CHAPTER 3:

DEVELOPING THE AFRICA WE WANT: ACHIEVING AGENDA 2063 ALSO IMPROVES AIR QUALITY AND ADDRESSES CLIMATE CHANGE

UN environment programme

CLIMATE & CLEAN AIR COALITION TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

African Union

ISBN: 978-92-807-3989-3

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SUGGESTED CITATION

United Nations Environment Programme (2023). Integrated Assessment of Air Pollution and Climate Change for Sustainable Development in Africa, Nairobi.

PRODUCTION

Climate and Clean Air Coalition (CCAC) convened by United Nations Environment Programme (UNEP), African Union Commission, Stockholm Environment Institute (SEI)

ACKNOWLEDGMENTS

The United Nations Environment Programme (UNEP) would like to thank the authors, reviewers and the secretariat for their contribution to the preparation of this assessment report. Authors and reviewers have contributed to the report in their individual capacities. Their affiliations are only mentioned for identification purposes. The preparation of this assessment has been supported by the Swedish International Development Cooperation Agency (Sida) through funding to the Stockholm Environment Institute (SEI) that coordinated the process and publication of the assessment report.

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SPECIAL THANKS

The Climate and Clean Air Coalition and partners appreciate the leadership and support from the H.E. Ambassador Josefa Leonel Correia Sacko, Commissioner for Agriculture, Rural Development, Blue Economy and Sustainable Environment, African Union Commission, and the entire team of officers for supporting and providing policy guidance to the assessment. We express gratitude to Dr. Harsen Nyambe, for Co-Chairing the International Advisory Group, Ms. Olushola Oyalide and Ms. Leah Naess Wanambwa for their policy support to the assessment coordination team. We would also like to express our gratitude to Frank Turyatunga (Regional Director) and Charles Sebukeera, UNEP Regional Office for Africa, and; David Ombisi and Julie Kaibe at the African Ministerial Conference on Environment (AMCEN) Secretariat, for their support of the Assessment and especially the policy engagement process. Special thanks also go to Andrea Hinwood, UNEP Chief Scientist, the head of the CCAC Secretariat, Martina Otto, and the Co-Chairs and Science Advisory Panel of the CCAC for advice and comments.

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3.1 INTRODUCTION

MAIN MESSAGES

- Two mitigation scenarios considering reductions in air pollutants and GHG emissions following the implementation of measures aimed at meeting SLCP and the AUC's Agenda 2063 targets were modelled.
- **SLCP Mitigation Scenario**: this scenario includes the implementation of mitigation measures that directly target the major sources of SLCPs, including BC, CH_4 and HFCs. These measures generally focus on those mitigation options that can be implemented quickly, generally achieving widespread implementation by 2030, although some continue to develop through to 2063. Most of the measures in this scenario are technical in nature, such as improvements in fuels and technology.
- **Agenda 2063 Scenario**: this second, more ambitious scenario, focuses on mitigation measures that more broadly achieve the aims and goals of the AUC Agenda 2063 and the SDGs. This scenario starts with the SLCP measures from the first scenario and then adds implementation of mitigation measures that result in more transformative change, including behavioural ones as well as technical measures.

3.1.1 MODELLING THE MITIGATION SCENARIOS

This chapter presents the results of modelling two different future scenarios to illustrate how Africa could follow a different development path to that outlined by the baseline scenario (Chapter 2). For the two mitigation scenarios developed in this chapter, changes in air pollutants and GHG emissions following the implementation of measures aimed at meeting SLCP and the AUC's Agenda 2063 targets were modelled. It is important to highlight that while the SLCP mitigation scenario includes only SLCP measures, their implementation can also potentially affect other short- and long-lived climate pollutants (Section 1.4.1).

The emissions modelling developed using the LEAP model includes assessment of the magnitude of GHGs and air pollutant emissions across Africa at national resolution for the three scenarios: firstly, the modelling estimates emissions levels for 2000–2018, then projections of emissions for 2019–2063 were estimated for a baseline scenario. The baseline scenario (Chapter 2) reflects possible changes in emissions in a future without the implementation of specific policies and measures designed to reduce emissions from key source sectors. It reflects how emissions might rise as a result of changes in Africa's population and economy, both of which are expected to grow substantially over the next 40 years (Section 2.3).

The third element of the emissions modelling was developing emissions projections to 2063, reflecting possible mitigation pathways for Africa, in which technical, social, political and financial barriers to implementation of key mitigation measures are overcome so that the measures achieve widespread implementation. This assessment of mitigation pathways, therefore, demonstrates the possible benefits for reducing emissions from major source sectors, and thus how Africa could mitigate climate change, reduce air pollution and improve human health and other development related factors. Two overarching mitigation scenarios are developed:

SLCP mitigation: this scenario includes the implementation of mitigation measures that directly target the major sources of SLCPs, including BC, CH_4 and HFCs. These measures generally focus on those mitigation options that can be implemented quickly, generally achieving widespread implementation by 2030, although some continue to develop through to 2063. Most of the measures in this scenario are technical in nature, such as improvements in fuels and technology.

Agenda 2063: this second, more ambitious, scenario focuses on mitigation measures that more broadly achieve the aims and goals of the AUC Agenda 2063 and the SDGs, with Agenda 2063 having sustainability ambitions beyond the 2030 target of the SDGs. This scenario starts with the SLCP measures from the first scenario and then adds implementation of mitigation measures that result in more transformative change, including behavioural ones as well as technical measures. As well as reducing emissions, the Agenda 2063 scenario also achieves other development priorities, such as eliminating hunger (SDG 2), access to safe sanitation (SDG 6) and increasing access to sustainable energy (SDG 7).

This chapter aims to provide an overview of the mitigation measures included in the SLCP and Agenda 2063 mitigation scenarios (Section 3.2), the potential of the measures to reduce emissions of SLCPs, GHGs and air pollutants (Section 3.3), the potential air quality and climate change benefits of implementing the measures (Section 3.4) and the implications of successful implementation of the measures for Africa's development priorities (Section 3.5). The results of the emissions mitigation modelling are used to answer key questions on how emissions will change in each scenario in different sectors across the African continent. Detailed implications for Africa's five main subregions are discussed in Chapter 4.

3.2 MITIGATION MEASURES MODELLED IN KEY SECTORS

MAIN MESSAGES

- The modelling in the Assessment identifies a feasible and cost-effective pathway that can guide the implementation of nationally appropriate measures. The measures and the key assumptions behind their implementation have been carefully assessed and validated for plausibility by the Assessment authors and other stakeholders.
- The Assessment models the implementation of 37 measures across 5 key areas: transport, residential, energy, agriculture, and waste to fight climate change, prevent air pollution, and protect human health and the environment.
- The measures identified are technically feasible and most of them are already being implemented in parts of the African continent across the key sectors but need to be scaled up to harness their full potential.
- The SLCP Scenario primarily focuses on implementing 17 technical and behavioural measures that directly target reductions in SLCPs, and co-emitted air pollutants and GHGs.
- The Agenda 2063 Scenario, models an additional 20 development and climate focused mitigation measures, in addition to the 17 under the SLCP mitigation scenario, making 37 in all.

3.2.1 MITIGATION SCENARIO MODELLING APPROACH

The mitigation measures included in the SLCP and Agenda 2063 scenarios in this Assessment are outlined in Tables 3.1–3.5 and summarized in Table 5.1 in Chapter 5. There are 37 measures in total, each with a target and timeline for its implementation. The list of measures was developed by the modelling team based on the types of measures implemented in past UNEP global and regional Assessments (UNEP and WMO 2011; UNEP and CCAC 2016; UNEP 2019b), but also reflecting additional concerns relevant for Africa as described in the SDG and Agenda 2063 literature. The list of measures considered are conservative in nature and only reflect technologies that are either already commercially available or which are expected to be commercially available in the coming decades – carbon capture and storage, for example. Technologies or broader industrial systems of production for which commercialization is generally considered more speculative over the study period are not included. These include, for example, the broad implementation of hydrogen as an energy carrier or the widespread implementation of carbon capture technologies such as direct air carbon capture.

The modelling team made an initial estimate of the implementation potential for each measure. These estimates were then carefully vetted and adjusted by the Assessment team through a series of consultations held remotely during 2021 and early 2022. This process ensured that a wide range of African stakeholders were comfortable with the scale of ambition for each measure.

The SLCP scenario focused on the measures and sectors through which SLCP emissions can be mitigated. These include emissions of CH_4 from agriculture, waste and fossil fuel production; BC emissions from the residential, transport, agriculture and waste sectors: and HFC emissions from industrial processes and product use. The 17 measures directly target reductions in SLCPs, and co-emitted air pollutants and GHGs, rather than broader behavioural or societal shifts. Measures in the SLCP mitigation scenario include electric vehicles, enforcing stringent vehicle emission standards, switching to cleaner fuels for cooking, and reducing CH_4 emissions from enteric fermentation and manure management. Broader changes, such as a modal shift in the transport sector, or off-farm changes, such as reducing food waste, are included in the Agenda 2063 scenario.

The Agenda 2063 scenario, which is more comprehensive and includes an additional 20 mitigation measures. Overall, the Agenda 2063 scenario implements measures to achieve three objectives:

i. the achievement of the development priorities outlined in the AUC's Agenda 2063;

ii. mitigate climate change through reduction of SLCP and/or GHG emissions; and

iii. reduce air pollution through reductions in SLCP and/or air pollutant emissions.

The scenarios included in this Assessment have been defined to give a first target for 2030 and a second target for 2063. Moreover, considering the need for the modelling to cover the whole continent, in which there are big differences between countries, it is important to recognize that mitigation targets need to reflect different national circumstances. The scenarios have therefore been established with two tiers of countries:

- Tier 2: the least developed countries (LDCs)[1];
- Tier 1: all other African countries.

In some cases, measures relative to Tier 1 targets have been designed to be more ambitious. All implementation targets, though, were reviewed/validated by stakeholders.

3.2.2 ENERGY: TRANSPORT SECTOR

3.2.2.1 DELIVERING ADEQUATE MOBILITY OPTIONS AND INFRASTRUCTURE

Anthropogenic emissions related to road transport are determined by the amount of fossil fuel consumed by vehicles, vehicle technology, fuel quality and transport planning (Soylu 2007). Moreover, the worldwide dependence on the motor vehicle has driven the increasing number of registered vehicles and vehicle miles travelled, resulting in growing emissions of GHGs and air pollutants that adversely impact urban air quality, exposing more people to air pollution and its numerous adverse health risks (HEI 2020). Furthermore, many African countries are experiencing rapid population growth, which has been accompanied by a similar growth in both the number of private vehicles for passenger and goods transportation and a consequent increase in urban air pollution levels (Brauer *et al*. 2016). In this scenario, the African road network is characterized by poor infrastructure and ageing vehicle fleets that are poorly maintained, contributing to increased emissions and air pollution (Zachariadis *et al.* 2001). The provision of efficient transport systems is a central issue for the growth of African urban areas as well as for the growth of the economies of emerging developing areas in Africa (Bubeck *et al.* 2014). Uncontrolled development and the lack of strategies for the mitigation of emissions connected to transport and congestion could have a severe effect on the health of the population as well as the economy (Thondoo *et al.* 2020).

Reducing transport-related emissions is a key challenge for air quality management and climate change mitigation requiring a wide range of strategies. Nakamura and Hayashi (2013), in their overview of possible strategies for low-carbon solutions, highlight how the effectiveness of different GHGs strategies is strictly dependent on urban planning in the development context and the existing type of urban land-use transport system.

Three main factors are considered to be the main contributors to transport emissions and their potential reduction could contribute to decreased air pollution:

a. emissions per fuel unit;
b. fuel consumption per passenger or per freight kilometre travelled; and
c. the number of passenger or freight kilometres.

These three elements can be used individually or in combination in the creation of new mitigation policies. Progressive changes in vehicle technology and/or fuel type; making public transport more efficient – reducing the circulation of private vehicles; and decreasing road traffic by improving, for example, rail systems are only some of the more common options (SA-ASPO 2008).

Some alternatives to reduce emissions connected with transport are represented by the transport emission control already implemented in few parts of Africa. These measures generally include promoting mass/public transport, improving the status of the vehicle fleet, alternative fuels, traffic management and urban planning (Chapter 5, Section 5.3.1). Some of these policies, such as road pricing, increasing the efficiency of existing systems and expanding public transit, have been considered in a few North African countries (e.g. Raey 2007) to reduce transport emissions. In others, including Egypt, legislation enforcing imported vehicles to be equipped with a catalytic converter has been put in place but it is not mandatory for vehicles to pass emissions test in majority of African countries (Ayetor *et al.* 2021).

