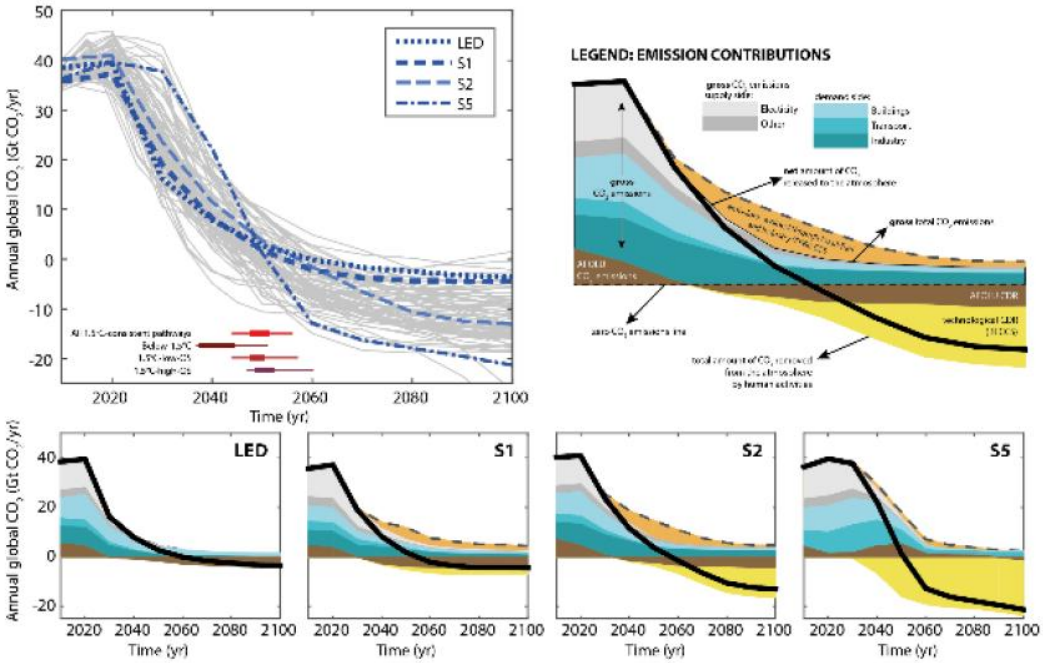


Figure 2-2-2 Characteristics of Different 1.5°C Emissions Scenarios, 2020–2100 (Gt CO_2/year)

Source: IPCC (2018).

According to the IPCC Fifth Assessment Report (IPCC, 2014), the remaining carbon budget after 2011 was estimated at 1,000 Gt CO_2 for limiting global warming to 2°C with a 66% probability, compared with 400 Gt CO_2 for the 1.5°C target. Between 2011 and 2017, global CO_2 emissions had already reached 290 ± 20 Gt CO_2. The IPCC Special Report on Global Warming of 1.5°C subsequently estimated the remaining carbon budgets for 2018–2100 at 1,100 Gt CO_2, 750 Gt CO_2 and 550 Gt CO_2 for probabilities of 33%, 50% and 66%, respectively.

Under scenario S1, global warming does not exceed 1.5°C. In scenario S2, global temperature increases reach 1.6–1.7°C around 2050, when global emissions approach net zero, while scenario S5 projects warming of 1.7–1.8°C.

The report concluded that limiting global warming to 1.5°C is achievable, but doing so would require extraordinary efforts. Its main findings are summarised below.

(1) Limiting global warming to 1.5°C requires rapid and far-reaching

transformations.

Global greenhouse gas emissions were approximately 52 Gt CO_2-equivalent in 2016 and were projected to reach 52–58 Gt CO_2-equivalent by 2030. To limit warming to 1.5°C, with no or limited overshoot, global annual emissions would need to be reduced by approximately half by 2030, to around 25–30 Gt CO_2-equivalent per year.

Although limiting warming to 1.5°C remains technically feasible, achieving these emissions reductions would require fundamental changes in human behaviour and technological systems. For example, under 1.5°C pathways, renewable energy is projected to account for 70–85% of electricity generation by 2050. Improvements in energy efficiency and fuel switching will be essential for the transport sector. Reducing energy demand, improving the efficiency of food production, changing dietary choices, and reducing food loss and waste could also make substantial contributions to emissions reduction.

(2) Limiting global warming to 1.5°C requires an unprecedented large-scale low-carbon transition.

Although rapid technological changes have occurred in specific technologies and sectors throughout history, the scale and magnitude of the transformations required to limit global warming to 1.5°C are unprecedented. In other words, the world has never experienced a transition of such breadth and speed, encompassing energy, land, industry, cities and other systems, across a wide range of technologies and geographical regions.

Achieving these ambitious transformations will require substantial additional investment in low-carbon technologies and energy efficiency. The report indicates that, to limit global warming to 1.5°C, investment in low-carbon technologies and energy efficiency would need to increase approximately fivefold by 2050 compared with 2015 levels.

The report also identified the main approaches to achieving the 1.5°C temperature goal. These include the complete decarbonisation of the electricity system, with the power sector achieving net-negative emissions by 2050; extensive electrification across sectors supported by the transition of the electricity system; and comprehensive improvements in energy efficiency. The relatively low cost of energy efficiency improvements can help offset the high costs of transforming the power sector during the process of deep emissions reduction, while also reducing expenditures in end-use sectors. To achieve deep emissions reductions and eventually net-negative emissions in

the power sector, bioenergy with carbon capture and storage (BECCS) represents an important mitigation option. Hard-to-abate industrial sectors require innovative production processes and technologies, such as the use of hydrogen as a feedstock and process input.

According to our research, the pathways towards achieving net-zero emissions are broadly similar across countries, involving sectors such as industry, buildings and transport. To achieve net-zero emissions, China will need to retire many coal-fired power plants ahead of schedule and address employment challenges affecting a large number of coal miners. Achieving net-zero emissions in China's industrial sector will be particularly challenging, as some industries still rely on coal in their production processes.

To support the achievement of the 1.5°C target, the IPCC Special Report on Global Warming of 1.5°C also presented specific projections for industries and technologies, including renewable energy, conventional internal combustion engine vehicles and electric vehicles. It also considered the development of aircraft powered by biofuels and hydrogen, among other technologies. One particularly controversial concept in carbon emissions reduction is that of "negative emissions". To achieve net-negative emissions in the electricity system by 2050, one proposed approach involves generating electricity from biomass derived from trees and forests while capturing the CO_2 released during power generation. This raises a series of questions: How many trees would need to be grown? How much land would be required? Would sufficient land be available? Could the substantial water resources needed to grow these trees be provided?

The contribution of Working Group III to the IPCC Sixth Assessment Report (AR6), published in 2022, expanded the feasibility assessment undertaken in the Special Report on Global Warming of 1.5°C by incorporating additional factors, further reinforcing the conclusions of SR1.5. During the government approval process, SR1.5 remained the subject of considerable debate. It also became the first IPCC assessment report to be merely "noted", rather than "welcomed", in the relevant intergovernmental response. The AR6 assessment therefore examined several of the issues that had generated controversy in SR1.5 in greater detail.

As with previous assessments, AR6 continued to evaluate a broad range of emissions scenarios, covering global warming outcomes from approximately 1.5°C to 4°C, corresponding to radiative forcing levels ranging from 1.9 to around 8 W/m^2. To maintain consistency in emissions pathways across the three IPCC Working Groups,

Representative Concentration Pathways (RCPs) were introduced in the assessment process to link the emissions scenarios evaluated by Working Group III with the atmospheric concentrations and radiative forcing considered by Working Group I. The climate model results from Working Group I could then serve as inputs for the climate impact assessments conducted by Working Group II. Subsequently, Shared Socioeconomic Pathways (SSPs) were developed to support modelling research across a wider range of fields. These pathways covered warming outcomes ranging from approximately 2°C to 4°C. Following the publication of SR1.5, the SSP framework was expanded to include SSP1-1.9, corresponding to the 1.5°C temperature goal. Relatively few studies using these pathways were available before the completion of SR1.5, but they received much more extensive assessment in AR6.

However, in light of the temperature goals established under the Paris Agreement, IPCC AR6 placed greater emphasis on emissions scenarios and pathways consistent with limiting global warming to 2°C and 1.5°C. It also provided assessments of the associated sectors, technologies and costs under these scenarios and pathways.

Based on the assessment presented in Chapter 3 of the IPCC AR6 Working Group III report, together with comparisons against the findings of previous IPCC assessments, the new conclusions of AR6 are summarised below.

(1) Limited remaining carbon budgets for the 2°C and 1.5°C temperature goals

The carbon budget refers to the cumulative amount of CO_2 emissions over a specified period, from a given year to a future point in time. Because cumulative CO_2 emissions have an approximately linear relationship with global temperature increases, the remaining carbon budget is critical for assessing future warming levels. Chapter 3 of the IPCC AR6 Working Group III report estimates that the cumulative CO_2 emissions budget from 2020 until net-zero CO_2 emissions are reached is 510 Gt CO_2 (330–710 Gt CO_2) for limiting warming to 1.5°C and 890 Gt CO_2 (640–1,160 Gt CO_2) for limiting warming to 2°C. These carbon budget estimates are consistent with those presented in the IPCC AR6 Working Group I report. Given that global CO_2 emissions have continued to increase since 2010, energy-related CO_2 emissions reached a record high of 36.8 Gt in 2021, while total anthropogenic CO_2 emissions amounted to 47.9 Gt. At these emissions levels, the remaining carbon budgets for limiting warming to 2°C and 1.5°C could be exhausted within a relatively short period.

(2) Emissions pathways consistent with the 2°C and 1.5°C temperature goals

require substantial near-term emissions reductions

The report classifies emissions pathways consistent with limiting warming to 1.5°C into two categories: pathways with no or limited overshoot and pathways with high overshoot. An overshoot pathway refers to a scenario in which global warming temporarily exceeds the temperature target before 2100, followed by a decline in temperature through net-negative CO_2 emissions. Under limited-overshoot pathways, warming may reach approximately 1.6°C around 2050 before falling below 1.5°C by 2100. Under high-overshoot pathways, warming may exceed 1.7°C around 2050 before returning to approximately 1.5°C by 2100.

Achieving the temperature goals of the Paris Agreement requires global CO_2 emissions to peak no later than 2025. In pathways limiting warming to below 2°C by 2100, global CO_2 emissions are projected to range from 30 to 49 Gt in 2030 and from 13 to 27 Gt in 2050. These levels represent reductions of 12–46% and 52–77%, respectively, compared with 2019 emissions.

The feasibility of achieving 1.5°C pathways with no or limited overshoot has declined compared with the assessment presented in SR1.5, as global CO_2 emissions have continued to rise since its publication. In the AR6 assessment, relatively few scenarios achieve the 1.5°C target without overshoot.

(3) Rapid reductions in non-CO_2 emissions, particularly methane, can reduce peak warming

Under pathways limiting warming to below 2°C, non-CO_2 greenhouse gas emissions are projected to remain at 4–11 Gt CO_2-equivalent when global CO_2 emissions reach net zero. Methane emissions need to decline by approximately 20% (1–46%) by 2030 and around 50% (26–64%) by 2050, relative to 2019 levels. Under 1.5°C pathways with no or limited overshoot, methane emissions are projected to decline by 33% (17–59%) by 2030 and 50% (33–69%) by 2050. In these mitigation scenarios, emissions of gases with a cooling effect also decline as fossil fuel use decreases.

Reducing emissions of short-lived greenhouse gases can help limit warming. Therefore, controlling emissions of short-lived greenhouse gases will be particularly important for limiting temperature increases towards the middle of this century, especially under pathways that aim to avoid temporarily exceeding the temperature target.

(4) Achieving net-zero greenhouse gas emissions requires net-negative CO_2 emissions to offset residual non-CO_2 emissions

Net-zero greenhouse gas emissions refer to a state in which positive emissions remaining from hard-to-abate sectors are balanced by negative emissions or carbon sinks, thereby achieving net-zero greenhouse gas emissions overall.

According to scenario studies, only around 30% of pathways limiting warming to 2°C or below achieve net-zero greenhouse gas emissions during the 21st century. In these pathways, net-zero greenhouse gas emissions are reached approximately 10–20 years later than net-zero CO_2 emissions.

Because eliminating non-CO_2 greenhouse gas emissions is more difficult than reducing CO_2 emissions, many scenarios indicate that additional net-negative CO_2 emissions are required to offset residual emissions of hard-to-abate non-CO_2 greenhouse gases and achieve net-zero greenhouse gas emissions.

(5) Pathways limiting warming to 2°C or below require emissions reductions across all sectors

Under 1.5°C warming pathways, CO_2 emissions from energy demand-side activities are projected to decline by approximately 77% (31–96%) between 2019 and 2050, while emissions from energy supply and land use are projected to fall by 115% (90–167%) and 148% (94–387%), respectively. Under pathways limiting warming to 2°C, the corresponding reductions are 49% for energy demand, 97% for energy supply and 136% for land use. Delayed or insufficient emissions reductions in one sector or region would require greater reductions elsewhere to compensate.

In pathways limiting warming to 2°C or below, demand for fossil fuels declines substantially, and coal-fired facilities without carbon capture and storage (CCS) are largely phased out. By 2100, low-carbon energy accounts for 88% (69–97%) of primary energy supply.

Pathways limiting warming to 2°C or below require increased electrification across transport, buildings and industry, which also leads to growing electricity demand. Almost all electricity generation would come from low-carbon sources, although the shares of nuclear power, bioenergy-based electricity and non-bioenergy renewable electricity vary across scenarios.

Mitigation measures under pathways limiting warming to 2°C or below also lead

to changes in land-use patterns. In these scenarios, land-use emissions reach net zero between 2020 and 2070. Under 1.5°C pathways with no or limited overshoot, forest area increases by approximately 322 million hectares (67–890 million hectares), while around 199 million hectares (56–482 million hectares) are allocated to bioenergy production, including bioenergy with carbon capture and storage (BECCS).

(6) Pathways limiting warming to 2°C or below require carbon dioxide removal (CDR) to offset residual greenhouse gas emissions after substantial reductions across sectors and regions

Carbon dioxide removal (CDR) can serve different purposes in accelerating emissions reductions. Major CDR approaches include bioenergy with carbon capture and storage (BECCS), forest enhancement and direct air carbon capture and storage (DACCS). Land-based CDR approaches may store carbon for several decades, although such storage is not necessarily permanent.

Mitigation scenarios also indicate that energy demand can be reduced relative to reference scenarios through a range of demand-side measures. Findings from bottom-up models and some models outside the integrated assessment modelling framework suggest substantial potential for energy savings on the demand side.

(7) Deep emissions reductions entail mitigation costs but can also deliver substantial overall benefits

Pathways limiting warming to 2°C without overshoot require faster near-term transitions and tend to fall towards the higher end of the mitigation cost range. However, they can also generate long-term economic benefits and health benefits associated with reducing warming in the near term. This conclusion holds regardless of the discount rate applied, although cost-optimal assessments of long-term mitigation strategies in modelling studies depend on the choice of discount rate.

Pathways limiting warming to 2°C indicate GDP losses of 1.3–2.7% by 2050 relative to reference scenarios, while pathways limiting warming to 1.5°C with no or limited overshoot indicate GDP losses of 2.6–4.2%. These estimates do not account for the benefits of avoided climate change.

Improvements in air quality resulting from mitigation actions can generate health benefits that are broadly comparable in magnitude to mitigation costs, with the potential for even greater benefits.

The overall employment impacts of mitigation pathways are relatively small compared with reference scenarios, although employment outcomes vary across sectors, with some experiencing substantial effects.

The timing and effectiveness of mitigation actions can have significant implications for sustainable development across multiple dimensions. Strong climate action can support progress towards the Sustainable Development Goals (SDGs), particularly for populations vulnerable to climate change. Achieving decent living standards, which is an objective of several SDGs, is also possible with lower levels of energy consumption.

Different pathways face different feasibility challenges, although supportive policies can help improve their feasibility. These challenges are particularly important over the next 10–20 years. Institutional and economic constraints tend to present greater feasibility challenges than technological factors, for which feasible solutions are relatively more readily available.

2.3 Current Status of Global Emissions

In 2025, global net anthropogenic greenhouse gas (GHG) emissions reached 58.4 Gt CO_2e per year, a substantial increase from 37.9 Gt CO_2e in 1990. However, the annual growth rate of emissions has slowed from an average of 1.7% during 1990–2015 to nearly zero growth between 2024 and 2025 (Deng et al., 2026).

Emissions by gas: Carbon dioxide (CO_2) is the dominant greenhouse gas, accounting for approximately 75% of total emissions. Methane (CH_4) has a particularly strong warming effect over the short term, contributing approximately 16% of the warming impact associated with anthropogenic emissions. Nitrous oxide (N_2O) and fluorinated gases, including hydrofluorocarbons (HFCs) and sulphur hexafluoride (SF_6), are emitted in smaller quantities but have global warming potentials hundreds to thousands of times greater than that of CO_2.

Sectoral distribution of emissions: Energy and electricity generation represent the largest sources of emissions, with fossil fuel-based electricity and heat generation contributing nearly 40% of global emissions. Industrial processes, including steel, cement and chemical production, account for approximately 24%, with cement manufacturing itself releasing substantial amounts of CO_2 directly through its production processes. Transport contributes approximately 14%, while emissions

across the building life cycle account for around 10%. Agriculture and land use contribute approximately 12% and are major sources of methane and nitrous oxide emissions.

2.4 Global Warming Trends

Global temperatures have reached unprecedented levels, with warming accelerating and substantial regional disparities becoming increasingly evident. Polar regions and high-altitude areas are experiencing the fastest warming, while continued heat accumulation in the oceans intensifies long-term warming. El Niño and La Niña events cause relatively small, short-term temperature fluctuations, whereas anthropogenic carbon emissions remain the dominant driver of the long-term warming trend. In recent years, global temperatures have frequently exceeded the 1.5°C threshold, while extreme heat, glacier retreat and accelerating sea-level rise have become increasingly common features of climate change.

The World Meteorological Organization (WMO) publishes its Global Annual to Decadal Climate Update each year, providing the international community with a benchmark for climate predictions over the next five to ten years. The latest report (2026–2035), released on 28 May 2026 (WMO, 2026b), draws on data from multiple global climate prediction centres. It indicates that global average temperatures are expected to remain close to or surpass historical records between 2026 and 2030, with a high likelihood of exceeding the 1.5°C warming threshold established under the Paris Agreement for the first time.

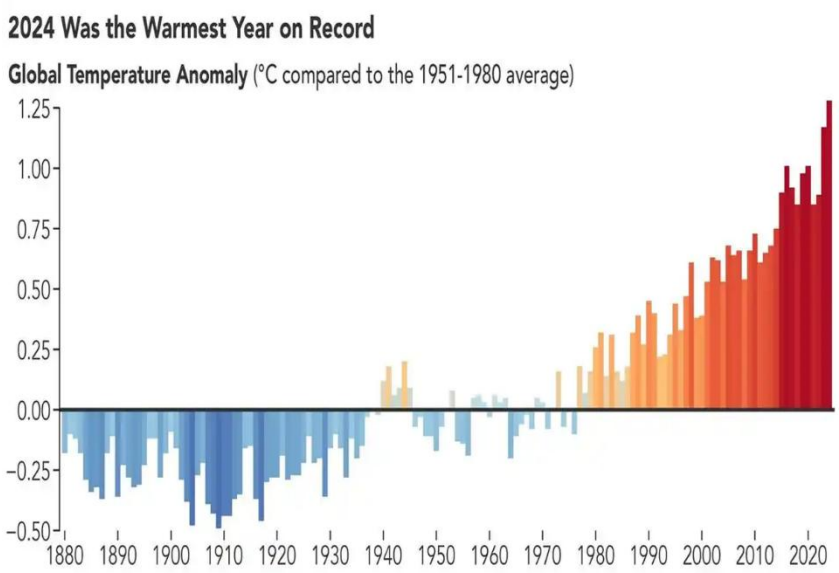


Figure 2-4-1 Global Mean Surface Temperature, 1880–2024 (°C, Relative to the 1951–1980 Average)

Source: Lindsey and Dahlman (2025), Climate Change: Global Temperature, NOAA Climate.gov.

The Next Five Years: A High Probability of Exceeding the 1.5°C Threshold. One of the report's key findings is that there is a 91% probability that the global annual mean near-surface temperature will exceed the 1850–1900 average by more than 1.5°C in at least one year between 2026 and 2030. More notably, there is also a 75% probability that the five-year average temperature over 2026–2030 will exceed the 1.5°C threshold. This means that global warming may not only exceed 1.5°C on individual days or months, but could also reach this threshold for the first time when averaged over a five-year period.

2.5 Challenges Posed by Rapid Near-Term Warming

Recent rapid warming has already far exceeded the findings of the IPCC Sixth Assessment Report Working Group I (IPCC, 2021). By 2035, global temperature increases could substantially exceed the projections of all IPCC warming scenarios (Figure 2-5-1). The frequent occurrence of climate-related natural disasters in recent years has already exposed human society to conditions associated with a changing climate. However, because the IPCC Working Group I report did not explicitly present the recent acceleration in warming, Working Group II was unable to assess the potential consequences of such rapid near-term temperature increases. Human society is now navigating a challenging and uncertain path for which relatively little academic research is available to guide our response. We therefore need to take more decisive action, both

by preparing thoroughly for climate-related disasters that may occur in the near term and by reassessing and comprehensively accelerating our emissions reduction pathways.

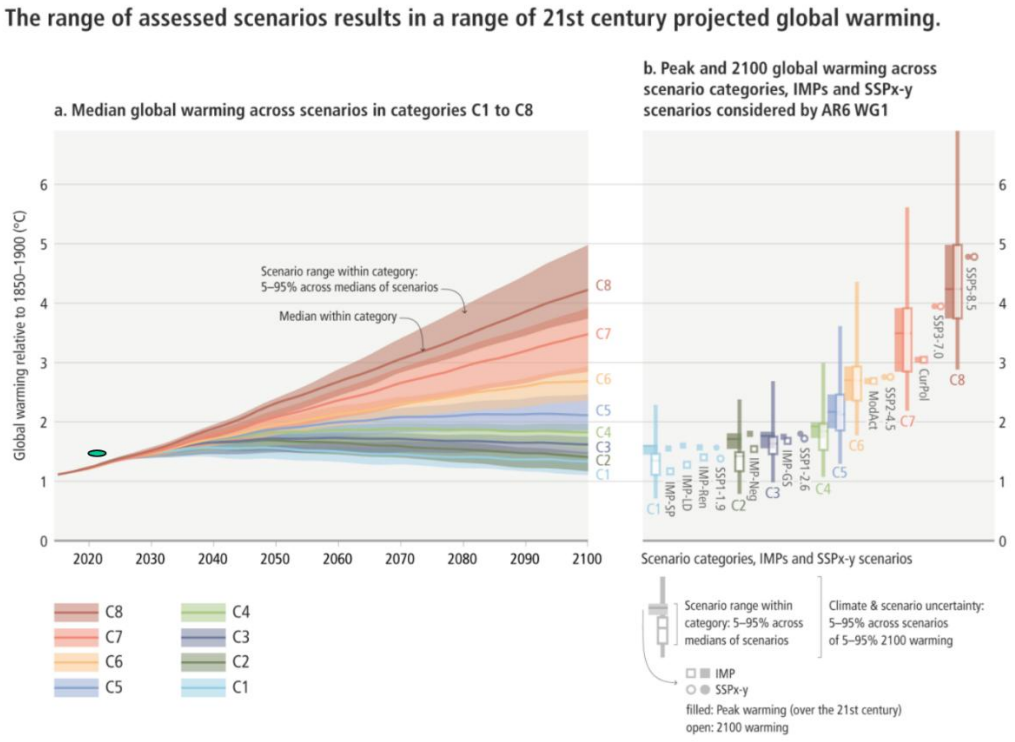


Figure 2-5-1 Global Warming Scenarios from the IPCC Sixth Assessment Report and Observed Warming around 2024 (°C, Relative to 1850–1900)

Source: IPCC (2022).

Two recent reports published by the UNEP, "*Limiting Overshoot: Navigating Exceedance of 1.5°C*" and "*Pathways Towards Return and the Emissions Gap Report 2026*", address recent rapid warming and the actions required in response (UNEP, 2026a, 2026b).

The UNEP report "*Limiting Overshoot: Navigating Exceedance of 1.5°C"* and "*Pathways Towards Return"*, published in June 2026, highlights that global warming will exceed 1.5°C above pre-industrial levels in the coming years, raising climate risks and impacts to new and dangerous levels. The world must strive to minimise peak warming and bring global temperatures back to 1.5°C or below as quickly as possible, while reducing the vulnerability of societies, communities and economies to unavoidable climate impacts.

Once global warming exceeds 1.5°C, associated risks and impacts will intensify with every additional 0.1°C of warming. These risks and impacts may accumulate gradually over time or emerge abruptly, including:

- Intensifying extreme weather, ecosystem loss and inundation risks facing Small Island Developing States (SIDS) and low-lying coastal cities. If warming approaches 3°C, glaciers could lose more than one-quarter of their mass by 2100, contributing 12.5 cm to sea-level rise. Degraded or fragmented ecosystems could further exacerbate climate change.

- Severe damage to human health, food security, water supply, natural ecosystems, cities, infrastructure and economies. For example, without effective adaptation measures, global food production could decline by as much as 14% by 2050.

- Crossing critical tipping thresholds that may be difficult or impossible to reverse on human timescales. Potential tipping points include irreversible changes to ice sheets, the Atlantic Meridional Overturning Circulation (AMOC) and the Amazon rainforest.

Following an "exceed, peak and decline" pathway represents the best feasible option for bringing global warming back to 1.5°C or below by the end of this century, which remains the current objective, while adapting to unavoidable climate impacts.

This pathway comprises three phases, which may overlap across different times and regions: an immediate response phase, a management and containment phase, and a long-term resilience phase.

- These phases aim to minimise peak warming through rapid and sustained reductions in greenhouse gas emissions, including methane, while progressing towards net-zero emissions, an essential milestone that cannot be bypassed. Sustained net-negative emissions would then help bring global warming back below 1.5°C by the end of the century.

- Achieving net-negative emissions requires carbon dioxide removal (CDR) in addition to rapid reductions in greenhouse gas emissions. However, CDR cannot substitute for the emissions reductions that are necessary.

- At the same time, these phases involve the continued development and strengthening of adaptation measures to reduce vulnerability to current, anticipated and unexpected climate impacts, including long-term adaptation in situations where irreversible limits have already been reached.

- In practice, different phases will coexist across different periods, between regions and within individual regions. Throughout the "exceed, peak and decline" pathway, climate impacts are expected to accumulate dynamically, with each phase inheriting the

consequences of preceding phases.

Rapid and collective global action is essential. The lower the peak warming and the shorter the duration of warming above 1.5°C, the smaller the associated risks and impacts, the lower the difficulty and cost of helping communities adapt, and the greater the likelihood of bringing global temperatures back down.

- The risk of triggering climate tipping points increases with every additional 0.1°C of warming. Taking early action and progressing towards net-zero emissions to minimise peak warming remain among the most effective ways of reducing these risks.

- Strong political commitment and multilateral cooperation, effective policies, inclusive governance and adequate financial support are essential for enabling action. The speed and scale of these efforts will determine the course of this pathway.

- Climate interventions can also generate multiple co-benefits, including improved air quality, better public health, lower energy costs, greater electricity access, increased equity and reduced pressure on energy systems.

The *Emissions Gap Report 2026*, published in October 2026, examines a "minimum-warming" 1.5°C overshoot scenario in which peak warming is limited to 1.7–1.8°C around the middle of this century, before returning to 1.5°C or below by 2100 with an estimated probability of approximately 50%. To follow this pathway, global greenhouse gas (GHG) emissions must decline by 18% by 2030, 45% by 2035 and 69% by 2040, relative to 2025 levels. In comparison, full implementation of Nationally Determined Contributions (NDCs) would reduce emissions by only 5–8% by 2030 and 11–15% by 2035, relative to 2025 levels. This implies that an average annual emissions reduction rate of 5.7% would be required between 2025 and 2035, exceeding the approximately 5% annual reduction rate associated with the pathways previously assessed in the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6).

Nevertheless, reaching a warming level of 1.7–1.8°C in the relatively near future would already represent an alarming degree of global temperature increase. We must therefore continue striving to minimise the extent of temperature overshoot as much as possible.

It is therefore necessary to further examine the feasibility of achieving rapid global emissions reductions.

3. Africa's Response to Climate Change

Alongside other countries around the world, African countries are also making efforts to reduce greenhouse gas emissions. Many have already committed to carbon neutrality targets, and numerous zero-carbon projects are currently being implemented. However, further efforts will be needed from Africa, together with the rest of the international community, to support the achievement of global temperature goals.

3.1 Africa's Climate Mitigation Efforts: Emissions, Renewable Energy and Investment

Economic expansion, population growth and a more than doubling of residential floor area will increase Africa's demand for energy and materials (AfDB, 2026a; UN DESA, 2024; IEA, 2022). To limit the emissions associated with meeting this demand, new electricity grids, transport systems, buildings and industrial facilities will need to adopt lower-carbon technologies and fuels. If per capita fossil CO_2 emissions across Africa's 54 countries had reached the 2024 global average of 4.73 tons, their combined emissions would have amounted to approximately 7.2 Gt CO_2, equivalent to around 18.5% of the global total for that year (authors' calculations based on Andrew and Peters, 2025; UN DESA, 2024; using the same accounting boundaries as Section 1.4.1 of Chapter 1). This static illustrative calculation is intended to demonstrate the influence of population size rather than to forecast Africa's future emissions. Given Africa's population size, convergence towards current global average per capita emissions would result in a substantial increase in global emissions. Meeting Africa's development needs with lower emissions per unit of energy and economic output is therefore important not only for Africa itself but also for the world as a whole.

Global emissions trajectories remain inconsistent with the objectives of the Paris Agreement, further highlighting the need to achieve economic growth with lower carbon intensity. According to UNEP (2026b), continued implementation of current policies would lead to approximately 2.8°C of global warming this century, while full implementation of Nationally Determined Contributions (NDCs), followed by continued mitigation efforts of similar ambition, would limit warming to approximately 2.6°C. Even under full implementation, warming would still exceed the temperature

goals of the Paris Agreement. For Africa, this means meeting growing energy demand through lower-emission systems, while economies with higher historical and per capita emissions need to reduce their emissions more rapidly. Renewable electricity offers a pathway to expanding energy supply without reproducing the emissions intensity of existing fossil fuel-based energy systems.

Growth in renewable energy capacity provides the clearest indication that lower-emission technologies are beginning to meet part of Africa's increasing electricity demand. Installed renewable energy capacity rose from 37.1 GW in 2016 to 51.4 GW in 2020 and 58.8 GW in 2022, reaching 82.4 GW by the end of 2025. Of the 45.3 GW added between 2016 and 2025, more than half was commissioned during the final three years of this period. Installed capacity grew by 15.9% in 2025, the largest annual increase in the African statistical series of the International Renewable Energy Agency (IRENA), with Ethiopia, South Africa and Egypt recording the largest capacity additions (IRENA, 2026).

The *Nairobi Declaration* set a target of achieving at least 300 GW of installed renewable electricity generation capacity by 2030 (AU, 2023). By 2025, installed capacity had reached only slightly more than one-quarter of this target. Meeting this commitment will require a substantial expansion of renewable energy capacity beyond existing operational projects, enabling renewable electricity to play a greater role in future power supply (Figure 3-1-1).

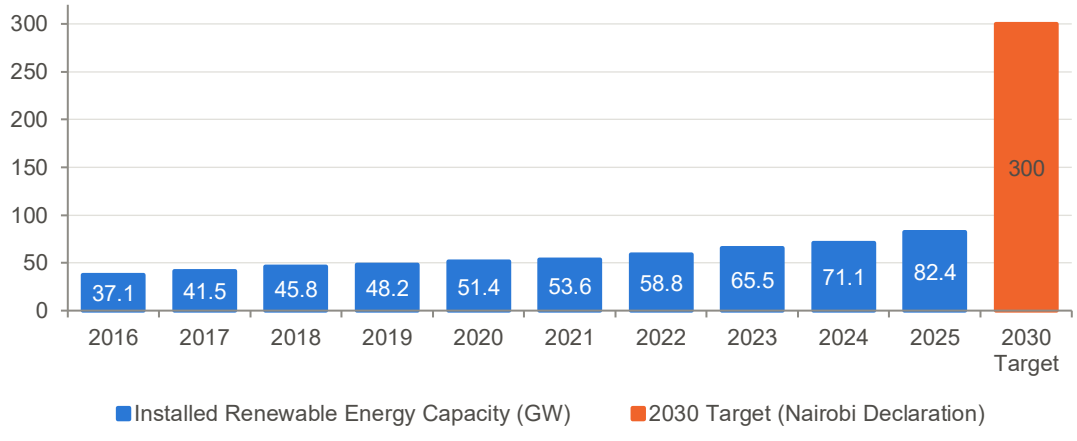


Figure 3-1-1 Africa's Installed Renewable Energy Capacity, 2016–2025, and the Continent-wide Target for 2030 (GW)

Note: Installed capacity refers to the total capacity at the end of each year.

Source: IRENA (2026), Renewable Capacity Statistics 2026; AU (2023), Nairobi Declaration, paragraph 49(i).

The financing required to expand renewable energy capacity towards the 300 GW

target brings the scale and composition of energy investment into focus. Africa accounts for approximately 20% of the world's population but receives only 3% of global energy investment. Clean energy investment increased by 17% between 2024 and 2025. The International Energy Agency (IEA) estimates that total energy investment in Africa will reach approximately US$110 billion in 2026, of which nearly US$50 billion will be directed towards clean energy (IEA, 2026a). Total energy investment is projected to increase by 11% in 2026, driven primarily by rising investment in fossil fuel supply (IEA, 2026a). Clean energy accounts for less than half of projected investment expenditure, indicating that growth in total energy investment does not necessarily imply a shift towards a lower-emission energy supply structure (Figure 3-1-2).

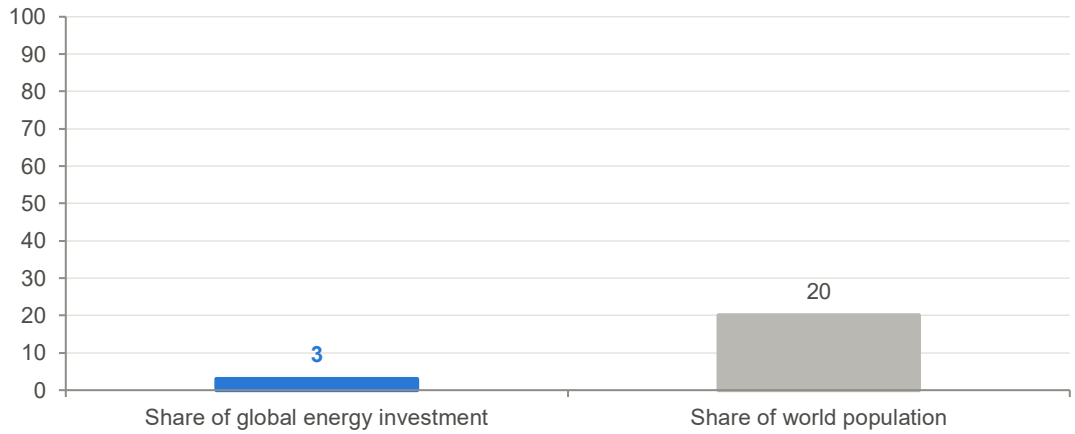


Figure 3-1-2 Africa's Share of Global Energy Investment and World Population, 2026 (%)

Note: Both figures are IEA estimates for 2026. Energy investment covers the entire energy sector.

Source: IEA (2026a), World Energy Investment 2026, p. 217.

Insufficient clean energy investment makes the support conditions attached to countries' mitigation commitments particularly important. Many African countries have made some or all of their mitigation commitments under their Nationally Determined Contributions (NDCs) conditional on international financial assistance, technology transfer or capacity-building support (UNFCCC NDC Registry, 2026). Understanding the level of national mitigation ambition therefore requires examining not only the emissions reductions countries have committed to achieving, but also the support on which their implementation depends.

3.2 National Targets: Nationally Determined Contributions (NDCs)

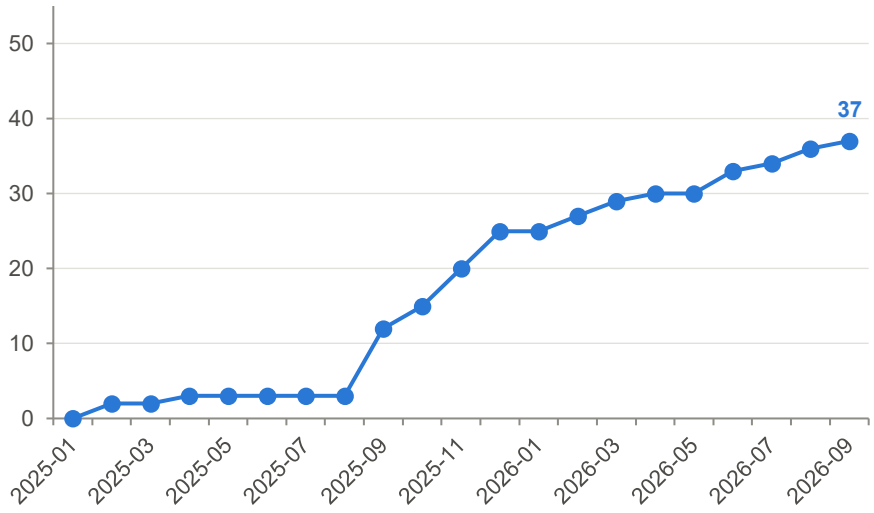
Of Africa's 54 countries, 53 are Parties to the Paris Agreement, although their latest national commitments were submitted at different times and cover two main target years. With the exception of Libya, all African countries are Parties to the Agreement, and their Nationally Determined Contributions (NDCs) are recorded in the United Nations Framework Convention on Climate Change (UNFCCC) NDC Registry (UNFCCC NDC Registry, 2026).

This section examines the latest NDCs of the 53 African Parties recorded in the Registry as of 7 September 2026. Of these, 37 Parties submitted new NDCs between 1 January 2025 and the cut-off date, with most uploaded to the Registry between September and December 2025, around the time of COP30 (UNFCCC, 2025; UNFCCC NDC Registry, 2026). Among the 37 new submissions, 33 included "3.0" in their titles, while Djibouti, Kenya, Lesotho and South Africa submitted their second NDCs.

In terms of target years, 32 of the 53 latest NDCs established explicit quantitative targets for 2035, including Burkina Faso's target extending to 2035. Mozambique's provisional draft presented an indicative emissions reduction range of 15–25% for 2035, while 20 NDCs retained 2030 as their target year. The latter group includes new submissions from Djibouti, Eritrea, Lesotho and Zambia, as well as 16 Parties whose earlier NDCs remained their latest submissions. The provisional range should not be treated as a final target.

