



# CHAPTER 1: AFRICA'S DEVELOPMENT IN THE CONTEXT OF AIR POLLUTION AND CLIMATE CHANGE



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# 1.1 AFRICA'S DEVELOPMENT: KEY OBJECTIVES, DRIVERS AND CHALLENGES

## MAIN MESSAGES

- The key development challenges faced by Africa include stimulating sustainable economic growth, creating opportunities for employment, education and knowledge generation and restoring Africa's degraded ecosystems. Ecosystems are the foundation for improving agricultural productivity, including ethno-food systems on which many of the poor depend. Many aspects of these challenges are affected by air pollution and climate change.
- Economic green growth, founded on policies of climate resilient development models, remains the greatest challenge and a binding constraint to Africa's sustainable development. The natural resources potential of Africa is significant, but Africa remains the least industrialized continent in the world, with an unemployment rate higher than the global average and an informal economy accounting for 80 per cent of employment in urban areas.
- Africa is grappling with significant negative health impacts linked to environmental degradation. For example, degradation of soil and water as well as air pollution and climate change. These impose a significant burden on economies including inefficiencies, costs of illness, reduced labour productivity, human capital losses and depletion of agricultural productivity and natural capital stocks like diversity of plants and animals.
- Africa has the fastest urban growth rate in the world with more than 60 per cent of urban dwellers living in slums, and cities having poor transport systems and waste management problems, especially the open burning of waste.
- More than 70 per cent of the population lack access to clean cooking and use biomass fuels like animal dung, crop residues, wood and charcoal in inefficient stoves for cooking and heating.
- Technological transformation remains critical to Africa's development, to diversify and drive

sustainable economies, stimulate a just, clean energy transition, encourage action on climate and air pollution and identify solutions to persistent socio-economic and environmental challenges.

- Intensified restoration of Africa's Degraded Forests and Landscapes, for example through African Union led African Landscape Restoration Initiative (AFR100) and the Great Green Wall present potential for improving the natural capital base, response to climate change and air pollution challenges.
- To meet its development aspirations, including national-level development objectives and regional integration, the Africa Union's Agenda 2063 and "the Africa we want", Agenda 2030 and the Sustainable Development Goals, as well as the Paris Agreement, technological transformation remains critical to Africa's development.

## 1.1.1 CURRENT DEVELOPMENT STATUS AND DRIVERS

More than half of global population growth between now and 2050 is expected to occur in Africa (UN 2019). Avoiding the negative impacts of air pollution and climate change on human health, agriculture and the economy that could accompany this growth is crucial for Africa but will require innovative, transformative and integrated planning for sustainable development, with cost-effective, efficient and pragmatically robust implementation approaches.

Across the world, including in Africa, COVID-19 has had devastating effects through the loss of lives, jobs and people's livelihoods. The long-term implications across individual countries are not known, specifically in relation to health and economic recovery (United Nations Development Programme [UNDP] 2021). The current conflict between Russia and the Ukraine is likely to impact African economies, the full effect of which is yet to be identified (Zeufack *et al.* 2022). Current understanding is that the war is expected to affect Africa directly and indirectly, whether through trade and financial links or through commodity prices, additionally amplifying debt distress (Zeufack *et al.* 2022). Both Russia and Ukraine export wheat, maize, and seed oil to many African countries; disruption of supplies and higher commodity prices are likely to affect food security negatively (Ben Hassen and El Bilali 2022).



### 1.1.1.1 ECONOMIC GROWTH

Economic growth remains the greatest challenge and a binding constraint to Africa's sustainable development (Ndulu *et al.* 2007). While great strides have been made compared to 1990 levels, average GDP growth is far below the target needed to sustain economic transformation (African Union [AU] 2022a). In addition, Africa's debt burden and its impacts on countries' economies and sovereignties is large (African Development Bank [AfDB] 2021). Genuine progress indicators (GPI) would be a better policy guide than GDP since they incorporate inequality, care for human beings and care for the environment in a single framework. The data intensity of GPI, however, makes them difficult to estimate in full for low-income economies (Berik 2018).

The productive base of economies in African countries is narrow and undiversified, depending largely on export of raw commodities, demand for which is driven by external market conditions (AfDB 2021). Economic growth, however, is uneven across African as countries and regions less reliant on commodities have fared relatively well. Gradually, the main drivers of growth are shifting from private consumption to investment and trade, with the latter being driven more by foreign direct investment than domestic savings.

The COVID-19 pandemic has amplified pre-existing vulnerabilities in the region and worsened economic prospects (AU 2022a). The level of economic activity is forecast to remain subdued in most countries, although, given the lifting of most COVID-19-related restrictions in many countries across the globe, consumption and investment is forecast to pick up on the demand side, and the industrial sector is predicted to grow faster on the supply side (Zeufack *et al.* 2022).

### 1.1.1.2 FROM MINERALS TO INDUSTRIALIZATION AND MANUFACTURING

The resource potential of Africa is significant. Mineral resources represent one of the continent's most important assets for mobilizing revenues for growth and transformation. Beside traditional minerals, Africa has significant quantities of critical minerals and metals, key to the clean energy transition, thereby underscoring the geostrategic importance of the continent for global trade (AfDB 2021).

Agenda 2063 aims to ensure that Africa's natural endowments, its ecosystems and environments are healthy, valued and protected with climate resilient

economies and communities. The exploitation of mineral resources for short-term income gains has, however, left the adjusted net savings, the portion of national income that reflects depletion of natural capital and the cost of pollution, lower than that of other regions and negative over the last two decades (Sopp and Leiman 2017).

Africa remains the least industrialized continent in the world (Signe and Johnson 2018; Hai 2020). African economies continue to rely heavily on raw commodities, importing, on average, more manufactured goods than they export (AfDB 2019). While industrialization through manufacturing has been common in countries aiming to diversify their structures of production, most African countries have remained relatively deficient in manufacturing activities (Signe and Johnson 2018). Moreover, the industrialization agenda to spur economic growth is frequently based on outdated technologies, resulting in air pollution and impacting climate change (Salazar-Xirinachs *et al.* 2014).

### 1.1.1.3 EMPLOYMENT, EDUCATION, AND KNOWLEDGE DEVELOPMENT

Africa has a high unemployment rate, higher than the global average and this has been worsened by COVID-19 (Organisation for Economic Co-operation and Development [OECD] 2020). More than half of African workers are employed in low-skilled jobs, a third in medium-skilled ones and only around 10 per cent in high-skilled jobs (AfDB 2021). The African informal economy remains among the largest in the world, accounting for 80 per cent of employment in urban Africa (World Bank 2021a).

Despite progress in recent decades, Africa is still lagging other developing regions in education and skills development, both in quantity, out-of-school rates and average years of schooling, and quality, test scores and proficiency in mathematics or in reading, for example, with school completion figures remaining low (AfDB 2020; Godfrey and Tunhuma 2020).

In 2018, about a third of Africans aged 25–64 years, and 20 per cent of young people aged 15–24 years, were illiterate (Godfrey and Tunhuma 2020). A severe shortage of facilities, learning materials and qualified teachers represent some of the obstacles to improved education in Africa (Godfrey and Tunhuma 2020). At the same time, people in Africa with intermediate and advanced education have among the highest rates of unemployment in the world (AfDB 2021).

#### 1.1.1.4 HEALTH SYSTEMS AND HEALTHCARE

Africa's large disease burden is driven by communicable conditions, non-communicable diseases (NCDs) and violence/injuries (WHO 2018a). Additionally, Africa is grappling with significant health impacts linked to environmental degradation, such as water and air pollution and climate change (WHO 2022). Most people are unable to afford healthcare, and even if they can, the state of healthcare services requires immense development to effectively improve health and wellbeing for all (WHO 2018a).

Environmental health impacts, such as those caused by air pollution, impose a significant burden on economies in Africa. While it is difficult to determine the exact costs, they include inefficiencies, costs of illness, reduced labour productivity, human capital losses and depletion of natural capital stocks. The economic benefits of controlling or preventing environmentally related diseases and ecosystems' harm upstream outweigh the costs incurred downstream, i.e., treating diseases and restoring ecosystems (Landrigan *et al.* 2018). Overall, health expenditure is rising faster in Africa than GDP growth. While significant progress has been made over the past decades to reduce the burden of disease on the continent, addressing risk factors influencing healthy lives remains one of the key challenges to achieving universal health coverage in African countries (WHO 2018a).

### 1.1.2 PERTINENT DEVELOPMENT CHALLENGES FOR AFRICA

Pressing development challenges confronting the African continent that influence air quality and climate change are related to urbanization, land-use change, economic growth, demographic change, poverty and healthcare.

#### 1.1.2.1 URBANIZATION

Africa has the fastest urban growth rate in the world (OECD 2020). The proportion of the continent's population living in towns and cities grew from 15 per cent in 1960 to 40 per cent in 2010 and is projected to exceed 60 per cent by 2050 UN-Habitat and IHS-Erasmus University Rotterdam (2018). Cities not only account for a large proportion of the world's GHG emissions but are also vulnerable to the impacts of climate change such as extreme weather events – droughts, floods, and intense storms (Godfrey and Tunhuma 2020). Informal settlements have been created around many African cities, and this occurs for a range of socio-economic reasons, such

as population growth and rural-urban migration, lack of affordable housing for the urban poor, weak governance, economic vulnerability/poverty, discrimination, marginalization and displacement caused by conflict, natural disasters and even climate change (UN-Habitat 2018). Climate change represents push factors in urbanization trends, pushing people into cities in the hope for a better life, even if this means moving into informal settlements without access to basic services (Henderson *et al.* 2017). More than 60 per cent of Africans who live in urban areas live in slums where many of the most vulnerable people, those with pre-existing diseases, the unemployed, elderly people, etc., also reside (Godfrey and Tunhuma 2020).

The development of African cities under conditions of rapid urbanization offers significant opportunities but also brings great challenges as new and even expanding urban centres need to cater for the increased population in terms of infrastructure, service delivery, healthcare, education and housing (OECD 2020). In a rapidly urbanizing Africa, ensuring sustainable urbanization, while protecting the environment, requires government policies that reconcile urban and sustainability concerns, and are built on adaptation strategies (OECD 2020).

Urbanization is associated both with air pollution and climate change. Urbanization trends and population growth in African countries have led to increased vehicular ownership, poor infrastructure development and maintenance, and densely populated areas with service delivery problems, such as access to electricity/energy supply and waste management challenges. People in many urban centres, particularly in informal settlements, burn solid fuels for cooking and heating (Amegah 2020). Limited and irregular waste collection in urban areas, mainly due to a lack of capacity in municipalities, results in waste dumping and open burning as a way of managing solid waste. Africa is forecast to become the dominant region globally in terms of total waste generation if current trends persist, with population growth and rapid urbanization among its main drivers (UNEP 2020).

It is not possible to deal with Africa's growth and poverty challenges without managing urbanization (Freire *et al.* 2014). Poor air quality and unpreparedness for the influx of people, as well as the occurrence of extreme weather events and their consequences in urban settings, such as the heat island effect and floods due to inefficient drainage mechanisms, pose serious health hazards and risks.

### 1.1.2.2 LAND-USE CHANGE AND AGRICULTURE

Apart from globalized trade, climate change and its associated impacts, such as extreme events, drought, and floods, represent important drivers of land degradation and land-use change (Winkler *et al.* 2021). Africa has seen unprecedented land-use and land-cover changes, affecting species abundance and distribution, but also altering ecosystem productivity and resilience to climate change (Brink 2021). Land is critically important both as a source and sink of GHG emissions and therefore represents an important factor in climate change solutions (Shukla 2019; IPCC 2021).

Agriculture is an important sector causing environmental issues, including human health problems, through exposure to ammonia, hydrogen sulphide, toxic organic compounds, pesticides, and particulate matter (Aneja *et al.* 2009). It also makes a contribution to climate change through GHG emissions and aerosols. Biomass burning is driven by agricultural practices, such as burning during the post-harvest season for fertilization and pest control. Thus, these emissions are predominantly anthropogenic (Bauer *et al.* 2019).

### 1.1.2.3 ENERGY

More than 80 per cent of the electricity produced in Africa is generated in thermal power stations (International Energy Agency [IEA] 2019) mainly as a result of the dominance of the South African coal-fired power plants, and oil-fired units in Nigeria and North Africa. The remaining constituents of the African energy mix are hydro and nuclear power, and, increasingly, natural gas and oil, geothermal, wind and solar plants (IEA 2019).

Africa has among the richest solar resources in the world but has only 1 per cent of the global installed solar photovoltaic capacity. It also has significant potential for developing other clean and renewable energy sources and technologies, crucial for the global energy transition (IEA 2019). In 2018, nearly half of Africa's population, about 600 million people, did not have access to electricity while around 80 per cent of African companies suffered frequent electricity disruptions leading to economic losses (IEA 2019).

For those who cannot make use of clean cooking solutions, biomass fuels constitute the dominant source of energy for meeting basic human energy needs. Rural households mostly use firewood for cooking, although coal is also used in rural areas located near coal-fired powered stations, while charcoal is the dominant energy source in urban

centres. More than 70 per cent of the population lack access to clean cooking and use biomass fuels for cooking and heating (World Bank 2014; IEA 2019). These biomass fuels include dried animal dung, crop residues, wood and charcoal (IEA 2019).

Alternative cleaner energy options in Africa in the short and long term include electricity, natural gas, liquified petroleum gas (LPG), bioethanol and biogas (IEA 2019). Developing gas infrastructure will be a major challenge because of typically small markets and concerns about affordability, although gas is well-suited for utilities that are hard to electrify (IEA 2019). In the future, Africa is predicted to emerge as a major supplier of liquified natural gas to global markets (IEA 2019).

### 1.1.2.4 POVERTY AND INEQUALITY

Millions of Africans live under the international poverty line. COVID-19 has further worsened the situation by reversing the progress made in poverty reduction over the past two decades, with up to 40 million people likely to fall below the extreme poverty threshold during 2020–21 (Zeufack *et al.* 2022). The United Nations Conference on Trade and Development [UNCTAD] stated that 478 million people lived in extreme poverty in Africa in 2019, and estimated that in 2021, 490 million people in Africa lived under the poverty line of \$1.90 purchasing power parity/day, 37 million people more than what was projected without the pandemic 2021a and b.

Poverty in Africa has many causes including low incomes; low levels of skills and educational attainment; inadequate livelihood opportunities; labour scarcity exacerbated by the HIV/AIDS pandemic; lack of employment, information and collateral and hence poor access to credit markets; poor infrastructure and markets; poor governance and macro-economic environments; and adverse biophysical conditions and declining woodland and forest resources (Addae-Korankye 2014).

Africa remains one of the most unequal continents with estimates for 2019 showing that 10 per cent of the population earns half the gross national income (Robilliard 2020). The African Development Bank (2020) reported persistently high inequality in Africa's economic growth with only about a third of African countries achieving inclusive growth. They concluded that countries with better education outcomes and higher rates of structural change are more likely to achieve inclusive growth. For every 1 per cent rise in inequality, mitigation and adaptation action for climate

change fall by 23 per cent across African countries (Nyiwul 2021). This has serious repercussions for communities, especially vulnerable groups such as women and children, the elderly, people with disabilities, people with pre-existing diseases, etc.

#### 1.1.2.5 EXTERNAL INFLUENCES

The COVID-19 pandemic has had devastating effects across the world and in Africa, through the loss of lives, jobs and people's livelihoods. Economic growth in Africa is estimated to have contracted by 2 per cent in 2020 during the pandemic (World Bank 2021b). In addition, the long-term implications of the COVID-19 pandemic on economic decline will be worse for countries with lower government capacity and higher labour shares in the agricultural sector (UNDP 2021).

A 1.4 per cent decrease in GDP is expected across the continent, with smaller African country economies facing up to a 7.8 per cent reduction (Gondwe 2020). This would mainly affect commodity exporting countries and result in tax revenue losses, which in turn will reduce governments' ability to extend public services. It is further expected that the COVID-19 pandemic will have significant developmental implications over the long term, necessitating policy measures tailored to individual country requirements (UNDP 2021).