In Mauritius efforts to modernize the private and public transport fleet have promoted the use of electric or hybrid cars since 2009 (Barry and Damar-Ladkoo 2016), increasing the number of new and second-hand hybrid vehicles from 43 in 2009 to 11 841 in 2019 (Ayetor *et al.* 2021). Nonetheless, only five other African countries, Algeria, Egypt, Morocco, South Africa and Sudan, have started to ban import of used vehicles with older technology, for example, with less than EURO IV standards (Baskin 2018; UNEP, 2020d), while countries including Cameroon, Malawi, Mali, Niger, Somalia, Togo and, Zambia have no import restrictions on them. Overall, West Africa accounts for 49 per cent of used vehicle imports to Africa while Nigeria and Kenya are the two countries that import the most used vehicles (Koener 2018). Importing large numbers of old vehicles is a strong impediment to modernizing national public and private vehicle fleets and reducing related emissions.

1. Angola, Benin, Burkina Faso, Burundi, Central African Republic, Chad, Comoros, Democratic Republic of the Congo, Djibouti, Eritrea, Ethiopia, Gambia, Guinea, Guinea-Bissau, Lesotho, Liberia, Madagascar, Malawi, Mali, Mauritania, Mozambique, Niger, Rwanda, São Tome and Principe, Senegal, Sierra Leone, Somalia, South Sudan, Sudan, Togo, Uganda, United Republic of Tanzania and Zambia (https://www.un.org/development/desa/dpad/least-developed-country-category.html)

Interventions intended to keep the number and type of motor vehicles constant but reduce the kilometres travelled, and thus fuel consumption, are also a way of reducing emissions of GHGs and air pollutants connected with road transport. Scenarios produced in South Africa show potential reductions of 15–21 per cent of all related pollutants (Thambiran and Diab 2011). Studies have shown that African countries that have implemented policies encouraging active transport, i.e., walking and cycling, such as Kenya, Nigeria and Uganda, have seen an increased uptake of this mode of travel (Loo and Silba 2019). Despite this, walking, cycling and public transport are still not popular due to poor infrastructure and safety concerns (Bester and Geldenhuys 2007; Wood 2020).

Other possibilities are represented by the high-shift scenario under which investment in urban passenger transport could result in a shift towards urban mass transport in Middle East and North Africa (MENA) region carrying significantly more passengers numbers and reduced emissions per person (Gettani *et al.* 2017). Moreover, investment in the creation of a more powerful intercity rail network intended for the movement of freight and passengers has been shown to decrease emissions as long as renewable energy sources are used to power the trains (Kageson 2009).

Finally, additional measures that do not change African vehicle fleets and fuel types are car-free policies aimed at restricting the use of motor vehicles in particular areas of cities. Several Asian and European cities have already adopted this idea to reduce air pollution levels in urban areas (Nieuwenhuijsen and Khreis 2016). For example, NO_2 concentrations decreased by 40 per cent on a car-free day in Paris and 20 per cent in Leeds during a leg of the Tour de France when roads were closed to motor vehicles (Nieuwenhuijsen and Khreis 2016). Furthermore, Paris, Madrid and Athens are introducing permanent bans on diesel vehicles from 2025 and placed other restrictions on private vehicles (Garfield 2017). This approach has been proposed for Nairobi to solve its traffic and air pollution problems (Kheris *et al.* 2018) while in other countries, including Ethiopia, Rwanda and Uganda, monthly car free days have been adopted by local government (UNEP 2020a).

3.2.2.2 MITIGATION MEASURES MODELLED IN THE TRANSPORT SECTOR

This Assessment modelled eight measures related to the transport sector (Table 3.1), including three technical measures that directly target reductions in SLCPs, co-emitted air pollutants and GHGs, and five measures involving behavioural and/or societal shifts, such as modal ones.

SHORT-LIVED CLIMATE POLLUTANT MITIGATION SCENARIO MEASURES

- **T1: Passenger electric vehicles** This measure, which is key to reducing GHG and SLCP emissions from road transport, particularly when implemented in conjunction with the promotion of the generation of clean electricity, involves a progressive increase in the percentage of EVs in the national fleets, including passenger cars, buses, light commercial vehicles and motorcycles. Starting in 2022, the measure foresees an increase in EVs to 10 per cent of the total vehicle stock by 2030 in the relatively higher income Tier 1 countries and to 3 per cent in Tier 2 countries – LDCs. These targets are roughly in line with NDC commitments made during 2020/2021 (Chapter 5, Section 5.3.1). By 2063 electrification of the vehicle fleets reaches 80 per cent of the stock in Tier 1 countries and 70 per cent in Tier 2 countries.

- **T2: Advanced emissions controls for internal combustion engined road vehicles** This measure focuses on reducing tailpipe emissions from internal combustion engined (ICE) road vehicles using advanced catalytic converter-based emission controls similar to those already implemented in Europe under the recent Euro VI emission standards. This measure is effective in reducing local air pollutants but does not directly reduce CO_2 emissions. Thus, it is most effective when implemented in conjunction with measure T1 that aims to gradually replace ICE vehicles with EVs. Enabling this measure will also require reductions in the S content of transport fuels in Africa to levels comparable with those currently seen in Europe. The measure aims to ensure that 98 per cent) of on-road ICE vehicles attain Euro VI emissions standards by 2050 in Tier 1 countries and by 2063 in Tier 2 ones. The S content of transport fuels in Africa will need to decrease to around 10 ppm to enable this.

- **T3: Hybrid Vehicles** Given Africa's limited capacity to transition to EVs by 2063, this measure works as a stop gap to increase the energy efficiency of road transport vehicles through the implementation of hybrid vehicle technologies. Hybrid vehicles are similar to ICEs but include larger batteries and regenerative braking systems able to capture and reuse energy during braking, thus improving the overall energy efficiency of vehicles by about 30 per cent. This measure foresees 25 per cent of the passenger vehicle stock being hybrid by 2030 in Tier 1 countries and 10 per cent in Tier 2 ones. By 2063, hybrid vehicles would be phased out in favour of EVs in Tier 1 countries, although 25 per cent of vehicles would still be hybrids in Tier 2 ones.

Table 3.1 Mitigation measures modelled in the transport sector, near-term (2030) and 2063 assumptions used in the modelling and links to Agenda 2063 priority areas

MEASURE	DESCRIPTION	NEAR-TERM ASSUMPTIONS (2030)	2063 ASSUMPTIONS	SCENARIO	RELEVANT AGENDA 2063 PRIORITY AREAS
TRANSPORT MEASURES					
T1. PASSENGER ELECTRIC VEHICLES	Key to reducing road transport GHG and SLCP emissions.	10% of stock are EVs in Tier 1. 3% in Tier 2.	80% of stock are EVs in Tier 1. 70% in Tier 2.	SLCP	Modern and liveable habitats and basic quality services
T2. ADVANCED EMISSIONS CONTROLS FOR ROAD VEHICLES	Advanced emissions controls, which also require low sulphur fuels, can help reduce tailpipe emissions from remaining ICE vehicles in medium term as EVs introduced.	By 2050 (Tier 1) and by 2063 (Tier 2) - 98% of all remaining ICE vehicles are Euro VI standard		SLCP	Modern and liveable habitats and basic quality services
T3. HYBRID VEHICLES	Hybrid vehicles are the main measure for improving vehicle efficiency other than full electrification.	25% of passenger the stock are hybrids in Tier 1. 10% in Tier 2.	0% of passenger stock is hybrids in Tier 1. EVs dominate. 25% in Tier 2.	SLCP	Modern and liveable habitats and basic quality services
T4. PUBLIC TRANSPORT	Higher occupancy public transport is cleaner and more energy efficient than private cars.	15% of passenger kilometres switched from cars to buses in Tier 1. 10% in Tier 2.	25% switched in Tiers 1 and 2	Agenda 2063	Modern and liveable habitats and basic quality services
T5. NON-MOTORIZED TRANSPORT	Cycling and walking promote health and reduce energy and emissions from transport.	10% of passenger kilometres switched from cars to cycling.	30% switched.	Agenda 2063	Health and nutrition
T6. SWITCH FREIGHT FROM ROAD TO RAIL	Rail transport is more energy efficient and easier to electrify than road freight.	5% of road tonne kilometres switched to rail by 2030.	25% in Tier 1, 20% Tier 2	Agenda 2063	Communications and infrastructure connectivity
T.7. RAIL ELECTRIFICATION	Moving from diesel to electric to reduce emissions	Tier 1 80% - Tier 2 60% by 2063 if electrification was below 50% in 2018. Otherwise 100% by 2063.		Agenda 2063	Communications and infrastructure connectivity
T.8. ROAD FREIGHT ELECTRIFICATION	Zero carbon freight at point of end use	0%	Zero until 2030 and 35% electrified by 2063 in Tier 1, 25% in Tier 2	Agenda 2063	Communications and infrastructure connectivity

AGENDA 2063 SCENARIO MEASURES

The five Agenda 2063 measures aim to deepen the emissions reductions achieved through the SLCP measures while also helping to achieve other development goals, such as alleviating congestion and making cities more liveable.

- **T4: Public transport** This measure involves the promotion of higher-occupancy public transport, especially buses, over private vehicles, an effective and cost-effective method for avoiding growth in both GHGs and SLCPs emissions. It should be noted that the current stock of buses in Africa tend to be associated with very high emissions of $PM_{2.5}$, BC and OC, so this measure is most effective when combined with T1 that promotes the electrification of public transport. The measure foresees 15 per cent of passenger kilometres switched from private vehicles to buses in Tier 1 countries by 2030 and 10 per cent in Tier 2 ones and, by 2063, 25 per cent of passenger kilometres, relative to the baseline scenario, switched from private vehicles to buses in both tiers. Without this measure, the total number of passenger vehicles on the road in Africa would increase in the baseline scenario from 132.4 million in 2019 to 188.7 million in 2030 and 658 million in 2063, almost a fivefold increase over the study period. The absolute number of private cars would still continue to grow with this measure, even with this high level of substitution, but the number of passenger vehicles on the road reaches lower levels: 132.3 million in 2030 but 499.1 million in 2063, a 28.8 per cent decrease relative the baseline and a more manageable 3.8-fold increase on 2019. The level of transport services provided, measured in passenger kilometres, is the same in both scenarios.

- **T5: Non-motorised transport (cycling and walking)** This measure helps to decrease energy use and emissions, and also contributes direct health benefits to the people who engage in these activities. The measure will require significant efforts to improve urban planning including the implementation of walking- and cycling-friendly infrastructure. The direct health benefits of the measure are also contingent upon improving air quality in towns and cities through the other measures targeting road transport emissions. The measure assumes ambitious levels of change across Africa, with 10 per cent of passenger kilometres switched from cars to cycling and walking by 2030 and 30 per cent switched by 2063. These targets are ambitious, but it is worth noting such changes that have already been achieved in a number of European cities. According to the Los Angeles Times, Copenhagen, for example, reported in 2019 that 62 per cent of its residents commuted to work or school by bicycle – an increase from 52 per cent relative to 2015 and 36 per cent on 2012. While not explicitly modelled, meeting these targets could be further enabled through the use of e-bikes, helping to make cycling more accessible to a broader proportion of the population with minimal additional energy requirements relative to traditional vehicles. When implemented in conjunction with measure T4 (public transport), the number of vehicles on the road in Africa would further decrease relative to the baseline scenario, reaching 128.9 million in 2030 and 338.8 million in 2063 – 42 per cent lower than the baseline.
- **T6: Switching road freight to rail** Rail is more energy efficient than road transport so can help to reduce GHG emissions. This measure foresees that by 2030, 5 per cent of road tonne kilometres can be switched to rail across all countries. By 2063, 25 per cent of road tonne kilometres s are switched to rail in Tier 1 countries and 20 per cent in Tier 2 ones.
- **T7: Rail electrification** While switching freight from road to rail is more energy efficient (T6), current diesel trains tend to emit high levels of SLCP pollutants. Electrification of rail networks will help to avoid these emissions and will also further reduce diesel GHG emissions. This measure foresees at least 80 per cent rail electrification in Tier 1 countries and 60 per cent in Tier 2 countries by 2063. Algeria, Morocco and South Africa already report electrification rates of 80 per cent or more so these countries are assumed to have 100 per cent electrified rail networks by 2063.
- **T8: Road freight electrification** Since freight accounts for roughly half of all transport energy demand in Africa and is dominated by road transport in most countries, it will be important to implement clean transport options in this area in addition to the options considered for passenger transport. The prospects for implementing low emission road freight are, however, more distant than for passenger transport due to such challenges as large payloads, long distances travelled and difficulties in implementing EV charging infrastructures. Even in Europe, options for electrifying road freight remain at the prototype phase. Beyond battery operated EVs, options include dedicated electric roadways, something that is currently being tested in a number of European countries. Thus, implementation of this measure is expected to lag significantly behind other options for passenger transport. No electrification of road transport is foreseen by 2030 but is assumed to reach 35 per cent of the road vehicle stock by 2063 in Tier 1 countries and 25 per cent in Tier 2 ones. As with other electrification measures, to achieve their full potential they will need to be implemented in parallel with measures that greatly increase the share of renewable sources in electricity generation (Section 3.2.3).