Compared with 2030 targets, mitigation commitments for 2035 allow more time for implementation. A higher pledged percentage reduction does not necessarily indicate faster mitigation action. Assessments of the pace of progress implied by national commitments must therefore consider the target year alongside the pledged reduction.

a. Cumulative Number of New NDC Submissions Since 1 January 2025 (37 of 53 Parties), by Month of Registry Upload



b. Target Years of the Latest Nationally Determined Contributions (NDCs) by Party (Number of Parties)

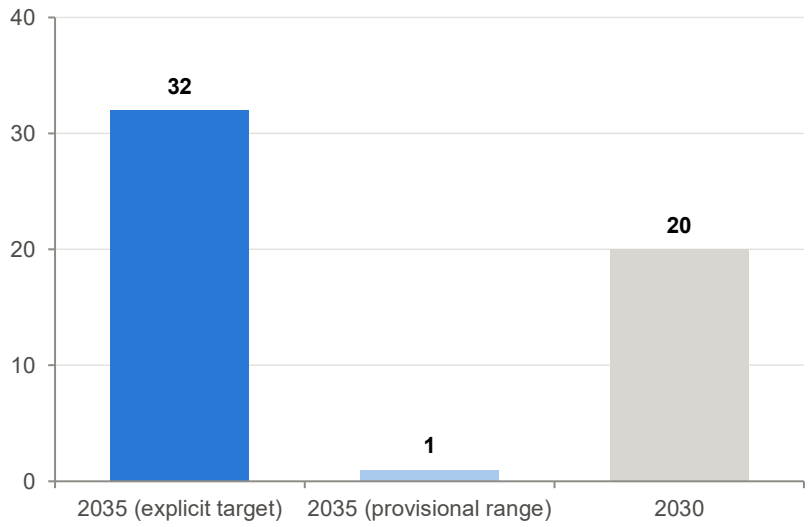


Figure 3-2-1 NDC Submission Status and Target Years among African Parties, as of 7 September 2026

Note: Panel (a) shows new NDC submissions from 1 January 2025 to 7 September 2026, grouped by the month of upload recorded in the Registry. Data for September 2026 cover only 1–7 September. Panel (b) shows the target years of each Party's latest NDC, with Mozambique's provisional 2035 reduction range presented separately. Libya is excluded because it is not a Party to the Paris Agreement.

Source: UNFCCC NDC Registry (2026), latest submissions from 53 African Parties, accessed 7 September 2026.

Most African NDCs commit to reducing emissions below projected levels rather than achieving absolute reductions from current levels. Excluding Mozambique's separately classified provisional draft, 47 NDCs define their mitigation targets as

percentage reductions relative to business-as-usual (BAU) projections, including BAU-based reduction targets expressed in terms of sectoral emissions, cumulative emissions or per capita emissions. Mozambique's provisional reduction range also falls within this category but is reported separately. If Zimbabwe's per capita target is classified separately as an emissions intensity target, the number falls to 46 (UNFCCC NDC Registry, 2026). Under BAU-based targets, countries can fulfil their commitments even if absolute emissions increase, provided that emissions remain below the projected baseline. Nigeria specifies an absolute quantity of emissions reductions in Mt CO_2e, while South Africa establishes a fixed emissions range. Other NDCs adopt emissions intensity targets or measures targeting specific sectors. In the Republic of the Congo and Namibia, carbon removals from the land sector exceed total emissions, resulting in negative net baseline emissions. Under such negative baselines, percentage targets partly reflect additional carbon removals rather than reductions from a positive net emissions level. Differences in target years, baselines and measurement metrics prevent national commitments from being aggregated into a single emissions target for Africa. The *Nairobi Declaration* provides a common continental reference through its target of at least 300 GW of installed renewable energy capacity, although this target is separate from the NDC process (AU, 2023).

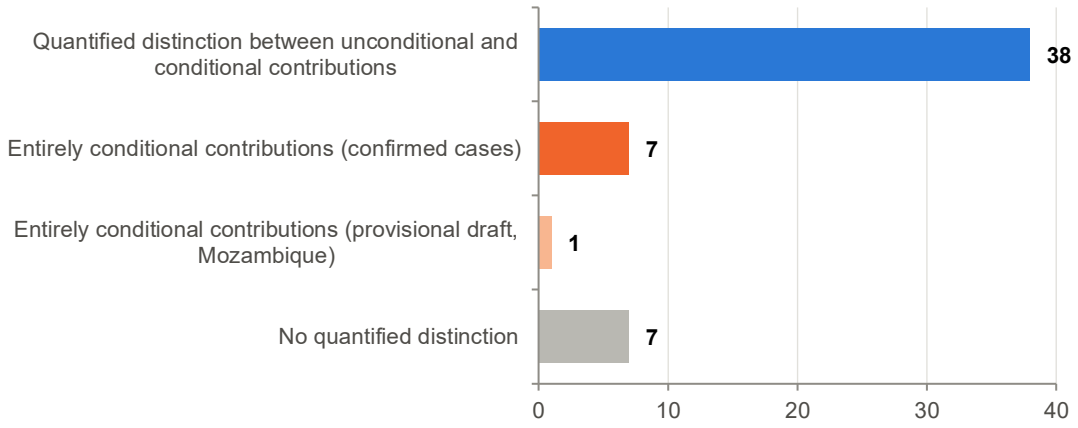


Figure 3-2-2 Classification of Conditionality in NDCs among 53 African Parties (Number of Parties)

Note: The classification is based on the support conditions specified in each NDC. "Entirely conditional contributions" refers to confirmed cases, while Mozambique's provisional draft is presented separately. "No quantified distinction" refers to NDCs that neither quantify the unconditional and conditional components nor explicitly make their entire contributions conditional on support. This does not imply that international support is unnecessary.

Source: Authors' classification based on UNFCCC NDC Registry (2026), accessed 7 September 2026.

Financing needs cover both mitigation and adaptation. All 53 African NDCs include adaptation components, and at least 49 quantify funding requirements for at least part of their implementation. However, quantified financing needs do not necessarily represent a comprehensive assessment of implementation costs (UNFCCC NDC Registry, 2026). The *Addis Ababa Declaration* estimates that implementing NDCs across Africa will cost approximately US$2.8 trillion by 2030 (AU, 2025). Conditional mitigation commitments, extensive adaptation priorities and quantified financing needs help explain why international climate finance occupies a central position in Africa's climate diplomacy.

3.3 International Commitments and Africa-wide Frameworks

African countries' dependence on international support for implementing their NDCs has also shaped a common continental negotiating agenda. The African Group of Negotiators (AGN) represents African countries in the United Nations Framework Convention on Climate Change (UNFCCC) process. The Committee of African Heads of State and Government on Climate Change provides political direction at the highest level, while the African Ministerial Conference on the Environment (AMCEN) coordinates the work of national environmental authorities. Together, these bodies coordinate African positions at the negotiating and political levels, with a particular focus on climate finance, adaptation, and loss and damage (AU, 2025).

The 2023 *Nairobi Declaration* translated this negotiating agenda into measurable continent-wide targets and proposals for reforming international finance and trade. The Declaration set a target of achieving at least 300 GW of installed renewable electricity generation capacity by 2030 (AU, 2023). It also advocated retaining more raw material processing activities within Africa, thereby linking renewable energy expansion with green industrialisation. To raise finance for climate investment, the Declaration urged world leaders to consider global carbon taxes on fossil fuel trade, maritime transport and aviation (AU, 2023). Its proposals for international financial reform also included US$100 billion in Special Drawing Rights (SDRs) and reforms to multilateral development banks (AU, 2023).

The 2025 *Addis Ababa Declaration* called for international climate finance to be scaled up to better reflect Africa's implementation needs. It estimated that financing requirements would exceed US$3 trillion by 2030 (AU, 2025). Separately, the Climate Policy Initiative (CPI) reported that tracked climate finance flows to Africa averaged

approximately US$43.7 billion annually in 2021–2022, covering public and private finance from both domestic and international sources (CPI, 2024). As these figures cover different time periods, they cannot be directly subtracted to calculate a financing gap. The Declaration considered the global target of at least US$300 billion annually by 2035 insufficient and welcomed the Baku to Belém Roadmap's efforts to mobilise at least US$1.3 trillion annually from all sources by 2035 (AU, 2025; COP29 and COP30 Presidencies, 2025). Both annual targets apply to developing countries collectively rather than representing funding specifically allocated to Africa. For African countries, the financing challenge therefore involves not only increasing the overall volume of global finance but also securing access to funding on terms that support implementation.

At the same time, the *Addis Ababa Declaration* endorsed two financing mechanisms centred on African priorities. The Africa Climate Innovation Compact and the African Climate Facility aim to mobilise approximately US$50 billion annually in catalytic finance (AU, 2025). The Declaration also proposed holding the Africa Climate Summit every three years, establishing a regular platform for reviewing shared priorities and implementation progress (AU, 2025).



Figure 3-3-1 Selected Key Milestones in African and International Climate Diplomacy, 2015–2025

Source: UNFCCC (2015), Paris Agreement; AU (2023), Nairobi Declaration; FOCAC (2024), Beijing Action Plan (2025-2027); AU (2025), Addis Ababa Declaration; COP29 and COP30 Presidencies (2025), Baku-to-Belém Roadmap to 1.3 Trillion.

Implementation is already under way: the African Development Bank (AfDB) has mobilised climate finance, while Mission 300 has helped expand access to electricity. The AfDB reported that it mobilised a total of US$25.5 billion in climate finance between 2020 and 2025, exceeding its commitment of US$25 billion. In 2025, climate finance accounted for 54% of the Bank's total project approvals, equivalent to US$5.93

billion out of US$11 billion (AfDB, 2026c). Regarding electricity access, the World Bank and the AfDB plan to allocate US$48 billion to Mission 300 by 2030. The initiative has already begun delivering electricity access, reporting that more than 50 million people across 40 countries had gained access to electricity as of June 2026 (World Bank and AfDB, 2025, 2026).

By contrast, several other initiatives remain primarily at the stage of financing commitments or mobilisation targets. The United States withdrew from South Africa's Just Energy Transition Partnership (JETP) on 28 February 2025. As of 9 December 2025, commitments from members of the International Partners Group (IPG) amounted to US$10 billion. Including other bilateral commitments brought the total to US$12.4 billion, while the addition of commitments from multilateral development banks increased the combined amount to US$13.7 billion (IPG, 2025b). These figures represent financing commitments rather than funds already disbursed. The US withdrawal also demonstrates that commitments may change before implementation. At the 2024 Forum on China–Africa Cooperation (FOCAC), China announced RMB 360 billion in financial support for ten partnership actions covering multiple sectors over the following three years, alongside a separate commitment to implement 30 clean energy and green development projects (FOCAC, 2024). The RMB 360 billion package covers multiple sectors and is not exclusively dedicated to climate action (Table 3-3-1).

South Africa's Just Energy Transition Investment Plan, announced in 2022, estimated that approximately US$98 billion would be required over five years to initiate the transition, drawing on investment from both the public and private sectors. At that time, the IPG's initial support commitment amounted to US$8.5 billion (IPG, 2022). Partnership commitments represent only one source of the required financing. Implementation also depends on the disbursement of funds, the availability of viable projects, financing terms, supporting electricity grid infrastructure and implementation capacity.

Table 3-3-1 Selected Finance Commitments, Goals and Results for Africa’s Climate Agenda, Mid-2026

Channel or initiative	Institutional form	Recorded amount or result	Evidence status
AfDB climate finance	African institutional finance	US$25.5 billion mobilised, 2020–2025; climate finance equalled 54% of 2025 approvals	Reported mobilisation and annual allocation share
South Africa JETP	Country partnership	US$13.7 billion committed by December 2025, including multilateral development bank commitments	Partnership commitments
Mission 300 finance plan	Multilateral delivery programme	US$48 billion planned through 2030	Planned allocation
Mission 300 electricity access	Multilateral delivery programme	More than 50 million people connected across 40 countries by June 2026	Reported service result
FOCAC	China-Africa partnership	RMB 360 billion over three years for 10 partnership initiatives	Broader development financing commitment
ACIC / African Climate Facility	African financing mechanisms	About US$50 billion per year in catalytic finance	Mobilisation goal

Note: Entries distinguish reported results from planned allocations, commitments and mobilisation goals. The FOCAC amount covers several sectors and is not dedicated solely to climate action.

Source: AfDB (2026c); IPG (2025a, 2025b); World Bank and AfDB (2025, 2026); FOCAC (2024); AU (2025).

Carbon markets can generate revenue through the trading of verified emissions reductions, complementing grants, concessional finance and partnership funding. The *Addis Ababa Declaration* called for the implementation of the Africa Carbon Markets Action Plan to support countries’ participation in cooperative approaches under Article 6 of the Paris Agreement (AU, 2025). The Africa Carbon Markets Initiative (ACMI), launched during COP27 in 2022, set targets of increasing annual retirements of African carbon credits to approximately 300 million, generating US$6 billion in revenue and creating or supporting 30 million jobs by 2030 (ACMI, 2022). Carbon market revenues can diversify climate finance sources, but the sale of carbon credits does not in itself guarantee that host communities will receive a share of the proceeds. National

institutional frameworks therefore need to combine the verification of emissions reductions with clearly defined revenue-sharing arrangements.

By mid-2026, African institutions had clarified common priorities and secured financing commitments, with AfDB mobilisation and Mission 300 electricity connections marking progress towards implementation. However, planned allocations and partnership commitments still need to become funded projects and services. National procurement, project development and regulatory administration are the next steps in carrying the collective financing agenda into domestic action.

3.4 National Actions: Laws, Policies and Programmes

National governments are translating collective commitments into domestic policy through framework laws, sector regulations, operating programmes and long-term strategies. Implementation is most visible in electricity, where renewable systems and large power projects already contribute to national supply. Hydrogen and adaptation are also advancing, although national action remains more concentrated in regulation, planning and individual programmes.

Framework legislation provides the broadest legal basis for domestic climate action. Kenya enacted the Climate Change Act in 2016 and brought carbon markets under the law through its 2023 amendment. The amendment provides for a national registry and rules on sharing benefits from carbon market projects. Nigeria followed with the Climate Change Act 2021. South Africa enacted the Climate Change Act 2024 in July 2024 and brought most provisions into force in March 2025, although specified sections remain deferred. Its Carbon Tax Act has applied since June 2019, making South Africa the first African country to introduce a national carbon tax (World Bank, 2020). Sector regulation addresses more specific markets and forms of conduct. Ethiopia's E-Mobility Strategy reports a ban on the import and assembly of vehicles with internal combustion engines. Mauritania promulgated Green Hydrogen Code No. 2024-037 in October 2024. Putting legislation into practice involves a further administrative task. Implementing regulations specify procedures and responsibilities, and public agencies need the capacity to enforce them (Table 3-4-1).

Table 3-4-1 Selected National Climate Actions by Form and Implementation Status

Country	Law or regulatory measure	Operating measure, programme or outcome	Strategy or project for future delivery
Kenya	Climate Change Act 2016, amended in 2023 to regulate carbon markets	Electricity mix dominated by renewable sources, led by geothermal	LT-LEDS prepared for 2022–2050
South Africa	Climate Change Act 2024, with most provisions in force from 2025. Carbon Tax Act 2019	Capacity procured and operating under REIPPPP	LT-LEDS with net-zero carbon dioxide emissions by 2050 as its national vision
Nigeria	Climate Change Act 2021	No case selected	Energy Transition Plan and net zero by 2060
Ethiopia	Ban on imports and assembly of vehicles with internal combustion engines, as reported in the E-Mobility Strategy	GERD inaugurated in 2025. Green Legacy initiative	LT-LEDS to 2050. E-Mobility Strategy
Morocco	No case selected	Noor Ouarzazate solar complex	Offre Maroc green hydrogen circular
Egypt	No case selected	Benban solar park, with all plots operating	National Strategy for Low-Carbon Hydrogen
Namibia	No case selected	No case selected	Green Hydrogen and Derivatives Strategy. Hyphen project under development
Mauritania	Green Hydrogen Code No. 2024-037	No case selected	No case selected

Note: Only representative cases are included. The absence of a selected case does not imply that the country has no relevant policies or activities. LT-LEDS stands for Long-Term Low-Emission Development Strategies; REIPPPP stands for Renewable Energy Independent Power Producer Procurement Programme.

Source: Authors' compilation based on national laws and official policy and project records; IEA (2025), IRENA and ILO (2026), AfDB (2019), KfW (2024), ENGIE (2025) and EEP (2026).

Renewable electricity already contributes to national supply through both established power systems and programmes that procure new capacity. Renewable sources supplied nearly 90% of Kenya's electricity in 2023, with geothermal providing 47% (IEA, 2024). Whereas Kenya's electricity mix reflects renewable development across the national system, South Africa uses REIPPPP to contract additional generation from independent producers. By March 2025, the programme had procured 7.8 GW from 104 independent power producers, of which 6.2 GW was operating and

connected to the grid (IRENA and ILO, 2026). Most capacity contracted under REIPPPP now supplies electricity to the grid, with the remaining projects still to enter operation.

Large power projects have also converted national energy priorities into new generating capacity. Morocco's Noor Ouarzazate complex combines four plants with 580 MW of capacity. It is a specific project developed under the country's national Noor Solar Programme (AfDB, 2019). More recent additions include the 270 MW Jbel Lahdid Wind Farm, which began operations in October 2024 (KfW, 2024). Egypt's Red Sea Wind Energy wind farm was commissioned in phases, with its full 650 MW capacity connected to the grid and entering full commercial operation in June 2025 (ENGIE, 2025). Ethiopia's Adama II Wind Farm has an installed capacity of 153 MW and is included in the generation portfolio of Ethiopian Electric Power (EEP, 2026).

National strategies extend climate planning beyond existing power projects by setting out cross-sectoral emissions reduction pathways. Kenya has developed a Long-Term Low-Emission Development Strategy (LT-LEDS), outlining a pathway towards carbon neutrality by 2050. South Africa's LT-LEDS establishes net-zero CO_2 emissions by 2050 as a national vision. Nigeria's Energy Transition Plan links its 2060 net-zero target to transition pathways for the power, cooking, transport, industry, and oil and gas sectors. The inclusion of cooking connects national mitigation planning with the development priority of achieving universal access to clean cooking identified in the *Addis Ababa Declaration* (AU, 2025). Ethiopia's LT-LEDS links its pathway towards net-zero emissions by 2050 to quantified changes in energy, agriculture, livestock, land use and forestry, waste, and industrial processes. By incorporating cooking, agriculture and industrial processes, these strategies extend climate planning beyond existing electricity generation projects. Sectoral authorities and implementing agencies can use these pathways to align budgets and regulations with investment plans, ensuring that individual projects contribute to longer-term national objectives.

Hydrogen policy is preparing a new industrial sector, with most projects still awaiting investment decisions. Namibia published its Green Hydrogen and Derivatives Strategy in November 2022, and the government and Hyphen signed a project agreement in May 2023. The Hyphen project remained at the feasibility stage in 2026 (Namibia Green Hydrogen Programme, 2026). Egypt's Supreme Council of Energy approved the National Strategy for Low-Carbon Hydrogen in February 2024. Morocco followed with the Offre Maroc circular in March 2024, establishing an investment framework for green hydrogen projects. Mauritania then introduced a statutory regime

through Green Hydrogen Code No. 2024-037 in October 2024. At the continental level, low-emissions hydrogen production amounts to only 6,000 t, and the project pipeline to 2030 includes 31 projects. Only 1 project has reached a final investment decision (IEA, 2026b). Government activity is concentrated on establishing investment conditions for a future industry. The immediate task is to move proposed projects through feasibility and financing into construction before large-scale production and exports can follow.

Adaptation moves national action from energy systems to climate resilience. National adaptation plans set country priorities, and African countries had submitted 23 plans to the UNFCCC by September 2025 (UNFCCC LEG, 2025). Specific projects connect national priorities to delivery, including community water initiatives in Kenya and wastewater reuse in South Africa (UNFCCC LEG, 2025). Landscape restoration broadens adaptation from individual infrastructure projects to land and livelihoods. The AU's Great Green Wall Strategy for 2024–2034 coordinates restoration across participating countries. AFR100 adds a continental commitment to restore 100 million ha by 2030 (African Union Commission, 2024; AFR100, n.d.). At the national level, Ethiopia's Green Legacy initiative carries restoration objectives into an ongoing programme. Local water projects address specific service needs, and restoration programmes extend action to the land and ecosystems that support livelihoods.

Domestic climate action now includes renewable electricity supplied to national grids and adaptation programmes addressing water and land. Hydrogen remains at an earlier stage, with strategies and proposed projects preparing future production. The differences call for distinct practical tasks. Electricity programmes must continue adding operating capacity, hydrogen developers must secure investment and build projects, and adaptation programmes must sustain measures beyond individual initiatives.

3.5 On the Way?

Africa has begun implementing its climate commitments, but progress remains insufficient to achieve the targets already set. In renewable electricity, the current pace of capacity expansion is not fast enough to meet the African Union's target of at least 300 GW by 2030. Accelerating implementation will require access to low-cost finance, coordinated development of transmission and distribution networks and vehicle

charging and battery-swapping infrastructure alongside technology deployment, and conditions that make low-carbon investments economically attractive to consumers and businesses. Growing electric vehicle adoption and employment in renewable energy-related activities indicate that new opportunities are emerging. However, high electricity prices, high financing costs and inadequate supporting infrastructure limit the benefits of lower-cost technologies. Adaptation faces a different challenge, as investment in preventing climate-related losses cannot rely solely on commercial returns. Africa urgently needs to accelerate investment, but declining technology costs and the growth of local economic activities are also creating opportunities to support the sustained implementation of some investments.

Achieving the 300 GW target will require a much faster pace of expansion than that recorded since 2020. Africa's installed renewable energy capacity increased from 51.4 GW in 2020 to 82.4 GW in 2025, equivalent to an average annual growth rate of 9.9% (IRENA, 2026). To reach 300 GW, installed capacity would need to increase to 3.6 times its 2025 level within five years, requiring an average annual growth rate of 29.5% (AU, 2023; authors' calculations). By comparison, Africa added 11.3 GW of renewable energy capacity in 2025, representing a record annual increase of 15.9% (IRENA, 2026). Closing the remaining 217.6 GW gap by 2030 would require average annual capacity additions of 43.5 GW, nearly four times the capacity added in 2025 (Figure 3-5-1).

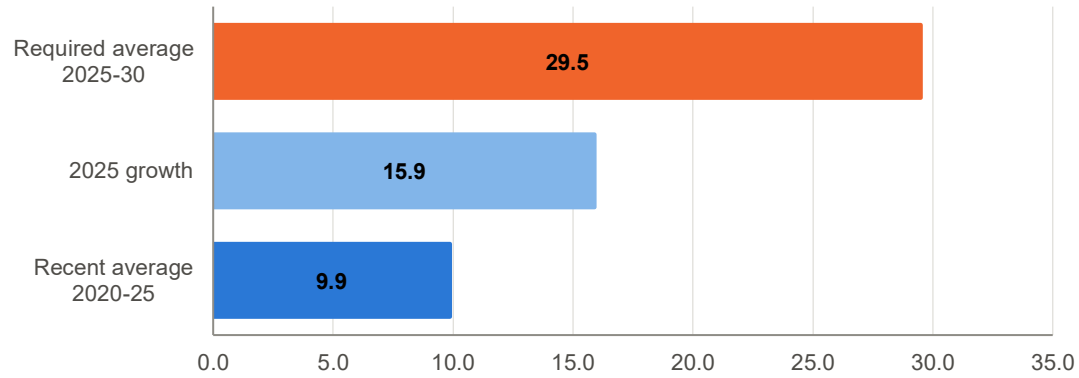


Figure 3-5-1 Recent Renewable Capacity Growth in Africa and the Pace Required to Reach 300 GW by 2030 (%)

Note: Recent and required averages are compound annual growth rates. The 2025 value is annual growth.

Source: Authors' calculations based on IRENA (2026), Renewable Capacity Statistics 2026; AU (2023), Nairobi Declaration, paragraph 49(i).

The size of the capacity gap makes financing conditions central to faster deployment. Of the 53 African NDCs, 45 make at least part of their quantified

mitigation contribution conditional on international support (UNFCCC NDC Registry, 2026). The *Nairobi Declaration* also reports that Africa received only 2% of global renewable energy investment during the preceding decade (AU, 2023). In response, the Nairobi and Addis Ababa declarations call for more affordable international finance and domestic reforms that reduce investment risk and improve conditions for public and private investment (AU, 2023, 2025). Faster deployment will require both more affordable capital and national institutions capable of directing investment into viable projects.

Adaptation faces a different type of financing imbalance. As of September 2025, the 23 National Adaptation Plans (NAPs) submitted by African countries had identified priority actions, but financial support had not yet reached the required scale (UNFCCC LEG, 2025; UNEP, 2025; AU, 2025). The United Nations Environment Programme (UNEP) estimates that developing countries will require US$310–365 billion annually for adaptation by 2035, compared with international public finance flows of only US$26 billion in 2023 (UNEP, 2025). For Africa specifically, the *Addis Ababa Declaration* identifies annual adaptation needs of nearly US$84 billion (AU, 2025). In 2021–2022, the Climate Policy Initiative (CPI) tracked average annual adaptation finance flows to Africa of approximately US$13.8 billion, around half of which were provided through debt financing instruments (CPI, 2024). Such financing entails repayment obligations, the burden of which depends on terms including interest rates, maturities and currency denomination, and may increase future budgetary pressures. Expanding adaptation finance therefore requires attention not only to the volume of funding but also to financing terms, so that measures to protect communities do not further constrain expenditure on essential services.

For mitigation investment, financing volume is only part of the challenge. Lower technology costs must also translate into affordable electricity. Only then can households and firms benefit from the transition and adopt low-carbon technologies more widely. The IEA finds that leading solar PV and onshore wind projects already cost less than new gas and coal generation in most African markets (IEA, 2022). Lower generation costs can reduce electricity prices, help extend electricity access and improve the competitiveness of electric transport and industrial production. Nevertheless, Kenya illustrates the obstacles between renewable generation and affordable electricity. Renewables supplied nearly 90% of Kenyan electricity in 2023, including 47% from geothermal, yet electricity prices remained among Africa's highest (IEA, 2024). Network losses reached 23%. Inflation, subsidy removal and currency

depreciation placed additional pressure on consumer prices (IEA, 2024). Across Africa, the cost of capital for energy projects can reach 7 times the levels recorded in Europe or North America (IEA, 2022). Reducing the cost of generation alone leaves network losses and financing charges to be recovered from electricity users. Improvements in utility performance and access to affordable capital are also needed for consumers to benefit from cheaper technologies.

Grid expansion presents a further implementation constraint independent of the cost of generation equipment. New generation capacity needs to be connected to the grid in a timely manner, transmission lines and substations must link resource-rich areas with demand centres, and distribution networks must be capable of delivering reliable electricity to end users. If planning, approval and construction fall behind the development of generation projects, new capacity may face grid connection delays or constraints on electricity transmission. Investment in generation, transmission networks and distribution systems therefore needs to be coordinated (IEA, 2023). South Africa's 2025 JETP progress report identified the need to construct more than 14,000 km of transmission lines over the next decade and highlighted local distribution challenges as an implementation priority (IPG, 2025b). This demonstrates that the value of additional generation capacity also depends on supporting networks and the operational capacity of electricity utilities.

Electric mobility is already attracting investment and expanding the market for low-carbon technologies. Africa's electric vehicle stock increased from about 4,000 vehicles in 2020 to 130,000 in 2025, and investment related to electric mobility grew by 50% between 2024 and 2025 (IEA, 2026a). Chinese manufacturers supplied 70% of the electric vehicles imported into Africa during 2025 (IEA, 2026a). Imported vehicles can make electric mobility available before domestic manufacturing expands. African firms can participate in the growing market not only through vehicle production but also through charging, maintenance and other services.

Growth in electric vehicle use also requires reliable charging services. Private passenger cars, bus fleets and electric two-wheelers have different usage patterns and therefore require infrastructure arrangements suited to parking conditions, fleet operations, and charging and battery-swapping networks. Charging and battery-swapping facilities need adequate distribution network connections and a stable electricity supply, and must be coordinated with local transport and electricity planning (World Bank, 2026g). Such facilities require substantial upfront investment in construction and equipment, while revenues develop gradually as utilisation increases.

If loan maturities, currency denominations and repayment schedules are not aligned with operating cash flows, infrastructure expansion may be constrained (OECD, 2026).

The economic contribution of the transition also includes employment in renewable energy. In 2024, renewable energy supported approximately 344,000 jobs in Africa, accounting for around 2.1% of global renewable energy employment (IRENA and ILO, 2026). Renewable energy-related employment connects technology deployment with local livelihoods. As technology adoption expands, increased opportunities for African businesses and workers to supply goods and services can broaden local economic benefits, even where equipment continues to be imported.

National climate action now encompasses renewable electricity generation, measures supporting electric mobility, and plans to address climate risks. Achieving national and continental targets requires translating commitments into projects that can secure financing, have the necessary supporting infrastructure and operate sustainably. In the electricity and transport sectors, low-cost finance, timely development of transmission and distribution networks, reliable charging and battery-swapping services, and effective electricity tariff structures together determine whether declining technology costs translate into savings for households and businesses. Greater participation by African suppliers and service providers can extend these benefits to local employment and incomes. International support should focus not only on mobilising finance but also on strengthening project implementation and service delivery capacity. Adaptation, meanwhile, continues to require sustained financial support, as commercial returns from energy markets cannot substitute for protection against climate-related losses. Assessing progress in the transition therefore requires consideration of deployment rates, funding disbursement, service reliability, affordability for users, and the circumstances of affected workers and communities.

Africa has the potential to further expand its electricity supply capacity, but declining costs of solar PV, wind and energy storage technologies must still be translated into affordable electricity for consumers through appropriate financing, investment in transmission and distribution networks, and effective tariff structures. Figure 3-5-2 compares average industrial electricity tariffs in South Africa and China, expressed in South African rand, although the observed differences are also influenced by exchange rates and statistical definitions. Improving industrial competitiveness requires continued investment in reliable electricity supply and affordable low-carbon power.

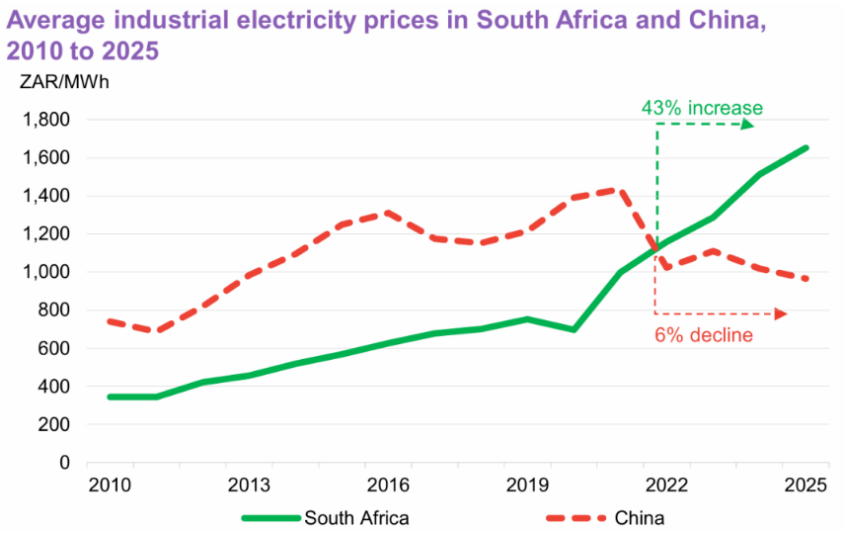


Figure 3-5-2 Comparison of Average Industrial Electricity Tariffs in South Africa and China, 2010–2025 (ZAR/MWh)

Note: China's industrial electricity tariffs were converted from CNY/MWh to ZAR/MWh using the average annual exchange rate between the Chinese yuan and the South African rand. The comparison therefore reflects changes in both domestic electricity tariffs and exchange rates. The definitions of average industrial electricity tariffs follow those used in the original sources.

Source: BloombergNEF (2026a), South Africa Transition Factbook 2026, p. 35. Original chart data sourced from Climatescope and BloombergNEF.

4. Africa's Energy and Economic Transition Scenarios

4.1 Methodology

The scenario analysis in this report was conducted using the IPAC-AIM/Technology model. Development of the IPAC-AIM/Technology model began in 1991, and it is one of the Integrated Policy Assessment Model for China (IPAC) modelling frameworks (Jiang et al., 1998, 2006, 2013, 2016, 2021; Jiang et al., 2021; Xiang et al., 2023, 2024). The model adopts a bottom-up modelling approach and uses linear programming-based least-cost optimisation to identify combinations of technologies capable of meeting specified future service demands. It then estimates energy consumption and associated emissions of greenhouse gases and air pollutants. The model covers the full range of energy-related activities, from mineral extraction and energy processing and conversion to final energy demand. To assess emissions of pollutants associated with atmospheric haze, it also incorporates certain non-energy activities, such as road dust, construction-site dust and cooking fumes. The IPAC-AIM/Technology model can simulate energy-related activities in considerable detail while reflecting policy requirements. It currently covers 65 sectors and more than 800 technologies. The modelling horizon depends on the research objectives, but generally extends to 2050.

The results presented in this study build on previous IPAC research and incorporate findings from the research team's recent global scenario studies, together with research on zero-carbon transition pathways for the Sahara region of North Africa.

4.2 Africa's Development Scenario

The central premise of this report is that rapid advances in zero-carbon technologies in recent years have made it possible to reduce greenhouse gas emissions and other environmental pollutants without additional investment, with the costs of low-carbon energy systems in some cases beginning to fall below those of conventional energy development. This is particularly relevant to Africa, which possesses some of the world's best solar PV resources, as well as substantial advantages in wind energy resources. By building an energy system centred on solar PV, wind and hydropower, supplemented by other zero-carbon energy sources such as nuclear power and biomass,

Africa could achieve net-zero emissions by 2050 while accelerating economic development and achieving a major socioeconomic breakthrough. At the same time, it could establish an entirely new energy supply system with a high level of energy security.

Rather than adopting a multiple-scenario approach, this report presents a single outlook for socioeconomic development that we consider achievable. Building on previous research by the IPAC modelling team, this outlook explores Africa's future development prospects. Relevant previous IPAC studies include:

（1） Industrial development in the Sahara region of North Africa based on zero-carbon electricity.
（2） Global distribution of zero-carbon ammonia, methanol, steel and aluminium production.
（3） Global emissions reduction scenarios and pathways consistent with the 1.5°C target.
（4） Energy and economic transition pathways under China's carbon neutrality target.
（5） Cost curves for direct air capture of CO_2.
（6） Cost-optimal configurations of zero-carbon pig farming systems.
（7） Zero-carbon development pathways and transport modes for global shipping.
（8） Geographical restructuring of industrial production under China's carbon neutrality target.
（9） Development models for zero-carbon industrial parks.
（10） Cost curves for key zero-carbon technologies.

The central conclusion of these studies is that the substantial decline in zero-carbon technology costs in recent years will bring about major changes in energy supply and energy-consuming systems. Low-cost zero-carbon electricity, with prices generally below 2.25 US cents/kWh, could reduce the cost of hydrogen production through renewable electricity-based water electrolysis to approximately US$1,050/ton. At this cost level, ammonia production and the manufacture of petrochemical products such as methanol, olefins and ethylene using CO_2 captured at low cost from industrial sources could compete with today's fossil fuel-based industries even without a carbon price, and could potentially become more competitive.

In North Africa, which is expected to become increasingly competitive, the cost of direct air capture of CO_2 could also fall below US$60 per ton, and has possibility to go

lower. This would enable the production of carbon-, hydrogen- and oxygen-based petrochemical products in areas without local CO_2 sources, while maintaining regional cost competitiveness. In the future, industrial production is expected to shift substantially towards regions with favourable zero-carbon electricity resources, such as Gansu Province in China and the Sahara region of North Africa. This geographical shift could extend beyond industry to agriculture, including livestock farming.

The potential relocation of industries can be illustrated by the shift of industrial production from eastern China towards the northwestern regions with abundant solar PV and wind resources. Figure 4-2-1 presents the geographical distribution of China's solar PV resources. The future distribution of low-cost zero-carbon electricity will be largely determined by the availability of solar and wind resources. Low electricity prices could make industrial products manufactured in these regions highly competitive, allowing them to remain profitable in end-use markets even after transport costs are taken into account.

Figure 4-2-2 presents the results of a 2021 study by the IPAC modelling team, illustrating the projected geographical distribution of China's major industrial products. The results indicate substantial changes in provincial production patterns between 2018 and 2050. China's economic activity has historically been concentrated in its eastern regions, where most industrial products were also manufactured in 2018. By 2050, however, production of these industrial products is projected to shift predominantly towards provinces in western, northwestern, northern and northeastern China, where solar PV and wind resources are more favorable.

According to the IPAC modelling results, this shift would involve not only the production of raw materials but also the manufacture of downstream products in these regions, further strengthening their competitiveness. For example, manufacturing an electric vehicle in Gansu or Inner Mongolia could cost more than 25% less than producing the same vehicle in eastern China.

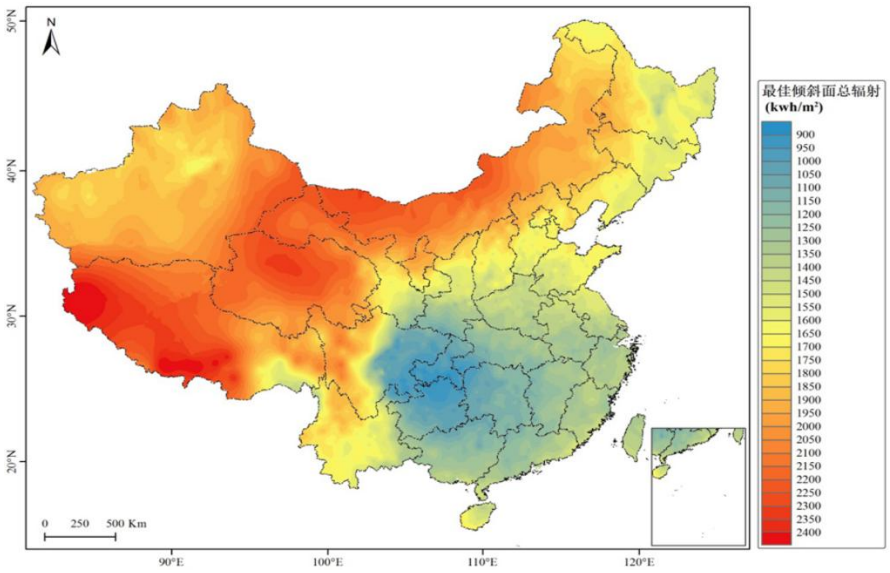


Figure 4-2-1 Solar Energy Resources in China (kWh/m^2)

Source: China Meteorological Administration (2026), 2025 Bulletin on China's Wind and Solar Energy Resources.