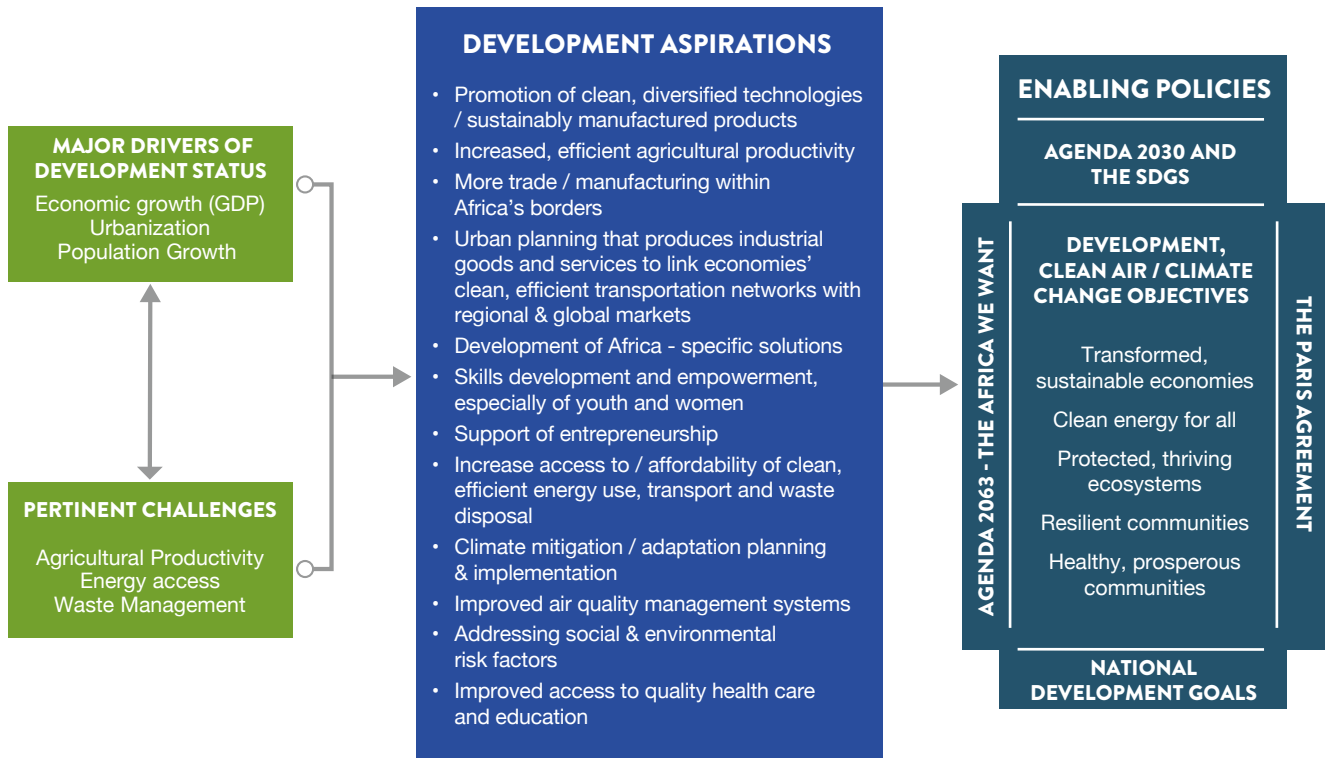
The African economy continues to be vulnerable to external shocks and, as mentioned earlier, this is now the case with the war in Ukraine, the full effects of which are yet to be determined.

### 1.1.3 TOWARDS CLEAN AIR AND CLIMATE CHANGE OBJECTIVES IN AFRICA

Drivers of Africa's development and the challenges it faces are critically linked with the continent's air quality and climate change objectives. Climate change threatens not only economic growth but also represents a human health risk and a poverty multiplier, deepening inequality. It aggravates the effects of population growth, poverty and rapid urbanization. Without serious, sustainable adaptation, climate change is likely to push millions of people further into poverty, limit the opportunities for sustainable development and inhibit people's ability to escape from poverty.

Outdoor and household air pollution threaten not only the health and productivity of millions of people on the continent but places a large burden on already strained health systems, increasing healthcare costs. Air pollution also impacts the health of ecosystems and agricultural yields, influencing food security and leading to significant economic losses (Fisher *et al.* 2021).

To meet its development aspirations, including national-level development objectives and regional integration, Agenda 2063 and "the Africa we want" (AU 2013), the Agenda 2030 for Sustainable Development and the SDGs (UN 2015), as well as the Paris Agreement (UNFCCC 2015), technological transformation remains critical to Africa's development (Figure 1.1). This could diversify and drive sustainable economies, stimulate a just, clean energy transition, encourage climate action and identify solutions to persistent socio-economic and environmental challenges (Fisher *et al.* 2021).



**Figure 1.1.** Africa’s development: Major drivers of development status and pertinent development challenges (left boxes); Development aspirations (middle box); and examples of enabling policies/agreements and clean air, climate change and sustainable development objectives (right box).

The transformations needed to meet development objectives require addressing issues of capacity for green growth, including knowledge, expertise and experience in managing technical change. Some companies from highly industrialized countries are starting to invest in Africa to enhance the host country’s environmental performance through the adoption of production structures which rely on green and more efficient technologies (Chen *et al.* 2021). In the long term, developing indigenous innovation capabilities, rather than just importing green technologies from abroad, will be critical for long-term growth. There is a need for building well-functioning innovation systems, able to connect research and development firms and organizations, and the use of green technologies through a supportive institutional system.

In terms of energy access, it was realized in the early 2000s that electricity trade between African countries could be increased considerably and would reduce total energy costs and increase energy security. At the same time, working together would also boost trade and bring benefits to the economies of participating countries, promoting the socio-economic wellbeing of their populations. To do this it is necessary to remove

existing barriers to trade and take action to introduce the reforms that are needed to attract investment. There are now examples of such initiatives in Africa that can be built on, for example in Western Africa (World Bank 2020).

The employment opportunities which accompany development and industrialization are plentiful, particularly for youth and women (Zeufack *et al.* 2022). It is possible to create employment in the green economy and as part of digital transformation. Initiatives across the continent are being created to advance a just transition to green growth, social inclusion as well as the development of skills and re-skilling to address existing and emerging development challenges (AfDB 2019).

Health and wellbeing are indicators of good urban and territorial planning ((UN-Habitat and WHO 2020)). Focusing on the health and wellbeing of people within urban areas can improve livelihoods, develop vibrant communities, empower vulnerable groups, and reduce inequalities. Doing so will ensure an integrated and holistic approach which will have air quality and other environmental improvements as key outcomes ((UN-Habitat and WHO 2020)).

## 1.2 SYNERGIES BETWEEN AIR POLLUTION, CLIMATE CHANGE AND DEVELOPMENT

### MAIN MESSAGES

- It is well established that air pollution and climate change are intimately linked and that they share many common emission sources from transport, energy, waste, manufacturing and agriculture sectors.
- Short-lived climate pollutants (SLCPs), such as black carbon (BC), methane (CH<sub>4</sub>), tropospheric ozone (O<sub>3</sub>) and hydrofluorocarbons (HFCs), can have impacts on the climate, and BC and O<sub>3</sub> can also have impacts on human health, crops, and ecosystems. Reducing these SLCPs can form part of integrated strategies that can more effectively manage air pollution and climate change and produce multiple benefits for society, the economy and the environment, while avoiding tradeoffs.
- There are also interactions between air pollution and climate change, as a warming climate can increase air pollution related to tropospheric ozone production and increase the frequency and/or intensity of wildfires. Action taken to reduce air pollution will improve air quality even as the climate changes.
- There are many links between air pollution and climate change and the SDGs, and hence between the Paris Agreement and Agenda 2063, which can be used to achieve national, regional and continental development goals more efficiently.

### 1.2.1 SHORT-LIVED CLIMATE POLLUTANTS AND THE SYNERGISTIC RELATIONSHIP BETWEEN CLIMATE CHANGE AND AIR QUALITY

Scientific evidence linking air pollution and climate change from their emission sources in the transport, energy, waste, manufacturing and agriculture sectors to their impacts on climate, human health, food and water security, and ecosystems has been well established (Melamed *et al.* 2016; Sillmann *et al.* 2021; Szopa *et al.* 2021; Hu *et al.* 2022). Thus, an integrated approach to addressing these issues as part of the policy process can lead to significant synergies and co-benefits to human health and ecosystems, resulting in the prevention of premature deaths and an increase in crop yields, for example, among other benefits (Nemet *et al.* 2010; Anenberg *et al.* 2012; Shindell *et al.* 2012; Scovronick *et al.* 2015; Anenberg *et al.* 2017; Sillmann *et al.* 2021).

By taking account of three key criteria: (1) emissions; (2) atmospheric lifetimes; and (3) benefits and trade-offs more comprehensive, sustainable policies can be developed to maximize the benefits of air quality and climate change mitigation (Melamed *et al.* 2016). Therefore, many options for improving air quality may also serve to limit climate change and *vice versa*, but importantly, some options for improving air quality cause additional climate warming, and some actions that address climate change can worsen air quality (Szopa *et al.* 2021).

Climate change and air quality are intimately linked because many of the human activities that produce long-lived greenhouse gases also emit air pollutants, and many of these air pollutants are also short-lived climate forcers (SLCFs) that affect the climate (Szopa *et al.* 2021). They are compounds that warm or cool the Earth's climate over shorter time scales, from days to years, than greenhouse gases such as carbon dioxide, the climatic effect of which can last for decades to centuries or more (Szopa *et al.* 2021). They can be directly emitted into the atmosphere as primary pollutants and/or formed through multiple atmospheric mechanisms as secondary pollutants, for example O<sub>3</sub> (Table 1.1). Cooling SLCFs are mostly made of aerosol particles, such as sulphate, nitrate and organic aerosols, that cool the climate by reflecting incoming sunlight. Warming SLCFs are either GHGs, for example CH<sub>4</sub>, O<sub>3</sub> and HFCs, or particles including BC, also known as soot, which warm the climate by absorbing energy and are also referred to as SLCPs, a key focus of this assessment (Table 1.1).

**Table 1.1** Short-lived climate pollutants (SLCPs): Methane, Ozone, HFCs and Black Carbon, their source type, atmospheric lifetime, indirect effect, other effects on the atmosphere or ecosystems, and whether they are covered by the WHO's Air Quality Guidelines.

COMPOUNDS	SOURCE TYPE <sup>2</sup>	LIFETIME	OTHER EFFECTS	WHO AIR QUALITY GUIDELINES
Methane (CH <sub>4</sub> )	Primary	~12 years	N/A	No <sup>1</sup>
Ozone (O <sub>3</sub> )	Secondary	Hours to weeks	Ecosystems/crops	100 µg m <sup>-3</sup> 8-hour mean
HFC	Primary	Days to years	N/A	No <sup>1</sup>
Black Carbon (soot)	Primary	Minutes to weeks	Cryosphere, Clouds Ecosystems	as part of PM <sub>2.5</sub> - 5µg m <sup>-3</sup> annual mean or 15 µg m <sup>-3</sup> 24- hour mean more than 3 - 4 days per year

1. Regulated through Kyoto/Montreal protocols.

2. Source type can be primary (emitted) and/or secondary (formed through multiple atmospheric mechanisms).

Unless otherwise noted, the stated lifetime refers to tropospheric lifetime.

Source: Szopa et al. (2021); WHO (2021)

As shown in Table 1.1, SLCPs, such as BC, an important component of PM<sub>2.5</sub>, CH<sub>4</sub> and tropospheric O<sub>3</sub>, can have effects on the climate, human health and ecosystems either directly or through their role in producing secondary pollutants in the atmosphere. Chemical compounds, for example, such as CH<sub>4</sub>, CO, non-methane volatile organic compounds (NMVOCs) and NO<sub>x</sub>, react with other chemical compounds in the atmosphere in the presence of sunlight to produce O<sub>3</sub> in the troposphere. As well as being a potent GHG, tropospheric O<sub>3</sub>, also known as ground-level O<sub>3</sub>, affects human health, is subject to a WHO Air Quality Guideline value (Table 1.1) and negatively impacts ecosystem vegetation and crops. Mitigation measures taken to control the precursors of O<sub>3</sub>, such as NO<sub>x</sub> and CH<sub>4</sub> emissions will lead to multiple benefits across climate, human health, ecosystems and crop yields (Chapter 3).

Compared to the rest of the world, Africa makes a relatively small contribution of CO<sub>2</sub> emissions with larger contributions of CH<sub>4</sub> and BC from the continent (Lund et al. 2020). Globally, agriculture, fossil fuel production and distribution, and waste management are important sources for CH<sub>4</sub> emissions, and residential and commercial fuel use, land transport and open biomass burning are important sources for BC emissions. How these key sectors are modelled in the baseline and mitigation scenarios for Africa in this Assessment is described in Chapters 2 and 3, respectively.

The *Sixth Assessment Report* of the IPCC describes how rapid decarbonization strategies can lead to air quality improvements but that they are often not

sufficient to achieve the WHO's Air Quality Guidelines set for PM<sub>2.5</sub>. There is high confidence that additional CH<sub>4</sub> and BC mitigation can contribute to offsetting the additional warming associated with sulphate (SO<sub>2</sub>) reductions that would accompany decarbonization (Szopa et al. 2021). Strong air pollution control as well as strong climate change mitigation, implemented separately, could lead to large reductions in exposure to air pollution by the end of the century (Szopa et al. 2021). There is also high confidence that implementation of air pollution controls, relying on the deployment of existing technologies, leads more rapidly to air quality benefits than climate change mitigation, which requires more systemic changes. In both cases, however, significant parts of the population are projected to remain exposed to air pollution exceeding the WHO Air Quality Guidelines. Szopa et al. (2021) conclude that only strategies integrating climate, air quality and development goals are found to effectively achieve multiple benefits and potentially also reduce the cost of interventions, as discussed in the rest of this Assessment and elsewhere (Anenberg et al. 2012; Shindell et al. 2012; Schmale et al. 2014a; Schmale et al. 2014b; Sadiq et al. 2017; Shindell et al. 2017; Fay et al. 2018; Harmsen et al. 2020).

Several studies have analyzed the co-benefits of current and planned air quality policies on long-lived GHGs and global and regional climate change impacts (Lund et al. 2014; Akimoto et al. 2015; Lee et al. 2016; Maione et al. 2016; Peng et al. 2017). Other studies consider co-benefits, focusing on impacts of climate change and air quality mitigation strategies to meet NDCs and/or to remain below specific global

temperature targets, and WHO Air Quality Guidelines based on latest epidemiological evidence (West *et al.* 2013; Rao *et al.* 2016; Shindell *et al.* 2016; Zhang *et al.* 2016; Chang *et al.* 2017; Haines *et al.* 2017; Shindell *et al.* 2017; Li *et al.* 2018; Markandya *et al.* 2018; Williams *et al.* 2018; Xie *et al.* 2018; Lelieveld *et al.* 2019; UNEP 2019b). A key conclusion of many studies is that co-benefits of climate change mitigation for air quality and human health can offset the costs of the climate mitigation measures (Saari *et al.* 2015; Li *et al.* 2018).

### **1.2.2 IMPLICATIONS OF NEAR-TERM CHANGES IN CLIMATE FOR AFRICA'S DEVELOPMENT AND THE RELATIONSHIP BETWEEN MITIGATION AND ADAPTATION**

The IPCC *Special Report on a Global Warming of 1.5 °C* (IPCC 2018) states “*avoided climate change impacts on sustainable development, eradication of poverty and reducing inequalities would be greater if global warming were limited to 1.5 °C rather than 2 °C, if mitigation and adaptation synergies are maximized while trade-offs are minimized (high confidence)*”. Implementing climate mitigation policies to reduce the impacts of near-term climate change has co-benefits (Shindell *et al.* 2012; Kirtman *et al.* 2013; Scovronick *et al.* 2015). It improves human and environment health while enhancing responsible production and consumption behaviour (Smit *et al.* 2001; Shindell *et al.* 2012; Vandyck *et al.* 2018). Adaptation to climate change impacts, however, requires a systems approach that considers the complexity of the interactions that exist between the different socio-economic development processes and the ecological system. Such an approach must consider planning and development pathways that are not only iterative and continuously evolve, based on evidence, but also inclusive and place-based (Denton *et al.* 2014; IPCC 2014; Andres *et al.* 2019). A major issue is the policy silos between the different institutions of both national and city governments and a need to consider new ways of planning (Andres *et al.* 2019; Apsan *et al.* 2019; Kareem *et al.* 2020).

There are also interactions between air pollution and climate change. A warming climate can increase air pollution through, for example, increased tropospheric O<sub>3</sub> production in the atmosphere and increased PM levels through changes in the frequency or intensity of wildfires, as well as worsen air quality-related health issues that can lead to premature deaths (United States Environmental Protection Agency [USEPA] 2022)). Action taken to reduce air pollution

will improve air quality even as the climate changes and action that reduces (mitigates) GHG emissions can also yield adaptation benefits by reducing the need to adapt to anticipated climate change.

To fully address climate change mitigation and adaptation challenges, the African continent requires place-based, well-funded and integrated approaches. Such approaches can build on existing knowledge and research in Africa. Approaches linked to the use of indigenous knowledge in the Sahel to tackle adverse impacts of droughts through both mitigation and adaptation (Nyong *et al.* 2007), the use of indigenous knowledge for climate change mitigation and adaptation in agriculture in Sub-Saharan Africa (Chikaire and Nnadi 2011), and climate change adaptation and mitigation in smallholder crop–livestock systems in Sub-Saharan Africa (Descheemaeker *et al.* 2016) are all practical examples.