LINKS TO AGENDA 2063 – THE AFRICA WE WANT

Each of these transport mitigation measures, in both the SLCP mitigation and Agenda 2036 scenarios, are directly linked to the Agenda 2063 priorities (Table 3.1). Electrification of transport, emissions controls, and increasing public and non-motorised transport all effectively reduce tailpipe emissions, and lead to a subsequent improvement in air quality. This will help to provide a liveable habitat and hence contribute to the Agenda 2063 priority area of *'modern and liveable habitats and basic quality services'*.

These mitigation measures also relate to the priority area of *'health and nutrition'* as they will alleviate respiratory diseases and deaths linked to BC and other air pollutants (Section 1.2.1). This links to the implementation of the Africa Health Strategy (2016–2030) and the ambition to prioritise programmes which address risk factors and premature mortality from respiratory diseases, and programmes to combat non-communicable diseases, such as asthma, which can be exacerbated by poor air quality. Increased active transport (T5) also contributes to the development of programmes promoting healthy lifestyles to minimise incidences of cardio-vascular diseases, hypertension and diabetes.

Measures T6 and T7 in particular also complement the Agenda's priority area for *'communications and infrastructure connectivity'* and the implementation of the PIDA.

EFFECT OF IMPLEMENTING MEASURES ON ENERGY DEMAND BY FUEL AND MODE

The effect of modelling the implementation of the eight transport measures on energy demand by fuel type and mode in the transport sector in Africa in 2030 and 2063 is shown in Figures 3.1 and 3.2. The energy demand in the baseline scenario is around 5 and 30 thousand petajoules[2] in 2030 and 2063 respectively. Implementation of the SLCP measures show a small change by 2030 but a large change by 2063 with total energy demand decreasing to around 20 thousand petajoules and with an increase in electrification equivalent to 2–3 thousand petajoules. The Agenda 2063 scenario measures further reduce demand to around 15 thousand petajoules, with an increase in electrification equivalent to around 3–4 thousand petajoules.

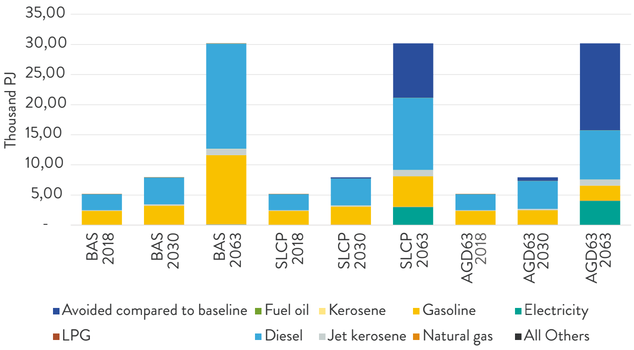

Figure 3.1 Transport energy demand by fuel, 2018, 2030 and 2063, thousand petajoules

(peta = 10^{15}). Energy use is divided across the scenarios by year (2018, 2030 and 2063) and by scenario: baseline (BAS), the SLCP scenarios (SLCP) and Agenda 2063 (AGD63). Emission reductions relative to the baseline are shown in dark blue.

The effect of implementing the Agenda 2063 measures on the proportion of road and rail transport in Africa is shown in Figure 3.2.

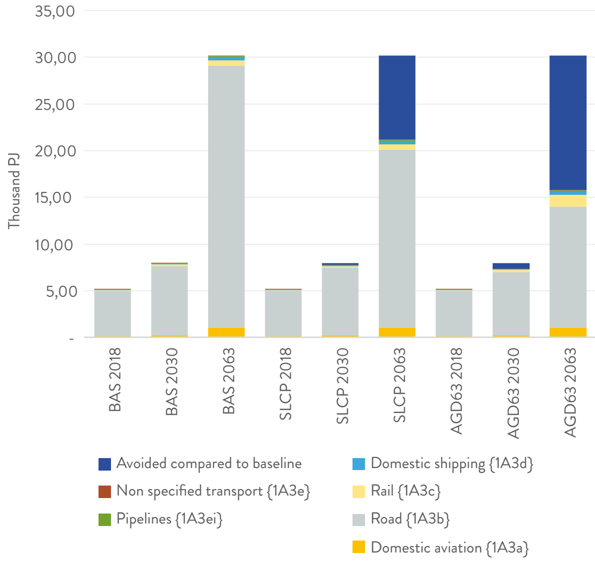

Figure 3.2 Transport energy demand by mode, 2018, 2030 and 2063, thousand petajoules

(peta = 10^{15}). Energy use is divided across the scenarios by year (2018, 2030 and 2063) and by scenario: baseline (BAS), the SLCPPC scenarios (SLCP) and Agenda 2063 (AGD63). Emission reductions relative to the baseline are shown in dark blue.

3.2.3 ENERGY: HOUSEHOLD SECTOR

3.2.3.1 DELIVERING MODERN HOUSEHOLD ENERGY

(i) Reducing the proportion of the urban population cooking on inefficient polluting biomass stoves and increasing the shift to the use of LPG and electricity for cooking.

The use of biomass and other solid fuels for cooking is a significant source of household air pollution (HAP) and one of the world's biggest killers, in addition to being a major cause of environmental pollution (Lacey *et al.* 2017a and b). Indications are that even households that report primary reliance on clean fuels and technologies for cooking may supplement them with polluting energy sources, including biomass, coal and kerosene, a phenomenon known as fuel stacking (AEO 2022).

The development and implementation of clean cooking technology for households in low- and middle-income countries (LMICs) offer enormous promise to advance at least five Sustainable Development Goals (SDGs): SDG 3 Good health and well-being; SDG 5 Gender equality; SDG 7 Affordable and clean energy; SDG 13 Climate action; and SDG 15 Life on land (Rosenthal *et al.* 2018). Adopting clean energy technologies will deliver modern, liveable habitats and reduce the occurrence of diseases related to household air pollution. In line with the SDGs it will promote healthy lives and well-being for all ages; reduce the amount of time that women and girls spend cooking using inefficient fuel and thus promote

2. Petajoules – 10^{15} joules

gender equality; make cities and human settlements inclusive, safe, resilient and sustainable through minimizing environmental pollution; and help combat climate change and its impacts, enabling some human settlements to remain inhabitable (Fisk 2000).

Despite these gains, however, it is estimated that about 2.3 billion people will still not gain access to clean energy by 2030 (IEA 2017). The IEA further projects that the uptake of clean energy in urban areas will increase faster than in rural ones and that the number of people using biomass in urban areas will reduce by more than 40 per cent by 2030, based on the observed trends.

A series of Policy Briefs were developed by WHO *et al.* (2018) to support strategies aimed at attaining SDG 7 Affordable and clean energy. Priority action outlined in the documents include the following.

- Countries with a high reliance on traditional inefficient cookstoves and fuels need to implement global commitments by developing policies and plans to increase access to clean and modern energy for cooking, and where this has been done, the initiatives need to be accelerated. As a transition solution, high-performance biomass technologies can be adopted as an interim measure within the cultural contexts of the participating communities. In addition, building technologies that enhance ventilation and proper air circulation can help minimize the build-up of pollutants within households.
- As a step towards attaining this goal, there is a need to monitor progress and take stock of gains and accompanying impacts. Small milestones can be celebrated and important lessons documented to help alter strategy as the need arises.
- Opportunities and synergies should be identified where clean and modern household energy could be mainstreamed or incorporated into other programmes and policies that support initiatives such as climate mitigation, sanitation improvement, and maternal and child health programmes. This, therefore, calls for a multi-sectoral approach. Since governments may not have sufficient resources, private investors can be encouraged to partner with governments and other stakeholders.

(ii) Increasing energy efficiency in lighting, residential appliances and air conditioning, and shift away from using hydrofluorocarbon*s as coolants*

Polluting gases that arise from inefficient appliances and household gadgets have been implicated in air pollution. The use of air conditioning is on the rise but, historically, addressing its adverse impacts has been a low priority, although this is rapidly changing. There are indications that there is a high level of dumping of environmentally harmful air-conditioning equipment taking place in parts of Africa. Countries in which this occurs do not manufacture their equipment, so rely on imported products or components. It has been reported that the exporting countries often produced higher efficiency air conditioners for their domestic markets. The importance of a combined strategy to improve the energy efficiency of cooling equipment while phasing down HFC refrigerants under the Kigali Amendment to the Montreal Protocol is increasingly being recognized as one of the most significant climate mitigation opportunities available today (UNEP 2020b).

To combat negative impacts, there is a need to have efficient appliances, including air conditioners, and phasing out HFCs. Efforts to accelerate this have emerged, including having this as an agenda in all the five themes at UNFCCC's COP26 and the Kigali Amendment to the Montreal Protocol, which was agreed in October 2016 and entered into force in January 2019. Additional initiatives are bringing about greater awareness. These include the Cool Coalition, Twinning Training for senior energy and environment officials from A5 Parties[3] and government leadership on developing national cooling plans, creating more visibility for these issues (UNEP 2020b). In this regard there is a need for quality control laboratories to avoid inefficient appliances and air conditioning and standards, and regulations and potentially taxes for non-inefficient ones are needed.

(iii) Building more efficient buildings to reduce energy demand, plan the orientation of buildings to reduce cooling demand and increase green areas to cool cities and reduce the heat island effect

Efficient and green buildings will help attain liveable habitats and the implementation of the concept should include design, construction, operation, maintenance, renovation and demolition phases of a building's existence. This requires close cooperation of various stakeholders, including architects, contractors and engineers (Yudelson 2008). Green construction principles can easily be applied to retrofitting as well as new construction.

Aspects achieved through green construction include energy efficiency, the use of energy from renewable sources, healthy interior air quality and minimal use of air conditioning. Different countries and regions have various characteristics, such as specific climatic conditions; unique cultures and traditions; diverse types and ages of buildings; and wide-ranging environmental, economic and social priorities, all of which shape their approach to green building (Allen *et al.* 2015). Governments should have the opportunity to set standards and put building codes that enhance this in place.

3. Article 5 Parties of the Kigali Amendment are divided into two groups: Group 1: The majority of Article 5 Parties. Group 2: Bahrain, India, Iran, Iraq, Kuwait, Oman, Pakistan, Qatar, Saudi Arabia, and the United Arab Emirates. Group 2 has a later freeze and phase-down steps compared with Group 1. https://multimedia.3m.com/mws/media/1365924O/unep-fact-sheet-kigali-amendment-to-mp.pdf

Different certification and rating systems for green construction have been developed. Examples include Leadership in Energy and Environmental Design (LEED) by the U.S. Green Building Council (2015); the British Building Research Establishment Environmental Assessment Method (BREEAM) (Garner and Keoleian 1995); The Living Building Challenge (LBC) (International Living Future Institute 2015) and the WELL Building Standard released in 2014 (International WELL Building Institute 2015). However, developed and emerging economies, including in Africa, often struggle to embrace this development at scale. The World Green Building Council researches the effects of green buildings on the health and productivity of their users and is working with the World Bank to promote green buildings in emerging markets through Excellence in Design for Greater Efficiencies (EDGE), the Market Transformation Programme and certification (e.g. Isimbi, and Park 2022).

3.2.3.2 MITIGATION MEASURES MODELLED FOR THE HOUSEHOLD SECTOR

This Assessment modelled five measures related to the residential sector (Table 3.2), including two technical measures that directly target reductions in SLCPs, co-emitted air pollutants and GHGs, and three measures involving behavioural and/or societal shifts.