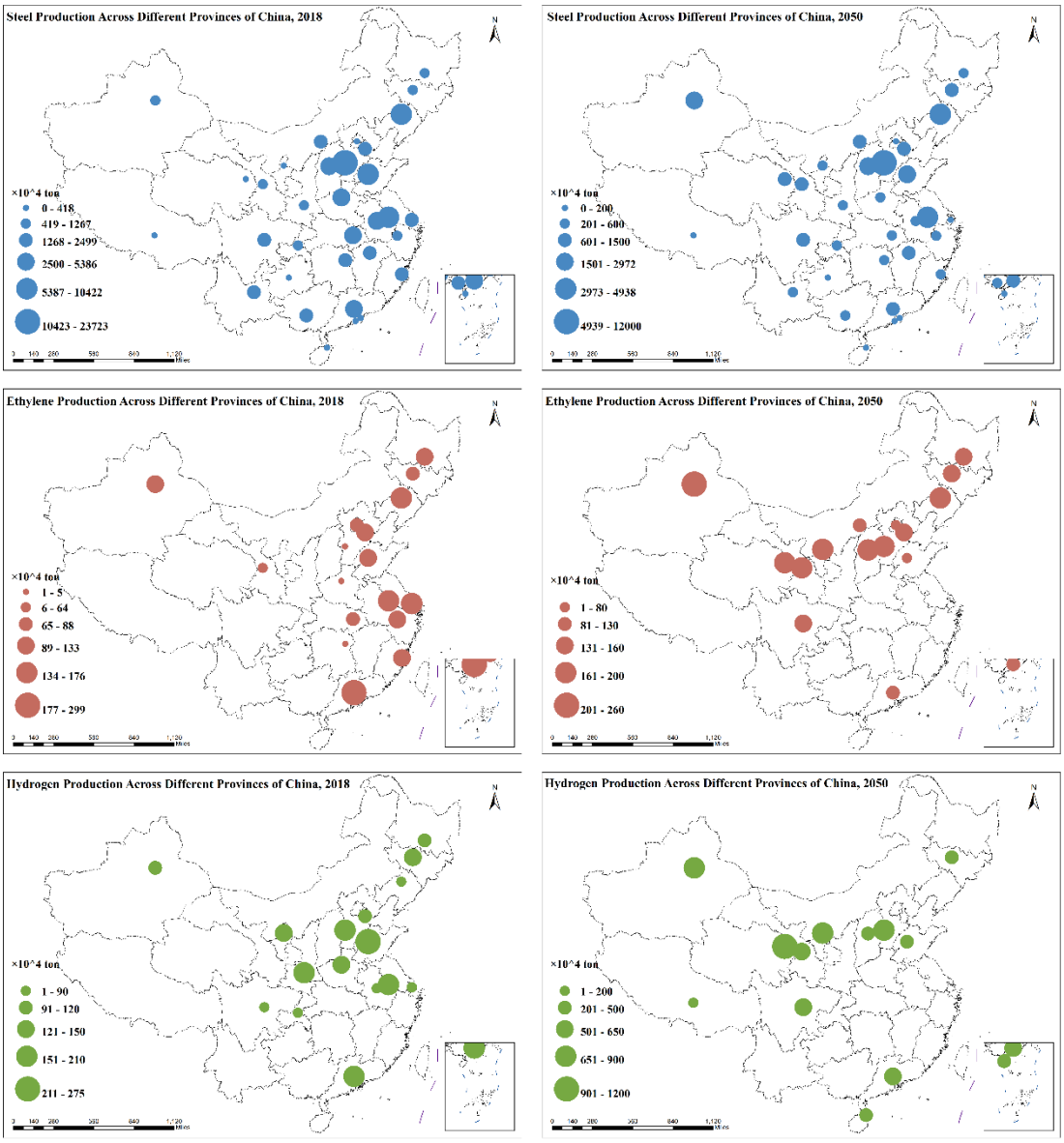


Figure 4-2-2 Geographical Redistribution of Industrial Production under China's Carbon Neutrality Target (10,000 tons)

Note: The left-hand panels show the provincial production volumes of these products in 2018, while the right-hand panels show the projected provincial production volumes in 2050.

Source: China Statistical Yearbook; IPAC model.

Building on this line of research, the IPAC modelling team has recently also conducted global scenario studies, with a particular focus on the global distribution of major industries. This report, in turn, focuses on Africa's development prospects within this broader pattern of transformation. Figure 4-2-3 presents the global distribution of solar PV resources, while Figure 4-2-4 and Figure 4-2-5 show global wind power potential and wind speed distributions. These figures indicate that Africa possesses highly favourable solar and wind resources, with enormous development potential.

North Africa, in particular, occupies a central geographical position in the world. Its transport distances to North America, Europe and East Asia fall within a commercially competitive range for products produced in North Africa.

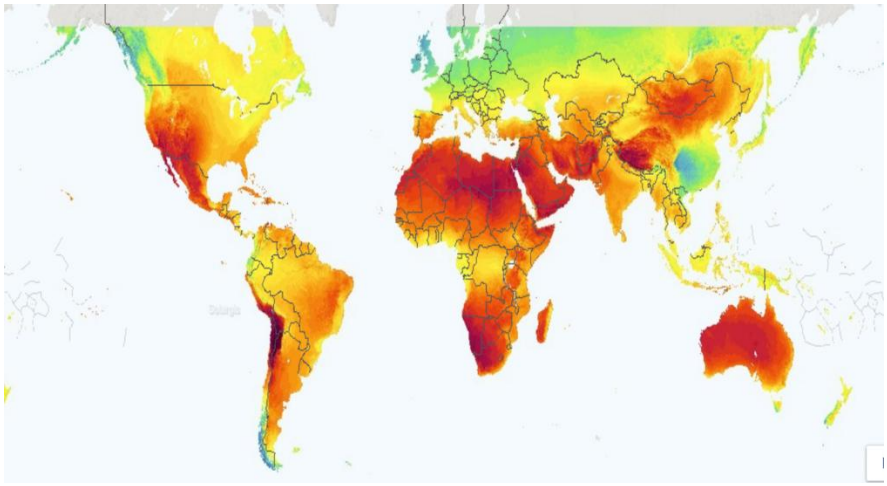


Figure 4-2-3 Global Distribution of Solar PV Resources

Source: Global Solar Atlas (n.d.).

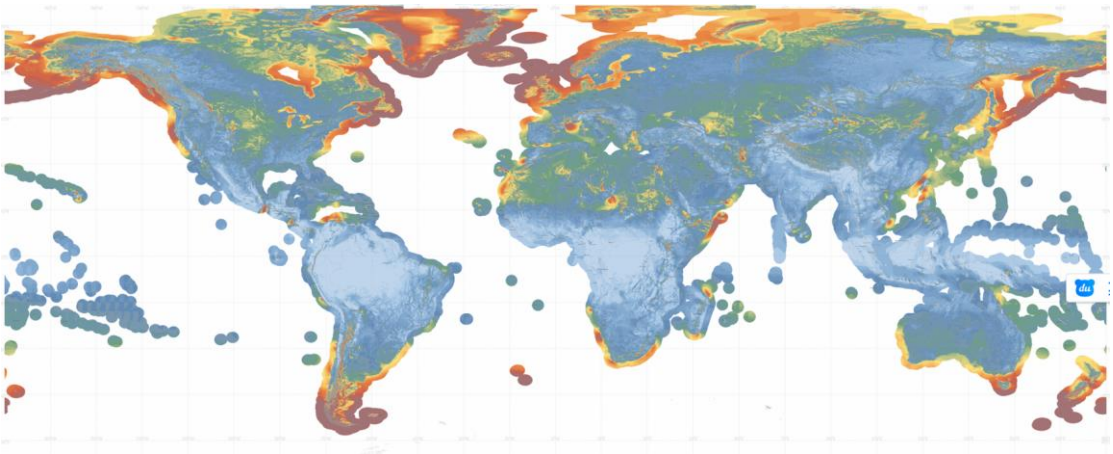


Figure 4-2-4 Global Distribution of Wind Energy Resources

Source: Global Wind Atlas (n.d.).

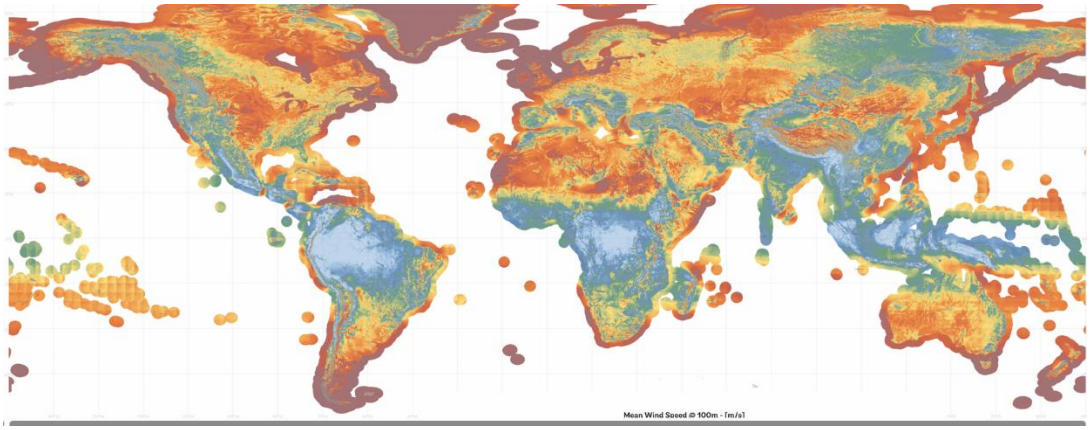


Figure 4-2-5 Global Distribution of Wind Speeds

Source: Global Wind Atlas (n.d.).

The key parameters driving these changes are presented in Table 4-2-1, using the Sahara as a case study for Africa.

Table 4-2-1 Key Parameters Influencing Future Industrial Development

Parameter	Unit	Value
Solar PV electricity generation cost	US cents/kWh	1.0
Electricity tariff for industrial parks	US cents/kWh	1.3
Green hydrogen cost	US$/ton	1,000
Direct air capture (DAC) cost of CO_2	US$/ton CO_2	50
Zero-carbon ammonia production cost	US$/ton	140
Zero-carbon methanol production cost	US$/ton	240
Electric arc furnace steelmaking cost	US$/ton	280
Hydrogen-based steelmaking cost	US$/ton	330
Zero-carbon aluminium production cost	US$/ton	1,670
Zero-carbon copper production cost	US$/ton	1,950

Source: Authors' calculations.

The IPAC modelling team has conducted research on global energy transition pathways and emissions scenarios. Table 4-2-2 presents projected changes in the costs of solar PV electricity, hydrogen production through water electrolysis, hydrogen-based methanol and hydrogen-based ammonia in North Africa. With advances in solar PV and water electrolysis technologies, the cost of solar PV electricity in North Africa could fall to US$0.0084/kWh (0.84 US cents/kWh) by 2050, while the cost of renewable hydrogen could decline to US$475 per ton of H_2. The production costs of ammonia and methanol using renewable hydrogen as a feedstock could fall to US$109 per ton of NH_3 and US$247 per ton of CH_3OH, respectively.

At present, ammonia and methanol production in North Africa relies primarily on natural gas as a feedstock, making production costs highly sensitive to fluctuations in international natural gas prices. At natural gas costs of US$108–162/$m^3$, the production costs of ammonia and methanol are estimated at US$249–268 per ton of NH_3 and US$210–257 per ton of CH_3OH, respectively.

Hoever, in some place of north Africa, the solar PV cost is already low as US$7/MWh, therefore good choice of solar PV site could already have cost potential to make ammonia, methanol production low enough to compete with these from fossil fuel process. And now the technology for ethylene, etc. from hydrogen and CO 2 are already there, and have the potential to make these production soon be market competitive,

Table 4-2-2 Projected Costs of Solar PV Electricity, Renewable Hydrogen, Hydrogen-Based Ammonia and Hydrogen-Based Methanol in North Africa

Year	Solar PV Electricity Cost (US$/MWh)	Renewable Hydrogen Cost (US$/t H_2)	Hydrogen-Based Ammonia Cost (US$/t NH_3)	Hydrogen-Based Methanol Cost (US$/t CH_3OH)
2020	22	5,106	1,020	1,229
2023	16	1,179	245	403
2025	14	836	181	331
2030	12	719	158	305
2035	10	632	140	283
2040	9	544	123	263
2050	8	475	109	247
2060	7	393	93	227

Note: The cost of CO_2 feedstock is assumed to be US$50 per ton of CO_2.

Source: Authors' calculations.

Figure 4-2-6 presents the scenario results for the global distribution of ammonia production in 2050. Africa, China, Latin America and the Middle East are the major ammonia-producing regions, with outputs of 1,811.3 million tons, 595.2 million tons, 575.7 million tons and 497.4 million tons, respectively, together accounting for 92% of global ammonia production. Similar to methanol, fuel ammonia produced in Africa is exported to Southeast Asia, Europe, India and Russia.

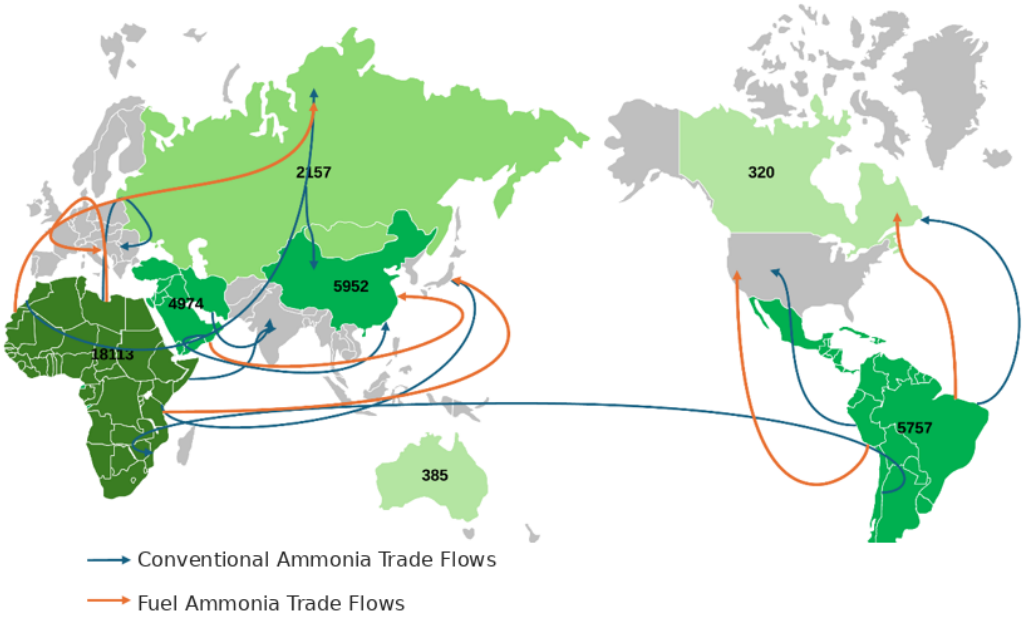


Figure 4-2-6 Global Distribution of Ammonia Production, 2050 (10,000 tons)

Source: IPAC model results.

The global distribution of methanol production in 2050 is presented in Figure 4-2-7. Methanol production is projected to be concentrated in three regions: China, the Middle East and Africa, with outputs of 130.38 million tons, 114.71 million tons and 86.39 million tons, respectively, together accounting for 99% of global methanol production. However, Africa is the only region projected to achieve fully hydrogen-based methanol production by 2050. In the Middle East and China, some carbon-based methanol production is expected to remain due to the availability of low-cost natural gas and coal feedstocks.

Future methanol trade is projected to be dominated by hydrogen-based methanol, which accounts for 75% of total non-fuel methanol trade. Hydrogen-based methanol trade between Europe and the Middle East alone reaches 18 million tons, while trade between Africa and the Middle East amounts to 3 million tons. Methanol trade between China and the Middle East is dominated by carbon-based methanol.

For fuel methanol, the model assumes that only hydrogen-based methanol is used for fuel supply. Consequently, all fuel methanol trade involves hydrogen-based methanol. As shown in Figure 4-2-7, Africa emerges as the principal supplier of fuel methanol, with Australia, Canada, Europe, India, Russia and the United States all importing fuel methanol from Africa.

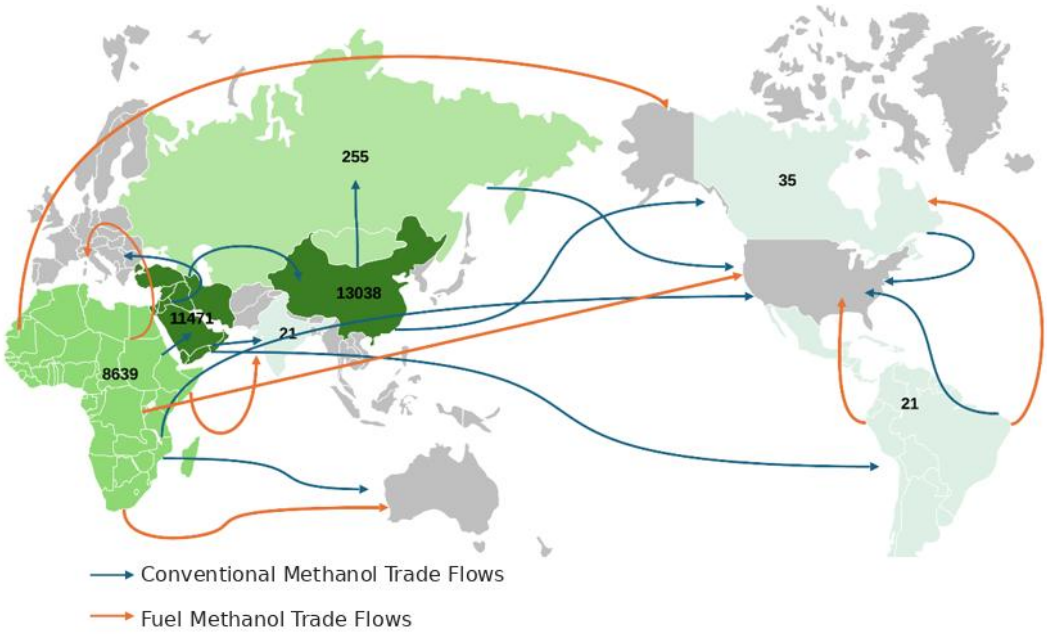


Figure 4-2-7 Global Distribution of Methanol Production, 2050 (10,000 tons)

Source: IPAC model results.

The global zero-carbon steel production capacity and trade patterns have long been shaped by a spatial division of labour based on mineral resources and energy endowments, with traditional long-process steel production concentrated in regions rich in iron ore and coal resources or located near end-use manufacturing clusters. Driven by the "dual carbon" transition, the locational logic of the steel industry is undergoing a transformation, with the cost of renewable energy replacing the cost of traditional coal as the core factor determining future steel production site selection and trade flows.

The global zero-carbon steel distribution in 2050 is shown in Figure 4-2-8, with total global steel production reaching approximately 2.4 billion metric tons by 2050. Production will be primarily concentrated in three regions: China, Africa, and the Middle East, with zero-carbon steel output of 700 million metric tons, 120 million metric tons, and 100 million metric tons, respectively.

Leveraging the African continent's abundant iron ore resources, high-quality wind and solar renewable energy, and ample land area, Africa possesses the inherent conditions for producing green hydrogen for direct reduction iron (H-DRI) steelmaking; therefore, Africa will become the primary production region for H-DRI by 2050. Similarly, western China and the Middle East, benefiting from a robust supply of renewable energy that significantly reduces H-DRI production costs, will also be major H-DRI production regions by 2050.

These regions will continue to supply cost-competitive H-DRI to Europe, Russia, North America, East Asia, and South Asia. As key global suppliers of iron ore, Australia and Brazil will continue to supply pellets and concentrates to regions such as China and the Middle East, thereby supporting the raw material supply required for the H-DRI process. H-DRI production in Africa does not rely heavily on imported raw materials or energy, ensuring sustained and stable production. Australia plans to scale back its iron ore exports; however, due to the high production costs of local photovoltaic power, the production costs of H-DRI there are not competitive compared to those in Africa, China, and the Middle East. Therefore, H-DRI produced in Africa still holds significant potential for export to regions such as Australia and South America.

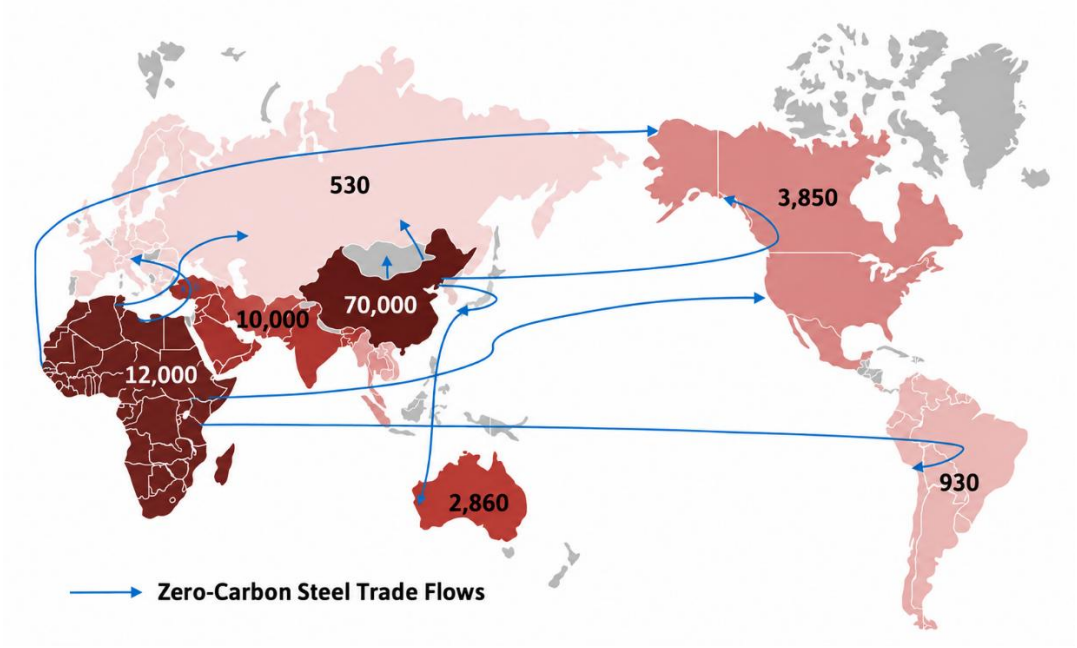


Figure 4-2-8 Global Distribution of Steel Production, 2050 (10,000 tons)

Source: IPAC model results.

Based on these parameters, products such as ammonia, fertilisers and olefins produced in Africa, particularly in the Sahara region of North Africa, could be competitive in major global markets even after transport costs are taken into account. This suggests that, with a successful transition, Africa could achieve a major socioeconomic breakthrough. Table 4-2-3 presents the projected production volumes of major industrial products in Africa under the future development scenario. The data for some products are different with studies mentioned above, such as ammonia, methanol, steel, are mainly due to the consideration on some other factors including global trade barriers, national strategies for domestic productions. Studies in IPAC global trade analysis presents the least cost results, but may not be actually happen in future.

Table 4-2-3 Projected Production of Major Industrial Products in Africa

Year	Ammonia (10,000 t)	Ethylene (10,000 t)	Methanol (10,000 t)	Green Hydrogen (10,000 t)	Steel (10,000 t)	Copper (10,000 t)
2020	3.8	1.5	2.2	0	20.1	1.8
2025	5.2	1.9	3.15	0	23.2	3.9
2030	8.9	2.7	4.9	0.6	35	5.6
2035	22.5	14.5	7.5	10.5	63	8.8
2040	88	39	28	54	270	17
2050	130	67	49	110	550	32
	Aluminium (10,000 t)	Glass (10,000 t)	Paper and Paper Products (10,000 t)	Cement (10,000 t)	Automobiles (10,000 vehicles)	Electric Two-Wheelers (10,000 vehicles)
2020	0.7	4.5	3	214	0.8	0
2025	1.2	7	5.1	245	1.41	0
2030	1.9	11	8.2	340	2.6	1.2
2035	3.5	18	14	520	3.6	3.9
2040	11	33	36	720	9.8	17
2050	37.5	49	55	980	21	28
	Bicycles (10,000 units)	Air Conditioners (10,000 units)	Solar PV (GW)	Wind Turbines (GW)	Batteries (GWh)	Meat (10,000 t)
2020	0.85	1.05	0	0	0	21
2025	1.5	1.45	0.014	0.04	0.06	23
2030	3.5	2.1	0.18	0.21	0.27	26
2035	6.6	3.8	0.65	0.48	0.53	31
2040	23	7.5	1.1	0.63	0.72	45
2050	35	11.5	1.4	0.69	0.88	68

Source: IPAC model results.

Table 4-2-4 presents the projected economic development scenario for Africa. The economic projections are derived from the development scenarios for key industries, taking into account the existing scale of related industrial activities and projected export volumes. Growth in the services sector is assumed to follow a pattern consistent with industrial development.

Table 4-2-4 Macroeconomic Scenarios for Africa

	Unit	2020	2025	2030	2040	2050
GDP	US$ trillion	2.48	3	3.94	8.43	18.88
Average Annual GDP Growth Rate	%		3.9%	5.6%	7.9%	8.4%
Population	Million people	1286	1450	1635	1805	1925
GDP per Capita	US$/person	1928	2069	2410	4668	9804
Population Without Access to Electricity	Million people	605	567	355	0	0
Population Experiencing Hunger	Million people	301	309	110	0	0

Source: IPAC model results.

4.3 Africa's Energy Transition Scenario

4.3.1 Energy Transition Scenario

Based on the socioeconomic development scenario presented in the previous section, the IPAC-AIM/Technology model is used to analyze Africa's energy transition pathway. The results are presented in Figure 4-3-1 to 4-3-4.

Figure 4-3-1 presents the projected primary energy demand in Africa. Africa's primary energy demand is expected to increase substantially in the coming decades. The main drivers are continued growth in household consumption as per capita incomes rise, together with increasing energy demand resulting from large-scale industrial development.

Traditional biomass consumption is projected to decline significantly and be replaced by commercial energy sources. Commercial primary energy demand is expected to increase substantially, from 387.85 million tons of standard oil equivalent (Mtoe) in 2025 to 1,043 Mtoe in 2050. After 2030, growth in primary energy demand will be met primarily by zero-carbon energy sources. Meanwhile, fossil fuel consumption is projected to decline from 364 Mtoe in 2025 to 100.2 Mtoe in 2050. Renewable energy including solar PV, wind, hydropower and modern biomass will become the dominant sources of primary energy by 2050, together accounting for 86.7% of commercial energy supply. As a result, Africa is projected to achieve a largely electrified energy system by 2050.

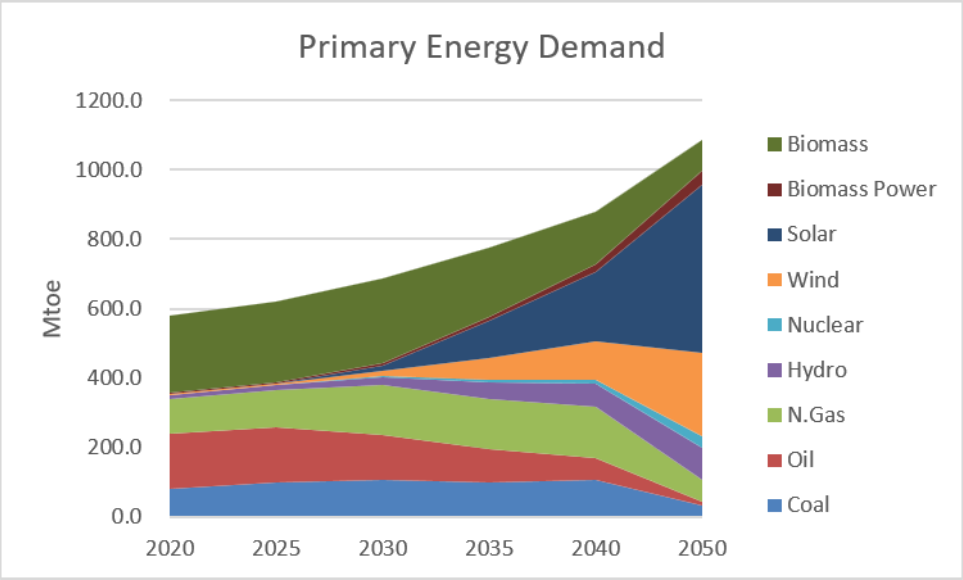


Figure 4-3-1 Africa's Primary Energy Demand Scenario, 2020–2050 (Mtce)

Source: IPAC model results.

Figure 4-3-2 presents the projected final energy demand in Africa. By 2050, electricity and hydrogen are expected to become the dominant forms of final energy. The share of electricity in final energy demand is projected to increase from 14% in 2025 to 64% in 2050 (equivalent to 73% of commercial final energy demand), while hydrogen is expected to account for 23% by 2050.

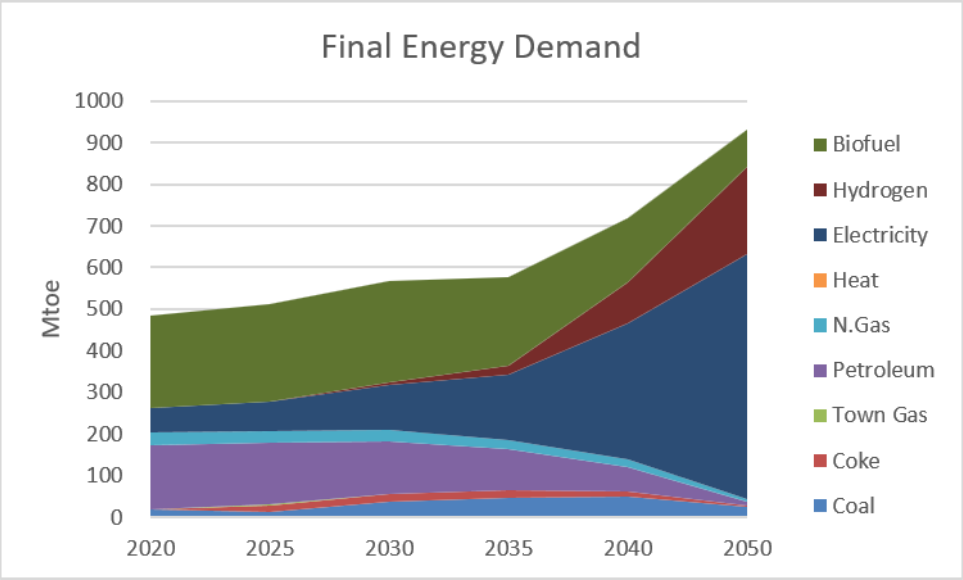


Figure 4-3-2 Africa's Final Energy Demand Scenario, 2020–2050 (Mtce)

Source: IPAC model results.

Figure 4-3-3 presents Africa's electricity generation scenario, while Figure 4-3-4 shows the projected installed power generation capacity. Given Africa's abundant solar and wind resources, electricity supply is expected to be dominated by solar PV and

wind power by 2050. Together with hydropower and nuclear power, these resources could support the development of a highly energy-secure electricity supply system based on domestic energy resources, while enabling a substantial reduction in electricity prices.

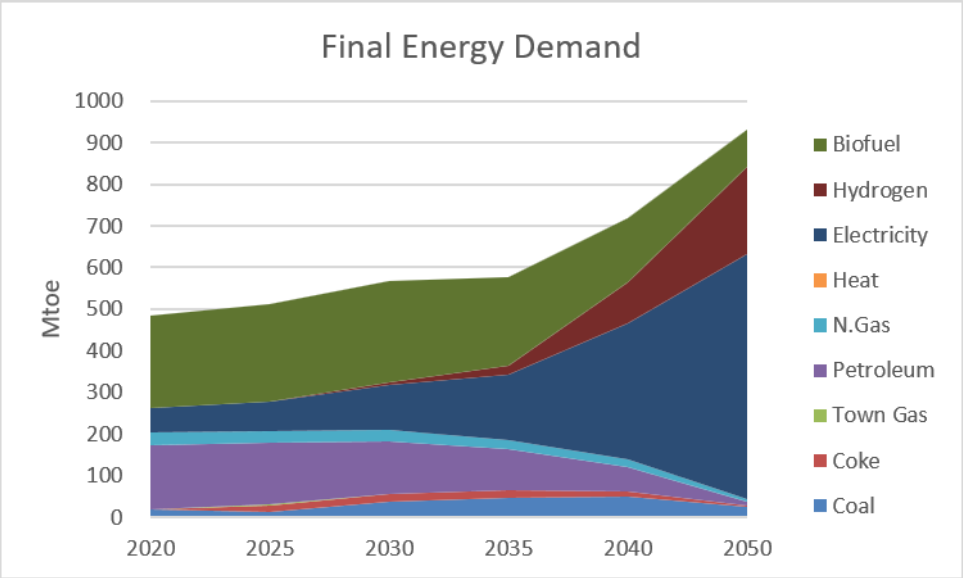


Figure 4-3-3 Africa's Electricity Generation Scenario, 2020–2050 (TWh)

Source: IPAC model results.

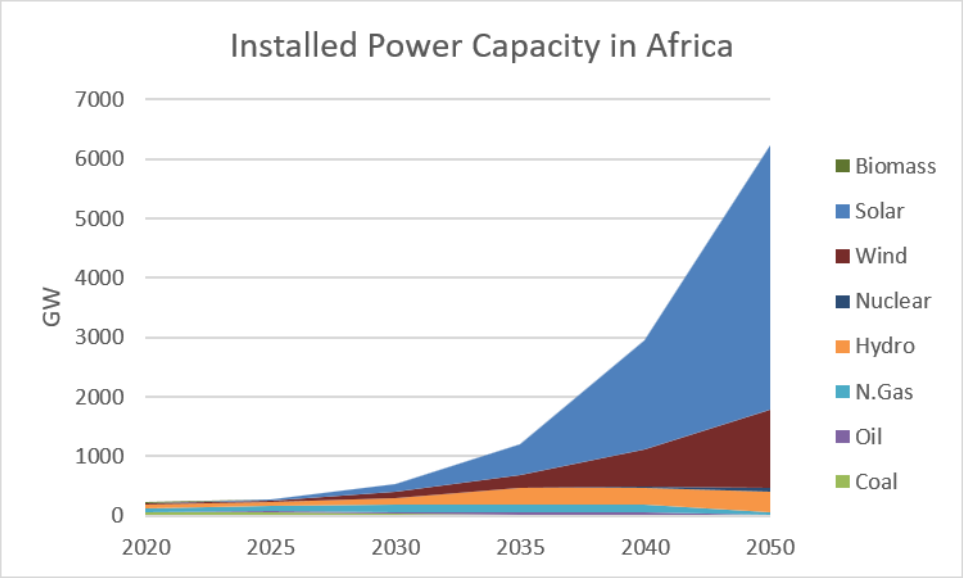


Figure 4-3-4 Africa's Installed Power Generation Capacity, 2020–2050 (10,000 kW)

Source: IPAC model results.

4.3.2 Emissions Scenario

Figure 4-3-5 to Figure 4-3-7 present Africa's sectoral CO_2 emissions scenario, anthropogenic methane emissions scenario and air pollutant emissions scenario,

respectively. According to these projections, CO_2 emissions from fossil fuel combustion in Africa are expected to decline from the current level of 1,260 million tons to 180 million tons by 2050. Anthropogenic methane emissions are projected to increase from 34 million tons in 2025 to 39 million tons in 2030, before declining to 23 million tons by 2050. The most substantial reduction is expected in emissions from energy-related activities, primarily driven by declining oil and natural gas production and transportation. Agricultural methane emissions are also projected to decrease, mainly through improvements in rice cultivation practices and the capture or utilisation of methane in intensive livestock production systems, made possible in part by access to low-cost electricity.

The energy transition could also substantially reduce emissions of air pollutants. As shown in Figure 4-3-7, emissions of air pollutants, including SO_2, NO_x, $PM_{2.5}$, volatile organic compounds (VOCs) and black carbon, are projected to decline significantly during Africa's energy transition. The principal driver of these reductions is the widespread electrification of energy use across Africa.

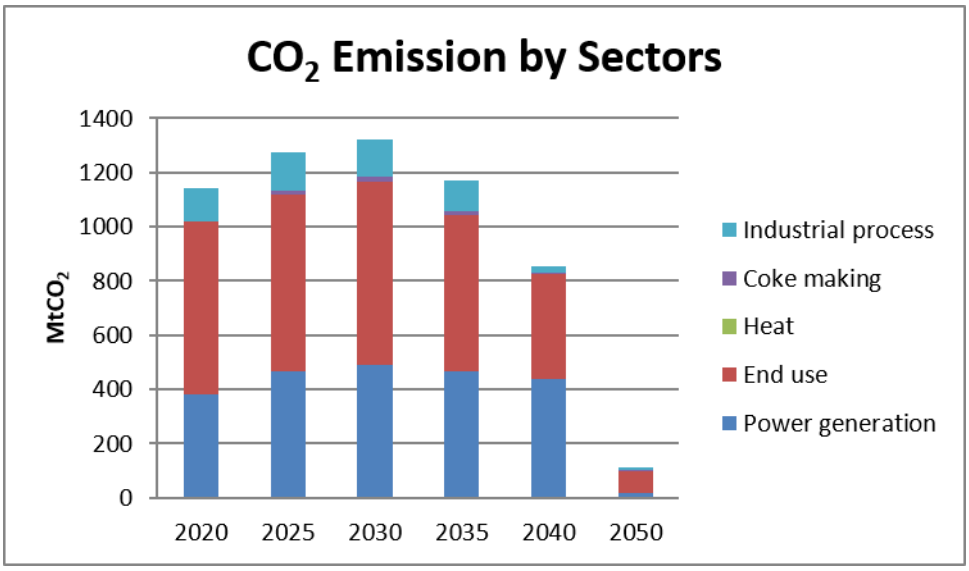


Figure 4-3-5 Africa's CO_2 Emissions Scenario, 2020–2050 (Million Tons)

Source: IPAC model results.