### **1.2.3 SYNERGIES BETWEEN AIR POLLUTION, CLIMATE CHANGE, THE SUSTAINABLE DEVELOPMENT GOALS, AGENDA 2063 AND NATIONALLY DETERMINED CONTRIBUTIONS**

At the global level, several of Agenda 2030's SDGs have directly and indirectly highlighted air pollution as a problem. Target 3.9 of SDG 3 Good Health and Wellbeing directly aims to achieve a substantial reduction in the number of deaths and illnesses from air pollution, hazardous chemicals, and water and soil pollution and contamination. Progress towards this target will be measured by the mortality rate attributed to household and outdoor air pollution. Similarly, target 11.6 of SDG 11 Sustainable Cities and Communities aims to reduce the per person adverse environmental impacts of cities, including addressing air quality and waste management. Progress will be measured by the annual mean levels of PM<sub>2.5</sub> and PM<sub>10</sub> in cities. These direct links between air pollution and SDG targets demonstrate the importance of addressing air pollution in sustainable development action. To achieve air pollution reduction objectives, however, action under other SDGs targeting sectors, such as energy, transport, agriculture and industry, among others, should be analyzed to understand the synergies and trade-offs required to enhance their achievement. In the energy sector, for example, the use of traditional biomass fuels in inefficient technologies is associated with household air pollution (WHO 2016).



Moreover, the use of kerosene for lighting and cooking, and dependence on fossil fuels for electricity generation are major sources of air pollutants which have adverse impacts on human health and are leading sources of GHGs that cause climate change (IEA 2016). The issue of air pollution and climate change is therefore simultaneously addressed by SDG 7 Affordable and Clean Energy and SDG 13 Climate Action, which call for action to support access to clean, affordable, reliable and sustainable modern energy for all.

Air pollution is also closely linked to SDG 9 Industry, Innovation and Infrastructure for the adoption of clean technologies by industry. Despite not being mentioned explicitly, achieving good air quality will be complemented by action targeting the achievement of (i) SDG 2 Zero Hunger, food production and food security since some food systems are a source of air pollutants and can be impacted negatively by air pollution (Section 1.3.2); (ii) SDG 5 Gender Equality due to the differentiated gender roles played by men, women, girls and boys (Section 1.5) (WHO 2016); (iii) SDG 10 Reducing Inequalities; and (iv) SDG 8 Decent Work and Economic Growth and employment, which relates to fuel switching and/or stacking (the use multiple cooking devices and fuel) (Yadav et al. 2021) and the negative impacts of air pollution and climate change on the productivity of different systems and the economy (OECD 2016; Dasgupta et al. 2021).

Similarly, the Paris Agreement is a key global framework ratified by 193 countries that addresses air pollution as a key driver of climate change by focusing on reducing GHG emissions from the energy, transport, industry, agricultural, waste management and land-use sectors that are the major sources of PM<sub>2.5</sub>, BC and O<sub>3</sub> precursors associated with negative human health impacts. For instance, WHO's Global Conference on Air Pollution and Health (WHO 2018b) reported that a reduction in BC emissions from major sources, such as transport, household combustion, waste, agriculture and industry would not only reduce warming by as much as 0.6 °C by 2050 but also avoid 2.4 million premature deaths from outdoor air pollution annually by 2030.

Working towards air pollution reduction, countries' action reported in their NDCs include promoting electricity generated from renewable energy sources such as solar and wind; removing/reforming fossil fuel subsidies; using biogas from such biomass resources as animal waste and agricultural residues; transitioning to more climate-smart food production systems; and the use of sustainable modes of transport.

In revising energy subsidies, countries are encouraged to use the Energy Subsidy Reform

Assessment Framework developed by the World Bank, in particular, the guidance note on estimating the local externalities of energy subsidies (Enriquez *et al.* 2018).

These climate change mitigation efforts will not only strengthen and promote health and sustainable development but also enhance synergies between climate change, air quality and health, thus creating a win-win opportunity at local, national, regional and global levels. Moreover, in the IPCC 2018 *Special Report*, improved air quality was highlighted as key for direct and improved population health for all the different emission pathways and systems transitions in the impacts of global warming at the 1.5 °C pre-industrial level (IPCC 2018).

The African Union Agenda 2063 acknowledges the energy sector as a key contributor to air pollution (AUC 2018) but there is no specific action mentioned that directly addresses air quality challenges. In the Agenda there are, however, links made between air pollution and other key sectors specifically included among the 20 goals that will indirectly address the air pollution challenge. Priority area 4 under Goal 1, for example, aims to provide modern, affordable, and livable habitats and quality basic services. This will contribute to the achievement of SDG 11 Sustainable Cities and Communities that directly targets reducing air pollution in cities and human settlements. Goal 3 under Agenda 2063 promotes healthy and well-nourished citizens, creating a strong direct contribution to SDG 3 Good Health and Wellbeing that explicitly aims to reduce mortality rates and illnesses related to air pollution. Moreover, action towards some goals in Agenda 2063, such as transformed economies, modernizing the agricultural sector, support for the blue economy and promoting environmentally sustainable and climate resilient economies and communities, will contribute to addressing the air pollution challenge and support the achievement of good air quality across the continent.

Addressing the complex air pollution challenge in Africa requires transdisciplinary approaches in co-producing the science-policy interface targeting the UN's Agenda 2030, the Paris Agreement and Africa's Agenda 2063. This can be done by addressing the lack of quality and up-to-date data on the status of Africa's air quality. This should be followed by an in-depth analysis of the synergies and trade-offs that exist at the goal and target/area of priority levels within the three international agreements and then identify opportunities for mainstreaming these goals into national development plans. Thus, taking advantage of existing in-country initiatives, reducing duplication of work, and ensuring that countries can meet their global, regional, and national commitments is imperative.

## 1.3 AIR POLLUTION AND CLIMATE CHANGE IMPACTS IN AFRICA

### MAIN MESSAGES:

#### 1.3.1 TYPES OF AIR POLLUTION EXPOSURE IN AFRICA

- Air pollution is a major threat to human health and wellbeing and the achievement of the SDGs. Outdoor air pollution is generated from power generation plants, industrial emissions, vehicular exhaust emissions, re-suspended road dust from paved and unpaved roads, livestock and crop management, wildfires and burning for land clearance, waste management, and dust storms. Household air pollution is generated by the use of solid fuels, such as firewood, agricultural residues, animal dung and coal in traditional stoves for cooking and heating.
- It is estimated that 77 per cent of households in Africa use solid fuels with almost all rural households in many African countries relying exclusively on solid fuels for cooking and heating, and people in those dwellings have very high exposure to particulate air pollution which is a huge problem across sub-Saharan Africa. The traditional use of such fuels accounts for more than 40 per cent of the total increase in final energy use between 2010 and 2019. High exposure to particulate matter air pollution and consequent health impacts are a major challenge especially among women, children, and the elderly.
- Those most exposed to outdoor air pollution are commuters, traffic wardens, drivers of public transport vehicles and street vendors, as well as children, particularly those of school-going age.

#### *Health impacts of air pollution exposure in Africa*

- It has been estimated that annually over 1.1 million premature deaths in Africa are attributable to exposure to air pollution such as fine particulate matter (PM<sub>2.5</sub>) and tropospheric ozone in Africa, representing about 16 per cent of global air pollution deaths.
- Air pollution health impacts have multiple additional negative effects, which are not well quantified, including negative impacts on economic productivity and children's development, as well as making polluted cities less attractive for investment.
- The cost of health damage from PM<sub>2.5</sub> air pollution has been estimated for 2019 as equivalent to 6 per cent of the sub-Saharan Africa's GDP of which the cost of outdoor PM<sub>2.5</sub> pollution was 2.4 per cent and the cost of household PM<sub>2.5</sub> air pollution was 3.6 per

cent of the GDP.

- Air pollution has a larger impact on children and in household situations in Africa than in other regions of the world. Impacts include respiratory illnesses, cardiovascular symptoms and disease, childhood stunting and poor cognitive developmental effects, and eye diseases.
- Limited data on impact of air quality in Africa goes beyond the need for increased air quality monitoring networks, data collection and management and increased exposure studies. The following are also required: improved accuracy of mortality data, investigation of the impacts of air pollution exposure, local source apportionment studies, the environmental inequalities and social determinants of health, cost-benefit analyses and studies focused on sound medical data in vulnerable groups.

#### *Air Pollution impacts on crops and ecosystems*

- Air pollution, such as tropospheric ozone pollution, can cause damage to ecosystems and reduce yields of crops like maize, rice, and wheat. It has also been shown to damage leaves of other African crop species, such as the common bean, sorghum, pearl millet and finger millet.
- There are interactions between air pollution impacts on crops, ecosystems and climate change, which make it important to have an integrated approach at tackling these environmental challenges.

#### *Climate change impacts on resources, development and health in Africa*

- Climate change exacerbates the water stress and variability of water resources across Africa, especially the arid- and semi-arid regions. It is emerging as the major challenge to agricultural development in Africa, with the increasingly unpredictable and erratic nature of climate systems placing an extra burden on food security and rural and peri-urban livelihoods.
- Climate change is accelerating environmental degradation, loss of biodiversity and the disruption of ecosystem services in Africa that is already occurring due to land-use expansion for food production and urban development.
- The forest sector needs to improve the management of forests to mitigate climate change, especially through the reduction in carbon dioxide emissions from deforestation and forest degradation.
- Climate change affects human health through a variety of mechanisms including temperature and precipitation variabilities which increase floods, heatwaves and droughts and affect the proliferation and transmission of infectious and water-borne diseases.

### 1.3.1.1 OUTDOOR AIR POLLUTION

Outdoor air pollution is generated from vehicular exhaust emissions, re-suspended road dust from paved and unpaved roads, industrial emissions, dust storms, biomass burning, emissions from landfill sites and power generation plants. Africa has the world largest source of desert dust emissions and produces approximately a third of the Earth's biomass burning aerosol particles (Bauer *et al.* 2019). Furthermore, dust storms may contain PM<sub>2.5</sub>, pathogenic biological materials – bacteria, pollen, fungi, and viruses – and environmental pollutants such as pesticides, heavy metals and dioxins from various sources in their trajectories increasing their toxicity (Ostro *et al.* 2021). Uncontrolled open burning of dumped waste is an important source of outdoor air pollution in Africa's urban areas (Van Vliet and Kinney 2007). Kodros *et al.* (2016) noted that the emissions from open waste burning produce significant contaminants to the environment exacerbating soil, water and air pollution, which is responsible for approximately 270 000 premature deaths annually worldwide. Bulto (2020) showed that emissions of PM<sub>2.5</sub> from the open burning of refuse were the main source of air pollution in Addis Ababa, Ethiopia's capital, with the concentrations of PM<sub>2.5</sub> on one day in November 2019 being 8.6 times higher than the recommended WHO Guideline.

### 1.3.1.2 HOUSEHOLD AIR POLLUTION

It is estimated that 2.8 billion people globally rely on traditional solid fuels, such as firewood, agricultural residues, animal dung and coal in traditional cookstoves in 2018 and often in poorly ventilated spaces (IEA 2019). Traditional stoves and these solid fuels produce pollutants such as PM which includes BC, CO, polyaromatic hydrocarbons and VOCs that have adverse effects on human health, inducing cardiovascular disease, respiratory illnesses, eye problems and cancer (WHO 2014). About 40 per cent of the global population, 95 per cent of whom live in Africa and Southeast Asia, use solid fuels for cooking and heating. It is estimated that 77 per cent of households in Africa use solid fuels at home (WHO 2018c; Katoto *et al.* 2019) with almost all rural households in many African countries relying exclusively on solid fuels for cooking and heating. The use of charcoal is widespread in urban areas of Africa with more than 80 per cent of urban households using charcoal as their primary cooking fuel (Zulu and Richardson 2013). The traditional use of such fuels accounts for more than 40 per cent of the total increase in final energy use between 2010 and 2019. Depending on how these fuels are gathered, it can also contribute to deforestation (IEA 2022). Monitoring in a roadside building in Nairobi, Kenya,

has also highlighted that road-related air pollution can also significantly impact those working inside buildings located near roads (Singh *et al.* 2021).

### 1.3.1.3 EXPOSURE

Daily air pollution exposure is determined by time-activity patterns and should be factored in both household and outdoor air pollution exposure assessments (Amegah 2020). The factors that determine variations in air pollution levels are meteorological factors, for example, wind speed and direction, and temperature, and emission sources. These factors can affect outdoor air pollution, but do not affect indoor air pollution, while emission sources affect both. A systematic review on the levels of outdoor air pollution and its adverse health effects in Africa emphasized that it is high relative to international guidelines and most studies indicated that children and the elderly are most susceptible to it (Katoto *et al.* 2019). Household air pollution disproportionately affects people of low socio-economic status and is related to use of biomass fuel for cooking, lighting or heating. It can also be caused when homes are near to industrial sources or roads.

### 1.3.1.4 VULNERABLE GROUPS

Populations most affected by household air pollution exposure are children, women, people with underlying chronic conditions and the elderly in the household environment (Section 1.4.2.1). Those most exposed to outdoor air pollution are commuters, traffic wardens, drivers of public transport vehicles and street vendors who dominate the urban landscape of African countries (Amegah 2020), as well as children, particularly those of school-going age. Informal waste service providers and recyclers operating around waste dump sites are also disproportionately affected by outdoor air pollution (Mebratu and Mbandi 2022).

## 1.3.2 HEALTH IMPACTS OF AIR POLLUTION EXPOSURE IN AFRICA

There is a substantial body of evidence linking exposure to air pollution with a wide range of negative health impacts (WHO 2021). Health problems causally linked to air pollution exposure include cardiovascular and cardiopulmonary diseases, lung cancer and respiratory infections. In general, the incidence of these diseases is rising in the region (Mbewu and Mbanya 2006; Parkin *et al.* 2008; Dalal *et al.* 2011; WHO 2013). There is also growing evidence of effects on other body systems such as a link between air pollution and gastrointestinal disorders in children (Tan *et al.* 2019) and the short-term effects of air pollution on blood

pressure (Choi *et al.* 2019). Exposure to air pollution has also been associated with intestinal diseases such as appendicitis, inflammatory bowel diseases (IBDs), irritable bowel syndrome (IBS), gastroenteric disorders, peptic ulcers and alteration of the gut microbiota (Vignal *et al.* 2021); liver diseases such as metabolic dysfunction-associated fatty liver disease (MAFLD) (Guo *et al.* 2022), liver cirrhosis (Orioli *et al.* 2020), and kidney, bladder and colorectal cancer (Turner *et al.* 2017).

Globally, air pollution is the most important environmental risk factor for disease and premature death (Landrigan *et al.* 2019). The impact of air pollution on mortality is primarily driven by increases in the incidence of diseases including ischaemic heart disease, stroke, chronic obstructive pulmonary disease, lung cancer, Type 2 diabetes and acute respiratory infections. According to the WHO, globally outdoor and household air pollution contribute to 4.2 million and 3.2 million premature deaths, respectively, every year (WHO 2022), with 99 per cent of the world's population living in places where air quality exceeds WHO Air Quality Guideline values (WHO 2021). For household air pollution, WHO (2022) also estimates more than 237 000 deaths of children under the age of 5 each year.

Other studies, such as the Global Burden of Disease (GBD), estimated 2.31 million (1.63–3.12) global deaths were attributable to household air pollution and accounted for over 4 per cent of all deaths in 2019 (Bennitt *et al.* 2021). According to the GBD, air pollution exposure is the fourth largest risk factor for premature death globally, behind high blood pressure, tobacco smoking and dietary risks. Based on WHO Global Health Observatory and GBD data, Fisher *et al.* (2021) estimated that household air pollution accounted for 697 000 deaths in Africa in 2019, almost a third of all global deaths attributable to it. The HAP-attributable burden remains highest in Sub-Saharan Africa and South Asia, with 3 770 (2 876–4 720) and 2 068 (1 412–2 799) age-standardized disability-adjusted life years (DALYs) per 100 000 population, respectively (Bennitt *et al.* 2021).

It is estimated that 394 000 deaths were attributable to outdoor air pollution in Africa in 2019 (Fisher *et al.* 2021), although Bauer *et al.* (2019) estimate approximately 780 000 premature deaths annually due to the extensive health impacts of natural emissions, high mortality rates caused by industrialization in Nigeria and South Africa, and, to a smaller extent, by fire emissions in Central and West Africa. Bauer *et al.* (2019) also show that natural sources, in particular windblown dust emissions, can have significant impacts on air quality and human health in Africa, especially in low- and middle-income countries.