Table 3.2 Mitigation measures modelled in the residential sector, near-term (2030) and 2063 assumptions used in the modelling and links to Agenda 2063 priority

MEASURE	DESCRIPTION	NEAR-TERM (2030) AND 2063 ASSUMPTIONS	SCENARIO	RELEVANT AGENDA 2063 PRIORITY AREAS
RESIDENTIAL MEASURES				
H1. CLEAN LIGHTING	Electric lighting provides better lighting conditions, avoids harmful pollutants and saves energy.	All lighting is electric (95%) or solar (5%) by 2040 in both tiers.	SLCP	1. Modern and liveable habitats and basic quality services 2. Health and nutrition
H2. CLEAN COOKSTOVES	Cooking is a key source of harmful household air pollution and traditional biomass cookstoves are placing an increasing burden on the wood resources.	Implemented in three parts: Part 1: Accelerate transition away from traditional to clean fuels (e.g. LPG, gas and electricity). Countries transition to clean fuels as their average incomes increase. Urban area transition occurs by time income reaches US$ 12 000/capita (vs US$ 30 000/cap in the baseline scenario); rural area transition occurs by time income reaches US$ 17 000/capita (vs US$ 35 000/cap in the baseline scenario). NB: each country progresses differently along this transition path based on how their GDP/peson grows in the scenario. Lookup function used in LEAP to model different transitions in each country: https://leap.sei.org/help/Expressions/Lookup.htm Part 2: For remaining wood and charcoal, assume 40% of use switches to efficient stoves by 2030 and 90% by 2063 in urban areas; and 60% and 90% in rural ones. Part 3: For modern fuels, assume transition from gas and LPG to efficient electricity (induction cooking) starting in 2030. By 2063 in urban areas, 70% of clean cooking is electric. By 2063 in rural areas, 30% of clean cooking is electric.	SLCP	1. Modern and liveable habitats and basic quality services 2. Health and nutrition
H3. EFFICIENT AIR CONDITIONING	Although small now, as incomes grow air conditioners will become an important contributor to overall and peak energy use. Efficient air conditioners can help reduce growth in demand and avoid use of dirtiest peak-load power plants.	Air conditioners' efficiency doubles by 2063.	Agenda 2063	Sustainable consumption and production patterns
H4. EFFICIENT REFRIGERATION	As with air conditioners, refrigerator use will grow considerably to 2063. Efficient fridges help save energy and emissions.	Fridge efficiency increases by 93% by 2063, i.e. 100% of stock are efficient fridges by 2063	Agenda 2063	Sustainable consumption and production patterns
H5. OTHER HOUSEHOLD ENERGY EFFICIENCY	Efficient appliances help reduce energy demands, vital for keeping electricity demand growth manageable.	Energy intensities for all other household energy use decreases by 1.4%/year versus constant in the baseline.	Agenda 2063	Sustainable consumption and production patterns

SHORT-LIVED CLIMATE POLLUTANT MITIGATION SCENARIO MEASURES

The SLCP scenario measures focus on implementing clean lighting and cooking, which together can significantly improve air quality and living conditions in African households. Clean cookstoves also reduce the increasing burden that traditional biomass cookstoves are placing on Africa's wood resources.

- **H1: Clean lighting** This measure foresees policies to enable lighting to be fully transitioned away from traditional fuels and technologies, such as kerosene lamps, to zero emissions lighting options by 2040. By that date it is assumed 95 per cent of lighting demand will be met with efficient electric-powered LED lighting, and the remaining 5 per cent through solar-powered LED lighting.
- **H2: Clean cooking** While some transition away from traditional fuels and technologies and towards clean cooking options is expected even in the absence of active policies and is explicitly modelled in the Baseline scenario (Section 2.4.2.2), this measure assumes policies to enable a significantly accelerated transition toward clean cooking – i.e., using electricity, natural gas or LPG. The measure is modelled in three parts by assuming that countries will transition to clean fuels as their population's average incomes increase. The first part assumes that urban areas will fully transition when average incomes reach USD 12 000/person as opposed to USD 30 000/person in the baseline and that rural areas will transition as incomes reach USD 17 000/person, *versus* USD 35 000/person in the baseline scenario. Each country progresses differently along this path based on how their GDP/person grows (Table 3.2). In addition to this overall transition, the second part assumes that the remaining cooking using wood and charcoal transitions to more efficient cooking devices, with 40 per cent of use switching to efficient stoves by 2030 and 90 per cent by 2063 in urban areas and 60 and 90 per cent switch to efficient stoves in rural situations in 2030 and 2063 respectively. Finally, the third part of the modelling assumes a transition from gas and LPG to more efficient and cleaner electric induction stoves starting from 2030. By 2063, 70 per cent of clean cooking is with electric induction stoves in urban areas and in rural ones, 30 per cent.

AGENDA 2063 SCENARIO MEASURES

The three Agenda 2063 measures (H3, H4 and H5) are all concerned with a societal move by 2063 to more efficient domestic appliances, especially refrigeration and air conditioning. The air conditioning share of energy use is relatively small in Africa now but with growing prosperity and a warming climate, more efficient air conditioning can help reduce demand for electricity and peak loads, which are often met by more polluting coal-fired power plants. Air conditioning efficiency is projected to double by 2063 (H3), refrigeration efficiency (H4) to increase by 93 per cent and energy intensities for all other household energy use (H5) to decrease by 1.4 per cent/year to 2063 as opposed to remaining constant in the baseline. All these measures help to keep the growth of demand for electricity to manageable levels, helping make space for the extra electricity consumption due to the electrification measures foreseen in the transport sector.

LINKS TO AGENDA 2063 – THE AFRICA WE WANT

Each of these mitigation measures in the household sector, both in the SLCP and Agenda 2063 scenario, are directly linked to Agenda 2063 priorities (Table 3.2). Measures H1 and H2 fall under the '*health and nutrition*' priority area as they will reduce morbidity and mortality linked to household air pollution. This also relates to the promotion of programmes to combat non-communicable diseases and the implementation of the Africa Health Strategy. Measures H3, H4 and H5 pertain to the '*sustainable consumption and production patterns*' priority area and mitigation measures associated with energy efficiency are also highlighted in Agenda 2063. The measures link to the ambition that all households, communities and government entities will be aware of and live sustainable lifestyles with respect to the use of water and electricity.

THE EFFECT OF IMPLEMENTING MEASURES ON HOUSEHOLD ENERGY PROVISION

The proportion of the African population households using different fuels and technologies for cooking is shown in the baseline and mitigation scenarios in Figure 3.3 and for each region in Figure 3.4. It should be noted that under both the SLCP and Agenda 2063 scenarios the only cookstove measure employed is an SLCP one (Table 3.2), hence the similar results for both scenarios.

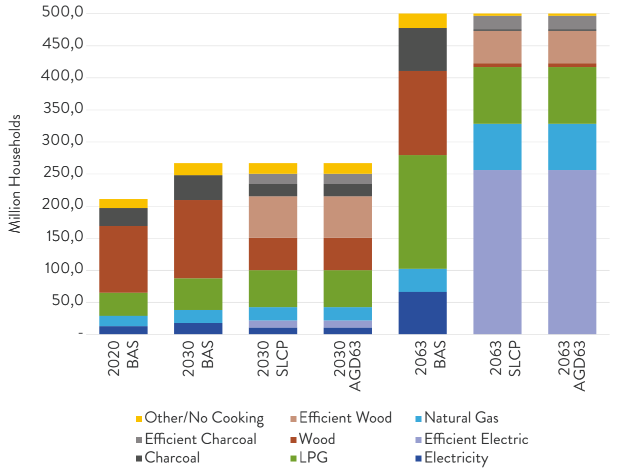

Figure 3.3 African households using different fuels and technologies for cooking, 2019–2063 in the baseline (BAS), short-lived climate pollutant (SLCP) and Agenda 2063 (ADG 2063) mitigation scenarios in 2020, 2030 and 2063, millions households.

Note: the Agenda 2063 scenario includes SLCP cookstove measures only (Table 3.2).

The mitigation scenarios for cooking include one key measure with two elements that differ from the baseline (Section 2.4.2.2). The first is a faster, larger shift to cooking using cleaner fuels, particularly electricity. By 2063, in all regions, the majority of households are cooking using cleaner fuels, and the largest single source of energy for cooking is electricity. The second is that in those predominantly rural homes that continue to cook using biomass, they are using efficient biomass stoves that comply with International Organization for Standardization (ISO) standards.

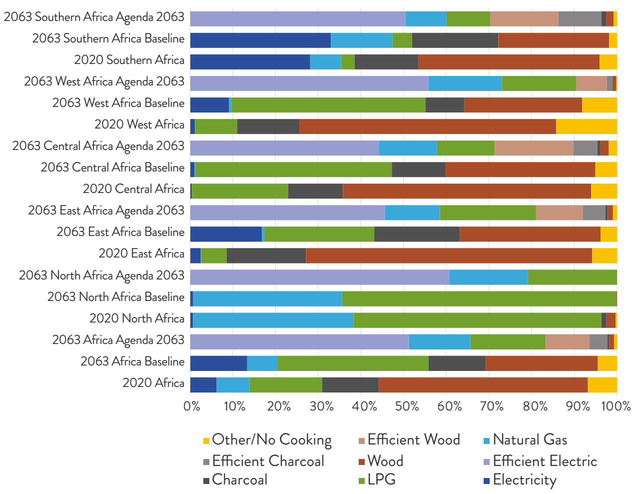

Figure 3.4 Percentage of households using different fuels and technologies for cooking per African region, 2019–2063, in the baseline (BAS) and Agenda 2063 scenarios.

Note: the Agenda 2063 scenario includes SLCP cookstove measures only (Table 3.2).

3.2.4 POWER GENERATION: INDUSTRIAL SECTOR AND ENERGY EFFICIENCY MEASURES

3.2.4.1 DELIVERING ENERGY EFFICIENCY IN THE ENERGY SECTOR

Around the world, energy use in commercial buildings, offices, shops, hotels, etc., is a significant source of GHG emissions. With a share of 6.6 per cent, it accounts for more than aviation, shipping and rail transport combined (OWD 2020) but significantly less than industry, which accounts for 29 per cent of global emissions,

African countries may have a path to economic emergence that is less polluting than their American, Asian or European peers. By investing in their human capital and leveraging 21st-century solutions, they could build knowledge-based economies that deliver value to their citizens with less need for high-emission activities.

A SHORTCUT TO EFFICIENCY

The classic examples of African countries leapfrogging older, inefficient technologies are in the telecom and banking industries. Many countries on the continent do not need to develop widespread landline infrastructure thanks to high mobile phone penetration. This technological advancement has, in turn, triggered the mobile banking revolution that some African countries have pioneered (Nguena 2019). In Kenya, for example, access to mobile banking far outweighs the number of regular bank accounts. Citizens have, therefore, access to essential banking services without the need for extensive physical banking networks. This means less construction, equipment and transport.

A similar revolution may be currently brewing in the online commerce sector. While there will always be a need for physical shopping centres, their prevalence and role are likely to shift in the coming years. In the US, according to Credit Suisse, about a quarter of malls will most likely close within the next five years, potentially bringing immense social, economic and urban consequences to their communities. In Africa, the rising middle class is driving significant growth in e-commerce activities (Nuruzzaman and Weber 2021). Whether this translates into more efficient supply chains may vary across cities, depending on logistics' infrastructure, congestion, city layouts and other factors African urban planners should therefore take account of changing consumption habits in designing future cities.

TOWARDS MORE EFFICIENT COMMERCIAL REAL ESTATE

In many African countries, power outages are so frequent that shops, offices and hotels are forced to have backup generators (AEO 2022). This is both costly, about three times the cost of electricity from the grid, and highly polluting (International Finance Corporation [IFC] 2019). Despite many efforts to increase power generation capacity and improve reliability, progress remains slow compared to the rising demand. Governments would benefit from putting more effort into improving their grid with better transmission networks and more generation capacity.

One low hanging fruit in terms of efficiency is the replacement of incandescent lightbulbs with more efficient alternatives such as LED ones (AEO 2022). Lighting often represents a significant share of peak load in Africa; therefore, improving its efficiency would result in more reliable power grids and free capacity to connect more users. Energy-efficient lighting uses 80–90 per cent less power and has a favourable payback over the lifetimes of bulbs (UNEP 2017c; AEO 2022). Many initiatives to introduce it have been launched and are at varying stages of implementation across the continent (Economic Community for West African States [ECOWAS] 2014). The main barrier to adoption remains the high upfront cost, but other barriers, such as the lack of consumer information, also hinder progress. This calls for an integrated approach that combines innovative financial incentives, such as pay-as-you-save schemes, with other supporting policies that address all barriers to adoption (UNEP 2017c).

THE KIGALI AGREEMENT: A BLUEPRINT FOR FUTURE CLIMATE DEALS?

Air conditioning is a major source of emissions worldwide and is bound to become more widespread in Africa as living standards rise. In October 2016, more than 170 countries signed a legally binding agreement to reduce the production and consumption of HFCs, which are potent GHGs used in air conditioning and refrigerants. The agreement builds on the success of the Montreal Protocol, signed in 1987 to restore the ozone layer. It is estimated that the Kigali Agreement would avoid a 0.5°C increase in global temperatures by the end of the century[4].

The African continent has shown strong leadership by committing to a stringent reduction timetable for HFCs, despite hosting some of the hottest and poorest countries that lack access to air conditioning[5]

RENEWABLE ENERGY

The African continent has huge potential to generate energy from renewable, unevenly distributed across diverse geographic areas (International Renewable Energy Agency [IRENA] 2019). While solar resources are available everywhere on the continent, hydropower and biomass energy resources are primarily located in wet and forested areas, such as the central and southern regions. Wind resources perform best in the east, north and southern regions where the environment is dry and windy. Geothermal energy is most common in the areas along the Great Rift Valley. Based on the climate and geographic features, a country can have specific renewable energy solutions. Possible applications of energy from renewable sources include power generation, transport, lighting, industrial cooling and heating, and direct mechanical energy use.