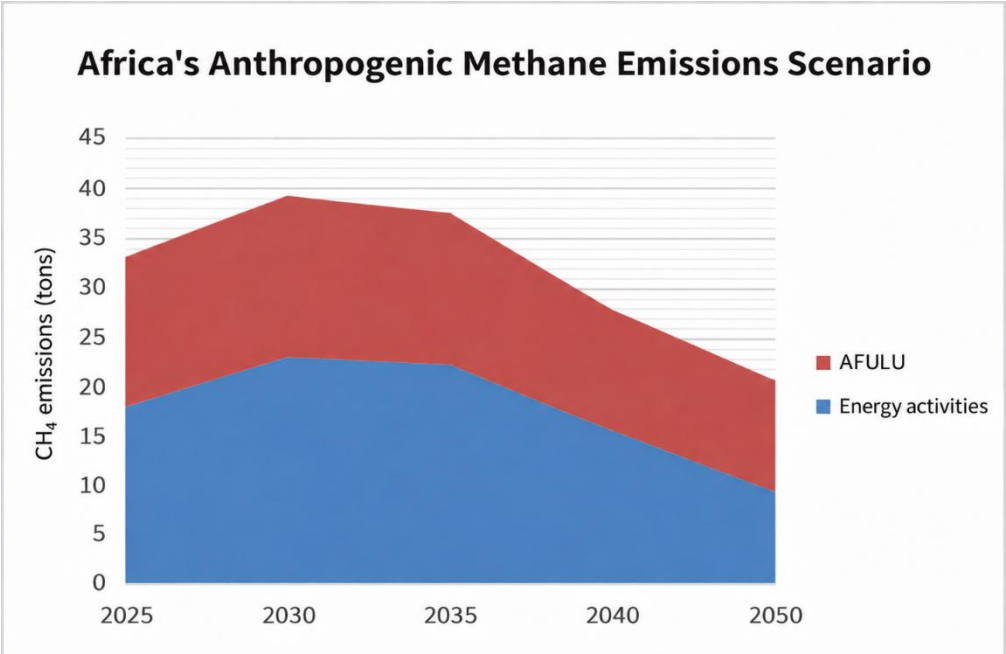


Figure 4-3-6 Africa's Anthropogenic Methane Emissions Scenario, 2025–2050 (Million Tons)

Source: IPAC model results.

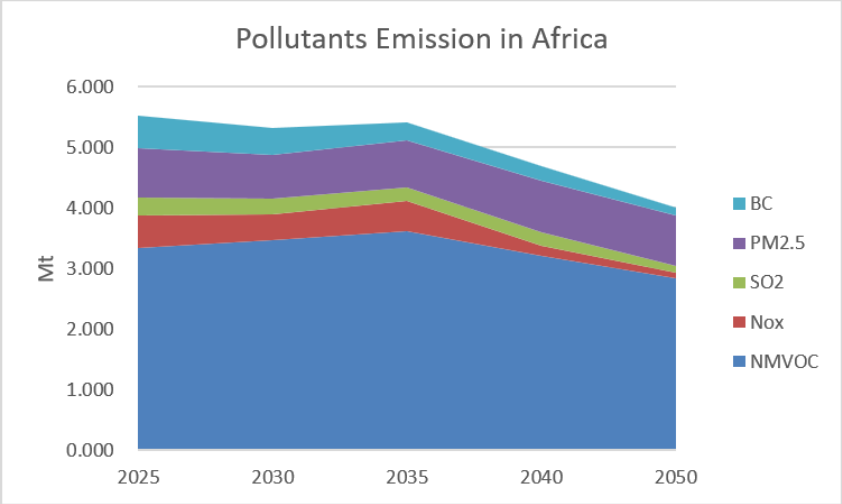


Figure 4-3-7 Africa's Air Pollutant Emissions Scenario, 2025–2050 (Million Tons)

Source: IPAC model results.

4.3.3 Contributions to Sustainable Development

Recent rapid technological advances have further enhanced the potential contributions of energy transition pathways to the Sustainable Development Goals (SDGs) compared with earlier assessments. An energy transition pathway towards zero-carbon emissions could support the achievement of virtually all 17 SDGs (Figure 4-3-8). Table 4-3-1 presents the relationships between Africa's energy transition and the SDGs, as analysed by the IPAC modelling team.



Figure 4-3-8 Sustainable Development Goals

Source: United Nations (n.d.), The 17 Goals.

Table 4-3-1 The Link Between Africa's Energy and Economic Transformation and the Sustainable Development Goals

Sustainable Development Goal	Contribution of the Energy Transition
SDG 1: No Poverty	The scenario results indicate a substantial increase in Africa's overall GDP per capita, with an increase of more than 25% by 2030 compared with 2025.
SDG 2: Zero Hunger	Low-cost zero-carbon electricity could enable large-scale development of greenhouse agriculture in Africa. In addition, the production of starch and proteins using green hydrogen and CO_2, together with the substitution of cotton by low-cost synthetic fibres, could free up more land for food production and help reduce hunger.
SDG 3: Good Health and Well-being	Rising incomes could substantially strengthen healthcare provision, improve health outcomes and enhance quality of life.
SDG 4: Quality Education	Higher income levels could support increased investment in education.
SDG 5: Gender Equality	Household energy supply from rooftop or small-scale local solar PV, wind power and small hydropower systems could encourage greater participation by women, enhancing their skills, knowledge, contributions to household well-being and participation in society.
SDG 6: Clean Water and Sanitation	Low-cost zero-carbon electricity creates opportunities for affordable clean water supply. Seawater desalination is already becoming commercially competitive, while obtaining clean drinking water through the evaporation and purification of contaminated water could offer new opportunities for water-scarce regions.
SDG 7: Affordable and Clean Energy	Clean energy is at the core of Africa's energy transition, while low-cost zero-carbon electricity could substantially reduce current energy prices.

Sustainable Development Goal	Contribution of the Energy Transition
SDG 8: Decent Work and Economic Growth	The zero-carbon energy transition could create substantial employment opportunities in emerging industries, provide quality jobs and support economic growth.
SDG 9: Industry, Innovation and Infrastructure	A central element of Africa's future energy transition is the development of new industries based on low-cost green hydrogen, supporting domestic industrial development, innovation and infrastructure expansion.
SDG 10: Reduced Inequalities	Future economic development will increasingly be influenced by the geographical distribution of solar and wind resources, creating opportunities for African countries that have historically been less developed.
SDG 11: Sustainable Cities and Communities	Stronger economic development could provide a solid foundation for the sustainable development of cities and communities.
SDG 12: Responsible Consumption and Production	Green and zero-carbon products could become available at lower prices, encouraging more environmentally sustainable and lower-carbon consumption and production patterns.
SDG 13: Climate Action	Rapid development of zero-carbon energy and industries could provide a strong foundation for Africa's participation in climate action.
SDG 14: Life Below Water	More sustainable lifestyles and production practices could substantially reduce the discharge of land-based pollutants into aquatic environments. These include toxic chemicals, heavy metals and antibiotics, whose release could be reduced through changes associated with the energy transition, contributing to the protection of aquatic ecosystems.
SDG 15: Life on Land	More sustainable lifestyles and production practices could substantially reduce pollutant emissions and releases into terrestrial environments.
SDG 16: Peace, Justice and Strong Institutions	A substantial energy and economic transition will require the establishment of new governance systems. Broad-based economic development could contribute to peaceful development and the establishment of more equitable institutions.
SDG 17: Partnerships for the Goals	Such an energy and economic transition will require greater international and regional cooperation.

Source: Authors' compilation.

4.4 Pathways to Energy Transition

4.4.1 Energy Supply and Electricity Rates in Africa

In 2025, Africa's primary energy consumption was approximately 720 million metric tons of oil equivalent (Mtoe), accounting for 6% of global primary energy consumption (IEA, n.d.). Within Africa's primary energy consumption, oil accounted for 43.5%, natural gas for 32%, and coal for 19%; fossil fuels collectively accounted for over 94%, making Africa one of the continents with the highest dependence on fossil fuels globally.

In 2026, the average residential electricity price in Africa was US$0.141/kWh, while the average commercial and industrial electricity price was US$0.134/kWh. Although these figures are below the global average, there are significant disparities in electricity prices among countries within the region, and the actual cost of electricity is far higher than the nominal price. The global average residential electricity price is US$0.179 per kWh; Africa's residential electricity price is 21% lower than the global average, making it the continent with the second-lowest residential electricity prices worldwide. The global average electricity price for industry and commerce is US$0.172/kWh. Africa's industry and commerce electricity prices are 22% lower than the global average, making it the continent with the lowest industry and commerce electricity prices worldwide. Electricity prices in Africa have continued to rise in recent years; from 2025 to 2026, residential electricity prices increased by 5.29% year-over-year, while industry and commerce electricity prices rose by 7.5% year-over-year—increases significantly higher than the global average (IEA, n.d.).

Some African countries have low electricity prices; for example, Sudan's residential electricity rate is 4.4 cents/kWh and its industrial rate is 5.6 cents/kWh. Other countries with low electricity prices include Nigeria, Algeria, Ethiopia, Angola, and Zambia, where residential electricity rates are below 6.2 cents/kWh and industrial rates are below 7 cents/kWh (IEA, n.d.). Most of these countries rely on domestic, low-cost energy resources such as hydropower, oil, and natural gas, and maintain extremely low end-user electricity prices through government subsidies; among them, Egypt, Ethiopia, and Sudan have electricity prices that are even lower than the average domestic electricity price in China.

Countries such as Nigeria suffer from insufficient grid reliability, leading a large number of industrial and commercial users to rely on their own diesel generators. The cost of diesel-generated power ranges from US$0.3 to US$0.5 per kWh, meaning the actual comprehensive cost of electricity is 5 to 10 times the nominal electricity price.

4.4.2 Potential for Photovoltaic Development

By 2026, the cost of solar PV electricity generation in areas of Africa with favourable solar resources had fallen to approximately 1 US cent/kWh, while the cost of electricity supply incorporating energy storage had reached 2.5 US cents/kWh, demonstrating a clear cost advantage. In some African regions, fully zero-carbon electricity supply systems based entirely on solar PV, wind power and energy storage have already achieved costs below 4 US cents/kWh. These costs are expected to decline further to 2.5 US cents/kWh over the next five years.

Africa's future energy transition could therefore begin in regions with abundant solar and wind resources. Where hydropower is available nearby, or where pumped-storage hydropower facilities can be developed, the resulting energy systems could become even more competitive. Where hydropower is unavailable or pumped-storage facilities cannot be constructed, gravity-based energy storage and battery energy storage systems could provide alternatives. Well-designed electricity pricing mechanisms can also influence electricity demand and encourage load flexibility. An increasing number of industrial facilities are becoming capable of adjusting their electricity consumption on a large scale to match the generation profiles of solar PV and wind power.

Large industrial parks operating entirely off-grid and relying on solar PV and wind power are developing rapidly. In China, the 100% off-grid green hydrogen and ammonia project in Chifeng, Inner Mongolia, is being developed by Envision Group at the Yuanbaoshan Industrial Park. It is the world's first commercially operated, fully off-grid integrated green hydrogen and ammonia production project powered by wind and solar energy. The first phase, with an annual production capacity of 320,000 tons, has been completed and entered operation.

Two large zero-carbon industrial parks led by Contemporary Amperex Technology Co., Limited (CATL) in Dongying, Shandong Province, China, are also approaching completion. Drawing on Dongying's existing solar PV and wind power capacity of more than 10 GW, together with energy storage technologies, these facilities are

expected to provide zero-carbon electricity for industrial parks with an annual electricity demand of 5 TWh (Figure 4-4-1).

One of these projects, the Dongying CATL Zero-Carbon Industrial Park, is China's first zero-carbon industrial park designed to operate with 100% direct-connected green electricity. Led by CATL, construction began on 26 July 2025 in Dongying, Shandong Province, with a total investment exceeding approximately US$1.5 billion. The project adopts an integrated wind–solar system combined with grid-forming technologies to establish an independent energy supply system. Wind turbines, solar PV facilities and energy storage systems are directly connected to manufacturing facilities. Through intelligent energy management and large-scale battery storage systems, the project aims to provide stable electricity supply for 8,000 hours annually. Blockchain technology is also used to certify and trace the origin of renewable electricity.

On the generation side, the project includes 345 MW of renewable energy facilities, supported by an energy storage system with a rated power capacity of 300 MW and an energy storage capacity of 1,200 MWh. The industrial park's core development is a 40 GWh lithium-ion battery manufacturing facility. Upon its planned completion in 2026, the facility is expected to generate approximately US$3.9 billion in annual production value and US$180 million in annual tax revenue, while creating approximately 2,400 jobs.



Figure 4-4-1 Dongying Zero-Carbon Industrial Park in Dongying, Shandong, China

Source: Baidu Baike.

4.4.3 Power Grid Construction

According to the scenario analysis presented above, Africa could achieve a high level of electrification in the future, with electricity accounting for nearly 90% of primary energy supply by 2050. The development of electricity supply infrastructure will therefore be of critical importance.

Africa's power grid development is currently characterised by substantial infrastructure gaps, accelerating regional integration and the rapid expansion of distributed energy solutions to address electricity access needs. Transmission and distribution bottlenecks have become a major constraint on unlocking electricity investment across the continent. According to a 2023 World Bank report, grid constraints prevent up to 25% of operational generation capacity in some sub-Saharan African countries from being connected to the grid. Across Africa, more than 30 GW of generation capacity remains stranded, with numerous solar, wind and hydropower projects awaiting grid connections. Global annual investment in electricity grids currently amounts to approximately US$400 billion, of which Africa receives less than 10%, far below the level required to address its electricity infrastructure needs. The total length of transmission and distribution lines in Africa is only around one-seventh of that in China, while grid assets per capita are less than one-tenth of the global average.

Cross-border grid interconnection through Africa's five regional power pools is a central priority for electricity infrastructure development. In October 2026, Africa's first entirely privately financed cross-border transmission project, the 330 kV Kalumbila–Kolwezi interconnector, reached implementation. The 200 km transmission line has a designed transfer capacity of 700 MW. Once operational, it is expected to reduce diesel-based electricity generation costs in the Democratic Republic of the Congo's copper and cobalt mining region by more than US$1 billion annually, while enabling the export of surplus hydropower from Zambia. South Africa has introduced one of the continent's most ambitious grid expansion programmes, targeting the construction of 14,500 km of new transmission lines and the addition of 133,000 MVA of transformer capacity by 2034 to accommodate large-scale renewable energy integration.

Africa's relatively underdeveloped electricity grids could also provide a latecomer advantage. The construction of new electricity supply systems can be designed around emerging power system configurations, particularly those dominated by solar PV, wind

power and energy storage. Experience from Europe and China could be applied effectively in Africa, enabling the development of highly reliable electricity supply systems at lower costs.

With sufficient financing and the application of experience from established power systems in managing the variability of large-scale solar and wind generation, future grid development in Africa may not present an insurmountable challenge. Grid infrastructure can be planned and developed in an integrated manner alongside solar PV, wind power, energy storage and industrial centres. For example, the investment in Mingyang Group's solar PV, wind power, green hydrogen and ammonia project in Ethiopia includes the development of electricity grid infrastructure. This grid is intended not only to supply the industrial park but also to provide electricity to other sectors. The project could help provide electricity access to half of Ethiopia's population currently without electricity.

4.4.4 The Potential of Nuclear Power

Africa has already begun developing nuclear power. After decades of uncertainty and shifting attitudes worldwide, the outlook for nuclear energy is becoming increasingly promising. Nuclear power is expected to play an important role in Africa's future development of a highly reliable zero-carbon energy supply system.

The direction of global nuclear power development is becoming clearer. Large-scale investment in the construction and commercial operation of Generation III nuclear power technologies will demonstrate the potential for a more reliable and stable zero-carbon electricity supply system. The development of nuclear power in leading countries could also provide a strong foundation for its expansion across Africa.

The integration of nuclear power into Africa's energy mix could strengthen energy security. Nuclear power and hydropower could form the backbone of baseload electricity generation while also contributing to peak-load management. Advanced Generation III nuclear technologies may also help reduce the overall cost of electricity supply. As a latecomer, Africa could benefit from declining costs and technological advances in nuclear power, providing a foundation for the rapid development of nuclear energy across the continent.

5. Rapid Advances in Zero-Carbon Technologies

This chapter reviews advances in zero-carbon technologies worldwide. These technological developments provide a foundation for zero-carbon transitions in Africa and other countries and regions, offering the technological support needed for Africa's future zero-carbon transition and the development of its domestic economy.

5.1 Solar Photovoltaic Technology

Global advances in solar photovoltaic (PV) technology have been driven primarily by China, Japan, Australia, the United States and the European Union. Rapid technological progress has enabled solar PV deployment to exceed expectations in 2023 and subsequent years. In China, newly installed solar PV capacity reached 210 GW in 2023, bringing total installed solar power capacity to 610 GW. This surpassed the approximately 420 GW of installed hydropower capacity, making solar power the country's second-largest source of electricity generation capacity and further strengthening its position in the electricity mix.

Annual solar PV capacity additions increased to 277 GW in 2024 and reached 345 GW in 2025. Figure 5-1-1 presents the cumulative installed solar PV capacity worldwide.

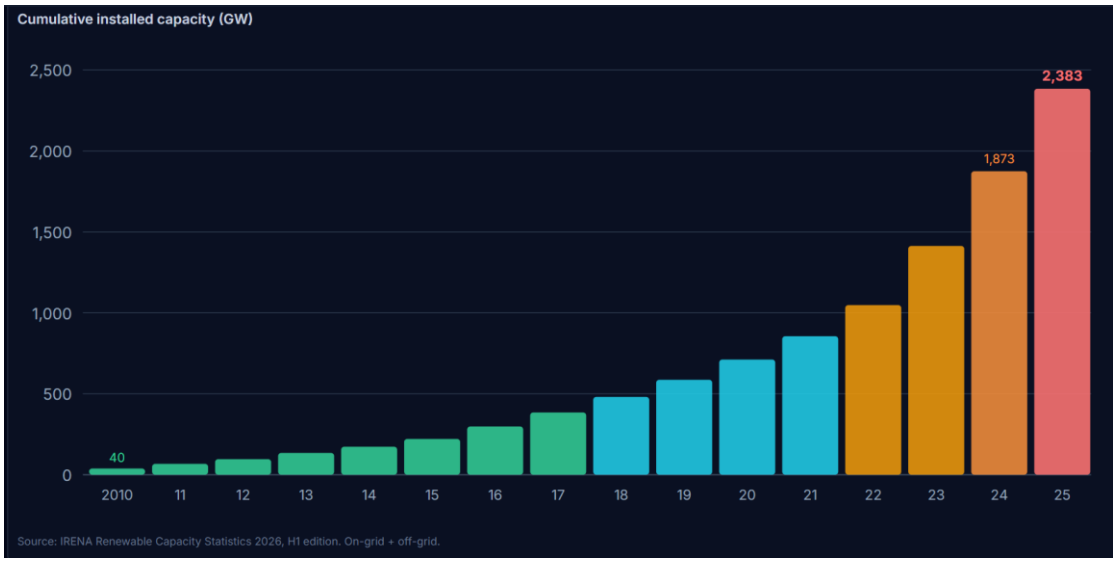


Figure 5-1-1 Global Cumulative Installed Solar PV Capacity, 2010–2025 (GW)

Source: IRENA (2026).

Like the semiconductor industry, the solar photovoltaic (PV) industry is characterised by rapid technological innovation, with successive generations of technology emerging every two to three years. Driven by technological advances, the levelised cost of electricity (LCOE) from solar PV declined by 89% between 2010 and 2022. Costs have continued to fall since 2022, ushering in an era of grid parity in which solar PV can expand through market competition without government support.

Figure 5-1-2 illustrates the exponential growth trajectory of global solar PV installations, highlighting the technology's increasingly dominant role in electricity capacity expansion. The sustained upward trend, even during periods of economic uncertainty, demonstrates the fundamental competitiveness of solar PV technology in today's energy markets. This exponential growth is expected to continue, with annual solar PV installations projected to enter the terawatt-scale market from 2027 onwards.

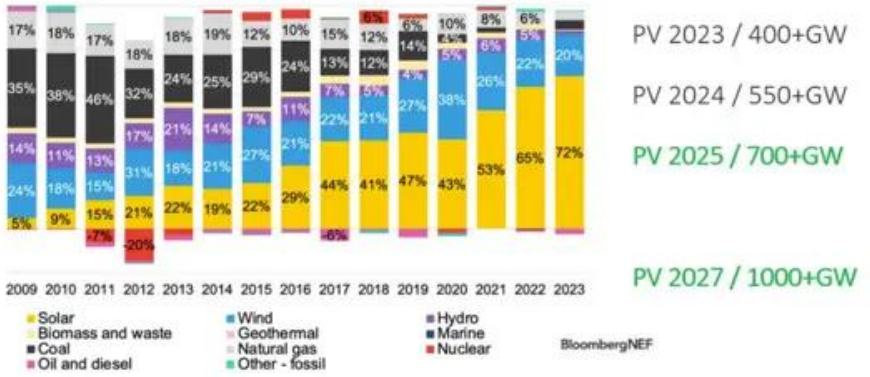


Figure 5-1-2 BloombergNEF's Illustration of the Growing Dominance of Solar PV in Annual New Power Capacity Installations, 2009–2023 (%)

Source: BloombergNEF (2026b), Energy Transition Outlook.

The photovoltaic technology landscape is becoming increasingly diverse, with various cell architectures competing in different market segments. TaiyangNews' 2025 Commercial Module Survey reveals a clear hierarchy of efficiency: back-contact (BC) technology leads the pack with a conversion efficiency of over 24%, followed closely by heterojunction (HJT) technology at over 23%, while TOPCon technology achieves an efficiency of 23%. Traditional PERC modules are currently targeted primarily at cost-sensitive projects, with efficiencies ranging from 21.5% to 22%.

The mainstream PV technologies in the market today primarily include PERC, TOPCon, and HJT. PERC technology is gradually being phased out. Given the current state of technological development, PERC cell efficiency has approached its limit of 24.5%, and costs are difficult to reduce further; consequently, the industry is gradually shifting its focus to other technologies. TOPCon and HJT (heterojunction) have become the mainstream choices today. Both technologies improve cell efficiency by reducing the recombination of photo-generated carriers. Relatively speaking, TOPCon cell production lines can be retrofitted from existing PERC lines, requiring a smaller equipment investment, which makes them more popular.

Heterojunction (HJT) solar cells require fewer manufacturing process steps. However, their relatively high equipment investment costs, high silver paste consumption and higher overall production costs have slowed their commercial deployment.

2023 was a major year for the expansion of Tunnel Oxide Passivated Contact (TOPCon) solar cell production capacity. Cumulative mass-production orders and

confirmed bids for laser-induced firing (LIF) equipment exceeded 100 GW, while signed contracts for TOPCon laser doping equipment surpassed 450 GW.

Compared with other technological pathways, Back Contact (BC) solar cells currently achieve the highest mass-production conversion efficiency, reaching 26.5%. They also have the highest theoretical efficiency limit of 29.4%, indicating considerable potential for further improvement. By comparison, the mass-production conversion efficiencies of both TOPCon and HJT cells are approximately 25.5%. In terms of theoretical efficiency limits, TOPCon reaches 28.7%, while HJT is slightly higher at 29.2%.

In terms of production costs, TOPCon cells cost approximately US$0.085/W, while HJT cells are slightly more expensive at US$0.088/W. BC cells demonstrate the strongest cost competitiveness, with production costs of approximately US$0.079/W.

Among the mainstream technologies currently on the market, the conversion efficiency benchmark for TOPCon cells generally hovers around 23%. However, it is worth noting that this benchmark is expected to continue rising. Perovskite cells have already achieved a breakthrough conversion efficiency of over 30%. Nevertheless, this technology has yet to resolve stability issues at this stage and still faces multiple challenges in terms of large-scale manufacturing and long-term maintenance. It is expected to take several more years of R&D before perovskite tandem cells can gain acceptance for commercial financing.

The period from 2024 to 2035 will be a time of competition among bifacial BC, HJT, and TOPCon technologies. During this phase, three major high-efficiency technology architectures will vie for market share: Back Contact (BC), Heterojunction (HJT), and TOPCon, all of which have achieved mass-production efficiencies exceeding 24%. Currently, TOPCon holds the largest market share, but this landscape may shift around 2028 or 2029 when BC technology becomes mainstream.

The period after 2035 will mark the integration of tandem cells with advanced BC technology. Technological development will advance towards a phase of innovative integration between tandem cell architectures and next-generation back-contact technology. The forefront of next-generation technology will likely involve perovskite-silicon tandem cell architectures, which are expected to break through the 30% efficiency barrier for commercial modules.

In June 2026, the procurement price of solar PV modules for several projects in

China was approximately US$0.091/W.

5.2 Wind Power

Since 2021, wind power technology has advanced significantly. Wind turbine technology has been evolving rapidly towards larger capacities, greater heights and lighter structures. By 2026, onshore wind turbines had entered the 8 MW and above category, while offshore wind power had achieved the installation of a 26 MW turbine and the completion of a 25 MW grid-forming turbine, setting several world records. The increasing size of wind turbines has substantially improved power generation efficiency.

Wind turbine rotor diameters have continued to increase, reaching 216 metres for onshore turbines and exceeding 300 metres for offshore turbines. Blade lengths have progressively increased from 99, 102, 103, 107, 110, 115.5, 118 and 123 metres to 153 metres for the latest 26 MW turbine, continuously setting new records.

Wind turbine hub heights have also increased substantially. In 2025, the mainstream hub heights of newly installed onshore wind turbines in China were concentrated in the range of 140–180 metres. Orders for towers with hub heights exceeding 160 metres surpassed 5,000 units, while orders for hub heights above 180 metres exceeded 500 units. Hybrid tower structures accounted for more than 90% of these orders. For newly installed offshore wind turbines in China, hub heights were primarily concentrated between 150 and 160 metres. A 17 MW floating offshore wind turbine jointly developed by China Huaneng Group and Dongfang Electric Corporation has a hub height of 152 metres.

Extended-lifetime wind turbine technology: By 2026, leading wind turbine manufacturers had extended the design operating life of wind turbines from the conventional 20 years to 25 years. This extension could increase total electricity generation profits over the equipment lifecycle by more than 56%, while further reducing the levelised cost of electricity (LCOE) by 6–7%.

Low-wind-speed turbine technology: Technological development focuses on large rotors and longer blades designed for low-wind-speed regions, together with advanced control systems for alternating loads in complex mountainous terrain. These innovations aim to unlock additional low-wind-speed resources for commercial electricity generation.

Development of higher-capacity turbines: Large-capacity onshore turbines in the 10 MW class and offshore turbines in the 20 MW class have entered large-scale deployment. Individual turbine capacities have increased more than fivefold compared with a decade ago, while swept area per unit of installed capacity has increased substantially, significantly improving wind energy capture efficiency.

Integrated wind power and energy storage technology: Integrated systems combine electricity generation, storage and supply within a single configuration. By adding modular energy storage units, sometimes described as storage "backpacks", conventional wind turbines can operate autonomously off-grid without extensive modifications. During wind farm construction, when grid connections may not yet be available, these systems can independently perform protective functions such as yaw control and vortex-induced vibration mitigation. Once connected to the grid, they can also store electricity during periods of strong winds and discharge it when wind speeds are lower, supporting peak shaving and load balancing.

Non-electricity applications of wind energy: Technologies such as wind-powered green hydrogen production and the synthesis of green ammonia and green methanol can convert intermittent wind electricity into zero-carbon fuels that can be stored over long periods and transported more easily. These fuels can subsequently be used in aviation fuels, green chemical production and low-carbon steelmaking, substantially expanding the potential applications of wind energy.

Offshore wind power technology: Offshore wind development is increasingly moving towards deeper waters and greater distances from shore. Floating foundations are expected to become a major direction for global offshore wind technology. Both the distance from shore and the water depth of offshore wind installations continue to increase. Monopile and jacket foundations are generally suitable for water depths of 20–60 metres, while offshore wind farms in waters deeper than 60 metres require floating foundation technologies.

As of October 2026, wind power had become one of the most economically competitive renewable energy technologies in China. The levelised cost of electricity (LCOE) for onshore wind power had declined to approximately US$0.029/kWh, while nearshore offshore wind power had reached around US$0.049/kWh. In high-quality onshore wind farms with favourable wind conditions in China's Three-North region (Northwest, North and Northeast China), generation costs could be as low as US$0.015–0.022/kWh, significantly below those of conventional fossil fuel-based

electricity generation.

Capital investment costs for wind power installations

Onshore wind power: In 2025, the benchmark total installed cost of onshore wind projects in China was approximately US$615/kW. High-quality wind farms on the northwestern plains achieved lower investment costs of approximately US$547–570/kW, while projects in the mountainous and hilly regions of southwestern China faced higher costs of around US$660–675/kW due to greater construction difficulties. In June 2026, the average winning bid price for onshore wind turbines, including towers, was approximately US$315/kW, while the average price excluding towers was only US$249/kW.

Offshore wind power: In 2025, the benchmark total installed cost of nearshore offshore wind projects in China was approximately US$1,424/kW, compared with around US$2,099/kW for projects in deeper waters farther offshore. In June 2026, the average winning bid price for offshore wind turbines, including towers, was approximately US$466/kW. In some large-scale centralised procurement projects, turbine prices fell to as low as US$275/kW.

Small-scale residential wind power: The investment cost of a household wind power system with a capacity of approximately 1 kW was around US$1,200–1,500. Complete small wind turbine units in the 1–5 kW capacity range were priced at approximately US$3,000–25,000, excluding additional installation and infrastructure costs.

In 2024, the global weighted-average LCOE of onshore wind power was US$0.034/kWh, approximately 53% lower than the cost of the cheapest fossil fuel-based electricity generation alternative. This made onshore wind power the most cost-competitive source of new electricity generation capacity worldwide. By comparison, the LCOE of offshore wind power projects outside China was approximately US$75–95/MWh in 2026, substantially higher than that of comparable projects in China.

Looking ahead to 2030, the LCOE of onshore wind power is expected to decline further to below US$0.0225/kWh. For deep-water floating offshore wind projects, the standardisation of floating foundations and the increasing specialisation of offshore construction vessels and equipment are expected to gradually bring installed costs per kilowatt closer to those of nearshore projects. These advances could enable floating offshore wind power to achieve grid parity and become commercially competitive

without subsidies.

5.3 Nuclear Energy

As of the end of 2024, there were approximately 440 nuclear power reactors in operation worldwide, with a total installed capacity of about 397 GWe; nuclear power accounted for approximately 10% of the global electricity supply. Approximately 70 reactors were under construction, with an expected addition of 77 GWe in installed capacity. Global nuclear electricity generation reached a record high of 2,667 TWh in 2024 (IAEA PRIS, n.d.; IAEA, 2025).

COP28 in 2023 marked an important turning point in the global policy environment for nuclear energy. Decision 1/CMA.5, adopted as the outcome of the first Global Stocktake under the Paris Agreement, explicitly identified nuclear energy alongside renewable energy, carbon capture, utilisation and storage (CCUS), and low-carbon hydrogen as zero- and low-emission technologies whose development should be accelerated. This marked the formal inclusion of nuclear energy in the global climate mitigation technology framework within a multilateral climate governance agreement (UNFCCC, 2024). At the same time, 25 countries endorsed a declaration during COP28 calling for global installed nuclear power capacity to be at least tripled by 2050 relative to 2020 levels. Based on approximately 393 GW of installed capacity in 2020, this corresponds to an aspirational target of nearly 1,200 GW by 2050 (U.S. Department of Energy, 2023).

Since then, support for the declaration to triple nuclear energy capacity has continued to expand. The number of endorsing countries increased to 31 during COP29 and reached 33 during COP30 following the accession of Rwanda and Senegal (World Nuclear Association, 2024, 2025). In March 2026, additional countries, including South Africa, China, Brazil, Belgium and Italy, joined the initiative, followed by Togo in September. As of October 2026, 39 countries had endorsed the declaration, including eight African countries: Ghana, Kenya, Morocco, Nigeria, Rwanda, Senegal, South Africa and Togo (World Nuclear Association, 2026a) (Figure 5-3-1).

It is important to note that endorsement of the declaration does not necessarily correspond to the maturity of nuclear power projects. Egypt, although not among the 39 endorsing countries, is the only African country currently constructing a large-scale commercial nuclear power plant (World Nuclear Association, 2026c). Meanwhile, several countries that have endorsed the declaration remain at the infrastructure

preparation stage. Endorsement therefore primarily reflects policy direction, while actual project implementation continues to depend on grid infrastructure, financing, regulatory frameworks and engineering readiness.

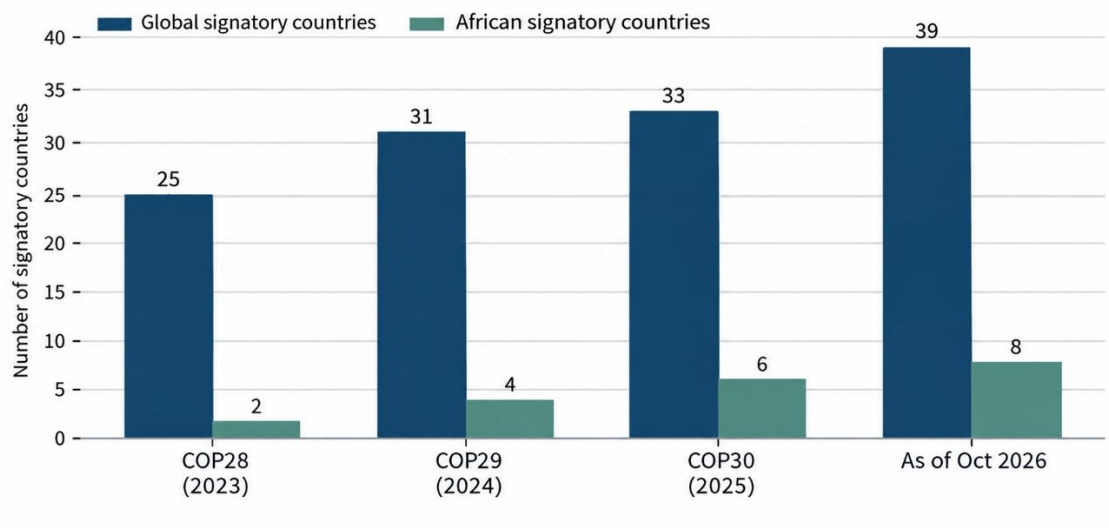


Figure 5-3-1 Changes in the Number of Signatories to the "Triple Nuclear Energy" Initiative, 2023–2026 (Number of Signatories)

Source: U.S. Department of Energy (2023); World Nuclear Association (2024, 2025, 2026a); authors' compilation.

From a broader perspective, the global nuclear energy debate is shifting from whether nuclear power is needed to whether new projects can secure financing, be replicated at scale and be delivered on schedule. Nevertheless, a substantial gap remains between policy ambitions and actual supply capacity. In its 2025 high-case projection, the International Atomic Energy Agency (IAEA) estimated that global operational nuclear power capacity could reach approximately 992 GW by 2050, still below the aspirational target of nearly 1,200 GW under the declaration to triple nuclear energy capacity (IAEA, 2025). According to IEA statistics published in 2026, global installed nuclear power capacity stood at approximately 420 GW at the end of 2025, with 78 GW under construction across 15 countries. New nuclear construction starts totalled 12.2 GW in 2025, while approximately 94% of reactors whose construction began over the past decade were based on Chinese or Russian designs (IEA, 2026d). These developments suggest that the main constraints on global nuclear power expansion are no longer primarily related to technological feasibility, but increasingly concern project financing, supply chain capacity, standardised licensing procedures, engineering delivery and the availability of skilled personnel.

As of October 2026, COP31 had not yet taken place and was scheduled to be held in Antalya, Türkiye, from 9 to 20 November 2026. According to the joint letter issued

by the COP31 Presidency and the President of the Negotiations, the conference's priorities include electrification and the energy transition, green industrial transformation, climate finance and resilience in vulnerable regions, with an emphasis on moving beyond commitments towards implementation (UNFCCC, 2026). This policy context has direct implications for nuclear power development in Africa. The discussion is increasingly focused on how nuclear energy can be integrated with electricity grids, industrial electricity demand, financing mechanisms and local capacity building to establish projects that are both implementable and sustainable over the long term.

As expectations for nuclear energy continue to rise, nuclear technologies are advancing rapidly. The main areas of technological progress are outlined below.

5.3.1 Third-Generation Nuclear Power Technology

Globally, third-generation nuclear power plants have now entered a mature implementation phase characterised by large-scale construction and grid connection, and they will be the dominant force in new global nuclear power projects in 2026. China's total capacity of third-generation reactors currently in operation and under construction ranks first in the world.

Globally, several mature, engineering-proven third-generation pressurised water reactor (PWR) technology systems have been established. The main technologies include:

China's Hualong One: One of the most widely accepted third-generation reactor series globally, it officially released its 2.0 upgrade in September 2026. This upgrade extends the reactor's ability to operate without intervention from 72 hours after an accident to 7 days, reduces the nuclear island volume by 21%, and significantly lowers construction costs.

U.S. AP1000: The world's first Generation III reactor to receive certification for its passive safety system, capable of operating without operator intervention for at least 72 hours following an accident. Units at the Sanmen and Haiyang projects in China have entered commercial operation, with the localisation rate of equipment rising to 80%.

French-German Joint EPR: Features a design with four independent safety systems, significantly reducing the probability of core damage. Unit 3 at Flamanville, France, officially connected to the grid and began commercial operation in December 2024.

Russian VVER-1200: A third-generation reactor model mass-produced domestically in Russia; Unit 2-1 at the Kursk plant is scheduled to be connected to the grid by the end of 2025. With a net capacity of 1,200 MWe per reactor, it is the core reactor model for Russia's overseas nuclear power exports.

South Korea's APR-1400: All four units at the Barakah Nuclear Power Plant in the United Arab Emirates have entered commercial operation, making the UAE the first country in the Middle East to achieve full-capacity operation of third-generation reactors.

Looking at the global trend of large-scale construction, China stands as the core market for third-generation reactor construction. Of the eight nuclear power units newly approved in August 2026, six utilise the Hualong One technology; these are the first nuclear power projects to be implemented during the 15th Five-Year Plan period. The construction period for a single unit has gradually converged from over 70 months for the first reactor to a standardised range of 55–60 months. Europe has resumed the pace of third-generation reactor construction. France has officially moved forward with preliminary preparations for two EPR2 units at Grafelin, while countries such as Finland and Poland have also successively initiated approval processes for their domestic third-generation reactor projects. Emerging nuclear power markets in Southeast Asia and the Middle East generally opt for mature, third-generation reactor designs—such as Hualong One and VVER-1200—that have been validated across multiple projects as the technical route for their first units, thereby significantly reducing the engineering risks associated with first-of-a-kind projects.

Currently and for the next 20 years, third-generation reactors possess a clear cost advantage that no other nuclear reactor type can match; in regions where the conditions for installing third-generation nuclear power exist, these reactors remain the preferred choice. At the same time, as third-generation reactors are commercially deployed, their safety is gradually gaining widespread recognition, laying a solid foundation for further expanding their application areas and scope in the future.

5.3.2 Small Modular Reactor (SMR) Technology

SMRs are intended for use in small-scale electricity or energy markets, particularly in remote areas or isolated grids that cannot be reached by long-distance transmission lines, where large reactors are not feasible. SMRs can meet the flexible power generation needs of a broader range of users and applications, including replacing

decommissioned fossil fuel power plants, providing small-scale cogeneration for developing countries or remote and off-grid areas, and enabling hybrid nuclear/renewable energy systems.