In addition to the impact of air pollution on premature mortality, it also contributes substantially to morbidity and non-fatal health outcomes. It has, for example, been estimated that ambient nitrogen dioxide (NO<sub>2</sub>) might be associated with 4 million new pediatric asthma cases annually, accounting for 13 per cent of global incidences (Achakulwisut *et al.* 2019) and in 2010, the number of PM<sub>2.5</sub>-associated preterm births was estimated as 2.7 million, 18 per cent of total preterm births globally (Malley *et al.* 2017). This is in addition to other morbidity impacts resulting from air pollution exposure, such as emergency room visits for respiratory and cardiovascular diseases.

Africa is one of the regions in the world most affected by air pollution exposure in terms of its impact on human health. In 2019, a study using data on household and outdoor air pollution from the WHO Global Health Observatory, and data on morbidity and mortality from the 2019 GBD Study, estimated that 1.1 million premature deaths attributable to exposure to air pollution occurred in Africa, representing 16.3 per cent of global air pollution deaths (Fisher *et al.* 2021). The impact of air pollution on public health in Africa is similar to many other regions of the world in some respects. Chowdhury *et al.* (2020) show that the global premature mortality attributed to outdoor air pollution exposure increased by 30 per cent, from 6.87 (95 per cent confidence interval (CI) 5.57–8.15) million in 2000 to 8.89 (7.29–11.04) million in 2015, with strong regional heterogeneity – large increases were found in South Asia, 46.1 per cent; East Asia, 32.4 per cent; and West Asia, 42.1 per cent; and most of Africa, 24–63 per cent, except Southern Africa, where mortality decreased by 9.1 per cent.

For the adult population only, global premature mortality from ambient PM<sub>2.5</sub> exposure increased by 37.1 per cent between 2000 and 2015, but only 6.2 per cent in Southern Africa; in the rest of Africa, however, it was estimated to increase by around 50 per cent (Chowdhury *et al.* 2020). On the other hand, premature child mortality from outdoor PM<sub>2.5</sub> exposure decreased globally by 43.8 per cent between 2000 and 2015, however the improvement was not as prominent in West Africa, -18.2 per cent, and Central Africa, -18 per cent, and in some countries it increased, for example, Zimbabwe, +75 per cent; Namibia, +9.6 per cent; Central African Republic, +9 per cent; and Chad, +6.5 per cent (Chowdhury *et al.* 2020).

The mortality burden from O<sub>3</sub> exposure increased globally by 17 per cent between 2000 and 2015, and increased considerably over the entire continent of Africa, with 15, 38.4, 35.2, 19 and 24.9 per cent increases in East, Central, North, Southern and West Africa, respectively (Chowdhury *et al.* 2020).

Furthermore, the overall health burden from air pollution in Africa substantially differs in two key respects from the impact of air pollution in other regions.

### LARGER IMPACT ON CHILDREN

Globally in 2019, 691 000 infant and children under 5 years, premature deaths were attributable to exposure to air pollution with 385 000 of these child deaths, almost 56 percent, occurring in Africa (IHME 2021). The infant mortality rate of 202 infant deaths attributable to air pollution per 100 000 population, is more than double the global average of 104 infant deaths per 100 000 population. The infant mortality attributable to air pollution is not equally shared across Africa, with the highest rates in West and Central Africa, and lower rates in North and Southern Africa (IHME 2021).

### CONTRIBUTION OF DIFFERENT EXPOSURE SOURCES

As described above, there are two main sources of air pollution exposure, exposure to outdoor air pollution and household air pollution, including in offices and factories, predominantly from cooking using solid fuels. Globally, outdoor air pollution exposure contributes the majority of the disease burden attributable to air pollution from all sources. Across Africa, however, most of the health burden from air pollution in 2019 was attributable to household air pollution, 697 000 premature deaths, with a smaller contribution from ambient air pollution, 383 000 premature deaths (Fisher *et al.* 2021). This is due to a larger fraction of African households using solid biomass fuels, wood and charcoal, for cooking compared to other regions. Across Africa, the trend in health burdens from outdoor and household air pollution are changing. There has been a decreasing trend in the health burden from household air pollution since 1990, a decline from approximately 140 to about 50 per deaths per 100 000 in 2019, compared with an increasing outdoor air pollution burden of 26 in 1990 to 29 per 100,000 in 2019 (Fisher *et al.* 2021).

Sánchez-Triana *et al.* (2021) suggested three steps in estimating health effects and costs of ambient PM<sub>2.5</sub> air pollution, starting with finding the number of people exposed, investigating the health effects of the exposure and then valuing the illnesses and premature deaths in monetary terms. As ground level air pollution monitoring stations are situated in large cities, the data, along with satellite imagery and chemical transport models, were used to estimate nationwide population exposure. Estimating the health effects of ambient PM<sub>2.5</sub> can best be done with annual exposures rather than daily ones, with mortality of specific diseases

rather than all-cause mortality, and covering a wide range of exposures to reflect the socio-economic reality of the population. The monetary valuation of health effects of PM<sub>2.5</sub> exposure in most low- and middle-income countries is, however, difficult and relies on the extrapolation of data from high-income countries (Sánchez-Triana *et al.* 2021).

The following subsections review existing evidence from across Africa on the link between air pollution and different major disease categories.

#### 1.3.2.1 AIR POLLUTION AND RESPIRATORY ILLNESSES

The association of outdoor and household air pollution with adverse respiratory outcomes is well established (Schraufnagel *et al.* 2019; Annesi-Maesano *et al.* 2021). Respiratory effects include acute symptoms such as cough, wheeze, and tight chest (Jindal *et al.* 2020; Raju *et al.* 2020), acute declines in lung function (Bloemsma *et al.* 2016), emergency-room visits, acute asthmatic attacks and pneumonias (Han *et al.* 2021; Leung *et al.* 2021; Yee *et al.* 2021). Chronic outcomes in both adults and children are higher prevalence of asthma symptoms (Tiotiu *et al.* 2020) and chronic obstructive lung disease (Bloemsma *et al.* 2016; Duan *et al.* 2020; Rosário *et al.* 2021).

The pollutants associated with these acute and chronic outcomes include PM as well as SO<sub>2</sub>, NO<sub>x</sub> and O<sub>3</sub> (Liu and Grigg 2018; Landrigan *et al.* 2019; Han *et al.* 2021). An emerging body of evidence provides dose-response relationships between pollutant exposure and respiratory outcomes in African settings. Well-designed epidemiological studies, using a range of approaches to characterize exposure, and well validated measures of outcomes have been undertaken in several African countries (Katoto *et al.* 2019).

Evidence exists associating outdoor air pollution with several respiratory symptoms and illnesses. Some of the most cited symptoms linked to it are cough, wheeze, chest tightness, ocular-nasal symptoms and the presence of phlegm. Commonly identified respiratory conditions and illnesses are airway inflammation, acute changes in lung function, bronchial hyper-responsiveness and obstructive lung diseases such as asthma. Using proxy measures of air pollution exposure, such as geographical location or proximity to point sources of exposure, studies have associated these proxy measures with adverse respiratory outcomes. Asthma and emphysema, for example, were significantly high among adults living closer to mine dumps in South Africa (Nkosi *et al.* 2015). Similarly, in the Niger delta, Nigeria, adults

living in a town with higher levels of total suspended particles experienced a greater prevalence of respiratory disorders than those in a neighbouring town (Ana *et al.* 2009). Cross-sectional studies have also associated respiratory symptoms such as cough, wheeze, shortness of breath, rhinitis and conjunctivo-rhinitis with exposure to traffic-related pollution (Nkosi *et al.* 2015; Wichmann *et al.* 2016) and industrial pollution (Naidoo *et al.* 2013).

Novel approaches, including characterizing antenatal and early life air pollution exposures, have investigated lung function in newborns and growing infants, and have provided insights into early-life lung effects on the African continent. The findings in the Ghanaian birth cohort showed that indoor CO was associated with important lung-function deficits in 30-day old infants, in a dose-response relationship (Lee *et al.* 2019), while exposure to tobacco smoke had similar effects in the Western Cape Drakenstein Child Health Study (DCHS) birth cohort (Gray *et al.* 2017; Donald *et al.* 2018). Particulate matter in the birth cohort from Durban, South Africa was similarly associated with adverse infant lung function outcomes in the first two years of life (Muttoo *et al.* 2022). These findings imply that this age group, already at increased risk for lower respiratory tract infections, have an added threat to their growing lungs, which will compromise their lung health in later childhood and adult life.

Across Africa, the majority of epidemiological literature on air pollution-related respiratory outcomes relates to household air pollution (Joubert *et al.* 2020). Exposure to this has been associated with shortness of breath, cough, wheeze, the presence of phlegm, reduced lung function, asthma and increased prevalence of lower and acute respiratory tract infections (LRTIs and ARTs). Using direct measurements of household air pollution exposure, PM exposure, for example, has been associated with LRTIs. There is robust evidence associating exposure to air pollution with impairment of lung function in children as well as impeding the development of their lungs, even at lower levels of exposure (WHO 2018d). Adults, particularly women, are also at increased risk for adverse respiratory outcomes due to household air pollution (Section 1.4.2.1.4).

### 1.3.2.2 CARDIOVASCULAR SYMPTOMS AND DISEASE

Death from cardiovascular diseases is highest in Africa and low and middle-income countries (LMIC), with an estimated 80 per cent of related global deaths occurring in these places (Lelieveld *et al.* 2015; Noubiap *et al.* 2015).

Traditional cardiovascular risk factors, such as diabetes, hypertension, obesity and hyperlipidaemia, are not enough to explain this level of mortality. Other non-traditional risk factors, such as infectious diseases, socio-economic status and air pollution exposure, need serious consideration when assessing cardiovascular disease mortality in Africa (McCracken *et al.* 2012; Noubiap 2015). Globally, cardiovascular diseases account for 60–80 per cent of air pollution-related deaths (Lelieveld *et al.* 2015).

Despite a growing body of research linking household air pollution with subclinical indicators of cardiovascular disease risk, including high blood pressure, carotid atherosclerotic plaque, and arterial stiffening, its impact on health indicators in Africa is likely to have been underestimated (Noubiap *et al.* 2015; Katoto *et al.* 2019; Mocumbi *et al.* 2019).

There is robust evidence that outdoor air pollution results in hospitalisation and mortality from heart failure, stroke, myocardial infarction, other cardiovascular diseases, respiratory diseases, asthma development in childhood, type 2 diabetes, hypertension and adverse pregnancy outcomes (Amegah 2020). In 2015, air pollution accounted for 26 per cent of coronary heart disease deaths and for 23 per cent of stroke deaths, reflecting 21 per cent of cardiovascular deaths overall (Landrigan *et al.* 2017). Furthermore, recent reports revealed that exposure to PM<sub>2.5</sub> from coal combustion and diesel-fuelled traffic lead to a higher risk of cardiovascular disease than other PM<sub>2.5</sub> sources. The fact that different particles and their composition can result in different health effects underscores the need for African countries' air-pollution control efforts to prioritize fossil-fuel burning – notably coal-burning power plants and traffic – for measuring the concentrations of the components of their particulate mix as a basis for defining economically efficient abatement strategies (Thurston *et al.* 2021).

Despite international evidence, there is paucity of data from African countries on adverse cardiovascular outcomes from exposure to air pollution (Tibuakuu *et al.* 2018). Only five long-term air pollution and cardiovascular disease studies of populations exposed to high PM<sub>2.5</sub> levels in China mirror levels seen in some parts of Africa (Hystad *et al.* 2020).

Despite Africa experiencing high levels of air pollution and a significant burden of cardiovascular disease, only few studies reported are part of systematic reviews and meta-analyses summarizing the evidence on the associations between air pollution exposure and cardiovascular health outcomes, which makes it difficult to assess the burden of air pollution on cardiovascular disease in Africa.

### 1.3.2.3 CHILDHOOD STUNTING AND COGNITIVE DEVELOPMENTAL EFFECTS

The potential relationship between air pollution and linear growth has received little attention compared to other health outcomes. In 2019, 57.5 million children in Africa under 5 were stunted, 29.1 per cent of global stunting (UNICEF *et al.* 2020). This suggests the need for increased evidence to establish the effect of air pollution on linear growth during the prenatal period and early years of life in Africa to develop comprehensive approaches to addressing the multiple causes of stunting and possible prevention measures.

Evidence from studies conducted across the world have associated air pollution with neurologic dysfunction in both children and adults. Conditions including intelligence quotient (IQ) loss, memory deficits, loss of cognitive function, behavioural dysfunction, reductions in brain volume, autism spectrum disorder (ASD) and increased risks of attention deficit/hyperactivity disorder (ADHD) in children, have been linked to PM<sub>2.5</sub> and other pollutant exposures (Calderón-Garcidueñas *et al.* 2011; Volk *et al.* 2013; Harris *et al.* 2015; Sunyer *et al.* 2015; Porta *et al.* 2016; Sram *et al.* 2017; Wang *et al.* 2017; Donzelli *et al.* 2019; Perera *et al.* 2019; Chun *et al.* 2020; McGuinn *et al.* 2020; Thygesen *et al.* 2020; Volk *et al.* 2020). In adults, associations are reported between PM<sub>2.5</sub> pollution and risk of dementia (Grandjean *et al.* 2014; Casanova *et al.* 2016; Heusinkveld *et al.* 2016; Kioumourtoglou *et al.* 2016; Sram *et al.* 2017; Dimakakou *et al.* 2018).

A recent study conducted in Africa has estimated that PM<sub>2.5</sub> pollution was responsible for 1.96 billion lost IQ points in African children in 2019. Specifically, according to the most conservative scenarios of this analysis, it was found that the total loss of cognitive function in children across all of Africa in 2019 was 1.96 billion performance IQ (PIQ) points, with air pollution was responsible for an estimated loss of 180.5 million PIQ points in Ethiopia, 43.7 million in Ghana, and 18.5 million PIQ points in Rwanda. Epidemiological evidence of air pollution-related neurocognitive outcomes among children is limited in Africa (Fisher *et al.* 2021).

### 1.3.2.4 EYE DISEASE

Studies conducted in Guatemala (Diaz *et al.* 2007), Kenya (Person *et al.* 2012) and Pakistan (Khushk *et al.* 2005) have associated household air pollution with eye irritation, as have analyses from two African cities, Lusaka and Maputo, and Hanoi, Vietnam (Ellegard 1997), specifically tears while cooking. A systematic review that summarised the evidence on household

air pollution and eye disease concluded that there is limited direct evidence on the associations between solid fuel use and major eye-blinding diseases (West *et al.* 2013b). The authors, however, found robust evidence of association with cataract. Of the 19 studies summarized, five emanated from Africa, including from Ethiopia (Sahlu and Larson 1992; Mesfin *et al.* 2006), Burkina Faso (Taylor *et al.* 1989; Turner *et al.* 1993). West *et al.* (2013b) recommended that, given the high burden of eye diseases in LMICs coupled with the widespread use of solid fuels for cooking and the plausibility of associations, further investigation is warranted.

## 1.3.3 ECONOMIC AND SOCIAL IMPACTS OF AIR POLLUTION ON HEALTH IN AFRICA

Air pollution has multiple additional negative effects, including negative impacts on productivity and human capital development, which may constrain long-term growth. Air pollution can reduce worker productivity and inhibit child development and knowledge of these effects can affect people's decisions on where to live, giving cities with less pollution a competitive advantage in attracting and retaining skilled workers and a greater likelihood of achieving long-term sustainable growth (Kahn *et al.* 2020).

Although there is one ground-level PM<sub>2.5</sub> monitor per 28 million people in Sub-Saharan Africa compared with one monitor per 370 000 people in high-income countries, the estimated cost of health damage due to PM<sub>2.5</sub> air pollution in Sub-Saharan Africa is still comparable to the rest of the world (World Bank 2022c). In 2019, the global cost of health damage from PM<sub>2.5</sub> air pollution was equivalent to 6.1 per cent of global GDP, US\$ 8.1 trillion, of which of outdoor PM<sub>2.5</sub> pollution accounted for 4.8 per cent of global GDP whereas the cost of household PM<sub>2.5</sub> pollution was 1.3 per cent of global GDP. By the same token, the cost of health damage from PM<sub>2.5</sub> air pollution was equivalent to 6 per cent of the Sub-Saharan Africa's GDP of which the cost of outdoor PM<sub>2.5</sub> pollution was 2.4 per cent and the cost of household PM<sub>2.5</sub> air pollution was 3.6 per cent GDP (World Bank 2022c).

Available evidence suggests that air pollution has a comparatively large effect on company competitiveness in Africa, strengthening the rationale for interventions that will improve air quality in the short term. Soppelsa *et al.* (2020) find two important links between air pollution and competitiveness, firstly the negative association between air pollution and

company performance can be seen at lower-than-expected levels of pollution, and secondly, the effects of capacity agglomeration on labour productivity growth are stronger in Africa than other regions. These findings suggest that cities in Africa should address pollution issues soon, as they continue to grow fast and pollution levels become of increasing concern.