Harnessing renewable energy resources could ensure that the continent has a cheaper, reliable, and sustainable energy supply. At the same time, it would support a cleaner environment (Petrie 2013), boost the African economy through job creation (Yumkella 2019) and savings from air pollution and climate financing, mainly required because of the use of coal and oil for energy generation. Another advantage is that the generation of energy from renewable sources could increase total electricity access across Africa (IEA 2017) and Africa's share of global energy generation (AEO 2022).

The use of hydropower can happen in several ways depending on how large or small the resource is. Dams are generally required for large-scale hydropower generation but are not essential for small scale generation – 1–10 MW. Run of river flows can efficiently power mini (100 kW–1 MW), micro (5–100 kW) and pico (less than 5 kW)[6] hydro schemes, enabling the distribution of electricity to areas far away from a grid. About 980 dams have been identified across Africa (Ayemba 2021), with a total combined generating capacity of 37 GW, of which 3 per cent is now in use (IHA 2020). The share of hydropower to the total electricity supply in Africa is 15 per cent; this is expected to increase to more than 23 per cent by 2040.

Solar power resources can be harnessed using two technologies: solar photovoltaic (PV) and concentrated solar power (CSP). The utilization of PV modules is universal and can range from household systems to utility-scale ones. On the other hand, CSP performs best in utility-scale projects located in desert regions. Africa, with a mean temperature higher than

4. https://www.unido.org/our-focus-safeguarding-environment-implementation-multilateral-environmental-agreements-montreal-protocol/montreal-protocol-evolves-fight-climate-change
5. https://ozone.unep.org/all-ratifications
6. 1000 watts = 1 kilowatt (kW); 1 000 kilowatts = 1 megawatt (MW); 1 000 = 1 gigawatt (GW)

the global average, has potential for solar power that exceeds future demand by a considerable margin. By 2014 the total capacity across the continent was 1 334 MW, more than 10 times the 127 MW capacity in 2009 (IRENA 2015). Plans to install more than 14 GW of solar PV and 6 GW of CSP (Global Data 2015) have already been announced across Africa and the growth in solar power is bound to continue.

Wind energy can be harnessed using wind turbines to drive electrical generators, power pumps, and other machinery. Similar to solar, the potential for wind power in Africa far exceeds the demand by orders of magnitude. Of the wind power potential, about 15 per cent is categorized as a high-quality resource. According to the Global Wind Energy Council (GWEC), the installed wind power capacity will range between 75–86 GW by 2030 (GWEC 2014). With about 140 wind farms at various levels of implementation in Africa, an additional 21 GW of new wind capacity was expected become available between 2014 and 2020 (Global Data 2015). Wind power installations in Africa have typically generated less than 150 MW, but there is now a shift towards increasing the scale of projects under consideration to 300–700 MW. The total electricity capacity from wind in Africa in 2013 was 1 742 MW, by the end of 2014 it had increased by 38% to 2 399 MW and by 2021 it had increased by 321% to 7 333 MW[7]

Geothermal energy can be harnessed by tapping energy stored in hot water or reservoirs that percolates into areas with volcanic activity. In Africa, this form of energy can be found in the Great Rift Valley, which stretches from Djibouti to Mozambique. The production of geothermal energy does not depend on the weather, which makes it is reliable and sustainable. The estimated power generating capacity for geothermal energy in Africa, as estimated by Geothermal Energy Association (2015), is 15 GW, of which only 0.6 per cent has been explored (IRENA 2015). Exploring geothermal energy has challenges, including a lack of technical expertise, poor governance and funding. As with fossil fuels, drilling has to be done to know the exact potential of a geothermal site, which can be very costly.

Biomass energy, also known as bioenergy, is another potential renewable energy resource commonly used in Africa. Various forms include fuelwood, charcoal and crop residues. Energy can be harnessed from these sources through direct combustion or the production of biogas from anaerobic digesters. Although about 80 per cent of Sub-Saharan Africa burns biomass for cooking and heating (Stecher *et al.* 2013), it has not been widely used for power generation even though there is enormous potential from the continent's huge biomass resources. Whilst more attention has not been placed on power generation from biomass in Africa, the power generating potential is about 15 GW (Dasappa 2011).

If all the renewable energy resources were fully utilized across the continent, Africa could meet more than its energy demand now and in the future, and meet the SDG 7 Affordable and clean energy and the energy targets of Agenda 2063 – The Africa we want. Africa has the world's fastest-growing population (Bello-Schünemann 2020), but only 57 per cent currently has access to electricity (World Bank 2020). The growing investment in renewable energy (UNEP 2020c) could make fossil fuel a stranded asset, reduce dependence on biomass as an energy sources, such as charcoal and wood, and provide a promising solution for sustainable energy in Africa.

INDUSTRIAL EFFICIENCY

Africa's current industrial development model is based on the wasteful linear development model of extracting raw materials, converting them into consumable products and discarding the resultant wastes into the landfill at every stage of the supply chain (Bermejo, 2014). There is a strong international consensus that over-reliance on wasteful linear economic development models is no longer sustainable (Khisa 2016). A much more promising economic development model seeks to promote a circular economy that is powered by enhanced efficiency of resource use, the adoption of the 4R philosophy of reducing, reusing, recycling and recovering wastes, before engaging industrial symbiosis, the process by which wastes or by-products of one industry or industrial process become the raw materials for another, to deal with inevitable residual wastes (Khisa 2016) Doing this will help divert waste streams from landfill, reduce pressure on virgin raw materials and help promote green wealth and green welfare while attracting green foreign direct investment (FDI) (Khisa 2016).

Without industrializing, it is unlikely that Africa will meet the SDGs by 2030, particularly SDG 9 Industry, innovation and infrastructure, and Agenda 2063 aspirations (UNIDO 2016). Inclusive and sustainable industrial development is associated with job creation, sustainable livelihoods, innovation, technology and green skills development, food security and equitable growth – some of the key requirements for poverty elimination in Africa by 2030 (UNIDO 2016). The African continent, however, remains on the margins of industrialization, as exemplified by the very low and declining shares of their manufacturing value added (MVA) in GDP since the 1970s and MVA per person lagging significantly behind developing country averages (UNIDO 2016). The continent's MVA accounted for only 1.6 per cent of the global total in 2014, and its growth has lagged far behind that of all other regions since 1990 (UNIDO 2016). Africa's participation in global value chains is small but growing (UNIDO 2016). The continent's global value chain participation in intermediary trade rose from 1.4

7. https://www.irena.org/How-we-work/Africa

per cent in 1995 to 2.2 per cent in 2011, representing an 80 per cent increase (UNIDO 2016).

Green-economy minerals are those that are required for low-carbon technologies, such as aluminium, cadmium, copper, gallium, indium, iron, lead, nickel, silica, silver, tellurium, tin and zinc used in solar PV technology, and aluminium, cobalt, iron, lead, lithium, manganese, nickel, and graphite for lithium-ion batteries (UNU-INRA 2019). A total of 42 out of 54 African countries have green-economy mineral deposits (UNU-INRA 2019). The African continent is host to 42 of the 63 green-economy minerals essential for the fourth industrial revolution (4IR) (UNU-INRA 2019). South Africa, for example, has more than 90 per cent of the world's reserves of the platinum group of metals; Namibia and Zimbabwe have 100 per cent of the world's caesium reserves and 89 per cent of its rubidium reserves; while the DRC holds 47 per cent of the world's cobalt reserves (UNU-INRA 2019). The strategic planning and management of these resources could position Africa as a key player in the 4IR (UNU-INRA 2019). The production of green-economy minerals could be managed by supporting and expanding artisanal and small-scale mining in different parts of Africa. It could also focus on value addition to ensure that African countries reap the maximum benefits from the 4IR (UNU-INRA 2019).

The emerging new industrial revolution (NIR), that includes the internet of things, big data, cloud computing, artificial intelligence, robotics, 3D printing, new materials, augmented reality, nanotechnology and biotechnology, has the potential to improve productivity, reduce energy and resource consumption, protect the environment while increasing resource-use efficiency (UNIDO, 2016). Africa needs to fully understand the NIR and its impacts on inclusive, sustainable industrial development to formulate sound industrial development strategies and programmes in line with it (UNIDO, 2016). The NIR should be promoted through the accelerated uptake of green, clean and smart technologies (UNIDO, 2016).

GREENING OF ECONOMIC ZONES AND INDUSTRIAL PARKS

The culture of industrialization through special economic zones (SEZs) and industrial parks (IPs) is gathering momentum in Africa (Khisa 2016). However good as the move might be in terms of wealth and employment creation, the transformation of these into eco-industrial parks (EIPs) will be important. Eco-industrial parks are usually designed and established based on the principles of cleaner production, a circular economy and industrial symbiosis. Enterprises are linked through logistics and energy flows to help form industrial symbiosis networks through which resources are shared and by-products/wastes exchanged, thereby minimizing waste and facilitating tiered use of energy and closed-loop circularity (PAGE 2019).

Green transformation is the process by which SEZs/IPs are enabled to achieve efficient use of energy and resources, reduce pollution and environmental impacts, increase labour productivity, and enhance capacity for sustainable industrial development (PAGE 2019). This green transformation should be seen from three viewpoints:

i. adjustment of the SEZ/IP's industrial structure to encourage agglomeration to increase overall resource-use efficiency, including that of land, while reducing production costs through technological eco-innovation;

ii. developing closed-loop supply chains through the tiered use of energy and the circular use of wastes and by-products, enabled by industrial symbiosis, and a shared use of common infrastructure; and

iii. achieving integrated and coordinated development of the economy, the environment and employment through integrated planning and rigorous management (PAGE 2019).

Proven policies that have enabled the green transformation of IPs in Asia and Europe have prioritized such aspects as the establishment of national standards for demonstration EIPs; the establishment of circular transformation programmes for IPs; and the setting up of national pilot programmes for low-carbon IPs; as well as evaluation criteria for green rating IPs (PAGE, 2019). National standards for demonstration EIPs will achieve policy objectives of reduced emissions of pollutants, improved energy and resource-use efficiency, adoption of waste and by-product exchange through industrial symbiosis; and strengthening institutional mechanisms for the promotion of EIPs through demonstrations (PAGE 2019).

National pilot programmes for low-carbon IPs prioritize reduced carbon intensity per unit of industrial output and low-carbon transition in both conventional and green sectors while the evaluation criteria for green rating IPs emphasize enhanced land-use efficiency and productivity; shared use of park infrastructure with improved recycling rates of water, heat and wastes; adoption of smart infrastructure (smart micro-grids); certification of green products and green factories; and the greening of the entire supply value chains (PAGE 2019).

The African continent needs to develop green markets, green its industrial development trajectory and strengthen policies for green entrepreneurship

(Brahmbhatt *et al.* 2017). In addition, there is a need to strengthen market incentives designed to preserve natural capital across the whole economy; expand green infrastructure while increasing infrastructural efficiency; promote agricultural modernization through expanded climate-smart agriculture; and adopt green urban policies (Brahmbhatt *et al.* 2017).

CEMENT INDUSTRY

Typical wastes that can be used as alternative fuels in cement kilns include discarded or shredded tyres; waste oils and solvents; pre-processed or raw industrial waste, including lime sludge from paper and similar industries; non-recyclable plastics, textiles and paper residues; fuels derived from municipal solid waste; effluent-treatment sludge from water and wastewater treatment plants; waste wood; sawdust; and sewage sludge (OECD 2018).

The use of agricultural waste as an alternative fuel in cement factories requires awareness-raising and capacity building programmes (EBRD, 2016). There is a need for technical assistance programmes to help support waste suppliers, aggregators and end users in setting up and operating agricultural waste pre-processing and co-processing installations (EBRD 2016). Feasibility studies will need to be undertaken to help determine the potential for creating agricultural waste aggregators or intermediary bodies (EBRD 2016). Where government incentives exist for the safe disposal of agricultural waste, waste aggregators should be allowed to bid for the wastes to be used as an alternative fuel for cement making. This will also require the development of safe-storage guidelines for agricultural wastes and should be backed up with an enabling legislative framework. Studies need to be undertaken to help identify efficient agricultural waste collection models (EBRD 2016). Pilot projects will need to be rolled out to help demonstrate the feasibility of the identified business models (EBRD 2016) and a total ban on the uncontrolled burning of agricultural waste will need to be enforced.