Highly innovative SMRs can offer new solutions to further enhance flexibility and promote distributed generation. Innovative designs include inherent safety features, modular design (integration of single or multiple reactor modules as needed), multifunctional applications (power generation, heating, and seawater desalination), factory integration, transport as a single unit, and installation as a single unit; as well as the application of other advanced technologies, such as high-performance fuel, increased burnup, and limited release of expansion and fission gases; accident-tolerant fuel capable of withstanding high temperatures without melting and preventing or limiting hydrogen generation in the event of an accident; improved in-core instrumentation offering greater accuracy and reducing conservatism in design analysis and operation; the application of digital technology and artificial intelligence; the use of new composite materials in low-pressure circuit systems to replace steel; and the use of advanced concrete with high mechanical strength and impermeability—all of which can significantly enhance the economic competitiveness of small modular reactors.

Small modular reactors are competitive compared to intermittent wind power, solar power, natural gas power generation, and diesel generators used for specific applications. If “plug-and-play” solutions—where the design is completely independent of the installation site—are proven viable, it may be possible to complete nuclear power projects in as little as 2–3 years, making them the optimal choice for meeting market demand and thereby contributing to the energy transition. The following are the various types of small reactors currently under development in China:

(1) Multifunctional Modular Small Reactor

The ACP100 is a modular pressurised water reactor (PWR) design developed by the China National Nuclear Corporation (CNNC) to generate 125 MW(e) of electricity. Based on existing PWR technology, the ACP100 employs a passive safety system and uses natural convection to cool the reactor. The ACP100 houses the main components of the reactor coolant system (RCS) within the reactor pressure vessel (RPV). The ACP100 is a multipurpose power reactor designed for electricity generation, heating, steam production, or seawater desalination, and is suitable for remote areas with limited energy or industrial infrastructure (IAEA, 2024b).

(2) Floating Nuclear Power Plants

A floating nuclear power plant combines a small nuclear reactor with a vessel, making nuclear power mobile. These plants typically use small nuclear reactors, which offer a high level of safety. Floating nuclear power plants can provide energy to offshore platforms, including electricity, steam, and heat, and can also desalinate seawater to supply fresh water to offshore platforms, thereby supporting offshore development. Floating nuclear power plants can also provide electricity and energy to isolated islands and enclosed bays.

(3) The Development of Mobile Nuclear Power Plants

The mobile nuclear reactors will be built in two capacities: 100 kW and 1 MW. These power plants can be moved safely and quickly by road, rail, sea, or air, and can be rapidly deployed and decommissioned to support various missions in desert regions, remote areas, and uninhabited zones.

(4) Pool-Type Low-Temperature Heating Reactor

The pool-type low-temperature heating reactor system is simple in design and primarily consists of the reactor system, primary circuit system, secondary circuit system, waste heat cooling system, refueling and spent fuel storage system, and auxiliary process systems. Heat enters the heating network after undergoing two heat exchange processes, ensuring that radioactive materials do not enter the heating network. Pool-type low-temperature heating reactors possess excellent inherent safety.

The pool has a large thermal capacity; even without any residual heat cooling measures, the more than 1,800 metric tons of pool water ensures that the reactor core will not be exposed, allowing the core to remain intact for 26 days without any intervention. They also demonstrate strong resistance to external events; since the pool is fully buried underground, this prevents nuclear accidents caused by damage to critical equipment resulting from natural or human factors; They are easy to decommission, with a small radioactive source, only one percent of that of a conventional nuclear power plant—and a simple system, resulting in a short decommissioning period; they offer significant environmental benefits, as a single 400 MWt low-temperature heating reactor can replace 320,000 metric tons of coal or 160 million cubic metres of natural gas.

Pool-type low-temperature nuclear heating reactors offer further opportunities for development and application. For example, they could provide heating in winter and

cooling in summer, with lithium bromide absorption chillers installed at the point of use to supply chilled water. Other potential applications include isotope production and neutron transmutation doping of single-crystal silicon. Pool-type low-temperature heating reactors could also be constructed at the sites of retired coal-fired combined heat and power (CHP) plants, reducing investment costs while maintaining heat supply through existing district heating networks.

5.3.3 Next-Generation Nuclear Power Technology

The widespread utilisation of nuclear energy must take into account the optimisation and efficient use of nuclear resources. In 2001, the Generation IV International Forum (GIF) initiated a joint research programme on future nuclear energy systems. GIF established technological objectives and associated evaluation criteria in six key areas: sustainability, economics, safety and reliability, waste minimisation, proliferation resistance, and physical protection. Six of the most promising nuclear reactor systems were selected. These include two gas-cooled reactor systems using helium, two liquid-metal-cooled reactor systems using sodium and lead alloys, one supercritical water-cooled reactor system, and one molten salt reactor system (Generation IV International Forum, n.d.).

(1) Sodium-Cooled Fast Reactor (SFR)

Among the selected reactor systems, almost all GIF member countries consider advanced sodium-cooled fast reactors (SFRs) using mixed oxide (MOX) fuel to have the greatest potential for commercial deployment during this century. China has completed the construction of an experimental sodium-cooled fast neutron reactor and is developing a 600 MWe sodium-cooled fast reactor demonstration power plant (CFR600). The CFR600 was scheduled for completion before 2025. Its primary objectives are to demonstrate a closed nuclear fuel cycle and establish standards and technical specifications for large-scale sodium-cooled fast reactors.

The main purpose of developing fast reactors is to breed nuclear fuel by enabling the fission of uranium-238 or its efficient conversion into plutonium-239 (Pu-239), thereby alleviating potential shortages of natural uranium resources. Fuel used in sodium-cooled fast reactors can achieve higher burnup levels, allowing it to remain in the reactor for approximately twice as long as fuel in thermal reactors. This can also reduce the concentration of minor actinides in spent nuclear fuel. In addition, sodium-cooled fast reactors can be designed to transmute long-lived radionuclides and

transuranic elements such as americium.

(2) High-Temperature and Very-High-Temperature Gas-Cooled Reactors

China began developing high-temperature gas-cooled reactors (HTGRs) in the mid-1970s, and the HTR-10 experimental high-temperature gas-cooled reactor was constructed in the 1990s. In 2023, the world's first commercial high-temperature gas-cooled reactor entered operation in Shandong Province, China (Tsinghua University INET, 2023).

The Shidaowan High-Temperature Gas-Cooled Reactor Demonstration Project has a total electrical capacity of 200 MW, with two reactor modules jointly driving a single turbine-generator unit. Construction officially began in December 2012, and the plant entered commercial operation in December 2023 after successfully completing a 168-hour continuous operation test.

The reactor features a low core power density and an inherent negative temperature reactivity coefficient, which automatically suppresses fission power as temperatures rise. Following reactor shutdown, decay heat can be removed naturally through heat conduction and thermal radiation, without relying on external emergency cooling systems. These inherent safety characteristics are designed to eliminate the risk of core meltdown.

The project employs modular pebble-bed high-temperature gas-cooled reactor technology, using chemically inert helium as the coolant. The helium temperature at the reactor core outlet reaches approximately 750°C, enabling an electricity generation efficiency of more than 40%, significantly higher than that of conventional pressurised water reactors.

(3) Thorium-based molten salt reactor

Thorium-based molten salt reactor (TMSR) systems use molten mixtures of fluoride salts containing lithium (Li), beryllium (Be), sodium (Na) and zirconium (Zr), together with dissolved fluorides of uranium (U), plutonium (Pu) and thorium (Th), as liquid nuclear fuel. These reactors operate at high temperatures of approximately 600–700°C under low pressure. LiF, NaF, BeF_2 and ZrF_4 serve as carrier salts, while UF_4 and PuF_3 provide fissile materials. ThF_4 and UF_4 serve as fertile fuel components, which can absorb neutrons and subsequently produce new fissile materials, including uranium and plutonium. Molten salt reactors use low-energy thermal neutrons to sustain nuclear fission reactions.

The structural components of molten salt reactors, including equipment and piping, are manufactured using high-temperature- and corrosion-resistant nickel-based alloys, particularly Hastelloy N. The molten salt transfers the heat generated by nuclear fission in the reactor core through an intermediate heat-transfer circuit to the thermal-to-electric power conversion system.

Construction of a thorium-based molten salt reactor began in Wuwei, Gansu Province, China, in 2020. As of November 2026, key technological validation had been completed, and the project had entered a critical stage in progressing towards engineering demonstration and practical deployment.

(4) Lead-cooled fast reactor

Lead and lead alloys have low neutron absorption and moderation capabilities, resulting in favourable neutron economy within the reactor and providing greater potential for nuclear waste transmutation and nuclear fuel breeding. Lead-based coolants have relatively low melting points and high boiling points, allowing reactors to operate at low pressure while achieving high coolant outlet temperatures. This reduces the risk of loss-of-coolant accidents associated with high-pressure systems and enables high thermal-to-electric conversion efficiency.

Lead-based coolants also exhibit high chemical stability and react only weakly with air and water, thereby reducing safety risks such as fires and explosions. Their effective heat-transfer characteristics and strong natural circulation capability allow residual heat to be removed through natural circulation, substantially enhancing the passive safety of the reactor.

Lead-cooled fast reactors (LFRs) offer high specific power, compact size and good operational stability, making them a feasible option for nuclear propulsion and mobile reactor applications.

5.3.4 Nuclear Fusion

Controlled nuclear fusion is an emerging industry of strategic importance for future energy security and the green, low-carbon transition. In recent years, continued breakthroughs in high-temperature superconductivity, plasma control and engineering integration have driven global fusion research and development from the demonstration of scientific feasibility towards a stage in which engineering development and

commercialisation are advancing in parallel. At the same time, differences among fusion technologies in terms of physical principles, engineering complexity, development timelines and levels of capital investment have become increasingly apparent, resulting in a competitive landscape characterised by the parallel development of multiple technological pathways. International research is progressing simultaneously across magnetic confinement, inertial confinement, and various emerging and hybrid confinement approaches. The development of these diverse technological pathways provides a foundation for further breakthroughs in nuclear fusion.

Driven by global efforts to achieve climate temperature goals, nuclear fusion technologies have advanced rapidly in recent years. Several projects have proposed demonstrating electricity generation around 2030, while substantial investment has also begun flowing into fusion research and development.

5.4 Energy Storage Technologies for Peak Load Management

As renewable energy deployment continues to accelerate, there is an increasing need for technologies that support peak load management and power system flexibility. Energy storage technologies offer rapid response capabilities, enabling the optimisation of the power generation mix and increasing the system's peak load regulation capacity. Integrating energy storage with thermal power plants to support grid peak load management can alleviate pressure on power system operations and reduce wind and solar power curtailment in regions with high renewable energy penetration.

5.4.1 Pumped-Storage Hydropower

Among the various energy storage technologies, pumped-storage hydropower is the most mature and widely established. Thermal energy storage has also reached the stage of large-scale deployment and is widely adopted in flexibility retrofits of coal-fired power plants in China. Lithium-ion battery energy storage has experienced rapid deployment over the past two years, while compressed air energy storage and flow batteries have also entered commercial application.

Pumped-storage hydropower offers several advantages, including technological maturity, low costs, long service life, large storage capacity and high efficiency. Its

operating principle involves converting energy between electricity and the gravitational potential energy of water. Storage capacity therefore depends primarily on the elevation difference between the upper and lower reservoirs and their water storage capacities. As losses caused by water evaporation and seepage are generally negligible, pumped-storage hydropower can retain stored energy for extended periods, making it suitable for a wide range of storage durations. System round-trip efficiency can reach 70–80%. In addition, the dam structures of completed pumped-storage facilities can have service lives of approximately 100 years, while electromechanical equipment is expected to operate for around 40–60 years.

The initial investment cost of pumped-storage hydropower is closely related to project location and site conditions. As the most economically attractive sites are progressively developed, future projects may face higher upfront investment costs. Assuming 300–500 operating cycles and excluding the cost of electricity used for charging, the levelised cost of electricity (LCOE) for conventional pumped-storage hydropower is estimated at approximately US$0.034–0.051/kWh.

5.4.2 Battery Energy Storage

Lithium-ion batteries can be broadly divided into two mainstream categories according to their cathode materials: ternary lithium batteries and lithium iron phosphate (LFP) batteries. LFP batteries have lower energy density than ternary lithium batteries, but they also offer lower costs. Since energy density is generally less critical for stationary energy storage applications, LFP batteries are increasingly preferred due to their lower costs and longer service life. According to the latest data from the International Energy Agency (IEA), the global battery energy storage market experienced accelerated growth in 2025, particularly in countries such as Australia and Saudi Arabia. In countries that have consistently led battery storage deployment, these systems are already playing a critical role in continuously balancing electricity supply and demand.

By 2026, the levelised cost of storage (LCOS) over the full lifecycle of mainstream LFP energy storage systems in China had declined to approximately **US$0.042–0.067/kWh**. Initial system investment costs had generally fallen to around **US$150/kWh**, while significant cost differences remained across different technological pathways.

In September 2026, the average winning bid price for two-hour battery energy storage engineering, procurement and construction (EPC) projects in China fell below US$146/kWh for the first time, reaching approximately US$145.6/kWh. Standardised gigawatt-hour-scale projects demonstrated particularly strong cost advantages through economies of scale. By comparison, the average winning bid price for one-hour peak-shaving storage projects remained substantially higher, at approximately US$292/kWh.

In overseas markets, the LCOS of four-hour battery energy storage systems in the Middle East and Africa was approximately US$120/MWh in 2026, already below the cost of peak-load electricity generation from local open-cycle gas turbines.

Economies of scale have become increasingly significant. The unit cost of a 1 MWh energy storage project is approximately 40% lower than that of a small-scale 10 kWh project. Furthermore, each doubling of production capacity can reduce unit manufacturing costs by approximately 15–20%.

Future battery energy storage cost reductions are expected to be driven by three major technological pathways.

Material substitution: Sodium-ion batteries, which use low-cost raw materials such as sodium carbonate, could achieve lifecycle costs 20–30% lower than those of LFP batteries. Aqueous sulphur-based flow batteries have a theoretical cost of only one-tenth that of conventional all-vanadium redox flow batteries.

Manufacturing process innovation: Cell-to-pack (CTP) technology, which directly integrates battery cells into battery packs, can reduce the use of structural components by approximately 40%. Dry electrode manufacturing processes can reduce production energy consumption by around 30%, while advances in 4680 large-format cylindrical battery technology can increase production capacity by approximately 30%.

Residual value recovery and second-life applications: Repurposing retired electric vehicle batteries for stationary energy storage systems could reduce initial investment costs by approximately 60%, substantially lowering the levelised cost of storage over the system lifecycle.

The material cost of sodium-ion batteries is approximately US$55/kWh and is expected to decline further as the supply chain matures. Including structural and electrical components, the initial investment cost per unit of storage capacity could be reduced to approximately US$75–105/kWh. In terms of performance, continued research and development and technological advances are expected to extend battery

cycle life beyond 8,000 cycles.

2026 marks the beginning of large-scale commercialisation of sodium-ion battery energy storage. The industry is transitioning from demonstration projects at the hundreds-of-MWh scale to large-scale deployment at the GWh level, becoming a major low-cost complement to lithium-ion battery energy storage systems.

Recent technological breakthroughs in sodium-ion batteries include the maturation of two mainstream cathode technology pathways, layered oxides and polyanionic compounds, suited to electric mobility and energy storage applications, respectively. Sodium iron phosphate-based composite materials have achieved cycle lives exceeding 15,000 cycles, while some innovative products can reach 20,000 cycles, supporting stable energy storage system operation for 15–20 years. Significant breakthroughs have also been achieved in anode materials, with hard carbon anodes entering large-scale industrial production. Biomass-derived hard carbon has achieved a reversible capacity of 354.7 mAh/g and an initial Coulombic efficiency of 85.8%. System performance has improved substantially. CATL's second-generation Naxtra sodium-ion battery cells have achieved an energy density of 175 Wh/kg, while experimental pouch-cell samples have exceeded 225 Wh/kg. Capacity retention at −20°C exceeds 90%, and the operating temperature range extends from −40°C to 80°C, significantly improving suitability for a wide range of applications. Safety performance has also improved, with the full product range passing overcharging, over-discharging, short-circuit and nail penetration safety tests without fire or explosion. Thermal runaway onset temperatures are significantly higher than those of lithium iron phosphate batteries, meeting the stringent safety requirements of large-scale grid-connected energy storage.

The cost and economic advantages of sodium-ion batteries are primarily reflected in their significantly lower raw material costs. Sodium resources are approximately 440 times more abundant than lithium resources. Sodium carbonate costs only around US$150 per ton, substantially lower than the approximately US$22,490 per ton of lithium carbonate. Aluminium foil can be used for both positive and negative electrode current collectors, eliminating reliance on copper foil. With large-scale production, system costs could be 30% lower than those of lithium iron phosphate batteries. Price volatility is very low, with sodium-ion batteries largely unaffected by sharp fluctuations in international lithium prices, significantly improving the predictability of investment costs over the full lifecycle of energy storage projects and making them well suited to the cost management requirements of long-duration grid-side energy storage. Sodium-

ion batteries also offer advantages in lifecycle electricity storage costs. For long-duration energy storage applications exceeding four hours, the levelised cost of storage (LCOS) could reach approximately US$0.052–0.082/kWh. In specific applications, such as low-temperature environments and high-rate fast charging, their economic competitiveness has already surpassed that of lithium iron phosphate batteries.

The main applications of sodium-ion batteries include large-scale grid-side energy storage, where they are becoming one of the preferred technological options for independent energy storage facilities supporting large-scale solar PV and wind power projects. They are suitable for peak load management applications requiring storage durations of four to eight hours, substantially reducing the costs of renewable energy integration. In extremely cold regions, they can operate at full power at temperatures below −20°C without additional heating, addressing the low-temperature performance degradation of conventional lithium-ion batteries. In integrated computing and electricity systems and data centre backup power applications, they can reach 80% charge within 15 minutes, with high-rate charging and discharging capabilities well suited to instantaneous peak load regulation and backup power supply. In telecommunications base station backup systems, low-speed vehicles and residential solar-plus-storage applications, their long cycle life and high safety characteristics enable them to replace conventional lead-acid batteries, with a potential market exceeding US$15 billion.

However, sodium-ion batteries still face considerable challenges. The maturity of their supply chain remains below that of lithium-ion batteries, production yields for certain core materials still require improvement, and the full potential for cost reduction across the value chain has not yet been realised. A comprehensive lifecycle recycling system has yet to be established, while sodium-ion-specific recycling processes and commercially viable recycling business models remain under development. Long-term operational data for some specialised applications are still being collected, and further experience is needed in the long-term operation and maintenance of large-scale energy storage facilities.

5.4.3 Compressed Air Energy Storage

Compressed air energy storage technologies have continued to advance in China. Research covers compressed air energy storage (CAES), advanced adiabatic

compressed air energy storage (AA-CAES), supercritical compressed air energy storage (SC-CAES), and liquid air energy storage (LAES). Demonstration projects with capacities of 500 kW, 1.5 MW and 10 MW have been completed. Among these, the world's first 100 MW advanced compressed air energy storage demonstration project in Zhangjiakou was successfully connected to the grid at the end of 2021, with its research and development progress and system performance reaching internationally leading levels.

Improvements in system efficiency and reductions in costs provide the foundation for the commercial development of compressed air energy storage. Based on completed projects and those under construction, MW-scale systems can achieve an efficiency of 52.1%, while 10 MW systems can reach 60.2%. The designed efficiency of systems with capacities of 100 MW or above can reach 70%, and advanced compressed air energy storage systems can approach 75%. As system capacity increases, unit investment costs continue to decline. Each tenfold increase in system capacity can reduce unit costs by approximately 30%. In 2022, for a 100 MW/400 MWh system with an initial investment of US$0.75–0.90/W and 450–600 annual operating cycles, the levelised cost of electricity ranged from US$0.038 to US$0.062/kWh.

By the end of June 2026, China's cumulative installed compressed air energy storage capacity had reached 1.433 GW/9.088 GWh. Newly installed capacity in 2025 amounted to 1.3 GW/7.4 GWh, representing year-on-year growth of more than 80%, substantially exceeding the average growth rate of new energy storage technologies overall.

Projects under construction have a combined capacity of 3.85 GW/19.05 GWh, with estimated total investment exceeding US$3.97 billion. More than 70% of this capacity is concentrated in regions hosting large-scale renewable energy bases, including Inner Mongolia and northwestern China, with the primary purpose of providing long-duration grid-side flexibility.

The main performance advantages of compressed air energy storage include its high level of safety. Ordinary air is used as the storage medium, eliminating flammability and explosion risks associated with the storage medium and avoiding chemical pollution throughout the system lifecycle. The designed service life can reach 40 years, with no significant capacity degradation during operation. Compressed air energy storage also provides strong grid support capabilities. It can supply rotational inertia comparable to that of conventional thermal power plants and requires only 6–8

minutes from the issuance of a dispatch instruction to grid-connected electricity generation. With grid-forming capabilities, it can directly address frequency stability challenges in power systems with high shares of renewable energy. Its economic performance is particularly favourable for long-duration storage. For applications requiring more than four hours of storage, its electricity storage cost is already lower than that of lithium-ion battery systems of comparable scale, with a lifecycle levelised cost of storage of approximately US$0.045–0.075/kWh.

Compressed air energy storage also faces several challenges. Initial unit investment costs remain higher than those of electrochemical energy storage systems, with the unit construction cost of a 100 MW-scale project at approximately US$225/kW. Further large-scale cost reductions still depend on the development of supporting industrial supply chains. Suitable salt cavern resources are geographically concentrated, while the integration of large-scale systems using artificial air storage facilities remains technically challenging. A unified industry standards framework has yet to be fully established. Commercial revenue models continue to rely primarily on grid peak load management and ancillary services, and some projects remain temporarily dependent on policy subsidies.

5.4.4 Other Energy Storage Methods

Several other energy storage technologies also have the potential to enter commercial application, mainly including phase-change energy storage and water reservoir thermal energy storage.

(1) Phase-Change Energy Storage

Phase-change energy storage technology utilises the ability of phase-change materials to absorb or release large amounts of latent heat during transitions between solid and liquid or gas and liquid states, enabling high-density energy storage and the transfer of energy across time and space. It is currently a major technological direction in long-duration energy storage, industrial waste heat recovery and building energy efficiency. During 2025–2026, significant advances were achieved in materials development, system process innovation and industrial applications across multiple sectors.

Phase-change energy storage is rapidly expanding from specialised applications,

such as industrial waste heat recovery and temperature control, into mainstream applications including long-duration electricity storage, residential building energy efficiency and power battery thermal management. As material costs decline further, phase-change energy storage is expected to become one of the major technological pathways supporting the stable operation of modern power systems, alongside electrochemical energy storage.

Current applications include the world's first 100 MW-class compressed CO_2 phase-change energy storage project, which was successfully connected to the grid in Mulei, Xinjiang, in 2026. Taking advantage of the fact that CO_2 can be liquefied at approximately 28°C under a pressure of 7 MPa, the project has an annual electricity generation capacity of approximately 200 million kWh, providing a new pathway for long-duration energy storage.

Medium- and high-temperature phase-change thermal energy storage applications in energy-intensive industries, such as steelmaking and chemicals, are expected to expand at an annual rate of 22%, supporting the development of systems for efficient, cascading recovery and utilisation of industrial waste energy and deep decarbonisation in industries such as petrochemicals and metallurgy. Building energy efficiency is also becoming the largest area of demand. The increasing adoption of passive ultra-low-energy buildings is expected to drive large-scale applications of phase-change walls and phase-change roof insulation panels. Temperature control applications in data centres are expanding rapidly. Phase-change-based peak load reduction and liquid cooling solutions are expected to be progressively deployed in large data centres, with particularly rapid growth anticipated over the next five years, becoming an important technology for further reducing data centre power usage effectiveness (PUE). Distributed residential applications are also expected to expand substantially. The adoption of residential phase-change energy storage systems integrated with distributed solar PV is projected to increase rapidly, particularly in regions with abundant solar and wind resources, significantly reducing differences between peak and off-peak household electricity demand (*China Phase-Change Energy Storage Industry Development and Outlook Report*, 2026).

(2) Water Reservoir Thermal Energy Storage

Water reservoir thermal energy storage represents a fundamentally different approach based on replacing electricity storage with thermal energy storage. For storage discharge durations exceeding six hours, thermal energy storage offers a low-

investment, high-efficiency alternative to electricity storage. The investment cost per unit of thermal storage capacity is only approximately US$0.30–0.90/kWh, substantially lower than approximately US$75/kWh for lithium-ion batteries and US$60–75/kWh for pumped-storage hydropower. This reduces storage costs by approximately two orders of magnitude and fundamentally changes the economics of long-duration energy storage.

Water-displacement thermal energy storage technology offers significant advantages. Technical comparisons have identified insulated hot-water reservoirs with thermal covers as the most suitable approach for seasonal thermal energy storage. Thermal storage efficiency can reach 85–90%, while construction costs are only approximately US$60–150/GJ, substantially lower than those of other thermal storage methods, including underground heat exchangers and phase-change materials. In addition, no additional electricity is required to operate heat pumps to raise the temperature of the stored heat.

This technology has already been applied in China. Five seasonal thermal energy storage reservoirs, each with a capacity ranging from 10,000 to 85,000 m^3, have been constructed. One of these is currently the world's largest thermal storage reservoir in terms of capacity and operates at the highest storage temperature. Demonstration projects in Zhongba County, Tibet, and Fanshan Town, Zhangjiakou, among other locations, have been operating reliably, with actual performance fully meeting design requirements.

5.5 Microgrid and Off-Grid Systems

As many regions face increasing pressure to integrate renewable energy into existing power grids, the development of microgrids or independent power systems could provide a solution. With rapid advances in renewable energy technologies, regions with favourable renewable energy resources can utilise solar PV and wind power on a large scale and at low cost. Research by the IPAC modelling team also indicates that many industries can align their electricity demand with the generation characteristics of solar PV and wind power, thereby meeting production and daily living needs without relying on external electricity supplies.

With advances in renewable energy and energy storage technologies, together with

the development of industries that do not require energy storage, local electricity supply systems could potentially rely entirely on locally generated electricity without support from the main grid, forming relatively independent power supply systems.

Declining costs of water electrolysis for hydrogen production and the development of hydrogen-based industries have substantially improved the feasibility of industrial activities that can adapt to the generation characteristics of solar PV and wind power. The development of such industries makes independent power supply systems increasingly feasible.

Early stage: Off-grid technologies initially consisted mainly of standalone solar PV systems, primarily addressing basic electricity needs in remote areas such as unelectrified rural communities and border outposts. System configurations were relatively simple, generally relying on basic combinations of solar PV and lead-acid batteries.

Demonstration and expansion stage: After 2010, off-grid technologies gradually evolved towards hybrid systems integrating solar PV, wind power and energy storage. Applications expanded to island communication base stations, remote exploration camps and similar locations. Key components, including maximum power point tracking (MPPT) controllers and pure sine wave inverters, increasingly became domestically manufactured in China.

Large-scale commercialisation stage: Since 2023, substantial reductions in solar PV and energy storage costs have transformed off-grid technologies from a solution adopted out of necessity into a more competitive alternative. Commercial applications have emerged in energy-intensive industries and off-grid hydrogen production, with lifecycle costs significantly lower than those of conventional grid connections or diesel-only power supply systems.

Major technological advances in 2026 include:

Significant improvements in core hardware performance: Solar PV module conversion efficiencies have exceeded 23%, while new-generation lithium iron phosphate batteries have achieved improvements in energy density. Overall system costs have declined by 8% year on year. The widespread adoption of silicon carbide power electronic devices has increased inverter conversion efficiencies to more than 99%, while electricity generation under low-light conditions has improved by 10–30%.

Maturation of technologies for extreme environments: Wide-temperature-range

battery cells have become standard components in industrial off-grid systems, with operating temperatures ranging from −40°C to 65°C. Capacity retention remains above 80% after 3,000 cycles, enabling stable year-round operation in extreme environments such as high-altitude regions, extremely cold areas and islands exposed to high levels of salt spray.

Widespread adoption of intelligent operation and maintenance: Predictive operation and maintenance systems based on edge computing and cloud-based digital twins have become standard configurations. By collecting 12 categories of key operational parameters and applying long short-term memory (LSTM) neural networks, these systems can achieve state of charge (SOC) and state of health (SOH) estimation errors of no more than 2.5%, provide fault warnings at least 72 hours in advance, and reduce lifecycle operation and maintenance costs by 34%.

Substantial improvements in system integration: The adoption of modular prefabricated systems has increased rapidly. Complete system equipment is integrated into standard shipping containers, with system commissioning and safety certification completed before delivery. On-site installation and commissioning periods have been reduced from 12–16 weeks to 5–7 working days, while interface protocols have become fully standardised.

Distinct regional distribution patterns: Northwestern China accounts for 35% of the country's large-scale off-grid microgrid projects. In southwestern China, household off-grid systems have achieved a household coverage rate of 70%. Eastern coastal regions focus on typhoon-resistant off-grid equipment for offshore platforms and islands, while shipments of specialised low-temperature-resistant products in northeastern China have increased by 20% year on year.

Increasing commercial competitiveness: The simple payback period for industrial off-grid systems has shortened to 4.2–5.8 years. In remote communication base station applications, diesel generator start-up frequency has declined from once per day to once per month, directly reducing fuel costs by 80% and eliminating dependence on policy subsidies.

Looking ahead, the total lifecycle cost of complete off-grid systems is expected to decline by a further 20% by 2030, while overall system reliability is projected to reach 99.9%. The market potential in specialised industries and high-end consumer applications is expected to reach hundreds of billions of yuan. Low-cost energy storage

technologies, including sodium-ion batteries, are expected to achieve large-scale commercial deployment, further reducing dependence on lithium resources and expanding off-grid technologies into a wider range of applications.

In 2026, CATL's 100% renewable electricity supply system for a large zero-carbon industrial park in Dongying, Shandong Province, China, introduced a new model of electricity supply based on solar PV and wind power. Despite the industrial park's substantial electricity demand, the system operates entirely independently of the main electricity grid, with the potential to supply electricity at a lower price than grid electricity.

5.6 Hydrogen-Based Industries

Hydrogen is an emerging industrial material and energy carrier with considerable potential for widespread applications in transport, industry and residential sectors. With the substantial decline in renewable energy costs, hydrogen production through water electrolysis powered by renewable electricity has become a commercially competitive technological pathway towards zero-carbon development, providing important support for the growth of hydrogen-based industries. By using renewable electricity for water electrolysis, China can produce low-cost green hydrogen on a large scale, further promoting the development and application of hydrogen technologies, optimising the energy mix and supporting sustainable regional economic development.

5.6.1 Hydrogen Production Technologies

Compared with conventional hydrogen production methods, the key factor determining the cost of renewable hydrogen production is the electricity price. Electricity accounts for approximately 70% of the cost of hydrogen production through water electrolysis. Producing 1 m^3 of hydrogen consumes approximately 4 kWh of electricity and 0.8 kg of water. Water electrolysis also produces oxygen as a by-product at a hydrogen-to-oxygen ratio of 2:1, and revenue from oxygen sales can offset part of the hydrogen production cost.

When electricity is purchased from the grid at commercial tariffs, the cost of hydrogen production through water electrolysis is substantially higher than that of other hydrogen production methods, making it economically uncompetitive. This is one of

the main reasons why water electrolysis has not yet achieved widespread large-scale deployment.

When electricity prices are reduced to approximately US$0.0375/kWh, the cost of hydrogen production through water electrolysis becomes comparable to that of conventional methods. Electricity prices below this level provide a cost advantage.

Over the past five years, the cost of renewable hydrogen production through electrolysis has declined by 40% in Europe and North America, while systems manufactured in China are 80% cheaper than those produced in Western countries. Costs are expected to decline further as electrolyser deployment expands. By 2050, renewable hydrogen production costs are projected to fall to US$0.8–1.6/kg, equivalent in energy terms to natural gas priced at US$6, making renewable hydrogen cost-competitive with current natural gas prices. Including storage and pipeline infrastructure costs, the delivered cost of renewable hydrogen could decline to approximately US$2/kg by 2030 and US$1/kg by 2050.

In 2024, the decline in alkaline electrolyser prices in China was expected to slow, while proton exchange membrane (PEM) electrolysers could experience substantial market price reductions. Electrolyser market prices depend on technological standards, the maturity of component supply chains, research and development costs, production scale, and market supply and demand. As alkaline electrolysers and PEM electrolysers are at different stages of technological development, the main factors influencing their market prices and the pace of cost reductions also differ. In 2024, the average price of alkaline electrolysers in overseas markets was expected to decline to approximately US$360,000/MW, while the domestic average in China was expected to fall to approximately US$217,000/MW.

Overseas alkaline electrolysers remain relatively expensive due to the need to comply with higher technical standards. In 2023, the average market price of alkaline electrolysers overseas was approximately US$360,000/MW. By 2024, growing demand was expected to reduce the average price to around US$330,000/MW. On the one hand, the scale of overseas green hydrogen projects and demand for alkaline electrolysers were increasing rapidly, driving higher production volumes and consequently reducing manufacturing costs and market prices. At the same time, many large-scale green hydrogen projects overseas were at the engineering design stage, making it likely that multiple orders ranging from tens to hundreds of megawatts would emerge in 2024. The concentration of these orders was expected to further reduce prices.

In China, alkaline electrolyser prices have continued to decline rapidly, benefiting from a mature supply chain and expanding market scale. In 2023, the average winning bid price for 5 MW-class alkaline electrolysers was approximately US$226,000/MW, representing a decrease of around 16% compared with 2022. By 2024, upgrades to technical standards were expected to slow the decline in domestic alkaline electrolyser prices, with average prices remaining above US$210,000/MW. As domestic green hydrogen projects gradually moved from demonstration to commercial operation, market requirements for alkaline electrolysers were shifting from basic functionality towards improved performance and reliability. Meanwhile, to expand into overseas markets, Chinese alkaline electrolyser manufacturers were expected to gradually align their technical standards with international requirements. This would drive further technological development and increase demand for high-performance electrodes, membranes and other components, keeping research and development and component costs relatively high.

Between 2021 and 2025, the price per unit of power capacity for proton exchange membrane (PEM) electrolysers in China declined substantially from more than US$1,500/kW, representing a cumulative reduction of 39% over four years. The main drivers were breakthroughs in the domestic production of core materials, expansion of manufacturing capacity and intense industry competition.

Overseas PEM electrolysers have reached relatively low market prices due to comparatively well-developed supply chains and substantial market demand. In 2023, the average international market price of PEM electrolysers was approximately US$1.20 million/MW. By 2024, the overseas average was expected to decline slightly to around US$1.12 million/MW. On the one hand, overseas demand for PEM electrolysers was expanding alongside the accelerated development of green hydrogen projects, contributing to further price reductions. At the same time, considering the relatively high cost of precious metal materials used in PEM electrolysers and the already mature overseas supply chain, international PEM electrolyser prices were expected to remain within the range of approximately US$1.05–1.20 million/MW in 2024. In China, PEM electrolyser prices also began to decline as domestic supply chains gradually improved.

For example, Saudi Arabia planned to develop large-scale green hydrogen projects, with an investment of US$5 billion in green hydrogen production. Egypt committed US$40 billion to green hydrogen investment in 2022, while China Energy Engineering

Corporation was expected to begin construction of a hydrogen energy project in Egypt in 2024.

5.6.2 Hydrogen-Based Industrial Application Technologies

The green hydrogen-based industrial production technologies that are currently ready for commercial-scale production primarily include ammonia synthesis, methanol production, olefin production, and steelmaking technologies.

(1) Synthetic Ammonia Production Using Green Hydrogen

The production of ammonia using green hydrogen is relatively straightforward from a process perspective. Conventional ammonia production already relies on the synthesis of hydrogen and nitrogen. Green hydrogen replaces the conventional hydrogen production process, without requiring substantial changes to the ammonia synthesis process itself.

The current mainstream technological pathway combines green hydrogen with the Haber–Bosch process. This approach has already been demonstrated in commercial applications, such as Envision Group's green ammonia project in Inner Mongolia, China.

The main technological advances in this process include flexible hydrogen production, typically using alkaline electrolysers (ALK) to provide baseload hydrogen production and proton exchange membrane (PEM) electrolysers to respond rapidly to fluctuations in solar and wind power output. A hybrid configuration improves operational flexibility. Hydrogen storage systems, using either gaseous or solid-state storage, can buffer fluctuations in renewable electricity supply, allowing hydrogen to be delivered steadily to the ammonia synthesis reactor. Intelligent scheduling across the entire production process uses integrated electricity–hydrogen–chemical control systems to adjust plant loads flexibly over a wide operating range. Demonstration projects have achieved load variations between 30% and 110%, enabling operations to follow forecasts of solar and wind power output. Energy efficiency improvements involve thermal integration of electrolysis, air separation, ammonia synthesis and synthesis gas compression, using heat generated by the synthesis reaction to supply upstream processes. Some configurations integrate solid oxide electrolysis cells (SOECs) with waste heat from ammonia synthesis, potentially achieving a theoretical

electricity-to-ammonia conversion efficiency of approximately 70%.

A potential future technological pathway is direct electrochemical ammonia synthesis, an emerging alternative that bypasses the Haber–Bosch process. This technology uses electricity to drive the direct reduction of nitrogen to ammonia and can operate at ambient temperature and pressure, making it particularly suitable for integration with distributed renewable electricity.

(2) Methanol Production Using Green Hydrogen

Methanol production using green hydrogen is also based on relatively mature technologies, with commercial projects already implemented. China, Europe, Iceland, India and Australia have developed different advantages in technological development, demonstration projects and regional deployment, forming an industry characterised by multiple centres of development.

In China, the first phase of Goldwind's 1.45 million ton green methanol project in Hinggan League, Inner Mongolia, with an annual capacity of 250,000 tons, has entered operation. The first shipment was delivered to Busan, South Korea, in September 2026, marking the beginning of large-scale exports. Baofeng Energy has planned an annual green hydrogen production capacity of 3.1 billion standard cubic metres, supporting a green methanol production capacity of 1.45 million tons. The first phase of Shanghai Electric's project in Taonan, Jilin Province, has entered operation, while the second phase includes a planned green methanol capacity of 200,000 tons per year and is scheduled to begin operation in 2028.

In Iceland, Carbon Recycling International (CRI) established the world's first geothermal electricity-powered CO_2-to-methanol plant in 2012, making it one of the earliest companies to commercialise green hydrogen-based methanol production. In India, ACME Group is developing a large-scale green methanol project in Odisha, drawing on the country's low-cost solar PV resources and targeting markets in South Asia and the Middle East. It is among the fastest-moving companies outside China in the Asia-Pacific region in developing green hydrogen-derived fuels.