### 1.3.4 PROSPECTS FOR IMPROVING EVIDENCE ON AIR POLLUTION HEALTH EFFECTS IN AFRICA

Air pollution-related health impacts in Africa have probably been underestimated. In addition, increasing population growth, urbanization and development trends are countering air quality measures being implemented as a result of policy interventions (Okello *et al.* 2023). It cannot be assumed that health responses to air pollution in Africa are the same as those in other regions.

The likely underestimation of air pollution-related health impacts in Africa is based, in part, on the limited data on air pollution exposure and associated health impacts in Africa, but also on the fact that integrated exposure-response functions from developed country locations with low outdoor PM<sub>2.5</sub> levels compared with those of Sub-Saharan Africa are being used in uniquely African contexts (Langerman and Pauw 2018; Amegah *et al.* 2020; Amegah *et al.* 2022). Africa-specific vulnerabilities and susceptibilities may influence exposure-response relationships of both household and outdoor air pollution, and so conducting more air pollution epidemiologic studies in Africa is critical to having locally derived exposure-response functions (Amegah *et al.* 2022). The density of accurate exposure data, health statistics and longitudinal health studies on the continent is not sufficiently high to provide the essential local and regional data needed to underpin the calculations required to inform policy (Amegah and Agyei-Mensah 2017). There is an urgent need to gather hard, country-level evidence of the health effects of air pollution to trigger policy action and dialogue, and inform partnerships and multi-sectoral cooperation at various government levels, as well as stakeholder engagement, to tackle air pollution for public health protection and increase awareness among communities alike (Koduah *et al.* 2015; WHO 2018b).

The need for more extensive exposure data is highlighted by the fact that only 6 per cent of children in Africa live within 50 kilometres of an air quality monitoring station, compared to 72 per cent in Europe and North America (United Nations International

Children's Emergency Fund [UNICEF] 2019). While regulatory monitoring networks need to be expanded, there are opportunities for using low-cost sensors for exposure and intervention studies (Wernecke *et al.* 2021). This opportunity requires emerging sensor technologies to be evaluated sufficiently, applied and managed using robust methods (Lewis and Edwards 2016). Major investment in collecting data on air pollution sources, exposure and health outcomes is needed across the region to inform targeted policies at local, national and regional scales. New low-cost air quality monitors are promising but must be evaluated carefully before being rolled out for health and regulatory applications. Data from such sensors, for example, are not being rigorously tested for quality assurance and control. Working across sectors, disciplines and levels of government is essential for addressing air pollution.

Programmes and studies in Ghana and Nigeria are investigating the value of low-cost sensors to assess relationships between air pollution exposure and adverse health outcomes (Alexander *et al.* 2018; Clark *et al.* 2020). There are also a growing number of low-cost air quality monitoring networks on the continent such as the AirQo project based in Uganda (<https://www.airqo.net/>) and the Ghana Urban Air Quality Project (GHAir) based in Ghana (Sewor *et al.* 2021). This can help leverage an increase in the air pollution-health estimates on the continent.

Uneke *et al.* (2020) discuss key recommendations for evidence-based policy making for public health at different government levels in the Economic Community of West African States [ECOWAS] region, which include defining policy problems, reviewing contextual issues, initiating policy priority setting, considering the political acceptability of policy, and commissioning research. To promote progress, rapid response services, policy advisory/technical/steering committees, policy briefs and dialogues are also recommended.

Lack of evidence on air pollution issues in Africa goes beyond the need for increased air quality monitoring networks and increased exposure studies. More information is required in the following areas to bridge the evidence gap.

**Improved accuracy of mortality data** to use alongside air pollution exposure data is required.

- More studies are needed to **investigate the cardiovascular impacts of air pollution exposure**, as Africa carries a disproportionate burden of cardiovascular illness and the links between air pollution exposure and cardiovascular ill-health have been proven world-wide.



- **Local source apportionment studies** can improve the understanding of the make-up of airborne PM to investigate the health effects of PM exposure in specific settings and to improve the understanding of the sources of the pollution for the design and targeting of interventions.
- **Environmental inequalities and social determinants of health** play a significant role in Africa (Koné *et al.* 2019). The WHO has highlighted the need for robust evidence on effect modification by complex factors such as environmental inequalities and socio-economic status in relation to air pollution exposure in low- and middle-income countries (WHO 2020).
- The execution of **cost-benefit analyses** in relation to air quality improvement initiatives and reduced health risks will help highlight healthcare costs and cost savings (Amegah and Agyei-Mensah 2017).
- Many air pollution health effects studies in Africa are based on self-reported data (Katoto *et al.* 2019). There is a need for **studies focused on sound medical data in vulnerable groups** of society, such as children, pregnant women and the elderly, who suffer disproportionately from air pollution exposure.

Addressing these issues would help reduce the burden of air pollution on the health of Africans by underpinning targeted policies. Systems should be leveraged to create alerts, deliver customized and easily accessible health information for potentially affected populations, and form the basis for cohort studies of air pollution exposures and eventually the development of local dose-response functions (Koné *et al.* 2019).

Africa needs African-specific, tailored solutions and models which consider individual and combined risk factors, along with an understanding of local beliefs, behaviour and attitudes towards potential problems and regulations (Koné *et al.* 2019). In short, Africa needs multi-faceted, multi-disciplinary solutions to tackle these challenging issues.

### 1.3.5 AIR POLLUTION IMPACTS ON CROPS AND ECOSYSTEMS

Studies from around the world, but notably Europe and North America, have shown that air pollution can have significant impacts on agricultural crops and ecosystems. The major air pollutants of concern are tropospheric O<sub>3</sub>, also known as ground-level ozone,

acidic and eutrophying depositions and PM (UNEP 2019b). Vegetation appears to be more sensitive than people to a number of air pollutants, including NO<sub>2</sub>, O<sub>3</sub> and SO<sub>2</sub> (Bell *et al.* 2011).

#### 1.3.5.1 TROPOSPHERIC OZONE IMPACTS ON VEGETATION

Internationally, tropospheric O<sub>3</sub> is widely recognized as the most damaging air pollutant to vegetation and crop yields due to its phytotoxicity and formation in the atmosphere at high concentrations over agricultural regions sources (Royal Society 2008; Ainsworth *et al.* 2012). Exposure to relatively low levels of tropospheric O<sub>3</sub>, for example, of less than 40 parts per billion (ppb), 80 micrograms per cubic metre (µg/m<sup>3</sup>), are known to have negative effects on crop productivity and natural ecosystems (Emberson *et al.* 2009; Ainsworth 2016).

Ground-level O<sub>3</sub> is a strong oxidizing gas and is known to pass through the leaves of plants (stomata) and trigger phytotoxic damage to the plant, which in turn affects vegetation, such as grasslands and forests, and the biodiversity that depends on them, as well as reducing agricultural yields (Jimenez-Montenegro *et al.* 2021). It can cause damage to foliage, with or without visible symptoms of injury, which affects plant growth and yield (Agrawal *et al.* 2003; Tomer *et al.* 2015). Damage inside the plant includes reductions in photosynthesis, changes in carbon allocation and reduction in yield quantity and quality (Fuhrer 2009; Feng *et al.* 2015).

Sampedro *et al.* (2020) used global modelling approaches to study current and projected relative yield loss of different crops to O<sub>3</sub> exposure and predicted 5–6, 6–7.5 and 7.5–8.5 per cent yield losses for maize, rice and wheat respectively in Northern Africa in 2020–2080. They conclude that the changes, generally reductions, in O<sub>3</sub> precursor emissions would reduce damage to agricultural yields. Very little work has been done exploring the O<sub>3</sub> sensitivity of other crops commonly grown in Africa. However, modelling studies that have been conducted emphasize that efforts to reduce O<sub>3</sub> precursors could contribute to reducing the yield gap in Sub-Saharan Africa (Sharps *et al.* 2021a). Sharps *et al.* (2021b) has also produced a visual guide to O<sub>3</sub> damage to leaves of African crop species, such as cultivars of wheat (*Triticum aestivum*), the common bean (*Phaseolus vulgaris*), sorghum (*Sorghum bicolor*), pearl millet (*Pennisetum glaucum*) and finger millet (*Eleusine coracana*). See also climate impact considerations in Section 1.3.6.2.

### 1.3.5.2 NITROGEN AND SULPHUR DEPOSITION IMPACTS ON VEGETATION

Air pollution such as SO<sub>2</sub> and NO<sub>x</sub> emissions from fuel combustion and ammonia (NH<sub>3</sub>) emissions from agricultural sources can cause acidification and eutrophication of the environment (Kuylenstierna *et al.* 2001). Sensitive terrestrial and aquatic ecosystems can receive a mixture of sulphur (S) and nitrogen (N) pollution close to emission sources, for example, dry deposition of SO<sub>2</sub> emissions close to a power station or NH<sub>3</sub> deposition near intensive animal-rearing farms can cause local impacts to soils, water quality and biodiversity. Wet depositions containing sulphate, nitrate and ammonium (NH<sub>4</sub>) can cause acidification and eutrophication impacts at a regional scale (UNEP 2019b). Kuylenstierna *et al.* (2001) showed that the potential for acidification effects of sensitive soils in Africa is limited to areas in Southern Africa with intensive industry. Josipovic *et al.* (2011) calculated total (non-organic) acidic deposition formed the basis for an assessment of exceedance of critical loads based on sensitivity of the regional soils and found that parts of the South African Highveld have the potential for critical load exceedance.

Nitrogen pollution is a key driver of environmental impacts in regions of the world with an excess of N use in agriculture (Sutton *et al.* 2013) but Africa is one of the regions of the world that suffers from low availability of nutrients for agriculture (Zhang *et al.* 2020). Regions, such as Sub-Saharan Africa, still need more nutrient inputs to reverse declining soil fertility and quality, boost yields, and feed the population, but fertilizers, high-quality manures and mulch are often unavailable or unaffordable (Sutton *et al.* 2020; Zhang *et al.* 2020). Air pollution inputs of nitrogen can be significant in certain parts of Africa, for example, Bakayoko (2021) has shown that there is a dominant contribution of nitrogen compounds in precipitation chemistry in the Lake Victoria catchment area in East Africa. Extensive in-shore and off-shore monitoring of wet and dry nitrogen depositions is recommended to help improve the efficiency of nitrogen use in agricultural areas and reduce its losses around Lake Victoria.

### 1.3.5.3 IMPACTS OF PARTICULATE MATTER ON VEGETATION

The amount of radiation reaching the Earth's surface is an important driver of ecosystem and agricultural productivity, especially as it affects photosynthesis. The influence of atmospheric particulate matter, including BC particles, on the quality of sunlight reaching vegetation can therefore impact plant growth

and productivity (UNEP 2019b). Changes in solar radiation, through the dimming effect of fine particles can reduce CO<sub>2</sub> uptake in both natural vegetation and agricultural systems and negatively affect vegetation (Mercado *et al.* 2009). On the other hand, fine particles in the atmosphere can increase the diffuse fraction of incoming solar radiation and may have a positive effect on plant productivity (Wild 2012). This may also help alleviate climate change as the carbon sequestered in plant biomass is increased, and it has been estimated that variations in the diffuse fraction, largely associated with global dimming, enhanced the land carbon sink by approximately 25 per cent between 1960 and 1999 (Mercado *et al.* 2009).

Research in Asia has shown that particulate matter in the atmosphere as a result of fuel use, crop residue burning and wildfires can also easily be deposited on vegetation and subsequently damage leaves (Gupta *et al.* 2016; Mishra and Kulshrestha 2017). The deposition of particulate matter to terrestrial ecosystems in Africa and it impacts requires further research.

### 1.3.5.4 INTERACTIONS AIR POLLUTION WITH THE CARBON CYCLE AND WATER USE EFFICIENCY OF VEGETATION

As previously described, tropospheric O<sub>3</sub> can damage plants and reduce yields (Section 1.3.5.1), while the increase in CO<sub>2</sub> concentrations in the atmosphere can have a fertilization effect and increase plant productivity (Wang *et al.* 2020). Global modelling has shown that a doubling of CO<sub>2</sub> concentrations in the atmosphere could increase the surface O<sub>3</sub> concentrations by 2–8 ppb (Sanderson *et al.* 2007), as increased CO<sub>2</sub> reduces stomatal conductance and subsequently uptake of gases such as O<sub>3</sub> into plants (Ainsworth and Rogers 2007). Reduced stomatal conductance can also enhance plant water use efficiency, especially when rainfall is reduced. These potential feedbacks are further complicated by the effect on the water balance of increased temperature, drought and plant transpiration that accompany a warming of the climate (Ainsworth *et al.* 2012).

## 1.3.6 CLIMATE CHANGE IMPACTS ON RESOURCES, DEVELOPMENT AND HEALTH IN AFRICA

According to the IPCC, there is high confidence that the frequency and intensity of heavy precipitation and associated flooding will increase in most regions of Africa if global warming of 1.5 °C, relative to 1850–1900, occurs (IPCC 2021a). There will also be more

frequent and/or severe droughts in some parts of Africa. If global warming increases beyond 1.5 °C, the expected effect on precipitation and associated flooding, as well as the frequency and severity of droughts, will increase (IPCC 2021a).

In its *State of Climate in Africa 2019* report, the World Meteorological Organization [WMO] (2020) stated that temperatures in Africa have been rising in recent decades faster than global mean surface temperatures, and the year 2019 was among one of the three warmest years for the continent. This was reflected in the sharp geographical contrasts in annual rainfall, and significant regional variability in sea-level trends around Africa (WMO 2020). Temperatures exceeding 2 °C above the 1981–2010 average were recorded in Namibia, South Africa and parts of Angola, and large areas, extending from the south to the north of the continent, were more than 1 °C above normal. Only limited areas in the northwest, including Mauritania as well as adjacent ocean areas, were slightly cooler than the 1981–2010 average (WMO 2020).

### 1.3.6.1 IMPACT ON NATURAL RESOURCES

#### Land and Water Impacts

One of the most serious impacts of climate change is how it affects water resources, which are closely tied to other resource and social issues such as food supply, health, industrial production, transport and ecosystem integrity. One of the greatest causes of poverty in Africa is the lack of access to clean water. Integrated watershed resource management (IWRM) tools are widely recognized for their ability to incorporate socio-economic, environmental and technical dimensions of aquatic environments and their drainage basins. If aquatic and marine resources are not properly managed and aquatic ecosystems deteriorate, then human health and wellbeing may be compromised. Climate changes threaten the quality of aquatic ecosystems on a global scale and particularly in Africa (Muchuru and Nhamo 2019). Rivers, reservoirs, lakes, snowpacks and subsurface waters, which are the main sources of freshwater for agriculture, household use and energy generation in Sub-Saharan Africa, are vulnerable to climate change (Sheffield *et al.* 2018). Climate change exacerbates the water stress and variability of water resources across Africa, especially the arid- and semi-arid regions (Nhemachena *et al.* 2020).

In a recent study on the impact of potential factors that affect groundwater recharge, MacDonald *et al.* (2021) found that only long-term rainfall has

significant impact on the long-term groundwater recharge. According to their model, those African countries with high groundwater storage capacity but low long-term annual recharge may experience depletion of groundwater resources as a result of long-term climate changes but will remain resilient for short-term changes in climate. By the same token, those countries/regions with low groundwater storage capacity and high recharge, groundwater supplies are affected by short-term climate droughts but remain resilient to long-term climate variabilities.

#### Biodiversity and Ecosystem Impacts

Unprecedented environmental degradation, loss of biodiversity and the disruption of ecosystem services threaten Africa's ability to attain the African Union Agenda 2063 goals and the UN's 2030 Agenda (Scheren *et al.* 2021). Land-use changes for food production and urban development are the main drivers of environmental degradation in Africa, and degradation is further accelerated by several factors including climate change, population growth, pollution and waste (Dougill *et al.* 2021; Bullock *et al.* 2021).

A phenomenon called the greening the Sahel has been observed as part of a global greening trend (Jong *et al.* 2011). Some attribute this to cyclical events following rainfall variability caused by climate change (Ouedraogo *et al.* 2014), while others argue that the greening is largely caused by CO<sub>2</sub> fertilization effects (Zhu *et al.* 2016). Pausata *et al.* (2020) conclude that climate change together with intensive land-use and land-cover changes are, in the future, likely to lead to even larger fluctuations than those that caused severe droughts in the Sahel in the 1970s and 1980s.

An understanding of how climate change is likely to impact forests in Africa is needed to inform adaptation strategies and also to improve the management of forests to mitigate climate change, through the reduction in CO<sub>2</sub> emissions from deforestation and forest degradation, and carbon sequestration from the atmosphere (Chidumayo *et al.* 2011).