Awareness-raising and capacity building programmes targeting municipalities, waste management companies and other key stakeholders covering technical, health, safety, environmental and financial aspects of using solid wastes as fuels need to be rolled out. Long-term MSW supply contracts between municipalities and waste management companies should be put in place to ensure the annual supply of predetermined volumes of MSW at a predefined tipping fee (EBRD 2016). Waste pre-sorting at the source needs to be introduced together with systematic MSW collection across counties (EBRD 2016). Waste pickers need to be assigned formal jobs in the pre-processing operations and trained accordingly (EBRD 2016). A one-stop shop for permitting waste management operations will need to be introduced to help reduce transaction costs. Overall, waste collection efficiency will need to be improved, and a strict ban on uncontrolled landfilling enforced (EBRD 2016).

Studies will need to be undertaken to help determine the most efficient collection models for waste tyres if this is to be used as alternative fuel in cement production (EBRD 2016). The roll out of an eco tax would help improve the efficiency of used-tyre collection. There is a need for a total ban on the landfilling and/or the open burning of used tyres.

There will be a need for increased public awareness programmes on the safe use of dried sewage sludge as a fuel for cement production. Health, safety and environmental guidelines for the proper handling and transport of dry sludge need to be published (EBRD 2016). Feasibility studies on low-cost solar sludge-drying also need to be undertaken as well as demonstration projects on how dried sewage sludge can be used as an alternative fuel by cement manufactures.

Growth in the demand for cement will be met by decreasing its clinker content to 80 per cent by 2025 (EBRD 2016). Awareness and training programmes will therefore need to be introduced to improve the understanding of what blended cement is. Furthermore, building codes and standards will need to be revised to permit the use of blended cement (EBRD 2016). In addition, there will be a need for resource mapping across countries to help identify sources of clinker substitutes.

Quality assurance certification schemes for ready-mix concrete installations and operations need to be introduced and governments should introduce and embrace a low-carbon cement procurement policy for all public-sector projects (EBRD 2016). In addition, there will be a need for capacity building among architects, engineers and construction companies on the use composite cement in reinforced concrete (EBRD 2016). Doing this promotes the ideals of industrial symbiosis. However, this switch to the use of wastes as fuel faces barriers in prohibitive waste management regulations, inadequate waste collection networks and bureaucracy (OECD 2018).

3.2.4.2 MODELLING POWER GENERATION, THE INDUSTRIAL SECTOR AND ENERGY EFFICIENCY MEASURES

This Assessment modelled 11 measures related to power generation, industry and energy efficiency (Table 3.3), including five technical measures that directly target reductions in SLCPs, co-emitted air pollutants and GHGs, and six measures involving behavioural and/or societal shift under the Agenda 2063 scenario.

Table 3.3 Other energy sector mitigation measures, near-term (2030) and 2063 assumptions used in the modelling and links to Agenda 2063 priority areas

MEASURE	DESCRIPTION	NEAR-TERM ASSUMPTIONS (2030)	2063 ASSUMPTIONS	SCENARIO	RELEVANT AGENDA 2063 PRIORITY AREAS
OTHER ENERGY SECTOR MEASURES					
E1. EFFICIENT CHARCOAL MAKING	Helps to conserve wood-fuel supplies by making charcoal as efficiently as possible. Charcoal making is also a significant source of SLCPs.	Switch from traditional kilns (27% efficient on energy basis) to efficient kilns (45% efficient). 45% of charcoal making with efficient kilns by 2030.	95% efficient kilns by 2063. Note also demand-side measures that reduce demand for charcoal.	SLCP	Sustainable consumption and production patterns
E2. POST-COMBUSTION EMISSION CONTROLS IN INDUSTRY	Reduces non-CO_2 emissions from industry.	Reduction in combustion-based emission factors for all indutrial pollutants other than CO_2 by 15% in Tier 1; and 10% in Tier 2 countries.	55% reduction in combustion-based emission factors for all industrial pollutants other than CO_2 by 2063.	SLCP	1. Sustainable consumption and production 2. Health and nutrition
E3. COAL METHANE CAPTURE	Reduces methane emissions from coal mining. (Note: have not modelled the potential co-benefit of electric generation from this methane).	All coalbed methane emissions eliminated by 2050.		SLCP	Sustainable consumption and production patterns
E4. OIL AND GAS METHANE EMISSIONS.	Reduces methane emissions from oil and gas operations. (Note: have not modelled the potential co-benefit of electric generation from this methane).	50% reduction in fugitive methane emissions in both tiers by 2030	90% reduction.	SLCP	Sustainable consumption and production patterns
P1. INDUSTRIAL PROCESSES AND PRODUCT USE (IPPU)	Implement Kigali Amendment to phase down HFCs	Freeze HFC consumption in 2024 compared to 2020 levels, 10% reduction in 2029 compared to 2020 levels	30% reduction in 2035; 50% reduction in 2040 80% reduction in 2045	SLCP	Sustainable consumption and production patterns
E5. TRANSMISSION AND DISTRIBUTION LOSS REDUCTION	Transmission and distribution loss reduction helps reduce growth in demand for electricity.	Depending on transmission and distribution (technical) losses in each country in 2018, countries approach best practice losses of 15% or less by 2030.	10% or less by 2063.	Agenda 2063	Sustainable consumption and production patterns
E6. INDUSTRIAL ENERGY EFFICIENCY	Helps to reduce energy demands and emissions.	Energy intensities decrease by 1.4%/year.		Agenda 2063	Sustainable consumption and production patterns
E7. SERVICE SECTOR ENERGY EFFICIENCY	Helps to reduce energy demands and emissions.	Energy intensities decrease by 1.5%/year.		Agenda 2063	Sustainable consumption and production patterns
E8. REDUCE DEMAND FOR CEMENT	Cement production is highly energy and carbon-intensive. Use substitutes to partially replace cement clinker.	Reduce cement clinker demands by 10%.	Reduce by 20%	Agenda 2063	Sustainable consumption and production patterns
E9. CARBON CAPTURE AND STORGAE (CCS) IN CARBON INTENSIVE INDUSTRIES AND ELECTRIC GENERATION	In some highly carbon- and energy-intensive industries (cement, iron and steel, coal-fired electric generation), carbon capture and storage may be practical for avoiding CO_2 emissions. But still far from being commercialized.	2% CO_2 capture and sequestration by 2030 (Tier 1), 1% Tier 2 only in C-intensive industries and coal-fired electric generation.	30% capture and sequestration by 2063.	Agenda 2063	Sustainable consumption and production patterns
E10. RENEWABLE ELECTRIC GENERATION: SOLAR, WIND, GEOTHERMAL AND HYDROPOWER	Need to pair strategies for electrifying energy demand with strong measures to decarbonize electric generation and promoting renewable energy and phasing down coal and other carbon-intensive fuels.	Implemented in 4 parts:		Agenda 2063	Renewable energy
E10A SOLAR	Used a simple target (share of capacity) but checked resulting values against IRENA (2014) assessment of solar potential in Africa.	7% of generating capacity is solar by 2040.	30% by 2063		
E10B WIND	Used a simple target (share of capacity) but checked resulting values against IRENA (2014) assessment of wind potential in Africa.	3% of generating capacity is wind by 2040.	20% by 2063		
E10C GEOTHERMAL	Based on IGA (2015) review of Geothermal potential in mainly East-African countries. Targets constrained if potemtial greater than overall capacity requirements.	25% of economic potential realised by 2040.	80% of economic potential realised by 2063		
E10D HYDROPOWER	Based on WEC (2010) survey of technical and economic potential of hydropower. Note that hydro may be significant source of methane, especially in tropical areas and where hydro has large dams due to inundation of biomass. These emissions have not been modeled here.	60% of economic potential realised by 2040.	90% of economic potential realized by 2040.		

SHORT-LIVED CLIMATE POLLUTANT MITIGATION SCENARIO MEASURES

The five SLCP measures aim to further deepen the emissions reductions while also helping to achieve other development goals such as alleviating congestion and making cities more liveable.

- **E1: Efficient charcoal making** In the baseline scenario, final demand for charcoal more than quadruples from 1.2 million TJ to 5.1 million TJ between 2019 and 2063, placing an unsustainable burden on Africa's wood resources. The SLCP and Agenda 2063 scenarios reflect policies to accelerate a transition away from cooking with charcoal, but the growing population and rapid urbanization mean that charcoal demand still continues to increase to almost 2.3 million TJ in 2063, even with these intensive demand-side efforts. It will therefore be important to ensure that where charcoal is used it is produced as efficiently as possible, to minimize the burden on Africa's wood resources. Charcoal making is also a significant source of SLCP emissions. This measure therefore envisages switching away from traditional charcoal kilns, which have an energy efficiency of 27 per cent, to ones that are 45 per cent efficient. By 2030, the measure foresees that 45 per cent of charcoal-making is carried out using efficient kilns and by 2063 efficient kilns account for 95 per cent of production.
- **E2**: **Post-combustion emissions controls in industry** As Africa's industry develops, its emissions will become increasingly important unless specific measures are taken to mitigate them. This measure reflects the implementation of post-combustion emissions controls to reduce all industrial pollutants other than CO_2 through the use of filters, baghouses, scrubbers, electro-static precipitators, etc. The measure foresees that emissions can be reduced by 15 per cent in Tier 1 and 10 per cent in Tier 2 countries by 2030 and by 55 per cent across Africa by 2063.
- **E3**: **Coal CH_4 capture** This measure reduces CH_4 emissions from coal mining through efforts to capture the CH_4 that is emitted during mining, particularly in underground mines. The measure assumes that all coalbed CH_4 emissions can be eliminated by 2050. It is worth noting that this measure will be less important if Africa is able to fully phase out the use of coal, but even in the Agenda 2063 scenario significant coal consumption remains in 2063. In the baseline scenario, the primary demand for coal more than doubles from 4.8 million TJ to 12.4 million TJ, while in the Agenda 2063 scenario primary coal consumption declines slightly to 3.7 million TJ by 2063. It should also be noted that the potential co-benefits of electric generation from the capture of this CH_4 have not been modelled. That would further enhance its benefits, although arguably it might be better to focus on fully phasing out remaining coal use in heavy industry, coal liquefaction and electric generation in the Agenda 2063 scenario.
- **E4: Oil and gas CH_4 emissions** Similar to E3, this measure quantifies the reduction of CH_4 emissions from oil and gas operations. As E3, the potential co-benefit of electric generation from utilising captured CH_4 have not been modelled although this would further enhance its benefits. The measure assumes a 50 per cent reduction in fugitive CH_4 emissions in both tiers by 2030 and a 90 per cent reduction by 2063.
- **P1: Industrial processes and product use** This measure reflects implementation of the Kigali Amendment to phase down the consumption of HFCs. This is assumed to be frozen in 2024 compared to 2020 levels, with a 10 per cent reduction achieved by 2029 compared to 2020 levels, 30 per cent by 2035, 50 per cent by 2040, and an 80 per cent reduction by 2045.

AGENDA 2063 SCENARIO MEASURES

- **E5: Transmission and distribution loss reduction** Reducing transmission and distribution losses helps reduce growth in the demand for electricity, thereby avoiding emissions in the power generation sector. This measure assumes technical losses in each country can be gradually reduced to approach global best practices losses of 15 per cent or less by 2030 and 10 per cent or less by 2063.
- **E6: Industrial Energy Efficiency** This measure helps to reduce energy demand and thus emissions. While it has not been possible to model the industrial sector in detail, targets for energy intensity reduction of by 1.4 per cent/year were set for the study period. This rate of reduction corresponds to overall reductions in energy intensity of about 45 per cent between 2020 and 2063, which is ambitious but supported in the literature (Graus *et al*. 2011). Note that such targets could also be achieved in part either through improvements in energy efficiency in the production of industrial products or by strategies that lead to reductions in the demand for industrial commodities.
- **E7: Service sector energy efficiency:** Similar to E6, this measure helps to reduce energy demand and emissions from the fast-growing service sector. The measure assumes energy intensities can be decreased by 1.5 per cent/year.
- **E8: Reduce demand for cement** Cement production is particularly energy and carbon intensive. This measure assumes that substitutes can be found to partially replace cement clinker. The measure reduces cement clinker demand by 10 per cent relative to the baseline by 2030 and by 20 per cent by 2063.