Large-scale development of green hydrogen-based methanol production began in 2026. In regions with favourable zero-carbon electricity resources, methanol produced using green hydrogen could become cost-competitive with conventionally produced methanol over the coming years.

(3) Olefins Production Using Green Hydrogen

Olefins production using green hydrogen is an area with considerable future potential. Olefins can be transported over long distances and in large quantities, and are widely used in end products such as synthetic fibre-based clothing, plastics and household furnishings. Green hydrogen-based olefins production is a technological pathway that uses renewable hydrogen as a key feedstock, combined with CO_2, syngas or low-carbon hydrocarbons, to produce low-carbon olefins such as ethylene and propylene. It is one of the main pathways towards deep decarbonisation of the petrochemical industry. In recent years, substantial progress has been made in catalyst development, process innovation and industrial applications.

In October 2026, Sinopec successfully established a complete process for producing ethylene from green hydrogen and CO_2 and began industrial-scale production. Currently, a significant proportion of olefins are produced through the methanol-to-olefins (MTO) process. In the future, direct production of olefins from green hydrogen and CO_2 could offer greater cost competitiveness.

(4) Hydrogen-Based Steelmaking

Hydrogen-based steelmaking is a key pathway towards deep decarbonisation of the global steel industry. Its core principle is to completely replace conventional coal and coke with hydrogen as the reducing agent for iron ore, reducing iron oxides to metallic iron and thereby substantially reducing carbon emissions from steel production. The global steel industry currently accounts for approximately 7% of total global carbon emissions. Hydrogen-based steelmaking can reduce carbon emissions by more than 90%, making it one of the most transformative technological pathways in heavy industries that are particularly difficult to decarbonise.

Hydrogen-based direct reduced iron (DRI) production combined with electric arc furnace (EAF) steelmaking is currently the most mature technological pathway and the one advancing most rapidly towards industrialisation. Using pure hydrogen as the reducing gas, iron ore is directly reduced in a shaft furnace or rotary kiln at temperatures of 700–1,000°C to produce DRI with a metallisation rate exceeding 90%. The DRI is then transferred to an electric arc furnace for steelmaking. The reduction reaction produces only water, avoiding the substantial CO_2 emissions associated with conventional blast furnace ironmaking. This is currently the mainstream technological pathway adopted in demonstration projects worldwide.

In 2025, the international SuSteelAG consortium (BAM, n.d.) completed an

industrial-scale pilot project in Namibia, achieving zero-carbon direct reduction of 80 tons of Australian iron ore in an electrically heated hydrogen rotary kiln. The project demonstrated a cross-border zero-carbon industrial supply chain linking Australian iron ore with green steel production in Germany.

5.7 Energy Utilisation Technologies

While zero-carbon energy supply technologies continue to advance, energy end-use technologies have also undergone remarkable developments. Rapid advances in these end-use technologies, together with progress in zero-carbon energy supply technologies, provide a solid foundation for the development of a fully zero-carbon society in the future.

Energy end-use technologies that have already undergone significant changes include electric passenger cars, electric heavy-duty trucks, electric buses, electric two-wheelers, electric agricultural vehicles, electric aircraft, electric cooking technologies, high-efficiency air conditioners, energy-efficient televisions, phase-change thermal energy storage, heat pumps, residential solar PV systems, greenhouse crop production and zero-discharge livestock farming. These technological developments are briefly summarised in Table 5-7-1.

Table 5-7-1 Advances in Energy-Using Technologies

Technology Category	Progress Description	Future Outlook
Electric Passenger Cars	By 2026, the purchase prices of electric passenger cars in countries such as China had approached those of conventional petrol-powered cars. However, their operating costs are significantly lower, resulting in much lower total ownership costs. This has established a commercially viable market for electric passenger cars.	Electric passenger car prices are already approaching their long-term levels. Future development will focus on highly automated vehicles with advanced safety features.
EV Charging Stations	In China, the price of a residential EV charging station has fallen to US$120–180.	Residential EV charging stations have already become widely available.

Technology Category	Progress Description	Future Outlook
Electric Heavy-Duty Trucks	By July 2026, electric heavy-duty trucks had reached a 49% market share in China, entering a stage of full-scale market adoption. As heavy-duty trucks in China are primarily used for commercial operations, electric trucks could capture the market faster than electric passenger cars. Charging stations for electric heavy-duty trucks are expanding rapidly, with convenient charging available along major transport corridors.	Electric heavy-duty truck prices are expected to decline further over the next year, improving their market competitiveness. Charging infrastructure for electric heavy-duty trucks will also continue to expand.
Electric Buses	Electric buses have become widely adopted in China and are commercially competitive.	Prices could decline further.
Electric Two-Wheelers	Prices can be as low as US$210 per vehicle. Petrol-powered two-wheelers have largely disappeared from the Chinese market, and electric two-wheelers are price-competitive with second-hand vehicles.	Limited scope for further price reductions.
Electric Agricultural Vehicles	Electric agricultural three-wheelers cost approximately US$400 and have already achieved commercial adoption.	Fully commercialised.
Electric Aircraft	Electric aircraft with 4–9 seats have begun entering commercial or semi-commercial operation. Their costs could fall below those of high-speed rail in the near future.	Considerable development potential, particularly in regions where high-speed rail cannot be developed.
Electric Cooking	Induction cookers are now available for US$5–10, offering considerable potential for cost savings in regions with low electricity prices. They can also significantly reduce indoor air pollution.	Expected to achieve widespread adoption.
High-Efficiency Air Conditioners	Commercially available air conditioners have achieved a coefficient of performance (COP) approaching 5, with competitive market prices.	The COP of commercially available air conditioners could approach 7, while prices remain comparable to current levels.
Energy-Efficient Televisions	Mainstream 55-inch televisions currently have a power consumption of approximately 110 W.	Power consumption is expected to reach 80–90 W.
Heat Pumps	Magnetic levitation centrifugal compressors are becoming increasingly widespread, enabling heat pump systems to achieve a COP above 5.0. The market for high-capacity industrial heat pumps rated at 10–50 kW has already developed. Heat pumps currently meet approximately 12% of global building heating demand.	Costs are expected to decline further, strengthening market competitiveness.

Technology Category	Progress Description	Future Outlook
Residential Solar PV Systems	The cost of complete systems, including PV modules, inverters and energy storage, has reached approximately US$525/kW.	Further cost reductions are expected.
Greenhouse Agriculture	Greenhouse agriculture is expanding rapidly in regions with low-cost solar PV electricity.	Considerable development potential.
Zero-Discharge Livestock Farming	Currently at the system design stage.	Considerable potential in regions with low-cost solar PV and wind power.
Artificial Protein Production	Artificial proteins are already commercially competitive as feed additives.	Considerable potential for future production using green hydrogen and CO_2.
Starch Production Using Green Hydrogen and CO_2	The technology remains at the research and development stage. By 2026, it had entered stable operation at the ton-scale pilot stage, with production costs declining substantially from approximately US$18/kg in 2021 to US$3.00–4.50/kg.	With low-cost renewable electricity from solar PV and wind power and continued reductions in enzyme costs, production costs could fall to approximately US$0.75–1.20/kg within 2–3 years, making the technology economically competitive with conventional agricultural starch production.

Source: Authors' compilation.

Many of these technologies have already become commercially competitive. For example, in lower-income developing countries such as Nepal, electric passenger cars have expanded largely through market forces and have captured a major share of the market. As these end-use technologies are now able to compete commercially with fossil fuel-based alternatives, they have the potential for rapid adoption across Africa while delivering multiple benefits. In 2024, Ethiopia banned imports of petrol- and diesel-powered vehicles to reduce its dependence on oil, stimulating the development of electric cars, electric two-wheelers and electric three-wheelers.

5.8 Progress in Africa

5.8.1 Solar Energy, Solar Photovoltaics and Wind Power

(1) Solar Photovoltaics (PV)

Solar and wind power are important technologies for expanding renewable energy supply in Africa, but significant differences remain among countries in terms of development scale and project progress. Africa has abundant solar and wind resources, yet investment, grid infrastructure and project implementation capacity continue to

constrain their development (IEA, 2022; IRENA and AfDB, 2022). To further examine the geographical distribution, scale and development stages of solar and wind power projects, this section uses the Global Integrated Power Tracker database released by Global Energy Monitor (GEM) in March 2026. The database primarily covers utility-scale power generation projects and does not include all solar and wind power facilities in Africa. It therefore cannot be considered a complete representation of each country's installed capacity.

The African project records extracted from the database cover 59 countries or territories, including 1,849 solar project phase or unit records and 422 wind power records (Figure 5-8-1). As some projects are developed in multiple phases, the number of consolidated projects is 1,558 for solar power and 323 for wind power. The total capacity of African solar and wind power projects recorded in the GEM database is 540.6 GW, of which 84.1 GW is classified as inactive or excluded from the active project pipeline. Among active projects, 28.2 GW is operating, 43.2 GW is under construction and 385.0 GW is planned. By technology, operating, under-construction and planned solar power capacities are 16.2 GW, 23.3 GW and 238.5 GW, respectively, while the corresponding figures for wind power are 12.0 GW, 20.0 GW and 146.5 GW (Figure 5-8-1). For both technologies, planned capacity far exceeds operating capacity, but most planned projects remain at the announcement or pre-construction stage, with relatively limited capacity actually under construction (authors' calculations based on GEM, 2026).

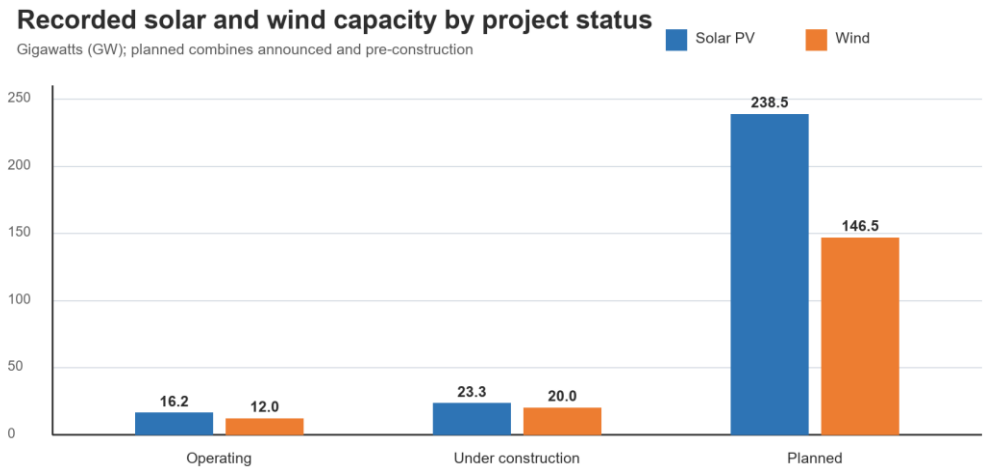


Figure 5-8-1 Capacity of Solar and Wind Power Projects in Africa Recorded in the GEM Database, by Development Stage (GW)

Note: The data include only utility-scale projects recorded by GEM and do not represent the total installed solar and wind power capacity in Africa. Planned capacity includes announced and pre-construction projects. Shelved, cancelled, retired and mothballed projects are excluded from the active project pipeline.

Source: Authors' calculations based on GEM (2026), Global Integrated Power Tracker, March 2026 release.

Solar and wind power projects are distributed across multiple African countries, but operating capacity remains concentrated in a small number of markets. Among the 58 countries or territories with solar projects recorded in the GEM database, 55 have operating projects. In contrast, only 20 of the 40 countries or territories with recorded wind power projects have operating projects. South Africa, Egypt and Morocco together account for 61.5% of the operating solar power capacity and 74.5% of the operating wind power capacity recorded in the database. When the ten largest markets are considered, these shares increase to 79.0% and 97.8%, respectively. In terms of combined operating solar and wind power capacity, the three countries account for 67.0% of the total. These findings indicate that solar power projects have reached a relatively broad range of national markets, while wind power development remains more geographically limited. Nevertheless, large-scale operating capacity for both technologies remains concentrated in a small number of countries (authors' calculations based on GEM, 2026).

Continued advances in global solar PV technology and declining module costs have created favourable conditions for expanding solar power development in Africa. According to the Global Energy Monitor (GEM) database, Africa's operating solar power capacity has reached 16.2 GW across 55 countries or territories. South Africa

leads with 5.38 GW, followed by Egypt and Morocco with 3.55 GW and 1.03 GW, respectively. Together, these three countries account for approximately 61.5% of the recorded operating capacity. Angola, Libya, Algeria, Ghana, Namibia, Zambia and Kenya have also developed operating projects of some scale, although their overall capacities remain relatively limited (authors' calculations based on GEM, 2026).

Beyond differences in capacity among countries, the distribution of project sizes also reflects different development patterns. Among consolidated operating solar power projects recorded in GEM, for which all project phases have a consistent development status, the median capacity is 4.2 MW, the mean capacity is 20.0 MW, and 75% of projects have capacities of no more than 16 MW. This indicates that operating projects are predominantly small to medium-sized, although large projects make a substantial contribution to total capacity. South Africa has 334 active consolidated projects, with a combined operating capacity of 5.38 GW. By comparison, Egypt has achieved an operating capacity of 3.55 GW through 105 active consolidated projects, equivalent to approximately two-thirds of South Africa's capacity. This difference demonstrates that Africa's major solar power markets vary not only in installed capacity but also in project size distribution (authors' calculations based on GEM, 2026).

Projects under construction show a different geographical distribution from existing operating capacity. GEM records 23.3 GW of solar power capacity under construction across 29 African countries or territories, approximately 43% higher than operating capacity. Egypt (5.99 GW), Tunisia (5.04 GW) and Namibia (3.83 GW) together account for 63.9% of the capacity under construction, while Algeria and South Africa also have substantial projects under development. Egypt and South Africa continue to expand their existing operating capacity, whereas the capacity under construction in Tunisia, Namibia and Algeria is several times greater than their respective operating capacities. This indicates that solar power construction is expanding into more African markets, with some countries that currently have relatively limited operating capacity potentially playing a more significant role in future capacity growth (authors' calculations based on GEM, 2026).

Looking at the longer-term project pipeline, Africa's planned solar power capacity reaches 238.5 GW across 50 countries or territories. Mauritania, Egypt and South Africa together account for 54.6% of this capacity, while Morocco and Mozambique are also important markets for planned projects. The median capacity of consolidated projects at the planning stage is 80 MW, with a mean capacity of 516 MW, both substantially

higher than those of operating projects. This reflects the important role of large-scale projects in future development plans (authors' calculations based on GEM, 2026; IEA, 2022).

(2) Wind Power

The geographical distribution of operating wind power projects in Africa is more limited than that of solar power, and installed capacity is more concentrated. The GEM database records 12.0 GW of operating wind power capacity, approximately one-quarter less than solar power, but this capacity is distributed across only 20 countries or territories, substantially fewer than the 55 recorded for solar power. South Africa, Egypt and Morocco are the leading wind power markets, with operating capacities of 4.26 GW, 3.05 GW and 1.63 GW, respectively. Together, they account for 74.5% of the operating wind power capacity recorded in the database. Western Sahara, Ethiopia and Kenya form a second tier of markets (according to the GEM database classification), while most other countries have recorded operating wind power capacities below 300 MW. Wind power development is currently concentrated in a small number of markets with favourable conditions for resource development, grid connection and project construction, and has not yet achieved the broad geographical coverage of solar power across Africa (authors' calculations based on GEM, 2026).

Wind and solar power also differ significantly in individual project size. Among operating projects recorded in GEM with consistent development stages, consolidated wind power projects have a median capacity of 100 MW and a mean capacity of 129 MW, substantially higher than the corresponding figures of 4.2 MW and 20.0 MW for solar power. When projects are classified according to their most advanced development stage, the database contains 95 consolidated operating wind power projects, compared with 781 solar power projects. Although the number of wind power projects is considerably smaller, their operating capacity is equivalent to approximately 74% of that of solar power. Kenya's 310 MW Lake Turkana Wind Power Project is a representative example of large-scale wind power development and accounts for a significant share of the country's relatively small portfolio of wind power projects (Obanor et al., 2024). These differences indicate that wind power development is more dependent on the financing, construction, grid connection and operation of individual large-scale projects, whereas solar power capacity can expand progressively through a greater number of projects of varying sizes (authors' calculations based on GEM, 2026).

Wind power projects under construction further demonstrate the concentration of

capacity. GEM records 20.0 GW of wind power capacity under construction, approximately two-thirds higher than operating capacity. Egypt accounts for 13.42 GW, Namibia for 3.54 GW and South Africa for 2.00 GW, together representing 94.8% of the total recorded wind power capacity under construction. This level of concentration is substantially higher than that of solar power projects under construction, indicating that wind power development in the coming years will depend primarily on large-scale projects in a small number of countries. If these projects are completed successfully, wind power capacity in the countries concerned could increase rapidly. However, financing, construction or grid connection delays affecting individual large-scale projects could also significantly influence the overall construction progress reflected in the database (authors' calculations based on GEM, 2026).

The scale of planned wind power projects also far exceeds existing operating capacity. GEM records 146.5 GW of planned wind power capacity across 34 countries or territories. Mauritania, Egypt and Morocco together account for 79.1% of this capacity, with some exceptionally large projects linked to future energy conversion and export-oriented industrial development plans. These projects indicate that the potential applications of wind power are no longer limited to supplying electricity to existing grids, but may also support new industrial production and energy product exports, although the associated investments remain at the planning stage. Among planned wind power projects with consistent development stages, the median capacity is 140 MW and the mean capacity reaches 848 MW, again demonstrating the substantial influence of a small number of exceptionally large projects on total capacity. Although planned wind power projects now cover more countries than the existing operating fleet, their capacity remains more concentrated than that of planned solar power projects. Future wind power development is therefore also more sensitive to the implementation outcomes of a small number of large-scale projects (authors' calculations based on GEM, 2026).

(3) Different Stages of Renewable Energy Development in Africa

The operating, under-construction and planned capacities of solar and wind power projects reflect different stages of development across African countries. Based on the project portfolios recorded in the GEM database, the major countries can be broadly divided into three categories. The first comprises countries with substantial operating capacity that are continuing to expand their construction and planning activities, represented by South Africa, Egypt and Morocco. The second includes countries with

relatively limited operating capacity but substantial capacity under construction. Namibia exhibits this pattern in both solar and wind power, while Tunisia and Algeria primarily demonstrate it in solar power. The third category consists of countries where planned capacity far exceeds operating and under-construction capacity, with Mauritania being the most representative example. These categories reflect only the project portfolios recorded in the GEM database and do not represent all renewable energy facilities in each country, nor do they constitute fixed development classifications. Their purpose is to distinguish between established operating capacity, projects currently under construction and investment plans that have yet to be implemented (authors' calculations based on GEM, 2026) (Table 5-8-1).

Table 5-8-1 Solar and Wind Power Project Portfolios and Development Stages in Selected African Countries Recorded in the GEM Database

Country/Territory	Technology	Operating (GW)	Under Construction (GW)	Planned (GW)	Number of Active Consolidated Projects	Main Development Characteristics
South Africa	Solar PV	5.38	2.35	31.96	334	Substantial operating capacity, a large number of projects and continued expansion
South Africa	Wind Power	4.26	2.00	4.59	72	Substantial operating capacity, with a relatively balanced portfolio of operating and planned projects
Egypt	Solar PV	3.55	5.99	45.21	105	Established operating capacity, with substantial capacity under construction
Egypt	Wind Power	3.05	13.42	34.48	24	Established operating capacity, with highly concentrated capacity under construction
Morocco	Wind Power	1.63	0.46	21.95	27	Established operating capacity, with substantial planned capacity
Namibia	Solar PV	0.33	3.83	10.44	69	Limited operating capacity, with rapidly expanding capacity under construction
Namibia	Wind Power	0.01	3.54	4.04	11	Very limited operating capacity, with development dominated by projects under construction

Country/Territory	Technology	Operating (GW)	Under Construction (GW)	Planned (GW)	Number of Active Consolidated Projects	Main Development Characteristics
Mauritania	Wind Power	0.13	0.00	59.53	12	Dominated by planned projects, with total capacity largely driven by exceptionally large projects

Note: The data include only utility-scale projects recorded by GEM and do not represent the total installed capacity of each country. Capacity at each development stage is aggregated from project phase or unit records. The number of active consolidated projects excludes shelved, cancelled, retired and mothballed projects. Projects involving multiple development stages are classified according to their most advanced stage.

Source: Authors' calculations based on GEM (2026), Global Integrated Power Tracker, March 2026 release.

Geographically, the solar and wind power projects recorded by GEM are mainly concentrated in North Africa and Southern Africa. In North Africa, Egypt and Morocco have established substantial operating capacity, while projects under construction and at the planning stage extend into other Maghreb countries and Mauritania. In Southern Africa, development is centred on South Africa's existing solar and wind power projects, alongside Namibia's rapidly expanding capacity under construction and planned solar power projects in neighbouring countries. In East Africa, Kenya and Ethiopia have operating wind power projects of some scale, while operating solar power capacity remains relatively limited. Overall, the recorded capacity in East Africa remains lower than that in North Africa and Southern Africa. These patterns reflect the geographical concentration of projects but do not imply that a unified regional electricity market has already emerged among these countries. The extent of cross-border transmission, energy trading and grid integration must be assessed using independent infrastructure and market data and cannot be inferred solely from the geographical locations of projects (authors' calculations based on GEM, 2026; IRENA and AfDB, 2022).

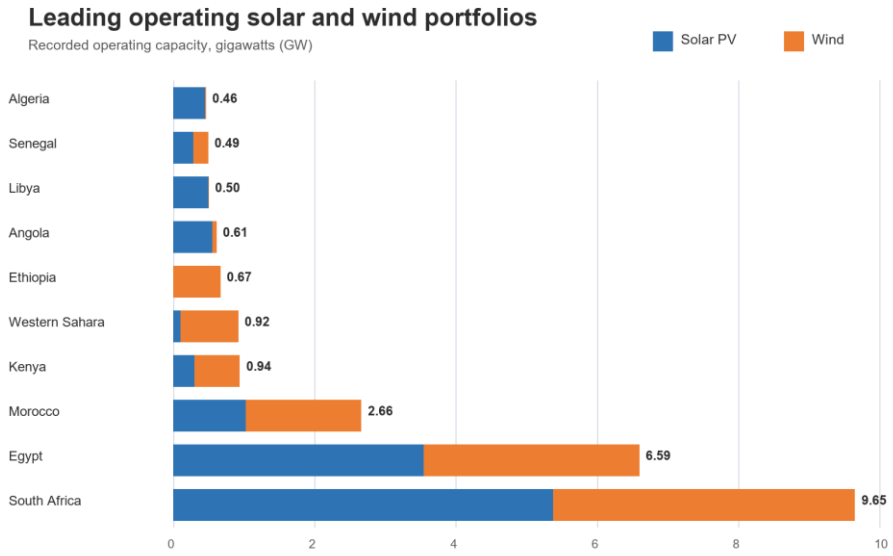


Figure 5-8-2 Operating Solar and Wind Power Capacity in Major African Countries or Territories Recorded in the GEM Database (GW)

Note: Country and territory classifications follow the GEM database. The figure shows only the operating capacity of recorded utility-scale projects and does not represent the total installed solar and wind power capacity of each country.

Source: Authors' calculations based on GEM (2026), Global Integrated Power Tracker, March 2026 release.

Project numbers and installed capacity provide different perspectives on renewable energy development across countries. South Africa has a large number of active solar power projects, indicating extensive development and construction experience across different locations and project scales. Egypt has fewer projects, but their larger average capacity has enabled the country to achieve a similarly high level of operating capacity. Namibia has substantial capacity under construction, reflecting an expansion from a relatively small operating base into a larger construction pipeline. By contrast, Mauritania's planned capacity far exceeds its operating capacity, reflecting future investment plans rather than existing power generation capacity. As wind power projects are generally larger, the completion or delay of an individual project can also have a greater impact on a country's recorded total capacity. Therefore, a larger number of projects may indicate more extensive experience in repeated project development and construction, whereas capacity concentrated in a small number of projects may also mean greater concentration of risks associated with project financing, approval and grid connection (Figure 5-8-2).

Overall, continued advances in global solar PV and wind power technologies, improvements in power generation efficiency and declining costs have created

favourable conditions for Africa to make greater use of its abundant solar and wind resources and expand renewable electricity supply. The GEM database shows that solar and wind power development in Africa has gradually expanded from a small number of established markets into more countries, with capacities under construction and at the planning stage far exceeding existing operating capacity, indicating substantial growth potential. The cost advantages and flexible deployment of solar PV allow it to meet electricity demand at different scales, while larger turbine sizes and improvements in generation efficiency give wind power considerable potential for large-scale development in regions with favourable wind resources.

The complementary development of these two technologies could support changes in Africa's electricity supply structure and provide a new energy foundation for green hydrogen, low-carbon metallurgy, chemical production and other electricity-intensive industries. However, resource availability and technological progress do not necessarily translate into actual electricity supply capacity. Future growth will continue to depend on parallel improvements in project financing, construction and implementation, grid expansion and power system flexibility (IEA, 2022; IRENA and AfDB, 2022; Barasa et al., 2018). Therefore, the long-term significance of solar and wind power development in Africa lies not only in increasing installed renewable energy capacity, but also in integrating clean electricity development with transmission and distribution networks, energy storage facilities and industrial infrastructure, gradually establishing a reliable electricity supply system capable of supporting local industrial production, energy conversion and zero-carbon industrialisation.

5.8.2 Nuclear Power in Africa

(1) From South Africa as the Sole Operator to the Coexistence of Operating, Under-Construction and Preparatory Projects

Unlike solar PV and wind power, which have expanded rapidly by drawing on favourable natural resources, nuclear power development in Africa has long remained limited in scale and concentrated in a small number of countries, with substantially longer project development cycles. The two units at South Africa's Koeberg Nuclear Power Station entered commercial operation in 1984 and 1985, respectively. For nearly four decades thereafter, South Africa remained the only African country with an operating commercial nuclear power plant (Eskom, 2025). The slow development of

nuclear power in Africa has not been primarily constrained by nuclear fuel resources. In 2024, Namibia, Niger and South Africa together produced approximately 8,495 tons of uranium, accounting for around 14.1% of global uranium mine production, with Namibia alone contributing approximately 12% of the global total (World Nuclear Association, 2026b). More significant constraints arise from the greater demands that nuclear power places on national capabilities and electricity system conditions. These include substantial upfront capital investment, a sufficiently large and robust electricity grid, an independent and mature nuclear safety regulatory framework, a sustained engineering and operational workforce over several decades, and long-term institutional arrangements covering construction, operation, decommissioning and waste management (IAEA, 2015). Nuclear power development in Africa is therefore primarily a question of energy systems and development capabilities, rather than resource availability.

By 2026, nuclear power development in Africa had entered a new stage, moving beyond South Africa as the sole operator towards the coexistence of operating plants, projects under construction and projects in preparation. South Africa's current priority is to maintain the safe and stable operation of its existing low-carbon assets. The two units at Koeberg have a combined installed capacity of approximately 1.86 GW, with Units 1 and 2 granted operating life extensions until 2044 and 2045, respectively (Eskom, 2025). Looking further ahead, South Africa's Integrated Resource Plan 2025 (IRP 2025) provides for 5.2 GW of additional nuclear power capacity by 2039 and proposes assessing the feasibility of further nuclear expansion through a nuclear industrialisation programme (Republic of South Africa, 2025a). However, this remains a long-term planning and decision-making framework and should not be equated with construction projects that have already secured financing and completed procurement.

Egypt's El Dabaa project has changed the longstanding situation in which Africa had operating nuclear power units but no new large-scale nuclear power projects under construction. The project comprises four Generation III+ VVER-1200 reactors with a combined capacity of 4.8 GW, all of which have entered the construction stage (World Nuclear Association, 2026c). In 2026, the project continued to progress into the installation phase for major equipment, with installation of the first steam generator for Unit 1 commencing on 8 October (Egypt State Information Service, 2026). According to Egypt's current official schedule, Unit 1 is expected to enter the commissioning and grid connection stage by the end of 2028, with all units scheduled for completion around 2030 (World Nuclear Association, 2026c). The total project investment is

approximately US$28.75 billion, with a Russian state loan covering around 85% and Egypt financing the remaining 15% (Egypt State Information Service, n.d.). This approach demonstrates that, in an environment of high financing costs, the advancement of nuclear power projects is often closely linked to supplier-country financing, long-term fuel services, engineering, procurement and construction (EPC) contracts, and intergovernmental cooperation arrangements.

Meanwhile, a number of countries are moving from expressing interest towards more concrete infrastructure preparations. According to IAEA information, Ghana and Nigeria have reached Phase 2 of the nuclear power infrastructure Milestones Approach. Nigeria has completed site selection and is prepared to proceed further with tendering and contract negotiations. Kenya is also advancing its nuclear power programme under the Milestones Approach and has incorporated small modular reactors (SMRs) into its medium- and long-term plans (World Nuclear Association, 2026d; IAEA, 2024b). Policy interest in nuclear energy is also increasing in Morocco, Rwanda, Senegal, Togo and other countries. However, substantial differences remain within this group, and some countries may still be several years or even more than a decade away from investment decisions and first concrete pouring. Assessing whether nuclear power development in Africa is genuinely gaining momentum should therefore focus on substantive progress in institutional development, project preparation and investment decisions (IAEA, 2015), rather than simply the number of countries announcing intentions to develop nuclear power.

Table 5-8-2 Project Development Stages of Major Nuclear Power Countries and Countries Preparing for Nuclear Power in Africa, as of October 2026

Country	Current Stage	Main Progress	Assessment
South Africa	Operating + Life Extension + Planned Expansion	Koeberg: 1.86 GW; operating lives of the two units extended to 2044 and 2045, respectively; IRP 2025 provides for 5.2 GW of additional nuclear capacity by 2039.	Strong, mature operational capabilities, but new projects still require financing, procurement and regulatory decisions.
Egypt	4.8 GW of Large-Scale Nuclear Power Under Construction	El Dabaa: 4 × VVER-1200 reactors; major equipment installation began in 2026; gradual grid connection targeted from 2028, with full capacity expected around 2030.	Africa's most advanced new nuclear power project, characterised by supplier-country financing and lifecycle services.

Country	Current Stage	Main Progress	Assessment
Ghana	Phase 2 of the IAEA Milestones Approach	Continued development of infrastructure, regulatory frameworks, site preparation and procurement readiness; has joined the Declaration to Triple Nuclear Energy.	Potentially among the first West African countries to advance towards project implementation, but construction has not yet begun.
Kenya	Phase 2 of the IAEA Milestones Approach	Incorporated approximately 300 MW-class SMRs into medium- and long-term plans, while advancing legal and regulatory frameworks and fuel cycle studies.	The suitability of SMRs for smaller electricity grids warrants attention, although the development timeline remains highly uncertain.
Nigeria	Phase 2 of the IAEA Milestones Approach	Site selection has been completed, and IAEA information indicates readiness to proceed to tendering and contract negotiations.	Large potential market, but grid infrastructure, financing and project governance remain key constraints.
Other Countries	Early-Stage Assessment / Capacity Building	Policy interest is increasing in Morocco, Rwanda, Senegal, Togo and other countries; several countries participate in IAEA-related regional cooperation.	Policy signals must be clearly distinguished from actual engineering and project development maturity.

Source: Compiled by the authors based on Eskom (2025), Republic of South Africa (2025a), Egypt State Information Service (2026, n.d.), IAEA (2015, 2024b), and World Nuclear Association (2026c, 2026d).

(2) IAEA's Latest Outlook: Significant Capacity Growth, but a Relatively Limited Overall Share

The IAEA's latest regional outlook, published in 2025, provides a relatively clear quantitative indication of the medium- and long-term scale of nuclear power development in Africa. In 2024, Africa's installed nuclear power capacity was approximately 1.9 GW, accounting for only 0.7% of total installed electricity generation capacity. By 2050, nuclear power capacity is projected to reach approximately 12 GW under the low-case scenario and 30 GW under the high-case scenario, representing roughly sixfold and sixteenfold increases from 2024 levels, respectively. Despite this substantial growth, Africa's total installed electricity generation capacity is projected to increase from 274 GW to 1,878 GW over the same period, leaving nuclear power with a share of only approximately 0.6–1.6% of total installed capacity in 2050 (IAEA, 2025). This indicates that even under a relatively rapid development trajectory, nuclear power would continue to account for a relatively limited share of Africa's electricity generation capacity.

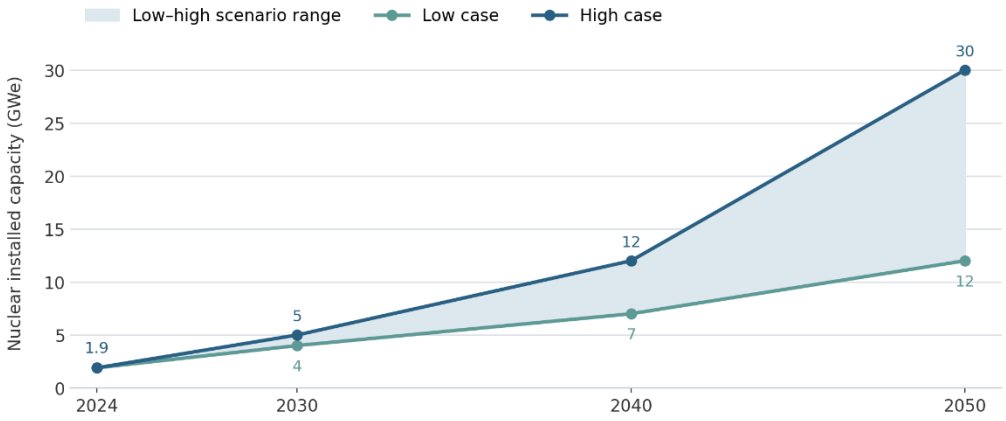


Figure 5-8-3 IAEA Low- and High-Case Projections of Nuclear Power Capacity in Africa, 2024–2050 (GWe)

Source: IAEA (2025).

Electricity generation shows a similar trend, although its implications for the electricity system are more significant. The IAEA projects that Africa's total electricity generation will increase from 919 TWh in 2024 to 5,852 TWh in 2050, while nuclear power generation will rise from 8 TWh to 97–237 TWh, corresponding to a share of approximately 1.7–4.0%. Meanwhile, electricity consumption in Africa is projected to grow at an average annual rate of approximately 7% between 2024 and 2050, reaching around six times its current level by 2050. The share of electricity in final energy consumption is expected to increase from 10.4% to 43.3%, while per capita electricity consumption is projected to rise from approximately 0.5 MWh to nearly 2.0 MWh (IAEA, 2025). This means that even with relatively rapid expansion, nuclear power is unlikely to keep pace with the overall growth in electricity demand driven by electrification and industrialisation in Africa. Its role is therefore more likely to lie in providing stable, low-carbon electricity at critical points in the power system rather than meeting the majority of additional electricity demand.

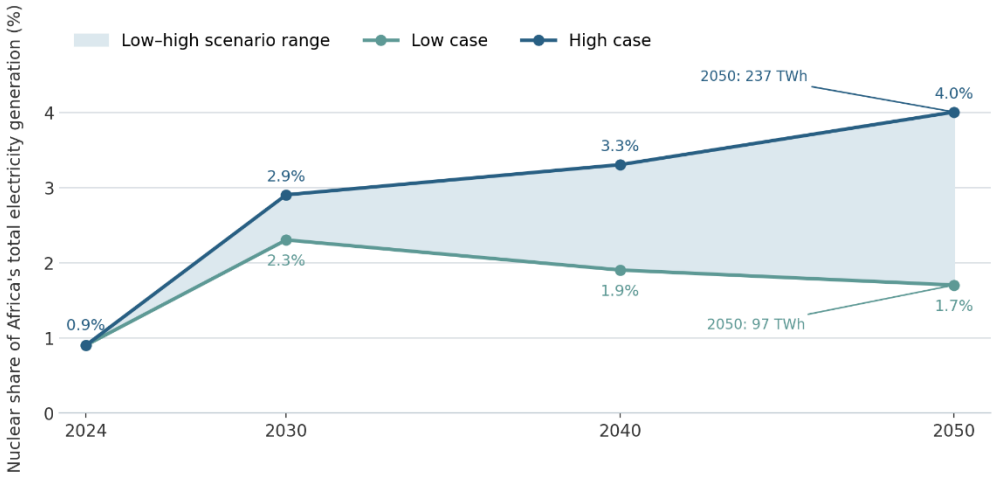


Figure 5-8-4 IAEA Low- and High-Scenario Projections for the Share of Nuclear Power Generation in Africa, 2024–2050 (%)

Source: IAEA (2025).

(3) Nuclear Power and Industrialisation in Africa: A Stable, Low-Carbon Power Source Supporting Green Hydrogen, Metallurgy, and Urban Load

The economic transformation in Africa discussed in this report involves not only improvements in basic electricity services but also the use of low-cost, zero-carbon electricity to drive the expansion of synthetic ammonia, methanol, steel, aluminium, copper, and related manufacturing sectors. The value of nuclear power within this framework must be assessed in conjunction with the nature of end-use loads. For aluminium smelting, certain mineral processing operations, large metropolitan areas, data centres, desalination plants, and chemical plants requiring long-term continuous operation, a stable power supply can reduce the need for large-scale batteries and backup fuel, improve equipment utilisation, and lower the risk of power supply disruptions during extreme weather or periods of low wind and solar output (IAEA, 2023). In industrial corridors with robust power grids and high load density, nuclear power may therefore have a system-wide value that exceeds its share of total electricity generation.

However, green hydrogen and synthetic fuels require a more detailed analysis. Electrolysers themselves have a certain degree of flexibility; in regions where solar and wind power are extremely low-cost and allow for lower utilisation hours, producing hydrogen using intermittent electricity and curtailed power may be cheaper than supplying electrolysers with round-the-clock nuclear power; Conversely, if downstream processes such as synthetic ammonia, methanol, or direct reduction of iron

require a continuous and stable flow of hydrogen, a hybrid power supply combining nuclear power and renewable energy may reduce the scale of hydrogen storage tanks, batteries, and backup power sources, thereby improving the load factor of downstream facilities (IAEA, 2023). Therefore, the relative advantages of nuclear power and renewable energy in green hydrogen systems depend on specific conditions such as electrolyser utilisation rates, hydrogen storage costs, downstream continuous production requirements, and different power source combinations; it cannot be assumed that a single technology route will be superior in all scenarios.

Africa's power systems also exhibit distinct spatial stratification. In many rural areas and regions with low load density, the immediate goal remains securing basic electricity services; distributed solar PV, microgrids, and distribution network expansion are typically more direct and cost-effective solutions than nuclear power. Nuclear power is better suited to a different set of system conditions: regional backbone grids, cross-border power pools, and major cities and industrial clusters. The advancement of the Southern African Power Pool (SAPP), the East African Power Pool (EAPP), the West African Power Pool (WAPP), and the African Single Electricity Market (AfSEM) can expand the effective market size, facilitate the sharing of reserve capacity, and enhance the acceptability of large-capacity units (AU, 2021). The future geographic expansion of nuclear power in Africa is likely to occur in tandem with cross-border interconnections and industrial corridors, rather than spreading evenly across national borders.