Climate change associated anomalies in precipitation, temperature and high CO<sub>2</sub> emissions affect the terrestrial ecosystems in Africa. Many impacts affecting ecosystems have been at least partly attributed to climate change including the disappearance of the ice cap on Mt. Kilimanjaro; the threat to habitats of Afromontane regions, especially the isolated plant populations, due to increased temperature; species range shifts; declines in tree productivity; the risk of colonization of coastal lagoons by mangroves due to sea-level rise; the risk of losing marine species such as manatees and

marine turtles; increased migration of endangered birds and wildebeest in the Serengeti area of Tanzania and Kenya's Masai-Mara. Potential range loss of animals in 141 national parks of Sub-Saharan Africa were studied and 10–15 per cent of the animal species are predicted to be critically endangered or extinct by 2050, with this percentage range expected to increase to 25–40 per cent by 2080 (IPCC 2014; Sintayehu 2018).

The restoration of natural habitats is now considered key to sustainable development and to have the potential of meeting multiple societal challenges including safeguarding human health and improving livelihoods while enhancing natural ecosystems (Cohen-Shacham *et al.* 2016). Several regional initiatives in Africa have been developed as a result of efforts in the United Nations Decade on Ecosystem Restoration (UN Decade). The African Green Stimulus Programme, for example, that encourages all African governments to accelerate the protection and restoration of biodiversity and ecosystems, will, in turn, address the global emergencies of loss of biodiversity, climate change and environmental pollution.

The Pan-African Action Agenda on Ecosystem Restoration has also been developed and embraces several regional and multi-country initiatives. Reforestation projects seeking to re-green the Sahel and the Sahara in an attempt to mitigate the effects of global warming have also been proposed. The Great Green Wall involves more than 20 African countries through the African Union and aims to restore 100 million hectares of degraded land, to sequester 250 million tonnes of carbon and create 10 million jobs in 11 countries. A second project, the African Forest Landscape Restoration Initiative (AFR100), that aims to recover 126 million hectares of deforested and degraded land, was signed by 30 countries.

### 1.3.6.2 AGRICULTURAL IMPACTS

Climate change is emerging as a major challenge to agricultural development in Africa, with the increasingly unpredictable and erratic nature of climate systems on the continent placing an extra burden on food security and rural and peri-urban livelihoods. Widespread flooding of farms and homes in 2022 in Mozambique, for example, and the prolonged drought in Ethiopia, demonstrate the extent of the threat posed by Africa's changing climate. The IPCC suggests that the frequency and intensity of heavy rainfall events will increase for most of tropical Africa while parts of northern and southern Africa will become drier (Trisos *et al.* 2022). In addition, Engdaw *et al.* (2021) analyzed trends in

recent decades, showing significant warming and an increase in the occurrence of heat waves in all regions of Africa.

The IPCC *Special Report on Climate Change and Land* (IPCC 2019) stated that climate change is exacerbating the rate of ongoing land degradation processes and introducing new degradation patterns. Climate change impacts on agriculture can come from changes in ecological conditions and the seasons. Changes in rainfall and temperatures may affect crop development and production. Furthermore, impacts on land systems have been observed from the faster rate of warming occurring over land and the effects of climate change on yields was evident in some crops. Maize and wheat in lower-latitude regions have been affected negatively, while in higher-latitude regions, yields of maize, wheat and sugar beet have improved. The pastoral system is the most vulnerable to climate change and there is high confidence that climate change has resulted in lower animal growth rates and productivity in African pastoral systems (IPCC 2019). The Southern African region is expected to suffer from reduced rainfall and increased temperatures that result in a 15–50 per cent reduction in agricultural productivity (Nhemachena *et al.* 2020).

Measurement of the likely magnitude of the economic impact of climate change on African agriculture has been a challenge. Kurukulasuriya *et al.* (2006) and Hassan (2010) used data from a survey of more than 9 000 farmers across 11 African countries to estimate how farm net revenues are affected by climate change compared with current mean temperature. An increase in precipitation was directly proportional to revenues from all farm types and vice versa. Thus, as the temperature rise and precipitation declines, revenue from all farm types declines and a 10 per cent increase in temperature leads to a 13 per cent decline in net revenue.

A statistical model developed to assess the sensitivity of wheat, maize, and soybean yields to O<sub>3</sub> exposure and temperature extremes showed that future warming and unmitigated O<sub>3</sub> pollution may cause 13, 43 and 28 per cent reductions in their production respectively (Tai and Val Martin 2017). They suggested stringent O<sub>3</sub> regulation, selection of heat- and O<sub>3</sub>-tolerant cultivars and the use of modern irrigation systems as possible adaptation mechanisms (Section 1.3.5).

Agriculture is a major contributor to Africa's GDP, and so will require effort and financial support to build adaptive capacity and mitigation efforts to reduce vulnerability to climate change. A number of successful

adaptation strategies have been implemented in Africa, such as diversification of farm products; access to irrigation, climate-resilient seeds and drought resistant crops; the introduction of modern planting techniques including changing cropping patterns and timing; shifting to modern farming and livestock-management practices; increasing awareness of agroforestry; improvements in the provision of climate information and early warning systems; and more rapid technological uptake and upgrading human and technical capacity (Yohannes 2016; UNDP 2018; Atube *et al.* 2021). It should, however, be noted that some of these adaptation strategies, such as irrigation, may alter the sensitivity of crop species to O<sub>3</sub> pollution (Tai and Val Martin 2017). Land-related mitigation options with potential co-benefits for adaptation include agroforestry, cover crops, intercropping and perennial plants, thus restoring natural vegetation and rehabilitating degraded land (IPCC 2022a). Risks of sea-level rise and extreme weather events can also be reduced by restoration of mangroves and coastal wetlands that sequester carbon, while also reducing coastal erosion and protecting against storm surges (IPCC 2022a).

Agricultural growth in Africa is generally achieved by cultivating more land and mobilizing a larger agricultural labour force, neither of which produces significant improvements in yields. According to a report by the New Partnership for Africa's Development (NEPAD 2013), despite the rise in the value of agricultural production, there has been very little improvement in production factors. During the last 30 years, Africa's population has doubled overall and tripled in urban areas. Despite growth in Africa exports, Africa has become a net importer of cereals, which can be linked to factors such as population growth, low and stagnating agricultural productivity, policy distortions, weak institutions and poor infrastructure (Food and Agricultural Organization of the United Nations [FAO] 2012). Generally, there has been a gradual shift from subsistence smallholder agriculture to agribusiness with a focus on adding value in Africa. An example of an African country which has seen high rates of agricultural growth is Ethiopia, which has characterized its new economic policy as "*agricultural development-led industrialization*", and which puts an emphasis on raising productivity of smallholder farmers to improve food security and generate broadly shared income gains (Jayne and Sanchez 2021). As a result, between 1993 and 2018, Ethiopia's agricultural output more than tripled, with growth averaging more than 5 per cent a year over 25 years (Jayne *et al.* 2021).

New initiatives, such as the provision of climate-smart

and inclusive financial packages to subsistence smallholders (Ostendorp *et al.* 2019), has increased investment in agricultural value chains with a focus on agribusiness while supporting smallholder farmers (Phiiri *et al.* 2016). Investment in irrigation water management, such as drip irrigation and canopy-cooling systems, has resulted in better water economy and agricultural yields, and is cited as best practice in climate change adaptation (Balana *et al.* 2017; Deligios *et al.* 2019) and could be further strengthened. To avoid the disadoption of practices such as conservation agriculture and address the limited uptake of climate-smart agriculture, it is important to ensure that effective and context-specific policies and institutional support programmes are implemented and that access to resources to maintain new production methods is ensured (Dougill *et al.* 2021).

The FAO *et al.* 2019 has called the strengthening of strategies for agricultural intensification and resilience of food production systems through the formation of key synergies between mitigation and food security. Action is needed to ensure that adequate insurance is in place to protect the rural poor against the dangers posed to food security, sustainable development and rural livelihoods. The FAO *et al.* 2019 emphasized the importance of expanding knowledge and capacity development by strengthening the ability of national and regional institutions to carry out forecasts and resource monitoring. The Comprehensive Africa Agriculture Development Programme (CAADP) policy framework is aiming to promote achievement of the Malabo Declaration on Accelerated Agricultural Growth and Transformation for Shared Prosperity and Improved Livelihoods in Africa by facilitating the participation of key stakeholders. Forty-seven African countries have signed the CAADP Compact resulting in an increase in public agricultural expenditures by more than 7 per cent a year (AU 2022a).

### 1.3.6.3 CLIMATE CHANGE IMPACTS HUMAN HEALTH

The link between climate change and human health is well documented (McMichael 2006). Some of the mechanisms include temperature and precipitation variabilities which increase floods, heatwaves and droughts and affect the proliferation and transmission of disease, especially infectious vector-borne ones. The way in which climate change and climate variability affect human health is complex as social, environmental, ecological, and economic factors interact and contribute to the health outcomes and their severity.

### Climate Change Impacts on Air Quality

Climate change is likely to have an impact on levels of O<sub>3</sub> and possibly particulates (Spickett *et al.* 2011; USEPA 2022), both of which are associated with increased mortality and a range of respiratory and cardiovascular health effects (Section 1.2). Regional health impact assessments of climate change should therefore address the issue of air quality, consider current capacity to tackle air pollution and determine the need for adaptation, particularly for vulnerable groups (Section 1.4.2). To improve policy interventions there is a need for continued monitoring of air pollutant levels, improved modelling and forecasting of air pollutant levels, monitoring of the incidence of air pollution health effects and increased efforts to reduce emissions of air pollutants in all countries in the region.

### Vector-Borne Diseases

In 2018, 238 million cases of and 405 000 deaths from malaria occurred globally. The WHO African region contributed 93 per cent of the 2018 global malaria burden and 94 per cent of the global malaria deaths (WHO 2019). There are varying estimates of the projected effect of climate change on the global distribution of malaria. One study suggests a 5--7 per cent altitudinal increase in the transmission of malaria in Africa (Tanser *et al.* 2003), another shows differences in future projections with latitude, with a projected increase in the highlands of East Africa but a decline in the Sahel fringes of West Africa (Endo *et*

*al.* 2017). In the highlands of eastern Africa, malaria will become endemic due to a combination of warming, land use and drug resistance (Hay *et al.* 2002; Siraj *et al.* 2014; Ngarakana-Gwasira *et al.* 2016). Southern Africa will likely be free from malaria by 2040 due to the drying trend caused by increasing temperatures.

Some studies suggest other arboviruses that cause dengue fever will emerge as bigger public health threats than malaria (Mordecai *et al.* 2020). Increasing temperatures and rainfall favourably affects the breeding pattern of the virus that causes dengue fever. About 6 billion people will be at risk of contracting dengue fever by 2080 as a result of a changing climate, compared to an estimated 3.5 billion if the climate remains the same (Hales *et al.* 2002). Table 1.2 shows the predictions of malaria and dengue fever cases for 2030 and 2050 for different regions of Sub-Saharan Africa. Western, eastern, and central African regions will be significantly affected but southern Africa will be significantly less affected by both diseases.

Yellow fever is also caused by a virus that uses the mosquito *Aedes aegypti* as a vector and thus increases in temperature and rainfall are associated with increased vector reproduction and more yellow fever cases. Gaythorpe *et al.* (2020) recently predicted that East and Central African will have a drastic proportional increase in burden and annual deaths caused by yellow fever. The number of deaths per year may also increase by 10–40 per cent under different climate change scenarios (Gaythorpe *et al.* 2020).

**Table 1.2** Estimated burden of malaria and dengue fever in Africa, incidence per million people

REGIONS	MALARIA PER MILLION PEOPLE		DENGUE FEVER PER MILLION PEOPLE	
	2030	2050	2030	2050
SUB SAHARAN AFRICA, CENTRAL	100.34	121.40	156.05	199.41
SUB SAHARAN AFRICA, EASTERN	209.57	260.92	490.14	610.69
SUB SAHARAN AFRICA, SOUTHERN	0.01	0.03	12.60	6.82
SUB SAHARAN AFRICA, WESTERN	461.45	520.72	494.87	593.23
WORLD	1 653.27	1 862.64	4 390	4 590

Source: Åström *et al.* (2014) and Beguin *et al.* (2014)

Other vector-borne diseases affecting Africa and the effects of which can be exacerbated by climate change are (vectors are in brackets): Lyme disease (ticks), chikungunya (mosquitos), Zika virus (mosquitos), leptospirosis (rodents), schistosomiasis (snails), visceral leishmaniasis (sand fly), west Nile fever (mosquitos), Chagas disease (triatomines), tick-borne encephalitis (ticks), onchocerciasis (blackflies), rift valley fever (mosquito) and plague (fleas) (Perrin 2008; Doumbia *et al.* 2014; Niang *et al.* 2014).

#### Food Security, Food Safety and Food- and Water-Borne Diseases

Food- and water-borne diseases, caused by bacteria, protozoa, viruses, helminths and toxins, can also be exacerbated by climate change (Rose *et al.* 2015). In the WHO African region, annual morbidity of 91 million and mortality of 137 000 people are attributed to food-borne diseases among which 70 per cent are diarrhoeal diseases caused by non-typhoidal salmonella, cholera and E.coli (WHO 2018). Climate change can exacerbate water- and food-borne diseases directly through, for example, extreme weather events such as floods and sea-level rise that result in contamination of the water source. or indirectly through climatic factors can favour the proliferation of pathogens, affect agricultural production, or cause scarcity of water (Cissé 2019). Salmonella, a strongly seasonal, climate sensitive bacteria, cholera and E. coli can be impacted directly or indirectly by climate change. The handling of food items with contaminated water and the consumption of raw or undercooked foods usually implicated in cholera and E. coli outbreaks (Semenza *et al.* 2022).

Although waterborne diseases in general have been declining globally, they are still significant in low-income countries (Semenza 2020). They mainly spread by contamination of drinking water supplies, inadequate sanitation and inappropriate hygiene. In 2016, there were 485 000 deaths due to diarrhoeal diseases attributed to inadequate water supplies, 432, 000 deaths due to inadequate sanitation and 165 000 deaths due to inappropriate hygiene (WHO 2018a). There are many mechanisms linking climate change to waterborne diseases. Firstly, low rainfall leads to water shortages, consumption of unsafe water and poor sanitation which have all been linked to a higher prevalence of diarrhoeal illness in Africa (Bandyopadhyay *et al.* 2012). This is concerning because diarrhoea is a leading cause of child death globally, and the majority of the diarrhoeal mortality in children occurs in Africa. Climate change leading to increased precipitation and frequent flooding

has also been linked to an increased prevalence of diarrhoea in some African countries (Bandyopadhyay *et al.* 2012).

Increasing annual temperatures and decreasing seasonal rainfall caused by climate change are already impacting food production and will have knock-on effects on the amount of land that is viable for agriculture and thereby food production (Section 1.3.6.2).

#### Health Burdens From Heat Stress

The health impacts of increases in heat across Africa is poorly researched, although there is some evidence from of an association between increases in mean temperature and health outcomes in Burkina Faso (Diboulo *et al.* 2012), Ghana (Azongo *et al.* 2012), Kenya (Egondi *et al.* 2012) and Tanzania (Mrema *et al.* 2012), with all the studies reporting a more pronounced impact on children under the age of five and the elderly.

Researchers investigated the effect of increased global warming, +1.5 °C and +2 °C, on heat stress in Central and West African countries and found that majority of the population will be exposed to dangerous heat-related risks such as heat cramps, heat exhaustion and heat stroke, which will be more pronounced once the global warming level exceeds 2 °C (Sylla *et al.* 2018; Fotso-Nguemo *et al.* 2022). Protective measures will be required for outdoor workers, workers in hot environments, and people engaged in strenuous activities. The future health burden of a warming climate in Africa is projected to be severe because of the lack of heat-health action plans and public health alert systems that have been shown to minimize the heat-health effects in other regions (Opoku *et al.* 2021).

#### Loss of Livelihood, Migration, Conflict and Injury

In Africa, drier and warmer years have led to significant increases in the likelihood of civil war (Burke *et al.* 2009). Evidence is emerging of the links between climate change and the threat to security – according to Mach (2020), 3–20 per cent of conflict risks over the last century have been influenced at least in part by climate change. The main mechanism cited for the conflict is loss of rainfall, impact on crop yields and the economic consequences on societies that are reliant on agriculture (Burke *et al.* 2009). The health impacts of climate driven conflict have not been quantified, although one study estimated that armed conflict substantially and persistently increases infant mortality in Africa, with effect sizes on a scale with malnutrition (Wagner 2018).