- **E9: Carbon capture and storage in carbon intensive industries and the generation of electricity** Although still far from being commercialized, in some highly carbon- and energy-intensive industries, such as cement, iron and steel production, and coal-fired generation of electricity, carbon capture and storage may be a practical option for avoiding CO_2 emissions. This measure assumes 2 per cent of CO_2 emissions from these sectors can be captured and sequestered by 2030 in Tier 1 countries and 1 per cent in Tier 2 ones by 2030. By 2063, 30 per cent of emissions from these sectors could be captured and sequestered.
- **E10: Electricity generation from renewable sources** It will be vital to pair strategies for meeting the demand for energy with electricity with strong measures to decarbonize its generation. This measure achieves that by promoting renewable energy sources and partially phasing down, but not completely eliminating, coal and other carbon-intensive fuels used in the generation of electricity. The measure is implemented in four parts:
- **Solar:** for solar energy, simple targets were set as a share of generating capacity, based on what stakeholders felt was achievable in Africa. These targets were cross-checked against a recent assessment of solar potential on the African continent conducted by IRENA (IRENA 2014). The measure assumes that 7 per cent of generating capacity can be solar by 2040 and 30 per cent by 2063.
- **Wind:** a similar approach to solar was adopted in setting wind's share of capacity. These targets were again cross-checked against the IRENA study (IRENA, 2014) The measure set targets of 3 per cent of generating capacity from wind by 2040 and 20 per cent by 2063.
- **Geothermal:** the evaluation of geothermal capacity is based on an assessment of its potential primarily in East Africa conducted for IRENA by the International Geothermal Association (IGA 2015). Based on mainly East African countries, the measure assumes that 25 per cent of the estimated potential of geothermal energy could be realised in each country by 2040 and 80 per cent of by 2063.
- **Hydropower:** based on a comprehensive assessment of the potential for hydropower included in the World Energy Council's Survey of Energy Resources (WEC, 2010), this measure assumed that 60 per cent of its potential would be realised by 2040 and 90 per cent by 2040. It should be noted that, apart from the well-known social and ecosystem impacts of the construction of hydropower systems, they can also be a significant source of CH_4, especially in tropical areas, where the construction of large dams leads to the inundation of large forested areas. These emissions can potentially be mitigated either by large-scale clearance of biomass ahead of inundation or through run-of-river hydropower systems that have much smaller reservoirs.
- **Fossil fuels:** fossil fuels are assumed to be gradually phased down as the above renewable systems expand. The scenarios do not foresee a complete phase out of coal and oil, and natural gas use significantly increases over the study period even in the Agenda 2063 scenario. The challenge of switching away from fossil fuels is exacerbated by the strategy of electrifying end uses to avoid direct emissions from energy-intensive sectors. Total electricity demand in 2063 is significantly higher in the Agenda 2063 scenario than in the baseline due to this electrification strategy, despite significant efforts to implement energy efficiency. The benefits of those efficiency measures can be seen when comparing the much lower total electricity generation in 2063 in the Agenda 2063 scenario than in the SLCP scenario. Even so, total electricity generation needs in 2063 increase by a factor of 5.9 relative to 2019 needs.

LINKS TO AGENDA 2063 – THE AFRICA WE WANT

Each of these mitigation measures, in both the SLCP mitigation and Agenda 2036 scenarios, are directly linked to the Agenda 2063 priorities (Table 3.3). Measures E1, E5 and E6, for example, are all associated with the '*sustainable consumption and production patterns*' priority area. They relate to energy efficiency which is highlighted in the agenda and the development of policies and standards including environmental laws and regulations, and green procurement for sustainable production and consumption processes. These measures, in particular E2, also contribute to a reduction in SLCPs, meaning that they alleviate illness linked to poor air quality and hence fall under the 'health and nutrition' priority area. Measure E10 is explicitly referenced in the 'renewable energy' priority area which seeks to develop and implement policies/regulations for low-carbon production systems and strategies, and regulations to promote the sustainable growth of the energy sector.

THE EFFECT OF IMPLEMENTING MEASURES ON ENERGY PROVISION AND USE

The Agenda 2063 scenario shows that by 2063 the energy mix across the African continent could be dominated by renewables (Figure 3.5a), which would underpin the sustainable electrification of domestic energy and vehicles which is needed for cleaner development. There is still a role for natural gas in 2063 under the Agenda 2063 scenario, although it is much diminished compared to the other scenarios (Figure 3.5b).

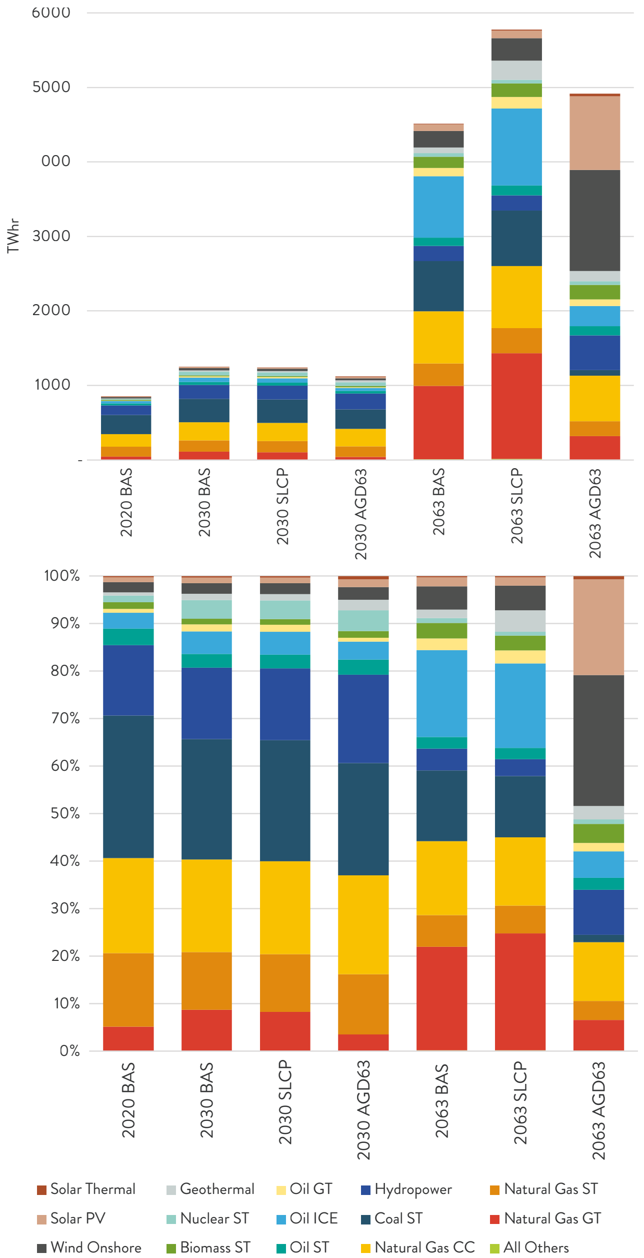

Figure 3.5 Africa's electricity generating mix under the baseline, short-lived climate pollutant mitigation and Agenda 2063 scenarios, for 2020, 2030 and 2063, in (a) terawatt[8] hours and (b) as percentage. GT = Gas turbine, ST = Steam turbine, CC = Combined cycle, ICE = Internal combustion engine.

3.2.5 MITIGATION IN THE AGRICULTURAL SECTOR

3.2.5.1 OPPORTUNITIES IN THE AGRICULTURAL SECTOR

INCREASED LIVESTOCK PRODUCTIVITY

Livestock production, which accounts for an average of about 40 per cent of Africa agricultural GDP (AU-IBAR 2015), is mainly associated with the emission of two potent GHGs, CH_4 and N_2O. Specifically, enteric fermentation and anaerobic decomposition of stored manure result in CH_4 emissions while microbial action on stored manure, and dung and urine deposited on grazed pastures can result in N_2O production and emissions (Gerber *et al.* 2013). Compared to other regions, total emissions from the African livestock sector are generally low. Emissions intensities, emissions per unit of animal product – meat, milk, calories and protein – are, however, very high due to low productivity and low feed digestibility (Herrero *et al.* 2013). This implies that if current practices continue and the size of the livestock herd grows to meet the burgeoning demand for livestock products, then livestock emissions will increase (Willett *et al.* 2019).

Major drivers of the projected increased demand for meat include socio-cultural change, and economic and demographic growth (Willett *et al.* 2019). The World Bank data show that an increase in GDP results in a rapid increase in per person consumption of livestock products, but this levels off once GDP reaches USD 10 000/person/year (Grace *et al.* 2018). If consumer perceptions do not change, and local production does not rise, the greater demand for meat products may be met through increased imports rather than domestic production (Asante-Addo and Weible 2020). Improving livestock productivity through better feed quality and availability, if coupled to enhanced manure management and animal husbandry could result in a decrease in emission intensities (Ericksen and Crane 2018). Productivity gains and emission intensity reductions of 24 per cent and 32 per cent respectively have been reported for semi-intensive systems (FAO and NZAGGRC 2017). Thornton and Herrero (2010), when modelling potential measures to reduce GHG emissions in the tropics, estimated that the emissions per unit of milk and meat produced could be reduced by 57 per cent and 73 per cent, respectively, when leaves of *Leucaenan leucocephala*[9] replace concentrates and part of the basal diet.

8. Terawatt 10^{12} watts
9. Common names include river tamarind, jumbay and pearl wattle

MANURE MANAGEMENT

The production of livestock directly results in the generation of manure, the storage and processing of which represents a source of nitrogen (e.g. NH_3 and N_2O) and CH_4 emissions. Currently, few African farmers store and manage their manure based on improved practices (Tittonell *et al.* 2010). These farmers, however, can maximize the use of manures for biogas energy production (Bruun *et al.* 2014) and improve soil quality and fertility and minimize environmental contamination (Rufino *et al.* 2021). However, Bruun *et al.* (2014) warn that as biogas digesters need to be properly managed, with proper distribution systems for biogas, otherwise significant amounts of methane can be released inadvertently through leaks and intentionally when production exceeds demand. Rufino *et al.* (2021), also warn that increasing agriculture and livestock production in Africa could increase the rate of on-farm nutrient losses if the current trends in nutrient management continue, as previously occurred in mid and high-income countries. The intensification of crop-livestock farms therefore has to integrate the biomass and nutrient flows between cropping and livestock activities to lead to sustainable outcomes.

ALTERNATE WETTING AND DRYING IN FLOODED RICE FIELDS

Rice is a critical source of dietary energy in many African countries. Currently, however, the continent's demand for rice exceeds production, and, consequently, significant volumes are imported. To reduce rice imports and meet the food demands of a burgeoning population, an expansion of the area under irrigated rice is unavoidable (Akpoti *et al.* 2021), albeit under increasingly water-scarce conditions. Continuous flooding irrigation is associated with high CH_4 emissions, which can be reduced by over 50 per cent by adopting alternate wetting and drying (AWD), an irrigation management method for saving water in irrigated rice systems (Jiang *et al.* 2019). Presently, there is a paucity of studies on field measurement on GHG emissions from rice systems in Africa (Akinbile *et al.* 2016; Boateng *et al.* 2017). However, given the current understanding of the mechanisms driving CH_4 production, it can be confidently assumed that an expansion of the area under irrigated rice will result in adverse health and environmental impacts unless farmers adopt water saving techniques such as AWD, which also reduces the density of malaria vectors and CH_4 emissions without compromising yields (Keiser, *et al.* 2002).

REDUCED BURNING OF CROP RESIDUES

The seasonal setting of fires to clear crop residues and return nutrients to the soil is common in several African countries as this practice may have yield benefits (Akanvon, *et al.* 2000; Seepamore, *et al.* 2020) and constitutes a strategy for reducing mouse populations (Ngwira, *et al.* 2013). Consequently, Africa has some of the world's highest rates of residue burning per hectare of harvested land (Cassou 2018). Even in African countries in which such burning is prohibited, to curb air pollution and GHG emissions (Yevich and Logan 2003), weak policing leads to farmers continuing the practice. Alternatives for reducing residue burning include the promotion of other beneficial uses, such as an organic soil amendment (Graham *et al.* 2002; Sommer *et al.* 2011), livestock feed (Rusinamhodzi, *et al.* 2016), an energy source (Yevich and Logan 2003; Mohammed *et al.* 2013) and as building materials (FAO 2014).

REDUCING FOOD WASTE

In addition to GHG emissions reductions linked to agricultural production, some GHG emissions are linked to food waste that occurs at the consumption stage. Whereas the FAO (2013) estimates that 30 per cent of food produced for human consumption is wasted, precise and accurate data on the quantity of food waste generated in Africa are lacking. Compared to medium- and high-income countries, however, food waste at the consumer level is generally lower in low-income countries (FAO 2015). In Africa, a large percentage of food is lost along the food supply chain due to poor storage and post-harvest processing, and a lack of infrastructure and distribution networks; as a result, it is estimated that more than 30 per cent the food grown in Africa never reaches the market (Sheahan and Barrett 2017).

3.2.5.2 MODELLING OF AGRICULTURAL SECTOR MEASURES

This Assessment modelled seven measures related to the agricultural sector (Table 3.4), including five technical measures that directly target reductions in SLCPs, co-emitted air pollutants and GHGs, and two measures involving behavioural and/or societal shifts under the Agenda 2063 scenario.