(4) Technology Pathways: Differences in Maturity Between Large Reactors, SMRs, and Long-Term Technologies

Over the next 10–15 years, the most practical nuclear power technologies for Africa will remain large-scale Generation III/III+ pressurised water reactors (PWRs), which already have established engineering and supply chains. The VVER-1200 reactors at El Dabaa are the most representative example. The advantages of large-scale reactors include technological maturity, accumulated experience in series construction and high generating capacity per unit. However, individual reactor capacities often approach or exceed 1 GW, placing significant demands on the electricity system capacity, reserve margins and transmission infrastructure of many African countries (IAEA, 2015; World Nuclear Association, 2026c). Large-scale nuclear power is therefore more suitable for South Africa, Egypt and countries that may develop large interconnected regional electricity markets in the future. For countries preparing to introduce nuclear power

with relatively small electricity grids, the deployment of GW-scale reactors cannot be easily replicated.

Small modular reactors (SMRs) offer another possibility for Africa. According to the definition commonly used by the IAEA, SMRs generally have an electrical capacity of no more than 300 MW per unit. Their modular design can reduce the scale of individual capacity additions, making them easier to integrate with smaller electricity grids, mining operations, industrial parks, retired coal-fired power plant sites and seawater desalination projects. However, the potential advantages of SMRs in construction time and cost have not yet been fully demonstrated through commercial deployment. Their economic viability depends on factory-based mass production, design standardisation, international regulatory coordination and learning effects associated with the transition from first-of-a-kind (FOAK) reactors to nth-of-a-kind (NOAK) units. Global commercial operating experience remains relatively limited (IAEA, 2024b). China's 125 MW(e) ACP100 Linglong One completed its cold functional tests in October 2025 (CNNC, 2025) and, according to publicly available industry information in early October 2026, had entered the hot functional testing stage (World Nuclear News, 2026). Key milestones, including fuel loading, first criticality, grid connection and commercial operation, have yet to be completed. Meanwhile, the HTR-PM at Shidao Bay, Shandong Province, entered commercial operation in December 2023 (Tsinghua University INET, 2023), providing valuable engineering and operational experience for modular high-temperature gas-cooled reactors.

Generation IV reactors still exhibit substantial differences in technological maturity, particularly in the transition from engineering demonstration to large-scale deployment. High-temperature gas-cooled reactors can provide higher-temperature process heat, offering potential applications in hydrogen production, chemical manufacturing and industrial steam supply. The commercial operation of the HTR-PM has already provided practical engineering and operational experience (Tsinghua University INET, 2023). In contrast, sodium-cooled fast reactors, lead-cooled fast reactors and molten salt reactors remain largely at the demonstration, experimental or early engineering development stages (Generation IV International Forum, n.d.). These technologies have long-term strategic significance in areas such as fuel utilisation, waste transmutation and high-temperature heat supply. However, during Africa's energy transition in the 2030s, they are more likely to remain at the stages of technology monitoring, demonstration and limited application, rather than serving as major energy supply technologies. Their prospects for large-scale deployment will depend primarily on

further advances in technological maturity, costs and regulatory frameworks after 2040.

Nuclear fusion has significant long-term technological potential, but considerable uncertainty remains regarding its commercial electricity generation prospects. ITER's latest baseline schedule sets 2034 as the start of research operations, 2036 for achieving full magnetic energy and 2039 for the commencement of deuterium–tritium operations. These are milestones for an experimental facility rather than a timetable for commercial electricity generation (ITER Organization, 2025). Therefore, in the context of Africa's energy transition towards 2050, nuclear fusion is more appropriately regarded as a long-term technological option rather than a reliable source of electricity in the near term. It should not replace current investment in mature low-carbon technologies, electricity grids and energy infrastructure.

(5) Financing, Supply Chains and Governance: Key Non-Technical Constraints on Nuclear Power Expansion in Africa

Nuclear power has a relatively low share of fuel costs, but is highly sensitive to capital costs, construction periods and financing structures (IAEA, 2024a). Against the background of public debt, high sovereign borrowing costs and electricity grid investment gaps in Africa, as discussed earlier in this report, large-scale nuclear power projects could crowd out investment in transmission and distribution networks, universal electricity access and other low-cost clean energy technologies if they rely primarily on government balance sheets and expose domestic governments to exchange rate risks, construction delays and cost overruns. The El Dabaa project, with approximately 85% of its investment financed through a Russian state loan (Egypt State Information Service, n.d.), provides a practical example of supplier-country financing. It also demonstrates that cooperation on large-scale nuclear power projects typically extends beyond equipment procurement, involving long-term arrangements for construction, fuel supply, operation and maintenance, training and spent fuel management.

The cooperation agreement signed between the World Bank Group and the IAEA in 2025 represents an important development in the nuclear power financing environment. The cooperation initially focuses on nuclear energy knowledge and capacity development, lifetime extensions for operating reactors and the potential of SMRs, while emphasising safety, nuclear security, safeguards and affordability. It therefore does not mean that the World Bank has opened unconditional lending to all new large-scale nuclear power projects (World Bank Group, 2025). For Africa, a more

practical financing framework may involve a combination of long-term power purchase agreements, mining and industrial consumers with stable electricity demand, supplier-country export credits, political risk insurance, guarantees from multilateral development institutions and regional electricity purchasing arrangements. Such mechanisms could reduce cash flow and sovereign risks, thereby lowering the weighted average cost of capital (WACC) (IAEA, 2024a).

Supply chain concentration is another emerging constraint. The IEA notes that approximately 94% of reactors whose construction began worldwide over the past decade have adopted Chinese or Russian designs (IEA, 2026d). For African countries entering the nuclear power sector, this means that project selection involves not only reactor technology but also financing sources, fuel supply, maintenance systems, digital control systems, workforce training, and diplomatic and trade relations. The key to improving the resilience of Africa's nuclear power sector is not simply to maximise local manufacturing content, but to identify areas where sustainable domestic capabilities can be developed. These may include civil construction, conventional island equipment, inspection and maintenance, engineering consultancy, quality assurance, digital operation and maintenance, and specialised training. Procurement contracts should also ensure that long-term responsibilities relating to fuel supply, spare parts, technological upgrades and decommissioning remain manageable.

Africa's uranium resource advantages must also be understood in the context of the complete nuclear fuel cycle. Africa accounted for approximately 14% of global uranium mine production in 2024 (World Nuclear Association, 2026b), but uranium mining represents only the starting point of the nuclear fuel value chain. Subsequent stages, including conversion, enrichment, fuel fabrication and spent fuel management, involve higher technical, capital, regulatory and safeguards requirements. Resource-rich countries can gradually increase value added through mining services, processing capabilities and nuclear technology workforce development, but possessing uranium resources should not be equated directly with having an independent nuclear fuel supply capability. Advancing regional cooperation within nuclear non-proliferation and safety frameworks may offer greater economies of scale than establishing a complete nuclear fuel cycle independently in every country.

Climate risks and water resource constraints are also important considerations in nuclear power plant siting throughout their operational lifetimes. Coastal projects in North Africa can use seawater for cooling and integrate non-electric applications such

as seawater desalination, but must account for sea-level rise, extreme heat, storm surges and rising seawater temperatures. Inland locations require comprehensive assessments of water withdrawals during dry periods, thermal discharges and ecological constraints. Dry or hybrid cooling systems may be necessary in some cases, with the associated efficiency losses and additional costs incorporated into project economic assessments. For nuclear power plants designed to operate for more than 60 years, potentially extending to 80 years following lifetime extensions, climate adaptation is itself an important component of site selection and economic viability (IAEA, 2016).

(6) A Phased Development Pathway: From Project Preparation to Regional Coordination

Considering global policy trends, the maturity of nuclear power projects in Africa and the energy-economic scenarios presented in this report, nuclear power development in Africa is likely to follow a phased and differentiated pathway. During the 2020s, actual progress is primarily concentrated on the safe lifetime extension of Koeberg, construction of El Dabaa, and improvements in the legal, regulatory, site selection, grid infrastructure, financing and workforce development frameworks of countries preparing to introduce nuclear power. At this stage, substantive progress in project preparation is a more meaningful indicator of project maturity than announced capacity targets (IAEA, 2015; Eskom, 2025).

During the 2030s, Africa may see the emergence of its first new nuclear power projects in countries such as Ghana, Kenya and Nigeria, provided they establish sufficiently robust national grids, independent regulatory systems and affordable financing arrangements. Large-scale reactors are more likely to be deployed first in countries with larger electricity systems, stable industrial demand and opportunities for cross-border interconnection. The application of SMRs will depend on whether the first commercial projects worldwide can establish sufficiently reliable records of costs, construction schedules and operational performance. Only then may SMRs find more specific applications in smaller electricity grids, mining operations, industrial parks and retired coal-fired power plant sites (IAEA, 2024b). Once projects enter the implementation stage, the coordinated development of transmission infrastructure, regional power pools and industrial parks will directly influence grid capacity, electricity demand absorption and long-term payment capacity.

After the 2040s, if regional electricity markets become more integrated, supply chain standards mature, SMRs achieve serial production and local engineering

capabilities in Africa develop at scale (IAEA, 2024b), nuclear power could gradually evolve from projects concentrated in a few countries into a regional clean electricity option. Its more valuable applications would not necessarily involve competing directly with ultra-low-cost solar power in the Sahara on the basis of the levelised cost of electricity alone. Instead, nuclear power could provide a limited but highly reliable supply of stable, low-carbon electricity in systems with high shares of renewable energy, supporting industrial facilities requiring high utilisation rates, urban agglomerations and strategic electricity loads, while reducing long-term dependence on fossil fuel-based backup generation.

Overall, nuclear power is not a universally applicable dominant technology, but its currently limited scale should not exclude it from Africa's long-term energy options. Under present conditions, its development is more likely to be concentrated in a small number of countries and regional centres with established grid infrastructure, financing capacity, regulatory frameworks and industrial electricity demand, and to involve lengthy construction and capacity-building periods. Low-cost solar PV and wind power will continue to supply most additional electricity generation, while distributed energy systems will support widespread access to electricity. Nuclear power will primarily provide a complementary source of highly reliable and stable low-carbon electricity. Therefore, assessing the role of nuclear power in Africa's transition towards net-zero emissions and economic development by 2050 requires examining it alongside renewable energy, energy storage, cross-border electricity grids, industrial development patterns and financing constraints within an integrated systems framework, with particular emphasis on whether it can reduce total system costs and risks in specific applications.

5.8.3 The Development of Energy Storage Technology in Africa

As solar and wind power generation expands, energy storage is becoming an increasingly important technology for improving electricity supply reliability and operational flexibility in African power systems. Among the representative projects selected in this section, energy storage is primarily used to shift solar electricity generated during the day to evening consumption, provide frequency regulation and reserve services, improve the reliability of weak grids and standalone power systems, alleviate transmission and distribution constraints, and reduce the impact of fluctuations

in renewable electricity generation on industrial production. Increasing installed solar and wind power capacity can expand electricity supply, but does not guarantee that electricity will be reliably available when and where it is needed. By adjusting the timing of electricity supply and demand and supporting power system operations, energy storage provides additional flexibility to coordinate renewable electricity generation with actual electricity demand.

The role of different energy storage projects depends not only on the technologies employed but also on the characteristics of the electricity system and their specific applications. For example, battery energy storage systems integrated with solar power plants and substations can shift part of the electricity generated to peak demand periods. Standalone battery storage facilities can provide capacity and balancing services according to grid operational requirements. Short-duration storage in standalone mining power systems is primarily used to smooth fluctuations in renewable electricity output and maintain production continuity. Pumped hydro storage differs from these battery-based applications, typically providing peak electricity supply and system flexibility through larger-scale power and energy regulation for national grids. Therefore, comparisons of energy storage projects in Africa need to consider technology type, system configuration, actual function and development stage, while distinguishing between renewable electricity generation capacity, storage power (MW) and energy storage capacity (MWh).

The cases selected in this section include operating solar-plus-battery storage projects in West, Central and Southern Africa, a hybrid power supply system for a mine in Mauritania, large-scale standalone battery storage projects under construction in South Africa, additional storage facilities at a solar power plant in Egypt, a planned solar–wind–storage hybrid project in Mauritania, and an operating pumped hydro storage plant in Morocco. These cases illustrate the main applications of different energy storage technologies and their stages of development. However, they do not constitute a comprehensive inventory of all energy storage projects in Africa, nor can they be used to determine the prevalence of particular battery technologies, storage durations or business models across the continent.

Operating solar-plus-storage projects in Africa are primarily used to extend the availability of solar electricity, support grid operations and improve electricity supply reliability, although their specific functions differ. Senegal’s Walo energy storage project combines a 10 MW/20 MWh lithium-ion battery energy storage system with a

16 MW solar power facility. It is designed to provide services including frequency regulation, spinning reserve, islanded operation and black start capability. The project developer, Africa REN, reported that the project entered operation in 2025 (Africa REN, 2025, n.d.). Mozambique's Cuamba project combines 7 MWh of battery storage with a 19 MWp (15 MWac) solar power plant. Its four-hour storage configuration shifts part of the daytime electricity generation to the evening demand peak and provides support to the Cuamba substation. The project began commercial operation in September 2023 (Globeleq, 2023, 2024). Although both projects integrate battery storage with solar power generation, Walo focuses on multiple ancillary grid services, whereas Cuamba places greater emphasis on evening electricity supply and local substation operations.

Projects in Cameroon and the Central African Republic further demonstrate the role of energy storage in improving electricity supply. In Cameroon, the Maroua and Guider power plants have a combined capacity of 36 MW of solar power generation and 20 MW/19 MWh of battery energy storage, and entered operation in September 2023. In an electricity system where droughts can affect hydropower generation, these facilities can increase electricity supply and improve supply reliability (Scatec, 2023). In the Central African Republic, the Danzi solar power plant combines 25 MWp of solar PV capacity with 30 MWh of battery energy storage. The project entered operation in November 2023 and is primarily intended to strengthen grid electricity supply and expand access to electricity (World Bank, 2025b). The subsequently proposed 15 MWp expansion is not included in the operating capacity reported here, as the available information has not confirmed it as part of the originally commissioned power plant.

Table 5-8-3 Technical Configurations, Main Functions and Development Stages of Representative Energy Storage Projects in Africa

Country / Project	Technology and System Configuration	Energy Storage Capacity	Main Application	Development Stage	Source
Senegal – Walo	Lithium-ion battery storage integrated with 16 MW of solar power	10 MW/20 MWh	Frequency regulation, spinning reserve, islanded operation and black start	Operating (2025)	Africa REN (2025, n.d.)

Country / Project	Technology and System Configuration	Energy Storage Capacity	Main Application	Development Stage	Source
Mozambique – Cuamba	Battery storage integrated with 19 MWp (15 MWac) of solar power	7 MWh; 4 hours; power rating not reported	Evening peak electricity supply and substation support	Operating (2023)	Globeleq (2023, 2024)
Cameroon – Maroua and Guider	Battery storage integrated with a combined 36 MW of solar power	20 MW/19 MWh	Improving electricity supply and reliability	Operating (2023)	Scatec (2023)
Central African Republic – Danzi	Battery storage integrated with 25 MWp of solar power	30 MWh; power rating not reported	Grid electricity supply and electricity access	Operating (2023)	World Bank (2025b)
Mauritania – Tasiast	Standalone mining power system integrated with 34 MW of solar power	18 MW/9 MWh; 0.5 hours	Smoothing weather-related fluctuations in power output and coordinating with conventional thermal generation	Operating (2024)	Kinross Gold Corporation (2024)
Egypt – Abydos I	Battery storage added to an operating 500 MWac solar PV plant	300 MWh; power rating not reported	Electricity time shifting and evening peak supply	Under construction / Final investment decision reached; storage commissioning not yet confirmed	IFC (2025); AMEA Power (n.d.)
Mauritania – IWA	Planned hybrid solar–wind–battery power plant integrating 160 MW of solar power and 60 MW of wind power	340 MWh; power rating not reported	Grid capacity support and energy supply security	Development and feasibility study stage	AfDB (2026d)

Country / Project	Technology and System Configuration	Energy Storage Capacity	Main Application	Development Stage	Source
South Africa – Mogobe	Standalone battery energy storage system	103 MW/412 MWh	Contracted grid capacity availability and balancing services	Under construction / Final investment decision reached	Scatec (2024, 2026)
South Africa – Red Sands	Standalone lithium iron phosphate (LFP) battery energy storage system	153 MW/612 MWh; 4 hours	Grid support and alleviation of transmission and distribution congestion	Under construction / Final investment decision reached	AGV Projects (2024); Globeleq (2026)
Morocco – Abdelmoumen STEP	Pumped hydro energy storage	350 MW; energy storage capacity not reported	Peak electricity supply, system balancing and grid stability	Operating (2024)	ONEE (2025)

Note: This table presents selected representative projects and does not constitute a comprehensive inventory of energy storage projects in Africa. Solar and wind power generation capacity, storage power (MW) and energy storage capacity (MWh) are reported separately. Storage duration is provided only where explicitly stated in the cited sources. "Not reported" indicates that the available information does not contain verifiable data for the corresponding parameter. Project development stages are determined based on confirmed construction or operational progress, and planned commissioning dates are not treated as evidence of actual operation. The Stor'Sun project is excluded from the comparison because the available sources provide conflicting information on its energy storage configuration.

Source: See the "Source" column in the table.

In addition to solar-plus-storage systems connected to national grids, battery energy storage is also beginning to be deployed in standalone industrial power systems. At the Tasiast gold mine in Mauritania, an 18 MW/9 MWh battery energy storage system is integrated with a 34 MW solar power facility to form a hybrid mining power supply system. The battery has a storage duration of half an hour and is primarily used to buffer fluctuations in solar power output caused by changing weather conditions and enable smoother transitions between solar generation and conventional thermal power generation, rather than providing several hours of continuous evening electricity supply. The hybrid power plant entered operation by the end of March 2024 (Kinross Gold Corporation, 2024). This case demonstrates that, for mining facilities requiring continuous electricity supply, energy storage can improve coordination between renewable energy and existing generation equipment, although short-duration batteries

cannot replace stable power generation sources over extended periods.

The Abydos I project in Egypt and the IWA project in Mauritania illustrate the development of larger-scale hybrid energy storage systems. Egypt plans to add 300 MWh of battery storage to the existing 500 MWac Abydos I solar power plant, shifting part of its electricity supply to the evening peak. Available information confirms that the storage project has secured financing and entered construction, but its formal commissioning has not yet been confirmed. It is therefore classified in this section as under construction or having reached a final investment decision (IFC, 2025; AMEA Power, n.d.). The proposed IWA hybrid power plant in Mauritania is designed to combine 160 MW of solar power, 60 MW of wind power and 340 MWh of battery storage to support grid electricity supply and energy security. However, the project remains at the development and feasibility study stage (AfDB, 2026d). These projects indicate that energy storage is increasingly being incorporated into larger-scale renewable energy development plans, but planned and under-construction capacity should not be treated as existing electricity supply capacity.

Differences in the technical parameters disclosed by individual projects also affect comparisons. Cuamba, Danzi, Abydos I and IWA have all reported their energy storage capacities (MWh), but the sources used in this section do not provide directly usable storage power ratings (MW). Therefore, the ratio of storage power to energy capacity or the actual discharge duration cannot be calculated solely from the reported energy storage capacity. In particular, the generation capacity of associated solar or wind power facilities must be distinguished from the power rating of the battery storage system itself, as these are not equivalent.

In addition to storage facilities directly integrated with solar power plants, South Africa has begun constructing standalone battery energy storage projects designed to meet broader electricity system requirements. Unlike batteries integrated with solar power plants, which primarily coordinate generation and electricity use at specific facilities, standalone storage systems can provide available capacity, supply–demand balancing and network support services according to grid requirements. Mogobe and Red Sands are representative projects in this area.

The Mogobe project is designed with a storage power rating of 103 MW and an energy storage capacity of 412 MWh. In 2024, the project signed a 15-year power purchase agreement with South Africa’s National Transmission Company and achieved financial close. According to information released by Scatec in the first quarter of 2026,

the project remained under construction and had not yet entered commercial operation (Scatec, 2024, 2026). The 120 MW of solar generation capacity associated with this project in some earlier records does not form part of its battery storage capacity and is therefore excluded from the energy storage figures reported in this section.

The Red Sands project uses lithium iron phosphate (LFP) battery technology, with a designed storage power rating of 153 MW and an energy storage capacity of 612 MWh, providing four hours of storage. Located in South Africa's Northern Cape Province, the project is primarily intended to support grid operations and alleviate congestion in transmission and distribution networks. The project achieved financial close in March 2026 and entered the construction stage, but has not yet been included in operating energy storage capacity (AGV Projects, 2024; Globeleq, 2026).

In addition to battery energy storage, pumped hydro storage is an important technology for improving the operational flexibility of African electricity systems. Morocco's Abdelmoumen pumped hydro storage power plant (Abdelmoumen STEP) has an installed power capacity of 350 MW and entered operation in the third quarter of 2024. The plant is primarily used to meet peak electricity demand, improve grid flexibility, support renewable energy integration and enhance the stability of the national electricity system (ONEE, 2025).

The representative projects examined indicate that energy storage development in Africa now encompasses operating, under-construction and planned projects. Walo, Cuamba, Maroua and Guider, Danzi, Tasiast and Abdelmoumen all have confirmed commissioning records. Most of these projects involve battery storage integrated with solar power generation or hybrid industrial power supply systems, while Abdelmoumen represents an operating pumped hydro storage project. Mogobe and Red Sands in South Africa are relatively large standalone battery energy storage projects that have secured financing and entered construction. The additional storage facilities at Egypt's Abydos I project are likewise classified as under construction or having reached a final investment decision, while Mauritania's IWA project remains at the development and feasibility study stage.

5.8.4 Africa's Hydrogen-Based Industries

(1) Development Framework and Project Progress

Africa's abundant solar and wind resources provide favourable conditions for the

development of renewable hydrogen and its downstream industrial products. Through water electrolysis, renewable electricity can be further converted into industrial products such as ammonia, methanol and direct reduced iron, providing new technological pathways for the development of low-carbon chemical, fertiliser and metal processing industries in Africa. However, the development of hydrogen-based industries depends not only on renewable energy resources and electrolyser capacity, but also on supporting water supply, product conversion and transport infrastructure, as well as market demand. Assessing the progress of hydrogen-based industries in Africa therefore requires consideration of hydrogen production, downstream industrial applications and actual project implementation (IEA, 2022; IRENA and AfDB, 2022).

The hydrogen project information compiled in this report includes 52 evidence records suitable for analysis, primarily covering project scale, technological configurations, infrastructure, market arrangements and implementation progress. These records do not represent 52 independent projects, nor do they constitute a comprehensive inventory of all hydrogen projects in Africa. The available evidence mainly covers Namibia, Mauritania, Morocco, Egypt and South Africa, reflecting the current concentration of hydrogen-based industrial development in African regions with abundant renewable energy resources, access to ports or an established industrial base.

In terms of geographical distribution and industrial foundations, hydrogen-based projects in Africa exhibit three main development patterns. Namibia and Mauritania are planning new hydrogen projects based on large-scale renewable energy resources, requiring the simultaneous development of energy, water supply and product transport infrastructure. Morocco is seeking to utilise both its Atlantic coastal export opportunities and the potential to integrate renewable hydrogen with its existing phosphate and fertiliser industries. Egypt and South Africa are developing hydrogen production and downstream chemical facilities through port-based industrial platforms, with the Sokhna Industrial Zone and the Coega Special Economic Zone representing notable examples. These differences indicate that resource endowments provide the foundation for hydrogen development, while industrial facilities, infrastructure and market conditions further influence project locations and development models (Hyphen Hydrogen Energy, n.d.; Chariot Limited, 2024; TotalEnergies, 2024; SCZONE, 2024; SLR Consulting, 2026).

The scale of announced projects varies considerably. Namibia’s Hyphen project is

planned to be developed in two phases, each comprising 3.75 GW of renewable electricity generation capacity and 1.5 GW of electrolysis capacity, with production of approximately 1 million tons of green ammonia. The completed feasibility study for Project Nour in Mauritania proposes 3 GW of renewable electricity generation capacity and up to 1.6 GW of electrolysis capacity in its first phase, with a designed annual hydrogen production capacity of 150,000 tons. Morocco's Chbika project plans to develop a combined 1 GW of onshore solar and wind power generation capacity, converting the hydrogen produced into 200,000 tons of green ammonia annually (Hyphen Hydrogen Energy, n.d.; Chariot Limited, 2024; TotalEnergies, 2024). These figures reflect the development targets of large-scale hydrogen projects in Africa, but the reported capacities are primarily planned or design specifications and do not yet represent actual operating production capacity.

Significant gaps remain between project implementation progress and planned capacity (Table 5-8-4). Hyphen signed a concession agreement with the Namibian government in May 2023 and has continued to advance front-end engineering design (FEED) and environmental and social impact assessment (ESIA), but the available information has not yet confirmed a final investment decision (FID). Project Nour completed its feasibility study in March 2024, although investment arrangements, engineering design and product offtake agreements still need to be finalised. Chbika has signed a preliminary land reservation agreement and entered activities related to pre-front-end engineering design (pre-FEED). South Africa's Coega Green Ammonia project obtained environmental authorisation in January 2026, but its financing and construction status have not yet been confirmed (Hyphen Hydrogen Energy, 2023, n.d.; Chariot Limited, 2024; TotalEnergies, 2024; SLR Consulting, 2026).

By contrast, some smaller-scale projects have achieved more tangible implementation progress. Egypt Green Hydrogen has reported pilot production and its first exports of green ammonia, and has secured a commercial supply contract under H2Global. Namibia's Dâures Green Hydrogen Village has completed part of its pilot infrastructure, but as of May 2025, its core hydrogen and ammonia production equipment remained in the installation and commissioning stages (SCZONE, 2024; Dâures Green Hydrogen Village, 2025). These projects demonstrate different levels of maturity, from early-stage development to pilot production. However, the available evidence remains insufficient to confirm that the large-scale export-oriented projects examined in this section have achieved sustained commercial-scale operation.

Table 5-8-4 Technical Configurations and Development Progress of Representative Zero-Carbon Hydrogen Projects in Africa

Country / Project	Development Stage	Main Technical Configuration	Target Market	Key Confirmed Progress
Namibia – Hyphen	Advanced feasibility study / FEED; FID not yet confirmed	Two planned phases, each comprising 3.75 GW of renewable energy capacity and 1.5 GW of electrolysis capacity, integrated with ammonia production	Primarily ammonia exports, with potential local electricity and water supply benefits	Concession agreement signed; FEED and environmental and social assessments underway (Hyphen Hydrogen Energy, 2023, n.d.)
Mauritania – Project Nour	Feasibility study completed	Phase 1: 3 GW of renewable energy capacity, up to 1.6 GW of electrolysis capacity, and designed annual hydrogen production of 150,000 tons	Potential domestic green steel production and ammonia exports	Feasibility study completed; investment framework and product offtake negotiations remain pending (Chariot Limited, 2024)
Morocco – Chbika	Land reservation / pre-FEED	1 GW of onshore solar and wind power, seawater desalination, hydrogen production through electrolysis, and green ammonia production	European ammonia market	Preliminary land reservation agreement signed, enabling pre-FEED studies (TotalEnergies, 2024)
Egypt – Egypt Green Hydrogen	Pilot production achieved and commercial contract secured	Renewable electricity-based hydrogen production integrated with ammonia production facilities in Sokhna	Renewable ammonia supply to the European Union	Pilot production and initial exports reported; H2Global contract secured (SCZONE, 2024)

Country / Project	Development Stage	Main Technical Configuration	Target Market	Key Confirmed Progress
Namibia – Dâures	Pilot infrastructure completed; production equipment still undergoing commissioning	Solar-powered hydrogen production, ammonia production, horticulture and fertiliser applications	Initially domestic utilisation, with potential expansion into regional and export markets	Some pilot facilities completed; commercial operation of hydrogen and ammonia production equipment not yet confirmed (Dâures Green Hydrogen Village, 2025)
South Africa – Coega Green Ammonia	Environmental authorisation obtained; construction not yet confirmed	Proposed 1.4 GW of electrolysis capacity and associated ammonia production facilities	Ammonia exports through the Port of Ngqura	Environmental authorisation obtained in January 2026 (SLR Consulting, 2026)

Note: This table presents selected representative projects and does not rank them by announced capacity. Development stages are determined based on actual progress confirmed by the cited sources. The 27 maturity coding records with conflicting information identified during data compilation were not used. Unless facilities are explicitly identified as operating, all technical capacities refer to planned or design capacities.

Source: Hyphen Hydrogen Energy (2023, n.d.); Chariot Limited (2024); TotalEnergies (2024); SCZONE (2024); Dâures Green Hydrogen Village (2025); SLR Consulting (2026).

(2) Renewable Hydrogen Production and the Ammonia and Fertiliser Industries

Large-scale renewable hydrogen projects in Africa are typically planned as integrated production systems combining solar and wind power generation, hydrogen production through electrolysis, water supply and downstream product conversion facilities. Among these, renewable ammonia is currently one of the more clearly defined downstream industrial applications. Hydrogen, as a key feedstock for ammonia synthesis, can be converted into ammonia through the Haber–Bosch process, which can then be used in fertiliser production or transported through ports to international markets. Hydrogen production is therefore closely linked to the development of the ammonia and fertiliser industries. Its commercialisation requires not only sufficient renewable electricity but also reliable water supplies, chemical production facilities and product transport infrastructure.

Large-scale projects generally use dedicated solar and wind power facilities to supply electricity to electrolysers and obtain production water through water treatment

or seawater desalination. Combining solar and wind power can improve electricity availability at different times, but projects must still coordinate electricity supply configurations, equipment operation and product conversion processes. Morocco's Chbika project plans to develop a combined 1 GW of onshore solar and wind power generation capacity, use seawater desalination to supply water for electrolysis, and convert the resulting hydrogen into 200,000 tons of green ammonia annually, primarily for the European market. Namibia's Hyphen project plans to establish an independent water supply system without relying on the existing municipal water supply in Lüderitz, while integrating renewable hydrogen production with ammonia production and export facilities. Mauritania's Project Nour identifies the deepwater port of Nouadhibou as a potential export route, although the associated water supply, product conversion and port facilities still require further development (Hyphen Hydrogen Energy, n.d.; Chariot Limited, 2024; TotalEnergies, 2024).

Compared with projects requiring extensive new infrastructure, existing ports and industrial parks can provide some of the necessary supporting facilities. Egypt Green Hydrogen is located in the Sokhna integrated industrial zone, where existing port and industrial infrastructure can connect ammonia production with export markets. South Africa's Coega Green Ammonia project plans to develop 1.4 GW of electrolysis capacity and associated ammonia production facilities within the Coega Special Economic Zone, with products exported through the Port of Ngqura (SCZONE, 2024; SLR Consulting, 2026). These projects demonstrate an approach to developing hydrogen-based chemical industries through existing industrial platforms, although renewable electricity supply, water supply, storage and production facilities must still be secured for each project. Existing ports and industrial land can provide some of the necessary development conditions but cannot entirely replace the infrastructure investment required for hydrogen projects.

In addition to large-scale export-oriented projects, integrating renewable ammonia production with existing fertiliser industries is another important development direction for hydrogen-based industries in Africa. Morocco's Jorf Lasfar pre-industrial pilot project is located within the OCP chemical complex. It plans to install a 2 MW proton exchange membrane (PEM) electrolyser and a 2 MW alkaline electrolyser, together with a Haber–Bosch synthesis unit designed to produce 4 tons of green ammonia per day. The project has signed a turnkey construction agreement and secured loan support, but the available information has not yet confirmed sustained operation (Proton Ventures, 2022; Invest International, 2022). Meanwhile, OCP and Fortescue have

proposed cooperation in developing renewable energy, green hydrogen, ammonia and fertiliser production, integrating emerging hydrogen production technologies with Morocco's established phosphate and fertiliser industries (OCP Group, 2024). Compared with independently developed large-scale export projects, this approach can make use of existing chemical production facilities, technical experience and potential product demand, creating opportunities for renewable hydrogen to enter established industrial production chains.

Smaller-scale projects are beginning to explore the use of hydrogen and ammonia in local agriculture. The pilot design of Namibia's Dâures Green Hydrogen Village targets the production of 18 tons of hydrogen and 100 tons of ammonia, integrating these activities with horticulture and future fertiliser production. The project has constructed some of its solar power, electricity, water supply and greenhouse facilities. However, as of May 2025, the hydrogen and ammonia production equipment remained in the installation and commissioning stages, with fertiliser production planned to begin in late 2026 or early 2027 (Dâures Green Hydrogen Village, 2025). Unlike large-scale projects targeting international markets, Dâures focuses on exploring the connections between renewable energy, hydrogen and ammonia production, and local agricultural demand at a smaller scale. Its main contribution lies in production system integration and technology demonstration.

Egypt Green Hydrogen has made progress in pilot product delivery and commercial market development. The Suez Canal Economic Zone reported that the project had undertaken pilot production and completed its first green ammonia exports in November 2023. Subsequently, the project secured a renewable ammonia supply contract worth €397 million through the H2Global pilot auction. Supply to the European market is planned to begin in 2027, with an initial potential supply volume of up to 19,500 tons and a possible cumulative supply volume of 397,000 tons by 2033 (SCZONE, 2024). This case demonstrates that some renewable ammonia projects in Africa have already established initial production and market linkages, although fulfilling future contracted supply volumes will still require facility expansion and sustained operation.

(3) Green Methanol and Hydrogen-Based Materials Production

In addition to ammonia and fertilisers, Africa is beginning to explore the production of green methanol and hydrogen-based direct reduced iron using renewable hydrogen, with the aim of expanding low-carbon chemical and metal processing

activities. These industries involve different production processes and feedstock requirements, but share the common characteristic of converting renewable hydrogen into products with downstream processing applications or market uses through further industrial conversion.

Green methanol (e-methanol) production requires renewable hydrogen and a reliable non-fossil carbon source, together with feedstock processing, chemical synthesis and transport facilities. The C2X project near the Suez Canal in Egypt is a representative example of green methanol development in Africa. In October 2023, the relevant parties signed a framework agreement to advance technical and commercial feasibility studies. The project plans an initial annual production capacity of 300,000 tons of green methanol, with a longer-term target of 1 million tons per year, primarily targeting the marine fuel and chemical markets (C2X, 2023; SCZONE, 2023).

The port and industrial infrastructure in Sokhna could help connect the project with international shipping markets and associated logistics facilities. However, the available information has not yet confirmed its final carbon feedstock supply arrangements, final investment decision (FID) or actual construction progress. Compared with renewable ammonia, green methanol requires the coordination of both hydrogen and carbon feedstock supply chains, increasing the requirements for feedstock procurement and production system integration. The project therefore primarily reflects an emerging investment direction for hydrogen-based chemicals in Africa, rather than providing evidence of sustained commercial production.

Hydrogen-based direct reduced iron production offers another pathway for Africa to expand the local processing of mineral resources. This technology uses hydrogen as a reducing agent to remove oxygen from iron ore, producing direct reduced iron (DRI), which can subsequently be processed into steel products using electric arc furnaces or other facilities. As DRI remains an intermediate industrial product, the construction of direct reduction facilities does not necessarily indicate the establishment of a complete green steel value chain, although it can increase the amount of processing undertaken before iron ore is exported.

Namibia’s HyIron Oshivela project provides a concrete implementation example of this industrial pathway. Located near Arandis, the facility held its inauguration ceremony in April 2025. It has an initial designed production capacity of 15,000 tons of DRI per year, supported by a 20 MW solar power facility in its first phase. Information from relevant government and European institutions confirms that the

facility has entered the commissioning and initial operation stage, but independently verified data on sustained annual production and equipment utilisation rates have not yet been published (BMWK, 2025; EEAS, 2025; HyIron, n.d.). This project demonstrates that the use of renewable electricity and hydrogen for iron ore processing has already reached the physical demonstration stage in Africa, although further development is required to achieve large-scale commercial production.

Mauritania also has favourable potential conditions for exploring hydrogen-based mineral processing. The feasibility study for Project Nour identified the possibility of using hydrogen for domestic green steel production, while the region hosting the AMAN project also has the potential to link abundant renewable energy and iron ore resources. However, the available information has not yet confirmed that AMAN has secured specific green iron reduction facilities, financing or product offtake arrangements (Chariot Limited, 2024). Resource availability and potential industrial applications provide directions for future processing activities, but these opportunities still need to be realised through specific production projects, infrastructure and commercial arrangements.

Table 5-8-5 Representative Hydrogen-Based Industrial Projects in Africa and Their Development Stages

Country / Project	Industrial Pathway	Development Stage	Designed Capacity or Actual Output	Main Industrial Application	Key Confirmed Implementation Progress
Morocco – Jorf Lasfar Pilot Project	Renewable ammonia and fertilisers	Construction agreement signed and financing support secured; sustained operation not yet confirmed	Designed ammonia production of 4 tons/day; 2 MW PEM electrolyser and 2 MW alkaline electrolyser	Pilot production within an existing phosphate and fertiliser complex	Turnkey construction agreement signed and loan support secured (Proton Ventures, 2022; Invest International, 2022)
Egypt – Egypt Green Hydrogen, Sokhna	Renewable ammonia	Pilot production and commercial supply contract reported	Actual pilot production volume not specified; future H2Global supply volumes do not represent current output	Ammonia supply to Europe through a port-based industrial platform	Pilot production, initial exports and H2Global contract reported (SCZONE, 2024)

Country / Project	Industrial Pathway	Development Stage	Designed Capacity or Actual Output	Main Industrial Application	Key Confirmed Implementation Progress
Namibia – Dâures	Ammonia and fertiliser demonstration	Pilot infrastructure completed; hydrogen and ammonia equipment still undergoing commissioning	Designed pilot production of 100 tons of ammonia; actual output not yet confirmed	Local horticulture and fertiliser applications	Some physical facilities completed; production start date remains planned (Dâures Green Hydrogen Village, 2025)
Morocco – Chbika	Renewable ammonia	Land reservation and pre-FEED stage	Designed annual ammonia production of 200,000 tons	European export market	Preliminary land reservation agreement signed to support early-stage engineering studies (TotalEnergies, 2024)
Egypt – C2X, Sokhna	Green methanol	Framework agreement and feasibility study stage	Designed annual production of 300,000 tons in Phase 1, with a planned capacity of 1 million tons/year in the final phase	Marine fuels and chemical markets	Framework agreement signed; FID and construction not yet confirmed (C2X, 2023; SCZONE, 2023)
Namibia – HyIron Oshivela	Hydrogen-based direct reduced iron	Inaugurated in April 2025 and completed commissioning	Initial designed production capacity of 15,000 tons of DRI per year; sustained actual annual output not reported	Supplying direct reduced iron for downstream steel processing	Inauguration of the hydrogen-based direct reduction facility confirmed (BMWK, 2025; HyIron, n.d.)