One of the manifestations of climate change is an increase in extreme weather conditions with very strong winds, heavy rain and storms accompanied by thunder and lightning. The health impacts of storms are mostly caused by secondary events such as storm surges, floods, landslides and tornadoes. These health consequences could be death, from drowning, electrocution, infrastructure collapse and water-borne diseases such as cholera; morbidity, due to infectious diseases, vector-borne diseases, mental health effects such as trauma, injuries from hidden sharp materials and animal bites from, for example, snakes and reptiles, disruption of health services due to bridge collapses, broken road access or damaged health infrastructures, and disruption of basic supplies of food, drinking water and electric lines, all of which can escalate in the aftermath of the storm events (Shultz et al. 2005). In Africa, 13.48 million people were affected and 3 686 reportedly died because of 172 storm events that occurred in 2000–2019 (CRED 2019).

#### 1.3.6.4 ECONOMIC IMPACTS OF CLIMATE ON HEALTH

Studies on the economic impact of climate-sensitive diseases are lacking in Africa and limited even among European countries (Hutton and Menne 2014). Limaye *et al.* (2019) estimated the health-related cost of 10 climate-related health outcomes in the United States in 2012 and found mortality costs, illness costs and lost wages were around US\$ 10 billion, adjusted to the 2018 dollar value. One can extrapolate that the economic impact of climate change on human health in Africa would be much higher than in the United States for just a single year because of the poorly developed and fragile healthcare system as well as inadequate adaptive capacity. Similar studies should be conducted for Africa and at sub-regional levels.

## 1.4. ADDRESSING VULNERABLE GROUPS AND SOCIAL INEQUITIES IN AIR POLLUTION AND CLIMATE CHANGE IN AFRICA

### MAIN MESSAGES

- There is limited knowledge on the impacts of air pollution and climate change in Africa, especially on vulnerable people because of few clinical studies and limited air quality monitoring capacity. It is therefore likely that the health and societal impacts are underestimated.
- Individuals within a community may experience varying levels of vulnerability to air pollution and climate change which are linked to socio-economic status, gender, age and multiple stressors or hazards.
- Urban areas are particularly vulnerable to the effects of climate change because of the urban heat island phenomenon which makes cities markedly warmer than the surrounding areas owing to high building density, paved surfaces, and lower vegetation cover, increasingly affecting people through heat stress.
- The effects of poor air quality and climate change is greater on people of lower socio-economic status and vulnerable groups such as young children, women and girls, people with underlying conditions and the elderly.

### 1.4.1 INTRODUCTION

Air pollution and climate change are twin challenges that invariably disproportionately impact the most vulnerable population groups and share many of the same drivers and solutions. The generation of GHG along with air pollutants in the form of pollutant gases and PM, including BC, contribute to both a warming climate and poor air quality (Section 1.3.1). Likewise, use of solid biomass such as wood in cookstoves not only affects health through indoor exposure to pollutants, but also contributes to climate change through deforestation and the unsustainable sourcing of firewood.

An analysis of observed trends annual-average near-surface temperatures in Africa over the last five decades reveals increases, particularly over parts of the subtropics and central tropical Africa, where



temperatures have been rising at more than twice the global rate (Engelbrecht *et al.* 2015). The ongoing and impending health and societal burdens from climate change in Africa are disproportionate relative to the contribution of GHG emissions GHGs per person. The equity implications of these differences are substantial because improving the living standards for many Africans would require development gains to be the same as those of wealthier countries, without increasing per person emissions.

The impacts of air pollution and climate change in Africa, especially on vulnerable people, remain largely unknown due to lack of air quality monitoring and limited research. It is therefore likely that the health and societal impacts are underestimated (Coker and Kizito 2018). The WHO reported that nine out of 10 people were exposed to outdoor air that exceeded the previously recommended levels of pollutants, which were less stringent than after 2021, with low- and middle-income countries having the highest exposure (WHO 2018a). The impacts are further aggravated by a low capacity to adapt (Section 1.4.2), and is related to poor housing, energy and transport; unreliable and disjointed healthcare provision and a reliance on rainfed agriculture for sustenance.

In the energy sector, health inequality resulting from a lack of access to clean cooking solutions leads to the high prevalence of indoor air pollution (Section 1.3.1.2). These impacts are felt most by women and children who spend much of their time cooking using or near polluting stoves and are therefore exposed to higher levels of these pollutants in their dwellings compared to their male counterparts (WHO 2016). The WHO *Burning Opportunity* report (2016) indicated that indoor air pollution causes almost 500 000 women's deaths each year from chronic obstructive pulmonary disease, while many more die from other non-communicable diseases related to household smoke.

## 1.4.2 ADAPTIVE CAPACITY AND VULNERABILITY

Action taken either to reduce or avoid risk of air pollution and climate change impacts can be termed adaptive capacity, although there are several methodologies for assessing it (e.g UNFCCC 2022). Adaptive capacity can enable people exposed to, or susceptible to, air pollution and climate change impacts to reduce their vulnerability by changing their behaviour. As the impact of poor air quality and climate change has a greater effect on certain sections of the populations, locations and occupations, it is important to understand the external risks involved

and the ability of people to cope without causing damage or loss. For example, low and moderate levels of environmental stressors, such as air pollution or changes in ambient temperature (heat exposure), may pose health concerns for some people who are unusually sensitive to these exposures due to age, pre-existing conditions or disability (Kuras *et al.* 2017). The rest of this section discusses variations in air pollution and climate change across society. Although prolonged exposure affects all groups, some variations in impact are evident – these are grouped into vulnerable populations, vulnerable locations and vulnerable occupations.

### 1.4.2.1 VULNERABLE POPULATIONS

The effects of poor air quality and climate change is greater on people of lower socio-economic status and factors including age, gender and level of education can modify the relationship between air pollution and its impacts in Africa. In addition, different pollutants may affect different social groups and gender in different ways. The WHO considers as vulnerable groups in the following categories: young children, the elderly, persons with certain underlying diseases, foetuses, groups exposed to other toxicants that interact with air pollutants, women and girls, and those with low socio-economic status (Makri and Stilianakis 2008).

#### Young Children

Children are particularly susceptible to the effects of air pollution, as they have higher breathing rates than adults, leading to higher intake of air pollutants per unit of body weight, and the developing lung may have limited capacity to cope with pollutants (Schwartz 2004; WHO 2005; WHO 2006; UNICEF 2017). Schwartz (2004) notes that 80 per cent of air sacks in the lung are formed after childbirth and changes in the lung continue throughout adolescence. Some children are especially vulnerable, including children with underlying chronic lung conditions such as asthma and cystic fibrosis. Exposure of pregnant women to high levels of air pollution may also impact on the development of foetuses, with the potential for health impacts in childhood and later in life (Malley *et al.* 2017).

Food production in Sub-Saharan Africa is affected by climatic variability (Section 1.3.6.2). This has a negative impact on children due to underlying determinants of child malnutrition such as food availability (Grace *et al.* 2012; Thiede *et al.* 2020). Emerging evidence from studies across several Sub-Saharan African countries shows the effects

of temperature and precipitation anomalies on the weight and wasting status of children (Thiede *et al.* 2020). Other studies make a direct link between surface temperatures and rainfall on nutritional deficiencies and childhood stunting (Grace *et al.* 2012). It is estimated that up to 30 per cent of children in some Sub-Saharan African countries have stunted growth, which indicates chronic malnutrition (Grace *et al.* 2012). The situation is complicated by the impact of air pollution on children's growth (Section 1.3.2.3).

#### Women and Girls

Exposure to household air pollution from the burning of solid fuels for cooking, heating and lighting accounts for a significant portion of the global burden of death and disease, and disproportionately affects women and children in the global south, especially Africa (WHO 2016). Given differences in activity patterns of men and women associated with the allocation of household tasks, household air pollution, particularly exposure to unclean cooking fuels, disproportionately impacts women (Okello *et al.* 2018). There is evidence of the disproportionate ill health burden borne by women and children in LMIC that highlights household cooking as the only risky activity of which men generally do less than women in all cultures (Jaquette and Summerfield 2006).

Climate change is expected to exacerbate ecological problems including water shortages, severely impacting water-related productive and reproductive tasks in agrarian societies (Sultana 2014). In Africa, women and young girls bear the greater burden of collecting water sometimes from faraway sources for domestic use which makes them more likely to experience the brunt of the impact of climate change on water availability.

Emerging and on-going research indicates that vulnerabilities to impacts of climate change are gendered (Omolo and Mafongoya 2019). A study on gender dimensions in small-scale farming found that women had less adaptive capacity because of financial or resource constraints (Jost *et al.* 2015). The study also found gender imbalances and male domination in receiving information and climate-smart support services such as information and advice on improving the management of soil and water (Jost *et al.* 2015).

#### People with Underlying Conditions

People with pre-existing cardiac conditions, respiratory diseases or living with HIV-AIDS in Africa are considered more susceptible to air pollution. Studies have shown that those with pre-existing

disease are more likely to seek medical attention or use medication to control their condition. For example, increases in the use of asthma medication in children has been associated with exposure to outdoor air pollution (Gauderman 2005). Exposure to air pollution might also worsen symptoms or trigger attacks in people with asthma or lung disease (e.g., chronic bronchitis – also called chronic obstructive pulmonary disease (COPD)). People with cardiovascular (heart) disease might experience symptoms such as palpitations, chest pain or shortness of breath because of exposure to air pollution (Jiang *et al.* 2016). People with pre-existing conditions such as cardiovascular, respiratory, and endocrine disorders are also more vulnerable to exposure to extreme heat. This is because high temperatures place extra strain on the cardiovascular system, or they are less likely to sense and respond to changes in temperature (thermoregulation) (Kovats and Hajat 2008). Certain medications such as anticholinergics interfere with sweating while diuretics can cause dehydration, making the effect of extreme heat worse (Kovats and Hajat 2008). Other illnesses or disabilities that affect mobility, awareness and behaviour also increase vulnerability (Kovats and Hajat 2008).

#### The Elderly

Exposure to air pollution by elderly people in Africa may lead to higher morbidity and mortality predominantly because of cardiovascular and respiratory disease (Hoek *et al.* 2013), and because older people generally have weaker immune systems, or undiagnosed respiratory or cardiovascular health conditions. Furthermore, an increase in vulnerability to climate-change induced extreme temperatures among the elderly in Africa is also likely to be linked to underlying medical conditions such as cardiovascular disease, diabetes or mobility problems, which increase susceptibility (Peters and Schneider 2021).

The prevalence of COPD and other chronic respiratory diseases increases with age and many physiological changes associated with ageing can increase susceptibility to particle effects. Virtually all components of the respiratory system are affected by ageing, including spirometry, diffusing the capacity for oxygen, lung elastic recoil, chest wall compliance and inspiratory muscle strength. In addition, maximal oxygen uptake and maximal cardiac output decline with age (Sharma and Goodwin 2006). The elderly may also be more susceptible to particle exposure because of lifetime exposure to PM as well as previous respiratory infections.

### Socio-Economic Status

Socio-economic status increases vulnerability to air pollution and extreme temperatures. In many African cities, economic and social differences exacerbate the impact of environmental exposures on the population and influence its susceptibility and vulnerability. Epidemiological studies often treat socio-economic status as a confounder or effect modifier since it correlates with other variables that modify risk (Villeneuve *et al.* 2003). For example, inadequate nutritional status, limited access to healthcare and higher exposures may be some of the reasons for the higher health impacts. However, in studies where socio-economic factors were included, a relationship has been shown between low socioeconomic status and air pollution exposure in North America, Asia and Africa, although results in Europe were more mixed (Hajat *et al.* 2015). Such analyses suggest that poor communities are the most affected by exposure but studies are limited and more research is needed.

The interaction between the effects of climate change and prevailing social-economic factors are significant as evidence continues to highlight the extent by which climate change in Africa is already undermining progress made towards Agenda 2030 (UN 2022). Droughts, flooding, and changes in rainfall patterns threaten livelihoods in communities that are reliant on rain-fed agriculture and smallholder farmers (Maganga 2021).

### 1.4.3 AIR POLLUTION VULNERABILITY AND SETTLEMENT

Risk assessment studies often ignore within-city variations that can change air pollution exposure, such as people's activity patterns, modes of transport, recreational activities and proximity to sources of air pollution such as major roads or polluting industry. Housing market dynamics also explain why certain populations experience both poor socio-economic status and greater air pollution exposure (WHO 2010). In rural settings, some house designs are influenced by socio-cultural dynamics, with the poor affected to a greater extent by inadequate housing conditions and higher environmental degradation (WHO 2010). Poor housing offers little protection from pollution infiltrating from outside, extreme temperatures or allergens (Lipfert 2004). It is important to sensitize people across different social groups to ventilation and practices that minimize indoor air pollution risks.

Studies in the UK, the Netherlands and France highlight that there are significant differences in exposure to air pollution that correlate closely with

areas of socio-economic deprivation (Fecht *et al.* 2015; Morelli *et al.* 2016).

There is a growing number of air pollution studies in poor urban residential areas of Africa that confirm observations identified elsewhere. For example, an air quality monitoring study in two informal settlements in Nairobi found average PM<sub>2.5</sub> levels of 166.4 µg/m<sup>3</sup> and 67.2 µg/m<sup>3</sup> indicating that residents in both settlements were exposed to PM<sub>2.5</sub> levels exceeding WHO Guidelines (Egondi *et al.* 2018). The study showed that, although the settlements were only 7 km apart there was a marked difference in pollution exposure demonstrating that the local situation and type of source exert an important influence on exposure to PM<sub>2.5</sub>. Also, a study of air pollution in Lagos, Nigeria (Alani *et al.* 2019) showed similar location variabilities in PM<sub>2.5</sub> concentrations but they were lower than the WHO Air Quality Guideline values of 25 µg/m<sup>3</sup> over a 24 hour period. Subsequently, however, the WHO has revised its air quality guideline for PM<sub>2.5</sub> to 5 µg/m<sup>3</sup> annual mean and 15 µg/m<sup>3</sup> per 24-hour mean.

Housing and places of residence are important mediators of extreme temperatures induced by climate change and the risk to human health. Urban areas are particularly vulnerable to the effects of climate change because of the urban heat island (UHI) phenomenon which makes cities markedly warmer than the surrounding areas owing to high building density, paved surfaces and lower vegetation cover. This risk of heat exposure is significantly higher among residents of informal settlements because of the type of building materials, high human congestion, high sensitivity because of underlying health conditions and generally low adaptive capacity to heat (Pasquini *et al.* 2020).

The lack of policy prioritization of heat-related health impacts in most African countries impedes efforts to reduce vulnerability, for example using heat and health adaptation plans (Pasquini *et al.* 2020) such as public health alert systems that have been shown to minimize the heat-health effect in other regions (Lowe *et al.* 2021).

Flooding resulting from increased severity of rainfall is another risk factor associated with climate change, and one that threatens many urban settlers living in flood prone areas in Africa (Planitz 2019). In 2015, floods in Accra, Ghana had a devastating effect on the residents of the informal settlements built in flood prone areas. The impact was exacerbated by poor infrastructure, characterized by clogged drainage systems (Planitz 2019).

#### 1.4.4 VULNERABLE OCCUPATIONS

The effects of occupation on air pollution exposure are often understudied (Fang *et al.* 2010). Exposure to air pollution in Africa can also result from occupational factors, such as working outdoors or inside factories and offices, and exposure to high concentrations of certain air pollutants. Occupations in transport or construction, for example, may lead to higher exposure to pollution (Rotko *et al.* 2000). Hazardous work can also include living near or working on waste dumps, where smoke from burning waste, and sorting and selling waste products can be serious health risks (Mebratu and Mbandi 2022). Informal workers, especially those trading in highly polluted areas such as the roadside traders – a common phenomenon in Africa – face a high risk of exposure to air pollution.

Studies show that environmental exposures are relatively constant while occupational exposures are more variable and generally higher than common outdoor levels (Fang *et al.* 2010). For example, a study in France showed that taxi drivers in their cars were exposed to levels of NO<sub>2</sub> twice as high as background levels and that the 8-hour average for black smoke concentrations was on average, almost four times higher than city background levels (Zagury *et al.* 2000). Occupational exposure to roadside emissions and inside informal settlements of four occupations have also been studied in Nairobi, Africa. Ngo *et al.* (2015) studied the different exposure to roadside emissions of bus drivers, female workers, mechanics and street vendors and found that bus drivers had the greatest exposure to PM<sub>2.5</sub>, experiencing statistically different exposure levels from the other three groups. In a study of informal public transport, workers in urban areas of Nairobi and Kisumu reported experiencing eye problems and attributed this to their exposure to air pollution (Kamau 2021).

Increases in temperature will increase occupational heat strain in Africa (Nunfam *et al.* 2019), although the evidence on this is sparse. A systematic review of the effect of heat strain on outdoor workers in tropical and subtropical settings in low- and middle-income countries suggests an imprecise but positive relationship between climate change and occupational heat strain on outdoor workers, and, most likely, the mechanism involves dehydration, fatigue, dizziness, confusion, reduced brain function, loss of concentration and discomfort (Habibi *et al.* 2021).

Recent studies on the economic costs of heat-induced reductions in worker productivity show an average decline of 1.4 per cent in global GDP (Orlov *et al.* 2020). The economic costs are higher in African and Asian countries due to higher increases in temperatures, lower capacity to adapt, the composition of employment related to the contribution of agriculture to the GDP and the share of workers employed in agriculture (Orlov *et al.* 2020).

##### 1.4.4.1 INTERSECTING VULNERABILITIES

###### Internally Displaced Populations

Internally displaced populations include people who leave their usual place of residence because their lives, livelihoods and welfare have been placed at serious risk because of adverse environmental, ecological or climatic processes and events (Gorlick 2007). There is increasing evidence linking anthropogenic and climatic factors to grave and relatively hasty alterations to ecosystems that have directly and indirectly caused people to migrate as temporary or permanent coping strategies. Vulnerabilities of climate change induced migrations, for example, of herders migrating southwards in Nigeria due to climate change induced advancement of the desert and other drastic ecological changes in northern Nigeria, are also an emerging issue in Africa (Ologeh *et al.* 2021).

###### School Settings

Children are exposed to air pollution in their homes, communities and even within their school environments (Egondi *et al.* 2018; Avis 2019; Rees *et al.* 2019)). In most African cities, children living in low-income areas are likely to be exposed to polluted playing fields and are also likely to attend schools that have higher exposure or risk of exposure to air pollution. Studies in Kenya reveal that children who live in Nairobi's informal urban settlements tend to attend schools that are within these settlements (deSouza *et al.* 2017). Often, these schools, located close to industries, open community fields, or near busy and sometimes unmettled roads, have poorer air pollution mitigation strategies either due to a lack of awareness about the risks they face or a lack of resources to support the greening of schools. Poor waste management options by schools, which, for instance, burn their waste, also contributes to air pollution within schools. Furthermore, children who must travel for long distances, especially in areas of high traffic congestion, experience exposure to air pollution on the journey to school (Masekela and Vanker 2020).

## 1.5. CONCLUSIONS

This chapter reviewed the current status and trends in Africa's development, including its key objectives, drivers and challenges. Africa continues to be confronted by wide-scale adverse effects of human-induced environmental change including climate change (IPCC 2021; IPCC 2022a) and air pollution (GBD 2021). Empirical data indicate that more than 1 million people are estimated to die prematurely each year in from exposure to outdoor and household air pollution (Fisher et al. 2021).

Africa has enormous potential for development and peace as well as for establishing flourishing, inclusive and prosperous societies (AUC 2015). This potential is, however, hampered and constrained by the impacts of climate change, to which development in many parts of Africa is particularly vulnerable (IPCC 2022a). The challenge is whether development can occur simultaneously while addressing air pollution and climate change.

This integrated assessment of the synergies between air pollution, climate change and development provides interesting scenarios in which many options for improving air quality in Africa may also serve to limit climate change and *vice versa*. Importantly, however, some options for improving air quality cause additional climate warming, and some action that addresses climate change can worsen air quality (Szopa et al. 2021).

In Africa, air pollution is a major threat to human health, wellbeing and the achievement of the SDGs. A warming climate can worsen air quality-related health and lead to premature death, so that action taken to reduce air pollutants will improve air quality even as the climate changes (USEPA 2022). The Paris Agreement, a key global framework ratified by 193 countries, points to air pollution as a key driver of climate change and focusses on reducing GHG emissions from the energy, transport, industrial, agricultural, waste management and land-use sectors that are the major sources of PM<sub>2.5</sub>, BC and O<sub>3</sub> associated with negative impacts on human health.

In many African countries, almost all rural households rely exclusively on solid fuels for cooking and heating. Approximately 923 million people in Sub-Saharan Africa alone lack access to clean cooking. The use of charcoal is widespread in urban areas of Africa with more than 80 per cent of urban households using charcoal as their primary cooking fuel. Uncontrolled open burning of dumped waste is an important

source of outdoor air pollution in Africa's urban areas. It is estimated that 394 000 deaths in Africa were attributable to outdoor air pollution in 2019 alone. A significant contribution to urban air pollution comes from the Sahara (Harmattan) dust and bush fires during the dry season in West Africa, usually from November to March.

Air pollution in Africa has multiple additional negative effects, especially economic and social ones, including negative impacts on productivity and the development of human capital, which may constrain long-term growth. Climate change impacts on resources, development and health in Africa, including land and water; biodiversity; agriculture; food security, food safety and water-borne diseases; and the effects of heat stress, including loss of livelihoods, migration, conflict, poor health and injury.

With the heavy health, social and economic burdens imposed by air pollution and climate change, measures to address vulnerable groups and social inequities in air pollution and climate change in Africa become imperative. The vulnerable populations include people of lower economic status, young children, jobless adolescents and young people, women and the elderly and people with underlying conditions.

BOX 1.3: EXAMPLES OF KNOWLEDGE GAPS AND REQUIRED ACTION

SOME KNOWLEDGE GAPS IDENTIFIED	POSSIBLE ACTION REQUIRED
Limited capacity to implement air-quality and climate-change policies	Build local capacity and strengthen inter-regional relations and support
Roles and responsibilities of policy makers not well understood	Clear understanding of desired policy outcomes
Separate and different air-quality and climate-change management strategies across Africa	An integrated approach addressing both air-quality and climate-change issues to ensure synergy and co-benefits to human health and ecosystems
Limited understanding of co-benefits and trade-offs between air-quality and climate-change policies	Develop more comprehensive sustainable policies to maximize the benefits for air-quality and climate-change mitigation
Limited air-quality monitoring data	More representative monitoring networks across countries and regions
Limited knowledge and information sharing	Integration of local knowledge and information throughout regions
Limited understanding of urbanization risks to human health and climate change	Reconcile urban and sustainability concerns, and build on adaptation strategies
Limited knowledge, expertise and experience in managing technical transformation	Developing indigenous innovation capabilities to ensure long-term growth
Use of conventional linear models that privilege formal research and development	Transdisciplinary approaches in co-producing the science-policy interface

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## ABBREVIATIONS AND ACRONYMS

AC	air conditioner
ACCP	African Clean Cities Platform
ADHD	attention deficit/hyperactivity disorder
AEC	African Economic Community
AERONET	Aerosol Robotic Network
AfDB	African Development Bank
AfCFTA	African Continental Free Trade Area
AFOLU	agriculture, forestry and other land use
AFR100	African Forest Landscape Restoration Initiative
AGNES	African Group of Negotiators Expert Support
AMCEN	African Ministerial Conference on the Environment
AMCOMET	African Ministerial Conference on Meteorology
AMCOW	African Ministers' Council on Water
AMMA	African Monsoon Multidisciplinary Analysis
APINA	Air Pollution Information Network for Africa
AOD	aerosol optical depth
ARBE	Department of Agriculture, Rural Development, Blue Economy, and Sustainable Environment (of the African Union)
ARSO	African Regional Organization for Standardisation
ART	acute respiratory-tract infection
ASAP	A Systems Approach to Air Pollution
ASD	autism spectrum disorder
AU	African Union
AUC	African Union Commission
AUDA-NEPAD	African Union Development Agency
AWD	alternate wetting and drying
BC	black carbon
BSC	Barcelona Supercomputing Center
BSFL	black soldier fly larvae
C	carbon
°C	degrees Celsius
CAADP	Comprehensive Africa Agricultural Development Programme
CAMRE	Council of Arab Ministers Responsible for the Environment
CAMS	Copernicus Atmosphere Monitoring Service
CAN	Climat Action Network
CAR	Central African Republic
CArE-Cities	Clean Air Engineering projects – Clean Air Engineering for Cities
CArE-Homes	Clean Air Engineering projects – Clean Air Engineering for Homes
CCAC	Climate and Clean Air Coalition
CCAK	Clean Cooking Association of Kenya
CCS	carbon capture and storage
CEDS	Community Emissions Data System
CIESIN	Center for International Earth Science Information Network
CH <sub>4</sub>	methane

CI	confidence interval
CMIP	Coupled Model Intercomparison Project
CMIP6	Sixth Coupled Model Intercomparison Project
CO	carbon monoxide
CO <sub>2</sub>	carbon dioxide
CO <sub>2</sub> -eq	carbon dioxide equivalent
COMESA	Common Market for Eastern and Southern Africa
COP	Conference of the Parties
COPD	chronic obstructive pulmonary disease
CRS	Common Reporting Standard
CSIR	Council for Scientific and Industrial Research
CSO	civil society organization
CSP	concentrated solar power
3D	three dimensional
DALY	disability-adjusted life years
DCHS	Drakenstein Child Health Study, Western Cape, South Africa
DICCIWA	Dynamics-aerosol-chemistry-cloud interactions in West Africa
DPSIR	drivers, pressures, state, impacts and responses
DRC	Democratic Republic of the Congo
EAC	East African Community
EASFCOM	Eastern Africa Standby Force Coordination Mechanism
ECCAS	Economic Community of Central African States
ECMWF	European Centre for Medium Range Weather Forecasting
ECOWAS	Economic Community for West African States
EDGAR	Emissions Database for Global Atmospheric Research
EEA	European Environment Agency
e.g.	exempli gratia (for example)
EIP	Eco-Industrial Park
EMEP	European Monitoring and Evaluation Programme
ERGP	Economic Recovery and Growth Plan
ETSAP	Energy Technology Systems Analysis Program
EV	electric vehicle
FAO	Food and Agricultural Organization of the United Nations
FDI	Foreign Direct Investment
FEER	Fire Energetics and Emissions Research
F-gas	fluorinated gas
FINN	Fire INventory from NCAR
FRM	Federal Reference Method
GBD	global burden and disease
GCF	Green Climate Fund
GCM	global circulation model
GDL	Global Data Labs
GDP	gross domestic product
GEDAP	Ghana Energy Development and Access Project
GEF	Global Environmental Facility
GEO	geostationary Earth orbit

GEOS	Goddard Earth Observing System
GFED	Global Fire Emissions Database
GFAS	Global Fire Assimilation System
GHAir	Ghana Urban Air Quality Project
GHG	greenhouse gas
GISS	Goddard Institute for Space Studies
GMAO	Global Modeling and Assimilation Office
GMP	Global Methane Pledge
GPI	genuine progress indicators
GPPDB	Global Power Plants Database
GPW	Gridded Population of the World
GRAP	Green Recovery Action Plan (of the African Union)
GSAT	global surface air temperature
GW	gigawatt (10 <sup>9</sup> watts)
GWh	gigawatt hours
GWP	Gridded Population of the World
HFC	hydrofluorocarbon
H <sub>2</sub> O	water
hPa	hectopascal
IBC	Integrated Benefits Calculator
IBD	inflammatory bowel disease
IBS	irritable bowel syndrome
ICAO	International Civil Aviation Organisation
ICCT	International Council on Clean Transportation
ICE	internal combustion engine
ICLEI	Local Governments for Sustainability
i.e.	id est (that is)
IEA	International Energy Agency
IGAD	Intergovernmental Authority on Development
ICLEI	Local Governments for Sustainability
IGO	intergovernmental organizations
ILO	International Labour Organization
IMF	International Monetary Fund
IMO	International Maritime Organization
INDAAF	International Network to study Deposition and Atmospheric
IP	Industrial Park chemistry in Africa
IPCC	Intergovernmental Panel on Climate Change
IPPU	industrial processes and product use
IQ	intelligence quotient
IRENA	International Renewable Energy Agency
IWRM	integrated watershed resource management
JICA	Japan International Cooperation Agency
kg	kilogram
KJWA	Koronivia Joint Work on Agriculture
km	kilometre

LEAP	Low Emissions Analysis Platform
LEAP-IBC	Low Emission Analysis Platform – Integrated Benefits Calculator
LED	light-emitting diode
LGV	Ligne à Grande Vitesse Maroc
LMIC	lower middle-income country
LPG	liquified petroleum gas
LRTAP	Convention on Long-Range Transboundary Air Pollution
LRTI	lower respiratory-tract infection
LULUCF	land use, land-use change and forestry
µg	microgram
m	metre
m <sup>2</sup>	square metre
m <sup>3</sup>	cubic metre
mm	millimetre
MAFLD	metabolic dysfunction-associated fatty liver disease
MDB	multilateral development bank
MEA	multilateral environmental agreement
MEPS	minimum energy-performance standards
MODIS	moderate resolution imaging spectroradiometer
MOPITT	Measurement of Pollution in the Troposphere
MSMEs	micro, small and medium-sized enterprises
MVOC	microbial volatile organic compound
MSW	municipal solid waste
MVA	Manufacturing Value Added
MW	megawatt (10 <sup>6</sup> watts)
N	nitrogen
NAIPS	National Agricultural Investment Plans
NARC	North African Regional Capability
NASA	National Aeronautics and Space Administration
NCAR	US National Center for Atmospheric Research
NCD	non-communicable disease
NDC	Nationally Determined Contributions (to the Paris Agreement)
NEPAD	New Partnership for Africa's Development
NGO	non-governmental organization
NH <sub>3</sub>	ammonia
NH <sub>4</sub>	ammonium
NIR	New Industrial Revolution
NMT	non-motorised transport
NMVOC	non-methane volatile organic compound
NO	nitric oxide
N <sub>2</sub> O	nitrous oxide
NO <sub>2</sub>	nitrogen dioxide
NO <sub>x</sub>	nitrogen oxides NO and NO <sub>2</sub>
NREL	National Renewable Energy Laboratory
NSB	national standards body
O <sub>x</sub>	containing oxygen

O <sub>3</sub>	ozone
OC	organic carbon
ODA	overseas development assistance
OECD	Organisation for Economic Co-operation and Development
OICA	International Organisation of Motor Vehicle Manufacturers (Organisation internationale des constructeurs automobiles)
OMI	ozone (O <sub>3</sub> ) monitoring instrument
PCFV	Partnership for Clean Fuels and Vehicles
PIDA	Programme for Infrastructure Development in Africa
PIQ	performance intelligence quotient
PM	particulate matter
PM <sub>1</sub>	very fine particulate matter (with a diameter of less than 1 micron)
PM <sub>2.5</sub>	fine particulate matter (with a diameter of less than 2.5 microns)
PM <sub>10</sub>	large particulate matter (with a diameter of 10 microns or less)
POLCA	Pollution de Capitales Africaines
ppb	parts per billion
ppbv	parts per billion by volume
ppm	parts per million
PPP	purchasing power parity
PREFIA	Air Quality Prediction and Forecasting Improvement for Africa
PV	photovoltaic
QFED	Quick Fire Emissions Dataset
R-COOL	Rwanda Cooling Initiative
REC	Regional Economic Community
ReCATH	Regional Climate Action Transparency Hub for Central Africa
RFA	regional framework agreements
RLP	Rural LPG Promotion Programme
3Rs	reuse, reduce and recycle
S	sulphur
SAAQIS	South African Air Quality Information System
SADC	Southern African Development Community
SDG	Sustainable Development Goal
SEI	Stockholm Environment Institute
SEZ	Special Economic Zone
SLCF	short-lived climate forcer
SLCP	short-lived climate pollutant
SNAP	Supporting National Action and Planning on Short-Lived Climate Pollutants
SNAQ	Sensor Network for Air Quality
SO <sub>2</sub>	sulphur dioxide
SSP	shared socioeconomic pathway
TAREA	Tanzania Renewable Energy Association
TROPOMI	Tropospheric Monitoring Instrument
TSP	total suspended particulates
TW	terawatt (10 <sup>12</sup> watts)
TWh	terawatt hour
U4E	United for Efficiency

UHI	urban heat island
UIC	International Union of Railways (Union internationale des chemins de fer)
UMA	Arab Maghreb Union (Union du Maghreb Arabe)
UN	United Nations
UNCTAD	United Nations Conference on Trade and Development
UN DESA	United Nations Department of Economic and Social Affairs
UNDP	United Nations Development Programme
UNEA	United Nations Environment Assembly
UNECA	United Nations Economic Commission for Africa
UNECE	United Nations Economic Commission for Europe
UNEP	United Nations Environment Programme
UNEP ROA	United Nations Environment Programme Regional Office for Africa
UNFCCC	United Nations Framework Convention on Climate Change
UN-Habitat	United Nations Human Settlement Programme
UNIDO	United Nations Industrial Development Organization
UN WPP	UN World Population Prospects
US	United States of America
VAT	value-added tax
VNR	Voluntary National Review
VOC	volatile organic compound
W	watt
WAGP	West African Gas Pipeline
WAPP	West African Power Pool
WDI	World Development Indicators
WEC	World Energy Council
WEPP	World Electric Power Plants Database
WEO	World Economic Outlook
WHA	World Health Assembly
WHO	World Health Organization
WMO	World Meteorological Organization
WRF	Weather and Research Forecasting