Note: This table presents selected representative projects and does not rank them by announced production capacity. Designed capacity does not represent actual output. Project development stages are determined based on progress confirmed by the sources used in this section.

Source: Proton Ventures (2022); Invest International (2022); SCZONE (2023, 2024); Dâures Green Hydrogen Village (2025); TotalEnergies (2024); C2X (2023); BMWK (2025); HyIron (n.d.).

The projects discussed above indicate that hydrogen-based industries in Africa are gradually expanding from renewable ammonia into other chemical and metal products,

although the level of development varies considerably across industries. Renewable ammonia has relatively well-established markets and industrial foundations, while green methanol remains largely at the early development stage, and hydrogen-based direct reduced iron has already reached the physical demonstration stage. Different technological pathways have different requirements for feedstocks, infrastructure and markets, resulting in differences in their commercialisation progress and opportunities for local industrial applications.

(4) Commercialisation Pathways and Local Industrial Value Creation

Hydrogen-based industries in Africa currently target both international export markets and domestic industrial applications, but commercialisation progress varies considerably among projects. Large-scale projects generally identify European and Asian markets as potential export destinations, aiming to connect green ammonia and other hydrogen-based products with international chemical and energy supply chains. Domestic industrial demand provides another development opportunity for hydrogen-based industries. Morocco is exploring renewable ammonia and green fertiliser production based on its existing fertiliser industry, Namibia's Dâures project integrates hydrogen-based products with local agricultural activities, and Mauritania has identified the potential to use renewable hydrogen for domestic green steel production.

From the perspective of industrial value creation, whether a project ultimately serves domestic or international markets is not the only criterion for assessing its local contribution. Even when products are primarily exported, undertaking important processing activities locally, such as hydrogen production, ammonia or methanol synthesis, and iron ore reduction, can increase local manufacturing activities and technological capabilities. Conversely, if equipment, engineering services and intermediate inputs depend heavily on imports, projects serving domestic markets may not necessarily establish extensive local supply chains. The actual contribution of hydrogen-based industries to African manufacturing depends on how much technological, processing and economic activity can be sustained locally along the production chain.

Existing industrial foundations provide important conditions for such value creation. Morocco's fertiliser complexes can integrate renewable hydrogen with established industrial production, while port-based industrial platforms in Egypt and South Africa facilitate chemical product conversion and exports. Namibia's hydrogen-based direct reduction facility demonstrates the possibility of expanding metal

processing activities in resource-producing regions. These development models can build on the existing industrial conditions of different regions, but their long-term outcomes will still depend on project operations, local supplier participation, workforce skills and the development of further industrial processing activities.

At present, publicly available information provides substantial evidence on project locations, technological configurations, planned capacities and implementation progress in Africa's hydrogen-based industries. However, systematic data on actual employment, local procurement shares, domestic product utilisation, production costs and local value added remain limited. Consequently, it is currently possible to identify the emerging production pathways of hydrogen-based industries with reasonable clarity, but difficult to quantify accurately the economic benefits they have already generated for African manufacturing. Future project assessments therefore need to extend beyond investment volumes and equipment capacities to include actual production, industrial inputs, supply chain participation and long-term economic benefits.

Overall, hydrogen-based industrial development in Africa is taking shape around large-scale renewable hydrogen projects, with downstream expansion into renewable ammonia, fertilisers, green methanol and hydrogen-based direct reduced iron. Although some projects have achieved progress in pilot production, commercial contracts and physical facility construction, the actual operating capacity of large-scale projects remains substantially below their announced planned capacity. Future industrial development will depend not only on expanding renewable hydrogen supply, but also on coordinating energy, water supply, industrial conversion and transport infrastructure, while connecting project development with actual product markets and local industrial activities. Only when these production processes establish stable operating systems can Africa's abundant renewable energy resources be further converted into sustained low-carbon manufacturing capabilities and opportunities for local industrial development.

5.8.5 Zero-Carbon Industrial Parks in Africa

The 18 representative project or case records and 9 industrial platform records compiled in this report indicate that different development models for zero-carbon industrial parks are emerging across Africa. Based on how low-carbon energy is integrated with industrial production, representative platforms can be grouped into four categories: renewable energy-powered manufacturing parks, clean technology

manufacturing platforms, port- and corridor-linked low-carbon industrial platforms, and low-carbon industrial retrofitting platforms built on existing industrial foundations. These categories are not entirely distinct, and some platforms perform multiple functions. In terms of project progress, only 1 of the 18 representative cases is operating, 3 have received formal approval or reached relatively advanced stages of development, and the remaining 14 are still at early stages, including conceptual planning, feasibility studies or pilot development (Table 5-8-6).

The first category comprises renewable energy-powered manufacturing parks. These platforms coordinate renewable electricity, industrial land and shared infrastructure to provide the conditions necessary for manufacturing. Ethiopia's Hawassa Industrial Park is a representative operating example. The park primarily accommodates textile and garment manufacturing and is equipped with a dedicated 75 MW hydropower supply line, factory buildings, one-stop administrative services and centralised wastewater treatment facilities. These supporting facilities enable industrial production and environmental management within the same industrial park (Zhang et al., 2018).

Kenya's Olkaria Green Energy Park is at a different stage of development. Existing geothermal power generation facilities and associated technical capabilities provide favourable conditions for attracting industrial enterprises through a stable renewable electricity supply. However, the industrial park itself remains under development and is still seeking tenants, while the available information provides limited confirmation of actual enterprise occupancy and production activities (KenGen, 2023). The distinction is that Hawassa has already established manufacturing activities supported by shared infrastructure, whereas Olkaria is still exploring how to convert its existing geothermal power generation advantages into new industrial production capacity.

The second category comprises clean technology manufacturing platforms. These platforms primarily promote the local development of clean technology industries through the production of renewable energy equipment, environmental technologies and related manufactured products. South Africa's Atlantis Special Economic Zone and East London Industrial Development Zone attract related manufacturing activities by providing industrial land, public services and support for technological innovation. Egypt's TEDA-Sokhna platform has also attracted announced investments in solar module manufacturing, some of which have held groundbreaking ceremonies (DTIC, 2025; East London Industrial Development Zone, 2022; authors' analysis based on

project and industrial platform information compiled in 2026).

The contribution of these projects to zero-carbon industrial development primarily lies in the localisation of clean energy equipment manufacturing, suppliers and technological capabilities. However, manufacturing renewable energy equipment does not necessarily mean that the manufacturing process itself has achieved zero-carbon emissions. For example, solar module factories can supply products to the clean energy industry, but whether their production processes use low-carbon electricity and achieve corresponding emission reductions still requires separate assessment. Therefore, the contribution of clean technology products to emission reductions in other industries should not be conflated with the emissions performance of the manufacturing facilities themselves.

The third category comprises port- and corridor-linked low-carbon industrial platforms. These platforms integrate renewable energy, hydrogen production through electrolysis and downstream product manufacturing with ports, industrial zones and transport corridors, supporting the processing and transportation of products such as hydrogen, ammonia and methanol. Egypt's Sokhna and South Africa's Coega make use of operating economic zones and port facilities to provide industrial land, logistics and administrative support for related low-carbon industrial projects. Namibia's Southern Corridor and South Africa's Boegoebaai development plans cover broader geographical areas and require further connections between renewable energy resource locations, water supply systems, electricity transmission networks, towns and export ports (SCZONE, 2020, 2024; Coega Development Corporation, 2024; SLR Consulting, 2026; ERM, 2025).

Existing infrastructure at ports and industrial zones can reduce the need for new projects to construct certain supporting facilities independently, but this does not mean that all the infrastructure required for hydrogen projects is already available. For example, an existing port can provide access to transport routes, but does not demonstrate that project-specific seawater desalination, pipelines, storage or product loading facilities have secured financing or been constructed. Therefore, the development maturity of port-based industrial platforms must be assessed separately from the implementation progress of new low-carbon production projects located within them.

The fourth category comprises low-carbon industrial retrofitting platforms built on existing industrial foundations. These platforms introduce renewable energy, green

hydrogen and other low-carbon production technologies into existing chemical, fertiliser, resource processing and logistics facilities. Morocco's Jorf Lasfar is a representative example. Its established chemical and fertiliser production facilities, together with industrial land, ports and transport networks, provide an industrial foundation for green ammonia pilot projects and broader renewable hydrogen and fertiliser production plans (MEDZ, n.d.).

The green ammonia pilot project at Jorf Lasfar has signed a construction agreement and secured loan support, but the available information has not yet confirmed sustained operation. The larger-scale cooperation proposed by OCP and Fortescue remains at the collaborative development stage (Proton Ventures, 2022; Invest International, 2022; OCP Group, 2024). These projects can benefit from existing industrial facilities and potential markets, but the operation of conventional fertiliser and chemical production facilities does not necessarily mean that newly introduced low-carbon production technologies have achieved commercial-scale output.

Table 5-8-6 Key Functions and Maturity Level of Representative Zero-Carbon Industrial Platforms in Africa

Platform and Development Model	Operating Functions	Functions Under Development	Planned or Unconfirmed Functions	Main Industrial Focus
Ethiopia – Hawassa Industrial Park Renewable energy-powered manufacturing	Manufacturing park, dedicated 75 MW hydropower supply line, factory buildings, one-stop services and centralised wastewater treatment	Park expansion and changes in enterprise occupancy require confirmation from updated sources	No clearly identified hydrogen or hydrogen-based product manufacturing functions	Export-oriented manufacturing supported by shared infrastructure
Kenya – Olkaria Green Energy Park Renewable energy-based industrial platform	Existing geothermal power generation and associated technical capabilities of KenGen	Industrial park development and investment attraction	Tenant composition, actual production, shared utility facilities and enterprise occupancy have not yet been fully confirmed	Development of domestic industries using stable geothermal electricity

Platform and Development Model	Operating Functions	Functions Under Development	Planned or Unconfirmed Functions	Main Industrial Focus
Morocco – Jorf Lasfar Low-carbon retrofitting of existing industrial facilities	Chemical and fertiliser complexes, industrial land, port, railway, road and logistics infrastructure	Green ammonia pilot construction agreement signed and financing support secured; sustained operation not yet confirmed	Broader plans for renewable hydrogen, ammonia, fertilisers and related manufacturing	Upgrading the existing fertiliser industry while also serving export markets
Egypt – Sokhna Multi-project port-based industrial platform	SCZONE industrial land, utilities, customs services and port logistics; Egypt Green Hydrogen has reported pilot production and initial ammonia exports	Future supply contract under H2Global; agreements signed or groundbreaking ceremonies held for some manufacturing and hydrogen-based product projects	Commercial-scale hydrogen, ammonia and methanol production; overall low-carbon energy supply and emissions performance of the industrial zone remain unconfirmed	Hydrogen-based product exports, clean technology manufacturing and potential domestic industrial applications
Namibia – Southern Corridor Cross-regional green hydrogen-based product platform	Existing urban and port infrastructure around Lüderitz	Hyphen concession agreement, front-end engineering design, environmental and social assessments, and corridor planning	Dedicated renewable energy generation, electrolysers, seawater desalination, ammonia production, electricity transmission and port expansion; FID and actual construction not yet confirmed	Primarily export-oriented, with potential benefits for local electricity and water supply, services and skills development

Note: This table distinguishes development maturity according to specific functions rather than assigning a single operational status to an entire industrial platform. The operation of existing industrial parks or port infrastructure does not imply that associated renewable energy, hydrogen, chemical or manufacturing projects have entered production. All planned capacities and future projects require verification based on actual construction and operational progress.

Source: Authors' analysis based on project and industrial platform information compiled in 2026; Zhang et al. (2018); KenGen (2023); MEDZ (n.d.); Proton Ventures (2022); SCZONE (2020, 2024); ERM (2025); Hyphen Hydrogen Energy (2023, n.d.).

The development of representative zero-carbon industrial platforms in Africa indicates that coordinated energy and infrastructure development is becoming an important feature of low-carbon industrial projects. Large-scale renewable energy and hydrogen projects typically require integrated planning of electricity generation, grid

connections, water supply, hydrogen production through electrolysis, product conversion and logistics facilities. Such integrated development can improve coordination among different technologies and infrastructure systems and may also provide shared facilities for multiple industrial projects. At the same time, however, these production systems require a higher degree of coordination in the construction of multiple project components. Delays in any component, such as electricity transmission, seawater desalination, storage, port upgrades or product conversion facilities, may affect the operation of the entire industrial system, even if other facilities have already been completed.

Existing ports and industrial parks provide an important foundation for low-carbon industrial development. Sokhna, Coega and Jorf Lasfar have industrial land, transport networks, warehousing, ports, customs services and relevant administrative institutions, which can reduce some of the difficulties associated with land development, logistics organisation and administrative coordination for new projects. Hawassa demonstrates how centralised electricity supply, wastewater treatment and public services can support manufacturing activities. However, these existing facilities cannot directly replace the energy supply contracts, dedicated water supply, energy storage, safety facilities, financing and product offtake arrangements required for new low-carbon projects.

Overall, zero-carbon industrial parks in Africa remain at a stage where multiple development models coexist. Some platforms are introducing low-carbon energy into existing manufacturing activities and shared infrastructure, while others are developing hydrogen-based products and clean technology manufacturing through port-based industrial zones. Other platforms are seeking to connect renewable energy resource areas with cross-regional industrial and export facilities. The long-term contribution of these platforms depends not only on the planned scale of new energy and industrial projects, but also on whether the associated facilities can be developed in a coordinated manner, sustain production and generate measurable industrial capabilities and economic value locally.

6. Africa's Economic Future

Based on the analysis above, Africa has considerable potential to achieve zero-carbon development and rapid economic growth as part of the global energy and economic transition towards meeting the temperature goals of the Paris Agreement, particularly the 1.5°C target. Here presents some discussion on the picture of future economic development factors which are key concerning for the potential departure of economic development in Africa.

6.1 The Technologies Are Already Available

Many zero-carbon technologies have already achieved full commercialisation or are approaching the commercialisation stage. Solar PV, wind power, microgrids, pumped hydro storage, battery energy storage, electric passenger cars, electric two-wheelers, electric agricultural three-wheelers, heat pumps and energy-efficient buildings are already commercially competitive. Over the next 3–5 years, in regions with favourable solar resources, green hydrogen production through water elecolysis, green ammonia synthesis using hydrogen, green methanol production using hydrogen, and electric heavy-duty trucks are expected to enter the commercialisation stage.

6.2 Sufficient Investment

Achieving rapid economic growth in Africa will require substantial investment. However, compared with conventional development scenarios, the energy and economic transition towards zero-carbon development no longer requires substantial additional costs. Technological progress may even make it possible to achieve the same level of energy services and energy security with lower investment. According to scenario studies, large-scale investment in Africa will primarily occur after 2035. By that time, most zero-carbon energy development and the zero-carbon transition of industry, transport and even agriculture will be driven by market forces. Investment will mainly come from commercial sources, without requiring substantial additional government expenditure. Government investment will increasingly focus on infrastructure supporting zero-carbon development, such as regional electricity grids.

Creating an environment that encourages commercial investment is therefore

essential. Investment conditions vary significantly among African countries. Countries that have already established favourable environments for commercial investment, such as Mauritius, Seychelles, South Africa, Morocco and Egypt, are better positioned to attract investment, achieve zero-carbon transitions and promote economic development in the future.

The development of emerging industries, particularly hydrogen-based industries, requires substantial upfront investment. For example, an integrated solar PV-powered green hydrogen and ammonia production complex with an annual production capacity of 500,000 tons requires an investment of approximately US$2.4 billion. African countries therefore need stronger financing capabilities and may adopt a range of financing mechanisms.

Some encouraging progress has already been made. The 8.4 GW wind, solar and green ammonia project developed by Mingyang Smart Energy in Ethiopia involves a total investment exceeding US$14 billion, making it the world's largest individual Chinese-invested green electricity project. In May 2026, the project formally obtained an investment licence from the Ethiopian Investment Commission, marking its transition from the framework agreement stage to substantive implementation.

The first phase involves an investment of US$7.47 billion and will develop 5.4 GW of wind power and 2.8 GW of solar PV capacity across three regions of Ethiopia: South Omo, Afar and Somali, with a stated combined renewable energy capacity of 8.4 GW. This scale is equivalent to 86% of Ethiopia's total installed electricity generation capacity in 2023. The wind power component alone is more than ten times the country's existing installed wind power capacity. The project is expected to fundamentally change Ethiopia's current electricity generation structure, in which hydropower accounts for 94%, and substantially reduce the instability of electricity supply during the dry season.

The second phase involves an investment of US$7.3 billion and will establish three core industries: a green ammonia production base, a transmission and distribution equipment manufacturing plant, and a local wind turbine assembly facility. This will extend the project beyond electricity generation into an integrated renewable energy industrial cluster, enabling a shift from selling electricity to exporting higher-value-added green ammonia products.

For Ethiopia, once completed, the project is expected not only to help address the lack of electricity access affecting nearly half of the country's population, but also to

produce green ammonia using low-cost renewable electricity and export it to global markets through the Port of Djibouti. This would convert the country's underutilised solar and wind resources into a stable source of foreign exchange earnings, while creating tens of thousands of local jobs and supporting the transfer of industrial technologies.

6.3 Priorities of African Countries

Promoting economic development and achieving the Sustainable Development Goals are the primary priorities of African countries. These priorities need to be addressed throughout the future energy and economic transition. In the African Agenda 2063, the Pan African Vision of An integrated, prosperous and peaceful Africa, driven by its own citizens, representing a dynamic force in the international arena was proposed. This vision need to be supported. Africa's future development will depend substantially on foreign investment. In supporting Africa's energy and economic transitions, the international community needs to place greater emphasis on local development, with investment and industrial support centred on promoting economic growth and increasing per capita income in African countries. Foreign investment in Africa should give greater consideration to its contribution to local economic activity, employment, technological research and development, and the expansion of production capabilities. Although Africa does not yet have a fully developed industrial system, local technological development will become increasingly important as African industries expand. Foreign investment therefore needs to follow a long-term strategy.

6.4 Enormous Opportunities

Low-cost zero-carbon electricity is essential to the transition towards zero-carbon development. Africa possesses extensive resources capable of providing some of the world's lowest-cost zero-carbon electricity, representing one of its most important development opportunities. Africa has more than 20 billion kW of solar PV potential with electricity generation costs below 0.1 US cents/kWh, widely distributed across the continent, with particularly favourable conditions in North and Southern Africa. Flat terrain and low land costs provide favourable conditions for developing low-cost zero-carbon electricity.

By drawing on the experience of countries that have already developed solar PV, wind power, energy storage and electricity grids at scale, Africa can adopt more effective development models and advance the transition towards zero-carbon energy systems dominated by solar and wind power more rapidly and with lower investment. Early adopters have incurred substantial learning costs, but Africa can avoid much of this burden and move rapidly towards a clearly defined transition pathway.

6.5 Achieving the Sustainable Development Goals Across the Board

Such an energy transition can already contribute to all of the Sustainable Development Goals for 2030. An earlier transition would help Africa make greater progress towards achieving the SDGs by 2030. Future energy development will not only enable Africa to achieve a zero-carbon transition at relatively low cost, but also allow its favourable domestic zero-carbon energy resources to support rapid economic and industrial development and higher per capita incomes.

Low-cost zero-carbon electricity will also change agricultural production models, making greenhouse agriculture commercially competitive in regions with favourable solar PV resources and substantially increasing agricultural output. Meanwhile, zero-carbon chemical production of starch and proteins using green hydrogen and CO_2 is already progressing towards commercial production. Africa could therefore have even greater opportunities to produce food through chemical processes in the future. These developments could all contribute to reducing hunger.

6.6 Challenges Faced

However, the challenges are equally substantial. Advancing such a transition faces numerous difficulties, including severe shortages of skilled personnel, inadequate government services, unfavourable investment environments and political instability.

Developing large-scale emerging industries requires substantial numbers of skilled personnel at various levels, including think tank researchers, entrepreneurs, managers, factory workers, and professionals involved in government decision-making, financing,

business services and social relations. Achieving the industrial development described in the scenarios above would require nearly 50 million or more highly skilled workers in the industrial sector alone. Given the rapid expansion of emerging industries expected in Africa in the near future, the continent is likely to face severe shortages of personnel across the entire system needed to support development on this scale. Available data indicate that 89% of employees in Chinese-invested enterprises are local Africans, but skilled technical workers account for only 5%, far below the 20% required for industrialisation. Manufacturing has long accounted for approximately 10% of Africa's GDP, while local supply chains remain fragmented and shortages of qualified technical workers are substantial.

To address regulatory challenges and strengthen energy sector capabilities, utility companies across Africa urgently need systematic reforms. Stronger institutions and reforms have become key drivers of private sector participation. Due to financial instability and inadequate infrastructure, many state-owned utilities in Africa are unable to provide stable and reliable energy services.

Effective government services are essential for industrial development. Assessments of investment in Africa indicate that bureaucracy, corruption and policy uncertainty are major obstacles in many countries. The quality of government services varies significantly across African countries. Overall, the continent is experiencing accelerating digitalisation and improvements in governance effectiveness in some countries, although uneven regional development and fiscal pressures continue to constrain public service provision.

Africa has already made substantial progress in this regard. For example, Rwanda scored 58 points in the 2025 global Corruption Perceptions Index, ranking among the leading countries in Africa. Its government has introduced one-stop business services, enabling newly registered enterprises to obtain approval within 24 hours and significantly improving administrative efficiency. Despite such progress, government services across Africa remain constrained by structural challenges and limited resources. High debt levels and debt-servicing pressures restrict government expenditure on public services, including education and healthcare. In 2026, African countries face external debt principal repayments exceeding US$90 billion, reducing fiscal space in some countries and affecting the sustainability of public services.

Infrastructure and workforce shortages also remain significant challenges. Although digital public services are developing rapidly, they continue to face

limitations arising from insufficient telecommunications network coverage, with many areas relying primarily on 2G and 3G networks, dependence on servers located outside Africa, and shortages of skilled personnel in digital innovation. These constraints limit the widespread availability of improved services.

Government services in Africa are gradually improving through digitalisation and institutional reforms, with Rwanda, Côte d'Ivoire and Cabo Verde among the leading countries. Nevertheless, addressing debt sustainability and infrastructure deficiencies remains essential across the continent to achieve more balanced and efficient public service provision.

Some countries also face political instability, terrorist attacks and public security challenges. For example, Angola has experienced unrest following increases in fuel prices, Mali has faced frequent terrorist attacks that have prompted calls for gold mining companies to withdraw, and armed attacks occur frequently in northwestern Nigeria. Political instability in some countries, together with emerging tendencies towards the nationalisation of foreign-owned assets in West Africa, has also contributed to weak policy continuity. Investments may consequently be disrupted or abandoned following political changes.

Equity issues in the energy and economic transition also require attention. Some countries currently depend on fossil fuels, and a rapid energy transition could affect existing assets and employment, making strategic preparation necessary.

6.7 Encouraging Developments

Although Africa faces considerable obstacles, the combination of the continent's abundant natural resources and growing investor interest offers a promising path forward, provided that governments and stakeholders can maintain a coordinated approach to reform, innovation and regional integration.

To implement its economic reform programme and create a more favourable investment environment, Tanzania enacted the Investment Act in 1997. In 2021, the country initiated revisions to the Act, including adjustments to provisions concerning preferential treatment for investors. The new Investment Act 2022 (hereinafter referred to as the "new Act") introduced substantial changes in investment service facilitation, talent attraction measures, investment incentives and regulatory strengthening.

An important aspect of the evolution of the Investment Act has been the facilitation

of investment services, primarily through the Tanzania Investment Centre (TIC). The establishment of TIC was a significant outcome of the Investment Act 1997. Under Part II of the previous Act, "The Centre and Its Functions", TIC was established as a government institution and a permanent independent legal entity, authorised to conduct legal affairs and assume responsibilities in its own name. Section 6 of the previous Act, "Functions of the Centre", defined its principal responsibilities, including assisting domestic and foreign investors in establishing business premises, obtaining facilities and legal approvals, and providing relevant advice and support.

Although the previous Act facilitated investment services to some extent, cumbersome approval procedures and overlapping responsibilities among government departments remained important challenges. The new Act therefore placed greater emphasis on the concept of "One-Stop Services", which had also been introduced in the previous Investment Act to reduce redundant administrative procedures for investors. The new Act strengthened this approach in terms of both the legal status and the substantive provisions of the relevant sections.

6.8 Achieving Substantial Economic Growth

In the future, regions of Africa with favourable solar and wind resources could achieve electricity generation costs of approximately 0.75 US cents/kWh, with electricity delivered to industrial parks at around 1.05 US cents/kWh. Under favourable conditions for flexible load operation, green hydrogen could be produced at a cost of approximately US$1,050 per ton. At these cost levels, basic industrial materials such as ammonia, olefins, steel, aluminium and copper could be produced at costs lower than those of conventional fossil fuel-based production. Even after accounting for transportation costs, these products could remain competitive in major global consumption markets. This would drive large-scale industrial development across Africa. Beyond the production of basic materials, downstream manufacturing activities could also relocate to and become concentrated in Africa, supporting the development of a comprehensive industrial system.

The development of a strong industrial system would, in turn, stimulate growth in the service sector. As the overall economy develops, per capita incomes rise and the middle class expands, education, scientific research, finance, healthcare and social services would also improve significantly. Looking ahead, Africa has the potential to

become a continent with a strong economy and a prosperous society. Africa's successful development would also contribute significantly to the global aspiration of building a better and more promising future for the world.

7. A Pathway for Africa Flying to the Sky

The prospects are now relatively clear, and preparations for this development model can begin. Africa already possesses abundant resources, while its currently underdeveloped industrial base may provide favourable conditions for leapfrog development. Achieving such development will require strategic arrangements in the following areas.

7.1 Get Young People Ready for the Future

The future transition towards zero-carbon development and economic growth will require a large workforce with relevant skills. Primary, secondary and higher education systems in Africa need to provide education and training that match these workforce requirements. African governments, international institutions and cooperation with other countries can create substantial opportunities for more targeted education and training, while expanding international exchange and cooperation.

7.2 A Favourable Financing Environment

Global capital is relatively abundant, particularly in countries experiencing rapid economic growth. Encouraging both domestic and international investment in Africa will be essential to achieving extraordinary economic expansion across the continent. As industrial expansion slows in developed economies, more investment capital will need to seek new markets, providing substantial potential sources of financing for Africa's development. Attracting greater investment requires a favourable financing environment. Africa has already made significant improvements in this area, although further progress is still needed.

7.3 Better Government Services

The quality of government services is continuing to improve in some African countries. In 2026, the overall average level of government services in Africa remained

below the global average. However, 71% of African countries recorded improvements in government service efficiency compared with 2025, making Africa the second-fastest improving region globally after Asia-Pacific. Nevertheless, no African country currently ranks among the world's top 50 in government service efficiency.

According to the World Bank's 2026 Country Policy and Institutional Assessment (CPIA) rankings for policy and institutional quality, covering 40 International Development Association (IDA)-eligible countries in sub-Saharan Africa, Rwanda ranked first with a score of 4.2, followed by Côte d'Ivoire, Benin, Cabo Verde and Kenya. Thirteen countries recorded higher scores than in the previous year, and the average score for sub-Saharan Africa exceeded the overall IDA average for the first time.

7.4 Open Markets

Attracting investment requires well-functioning and open markets, and Africa has already made considerable progress in market openness. In 2026, market openness across Africa continued to improve rapidly. The average financial market openness score of 29 major African countries increased compared with the previous year, with 21 countries recording notable improvements in related indicators. The overall rate of improvement in market openness across the region was among the highest in global emerging markets.

According to the latest 2026 Absa Africa Financial Markets Index, the leading African countries in terms of market openness are as follows:

South Africa: With a score of 85, South Africa ranks first in Africa. It has the continent's most mature and fully open financial market, with freely convertible foreign exchange and almost no additional restrictions on cross-border capital flows, making it a major capital hub connecting Africa with global markets.

Mauritius: As an international financial centre in Africa, Mauritius ranks second in market openness. It has signed double taxation avoidance agreements with 46 countries, allows unrestricted cross-border investment capital flows, and facilitates more than US$700 billion in investment flows across Africa annually.

Namibia: Ranked third in Africa, Namibia has highly relaxed foreign exchange

controls and almost no sectoral restrictions on foreign direct investment, making it a leading example of international market openness in Southern Africa.

Following the full implementation of the African Continental Free Trade Area (AfCFTA), more than 90% of goods traded within the region will be able to circulate tariff-free, substantially reducing trade barriers across African markets. The AfCFTA is one of the world's largest free trade areas.

A second group of rapidly advancing countries includes Cabo Verde, Ghana and the Democratic Republic of the Congo, which recorded the greatest improvements in market openness in Africa in 2026. Cabo Verde has completely removed its negative list for foreign investment, allowing 100% foreign investment in all sectors except public utilities, and has reduced cross-border investment approval procedures to fewer than seven working days. Ghana has liberalised foreign exchange trading and removed previously imposed restrictions on cross-border capital outflows, substantially reducing barriers to profit and capital repatriation for foreign investors in mining and green energy projects. The Democratic Republic of the Congo has introduced new policies to open its mining sector to investment, removing limits on foreign equity ownership and simplifying mineral export approval procedures to attract international mining capital.

7.5 International Support

Africa's own financial resources are limited, and substantial international investment is needed. At present, development banks such as the World Bank and the African Development Bank play an important role in Africa, alongside policy-driven investment support from certain countries and regions, including government assistance from the European Union. In the future, however, commercial investment will become increasingly important. Africa can take full advantage of the current favourable international environment, strengthen cooperation with major partner countries, expand technological collaboration and secure greater investment and technical support.

Traditional investors in Africa, including Europe, the United States and Japan, can continue to maintain their investment commitments. Meanwhile, emerging economies such as China, India and Brazil can play a greater role. China, in particular, is among the global leaders in energy transition, with rapid technological progress. China and Africa also share more common ground in their development experiences, while China's approach to international assistance places greater emphasis on respecting the development priorities of individual countries. There is therefore considerable potential

for further expansion of China–Africa development cooperation.

Beyond financial resources, Africa's development requires comprehensive capacity building. Substantial support is needed in education, workforce training, technological research and development, industrial services, financing capabilities, industrial innovation and the development of independent capabilities.

7.6 Countries Leading the Way

Some African countries have already begun developing green energy and hydrogen-based industries, demonstrating the emerging momentum of Africa's economic takeoff. Ethiopia, Egypt, Morocco and South Africa are among the current investment hotspots, having attracted substantial investment from Europe, the United States and China. The first signs of Africa's zero-carbon energy development are already emerging, with significant progress expected between now and 2030. African countries with favourable conditions can take the lead, establish demonstration projects, develop industries and expand their economies. In doing so, they can demonstrate the potential for future development, strengthen aspirations for a better quality of life and build confidence that such aspirations can be realised.

7.7 Putting Africa's Development First

External investment should not only support project implementation and industrial development, but also aim to advance Africa's broader socioeconomic development. Investment policies in many African countries already emphasise local production and contributions to local development. External investors should likewise place greater emphasis on Africa's development priorities and make their contribution to African development one of the core criteria for investment.

7.8 Comprehensive Development of the Energy System

Africa's energy systems are currently relatively underdeveloped. However, this could become an advantage in the broader process of energy and economic transition, allowing Africa to achieve the transition at a lower cost than countries and regions with well-established energy supply systems. By drawing on the experience of early adopters of energy transition in Europe and China, and taking advantage of technological progress, Africa could achieve leapfrog development, upgrade its energy systems,

reduce energy supply costs and promote economic development across the continent.

The advantages of solar PV and wind power in Africa have already been extensively discussed. Africa also has enormous potential for hydropower and pumped hydro storage, providing favourable conditions for developing an energy system capable of integrating large-scale solar and wind power generation. At the same time, Africa has considerable potential for large-scale nuclear power development. With the demonstrated safety of Generation III nuclear reactors, their favourable cost advantages and potential for load following, Africa could establish a highly secure energy supply system while achieving zero-carbon targets. Low-cost energy supply could, in turn, stimulate local economic development.

7.9 The Journey Is Already Underway

Development has already begun in several African countries. Recently, a number of notable investments in zero-carbon development have emerged across the continent, including the following:

（1） Mingyang Smart Energy Group’s Investment in Ethiopia

Mingyang Smart Energy Group (Mingyang Group) has concentrated its major investments in Africa in Ethiopia. Its project is currently one of the largest single foreign direct investments in Africa’s energy sector, with a total planned investment of US$14.1 billion. In April 2026, the company signed an initial US$10 billion investment agreement at the Ethiopia Investment Forum. In May of the same year, it formally obtained an investment licence from the Ethiopian Investment Commission, with the total investment commitment subsequently increasing to US$14.1 billion.

The project is concentrated in three regions of Ethiopia, South Omo, Afar and Somali, covering key solar and wind resource areas in East Africa. It aims to establish an integrated industrial chain covering wind power, solar PV, energy storage, hydrogen and ammonia, helping Ethiopia diversify its electricity generation structure, which currently relies on hydropower for 94% of its electricity supply, while positioning East Africa as an emerging green hydrogen hub.

The first phase, involving an investment of US$7.47 billion, plans to develop a total of 8.4 GW of renewable energy capacity, including 5.4 GW of wind power and 2.8

GW of solar PV. Supporting infrastructure will include long-duration energy storage systems and an interregional ultra-high-voltage transmission network. Once completed, the project will approach Ethiopia's current total national installed electricity generation capacity and substantially reduce electricity shortages during the dry season.

The second phase, involving an investment of US$7.3 billion, will extend into downstream industries through the development of a green ammonia production base, a transmission and distribution equipment manufacturing plant, and a local wind turbine assembly production line. This will enable the conversion of renewable electricity into exportable green ammonia products, generating foreign exchange earnings for Ethiopia while supporting local technology transfer in renewable energy equipment manufacturing. Upon completion, the project could help address Ethiopia's electricity shortages.

（2） European Investment in Green Energy in Africa

European investment in green energy in Africa has supported several major projects. Morocco has already developed the Noor Ouarzazate Solar Complex, a flagship project with an installed capacity of approximately 580 MW. Morocco and Spain are also connected through subsea electricity interconnections, with the two existing transmission links providing a combined rated capacity of 1.4 GW. Planned investment in green hydrogen-related projects across Morocco has exceeded US$32.5 billion.

Tunisia is developing the ELMED subsea electricity interconnection project to establish an energy link with Italy, positioning the country as an important connection point for exporting green electricity from North Africa to Europe.

In September 2025, the European Union allocated a dedicated €545 million funding package covering ten countries in West and Central Africa, including Côte d'Ivoire and Cameroon. Côte d'Ivoire received €359.4 million to develop the Dorsale Est cross-regional high-voltage transmission backbone, enabling electricity interconnections among several West African countries. Cameroon received €59.1 million to advance rural electrification in 687 communities, directly benefiting more than 2.5 million people without electricity access. All projects are required to adopt European electrotechnical standards to ensure future compatibility between African electricity grids and European energy systems, creating a standards-based dependency that could last for 20 years.

The North African green hydrogen corridor initiative involves dedicated cooperation agreements between the European Union and Morocco, Egypt and Tunisia. The initiative aims to develop 40 GW of green hydrogen electrolysis capacity by 2035, using low-cost local solar and wind electricity to produce green hydrogen for direct transportation to Europe through pipelines or specialised ships, establishing one of Europe's largest external green hydrogen supply bases.

For Namibia's green hydrogen industrial development, Germany's KfW Development Bank has provided €361 million in dedicated guarantee support to facilitate the participation of European companies in green hydrogen projects with total planned investment exceeding US$10 billion. These projects will be supported by solar and wind power generation facilities and ultimately aim to produce 2 million tons of green ammonia annually, with most production intended for export to European markets.

（3） African Development Bank Green Hydrogen Programme

Through its African green hydrogen programme, the African Development Bank has selected representative projects in Egypt, Morocco, Namibia and South Africa. The programme includes US$20 million in preparatory grants to support project implementation, with an overall planned deployment of 20 GW of solar and wind power capacity, 7 GW of electrolysis capacity and 2,950 MWh of energy storage, representing a total planned investment of US$23 billion. It constitutes a major strategic support initiative for Africa's green hydrogen industry.

Egypt's Ra Green Hydrogen Project has received a dedicated grant of US$3.55 million, focusing on sustainable aviation fuel production. Drawing on low-cost renewable electricity from wind power facilities in the Gulf of Suez and the Benban Solar Park, the project aims to establish East Africa's first large-scale production base for green aviation fuels.

Morocco's Guelmim Green Hydrogen Valley project focuses on the export of green ammonia and sustainable aviation fuels. By taking advantage of high-quality wind resources in southern Morocco, where average annual wind speeds exceed 9 m/s, the project aims to establish North Africa's largest green hydrogen industrial cluster.

Namibia's green hydrogen project focuses primarily on green ammonia production, with products intended for export to Europe. It is positioned as a representative green hydrogen export project in Southern Africa.

South Africa's low-carbon iron and green hydrogen project is described as the world's first demonstration project for hydrogen-based direct reduction of iron. By utilising local green hydrogen resources, the project aims to achieve zero-carbon steel production throughout the production process, fundamentally changing South Africa's traditionally carbon-intensive steel industry.

（4） The 1.1 GW Gulf of Suez Onshore Wind Power Project

The 1.1 GW Gulf of Suez onshore wind power project is the largest onshore wind project under construction in Egypt. Constructed by PowerChina, the project comprises 138 wind turbines, each with a rated capacity of 8 MW. By August 2026, the installation of all turbine towers had been completed.

The project is expected to generate more than 4.3 TWh of electricity annually, sufficient to meet the annual electricity needs of approximately one million Egyptian households, while reducing CO_2 emissions by more than 2.2 million tons per year.

（5） Investment from Gulf Countries in Africa

Investment from Gulf countries in Africa represents one of the fastest-growing financial flows within South–South cooperation. Led primarily by sovereign wealth funds and state-owned energy companies, these investments focus on four major sectors: energy and mineral resources, ports and logistics, agriculture and food supply, and digital infrastructure. They are reshaping Africa's economic geography and geopolitical landscape.

For example, Saudi Arabia's Public Investment Fund (PIF) invests in energy, mineral resources, infrastructure and agriculture. Since 2023, Saudi Arabia has incorporated investment in Africa into its national strategy through mechanisms such as the Saudi–African Summit, with plans to direct more than US$100 billion in investment to Africa by 2030.

These projects are expected to serve as demonstrations and further stimulate the development of zero-carbon energy projects in other countries and regions. As implementation progresses and experience accumulates, the opportunities for deploying zero-carbon technologies across Africa will continue to expand, supporting the potential for substantial growth across the continent after 2030.

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