Table 3.4 Mitigation measures in the agricultural sector, near-term (2030) and 2063 assumptions used in the modelling and links to Agenda 2063 priority areas

MEASURE	DESCRIPTION	NEAR-TERM ASSUMPTIONS (2030)	2063 ASSUMPTIONS	SCENARIO	RELEVANT AGENDA 2063 PRIORITY AREAS
AGRICULTURE					
A1. LIVESTOCK - ENTERIC FERMENTAION	Increase productivity of livestock herd to reduce emission intensity of meat and dairy	33% productivity improvements achieved by 2030	33% increase in calf weight (maximum: 31.1 kg); 34% increase in adult male and female weight (maximum: 500kg); 9% increase in fertility rate (maximum 78.2%); 11% reduction in age at first calving)	SLCP	Agricultural productivity and production
A2. LIVESTOCK - ENTERIC FERMENTAION	Increase digestibility of feed to reduce methane emissions from enteric fermentation	Eliminate 20% least-digestible feed from diet of livestock		SLCP	Agricultural productivity and production
A3. LIVESTOCK - MANURE MANAGEMENT	Switch to manure management systems with lower methane and nitrogen emissions	Manure switched from solid storage, dry lot and liquid slurry to composting, anaerobic digestion and daily spread (75% switch)	Manure switched from solid storage, dry lot and liquid slurry to composting, anaerobic digestion and daily spread (100% switch)	SLCP	1. Agricultural productivity and production 2. Climate resilience
A4. CROPS - RICE	Implementation of alternate wetting and drying (AWD) for flooded rice	50% flooded rice has multiple aeration AWD implemented	100% flooded rice has multiple aeration AWD implemented by 2040	SLCP	Agricultural productivity and production
A5. BIOMASS BURNING	Eliminate open burning of agricultural residues	50% reduction in open burning of agricultural residues	100% reduction in open burning of agricultural residues by 2040	SLCP	1. Sustainable consumption and production 2. Health and nutrition
A6. FOOD WASTE	Reduce food waste at point of consumption	100 % reduction in food waste by 2063	100% reduction in food waste by 2023	Agenda 2063	1. Poverty, inequality and hunger 2. Sustainable consumption and production patterns
A7. DIET - PROTEIN SOURCE	Shift in diets to reduce red meat consumption and increase plant-based protein sources	No change	If average red meat is more than 23g per day then then the meat consumption is reduced to this value from the baseline value	Agenda 2063	Health and nutrition

SHORT-LIVED CLIMATE POLLUTANT SCENARIO MEASURES

- **A1: Increase the productivity of the livestock herd to reduce emission intensity of meat and dairy** Modelled cattle productivity increases were linked to increased feed digestibility, animal weights, fertility rates and reductions in age at calving. Productivity is projected to increase by a third by 2030 and by 2063 calf weight (maximum: 31.1 kg) to be improved by 33 per cent; adult male and female weight (maximum: 500kg) by 34 per cent; fertility rate (maximum 78.2 per cent) by 9 per cent; and a reduction in age at first calving) by 11 per cent.
- **A2: Increase digestibility of feed to reduce CH_4 emissions from enteric fermentation** Reduced CH_4 emissions were modelled by eliminating 20 per cent of the least digestible feed from the diet of livestock.
- **A3: Switch to manure management systems with lower CH_4 and nitrogen (NH_3 and N_2O) emissions**. Emissions were based on a 75 per cent by 2030 and 100 per cent by 2063 switch from solid storage (manure stacked on a concrete slab or soil for short term storage), dry lot (shed and lot storage) and liquid slurry to composting, anaerobic digestion and daily spreading.
- **A4: Implementation of alternate wetting and drying for flooded rice**. Two scenarios were modelled, 50 per cent and 100 per cent of flooded rice production systems adopting AWD by 2030 and 2040 respectively.
- **A5: Eliminate open burning of agricultural residues**. Two scenarios modelled, 50 per cent and 100 per cent reduction in the area of cropland subjected to residue burning by 2030 and 2040 respectively.

AGENDA 2063 SCENARIO MEASURES

- **A6: Reduce food waste at point of consumption**. Modelling assumes that through technological advancements and behavioural changes, food waste will be completely eliminated by 2063. It was also assumed that food demand will be reduced as less food is lost, and production then adjusts to meet the lower demand.
- **A7: Shift in diets to reduce red meat consumption and increase plant-based protein sources**. No change modelled by 2030 but by 2063 if average red meat is more than 23 g per day, the minimum risk exposure level for red meat (GBD 2019), then meat consumption was reduced to 23 g per day from the baseline value.

LINKS TO AGENDA 2063 – THE AFRICA WE WANT

Each of these mitigation measures in the agricultural sector, in the SLCP mitigation and Agenda 2036 scenarios, are directly linked to the Agenda 2063 priorities (Table 3.4). Agenda 2063 considers *'agricultural productivity and production'* a priority area. The mitigation measures modelled here also contribute to the science agenda for agriculture and can contribute to the ambition of doubling agriculture total factor productivity by 2025. They link to the promotion of climate smart agriculture including priorities under the Agenda 2063's continental initiative, the Comprehensive African Agricultural Development Programme (CAADP). Through reducing emissions, particularly eliminating open burning of agricultural residues (A5), these measures will also help achieve the Agenda's *'health and nutrition'* priority while A7 will contribute through more healthy diets. Measures A6 and A7 also fall under the goal of '*sustainable consumption and production patterns'* and can contribute to the alleviation of '*poverty inequality and hunger*' which is also a priority area in Agenda 2063.

THE EFFECT OF IMPLEMENTING MEASURES IN THE AGRICULTURAL SECTOR

Results show that compared to the baseline scenario, the implementation of Agenda 2063 scenario measures would result in more than 25 per cent and 60 per cent reductions in GHG emissions from the AFOLU sector by 2030 and 2063 respectively. Implementation of SLCP mitigation measures, however, resulted in less than 20 per cent reductions in GHG emissions (Figure 3.6).

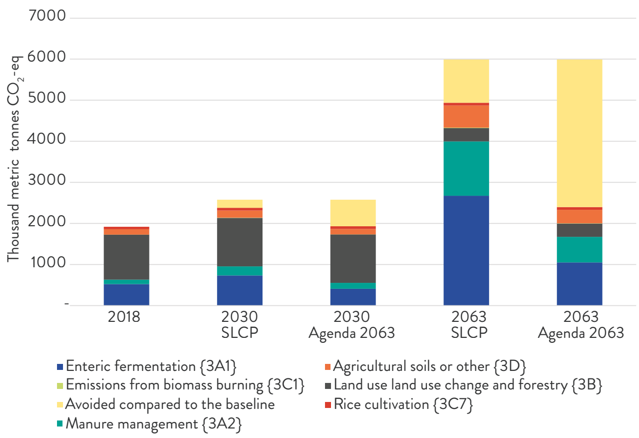

Figure 3.6 Greenhouse gas emissions from the agriculture, forestry and other land use sectors in the SLCP mitigation and Agenda 2063 scenarios, in 2018, and 2030 and 2063, thousand metric tonnes of carbon dioxide equivalent.

Note: emissions avoided are calculated using the baseline scenario values in 2030 and 2063 as appropriate.

When disaggregated by the type of GHG, by implementing the strategies in the Agenda 2063, CH_4 emission reductions in 2030 and 2063 were modelled to be 51 per cent and 72 per cent lower than the baseline. Even though the SLCP mitigation scenario places special attention on CH_4 as one of the SLCPs, compared to the baseline, SLCP mitigation measures were modelled to result in only 20 per cent and 32 per cent reductions in CH_4 emissions by 2030 and 2063, respectively (Figure 3.7). This highlights the importance of behavioural change, such a reduced meat intake and waste, and for obtaining the larger reductions under the Agenda 2063 scenario.

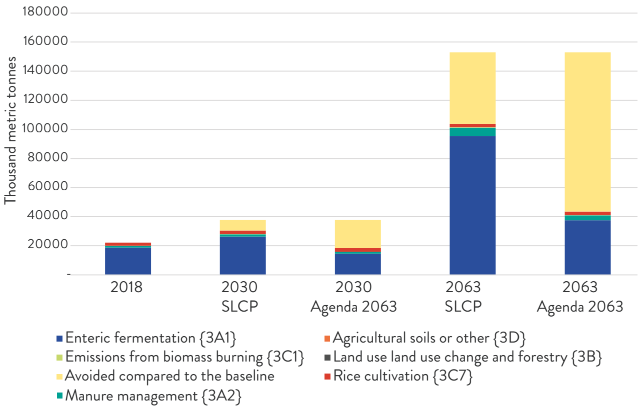

Figure 3.7 Methane emissions from the agriculture, forestry and other land use sectors in the SLCP mitigation and Agenda 2063 scenarios, 2018, and 2030 and 2063, thousand metric tonnes.

Note: emissions avoided are calculated using baseline scenario values in 2030 and 2063 as appropriate

Black carbon, which is also a climate forcer (Bond *et al.* 2013), was modelled for biomass burning. Results show that in 2030, the SLCP mitigation and Agenda 2063 measures resulted in a 53 per cent and 57 per cent reduction in BC emissions respectively compared to the baseline (Figure 3.8). In 2063, the proportions of BC emission reductions were modelled to be about 40 and 48 per cent for the SLCP mitigation and Agenda 2063 scenarios respectively.

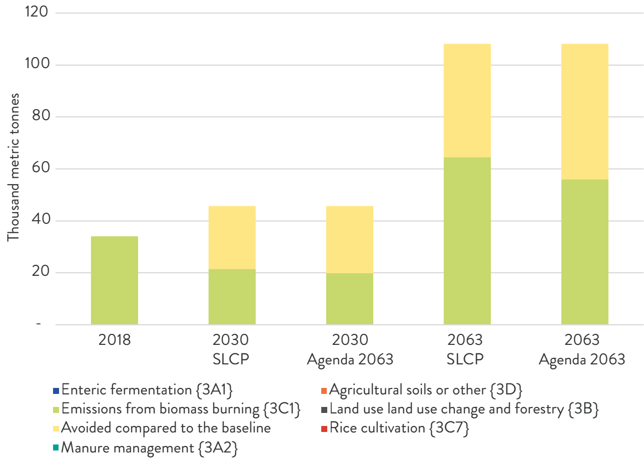

Figure 3.8 Black carbon emissions from the agriculture, forestry and other land use sectors in for the SLCP mitigation and Agenda 2063 scenarios, 2018, 2030 and 2063, thousand metric tonnes.

Note: emissions avoided are calculated using baseline scenario values in 2030 and 2063 as appropriate.

Ammonia emissions can indirectly contribute to GHG emissions (Zaman *et al.* 2021) as well as contributing to acidification and eutrophication of soils and waters, and $PM_{2.5}$ formation in the atmosphere that can have health and climate impacts (Hicks *et al.* 2022). In 2030 NH_3 emissions that are mainly from agricultural soils and manure management were modelled to be 23 per cent and 48 per cent lower than the baseline if SLCP mitigation or Agenda 2063 measures were implemented, respectively. In 2063, NH_3 emissions were modelled to be 41 per cent and 69 per cent lower than the baseline following the adoption of SLCP mitigation and Agenda 2063 measures, respectively (Figure 3.9).

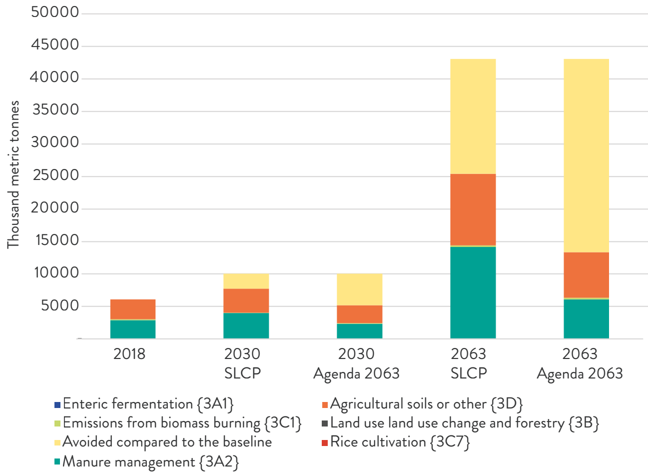

Figure 3.9 Ammonia emissions from the agriculture, forestry and other land use sectors for the SLCP mitigation and Agenda 2063 scenarios, 2018, and 2030 and 2063, thousand metric tonnes.

Note: emissions avoided are calculated using baseline scenario values in 2030 and 2063 as appropriate.

Nitrous oxide emissions were mainly from agricultural soils and manure management. In 2030 the N_2O emissions were modelled to be -3 per cent and 30 per cent lower than the baseline following the adoption of SLCP mitigation and Agenda 2063 measures respectively. In 2063, SLCP mitigation and Agenda 2063 measures correspondingly resulted in a -23 per cent and 38 per cent reduction in N_2O emissions compared to the baseline (Figure 3.10). The negative results for the SLCP mitigation scenario, indicating that emissions are increasing, are because of the SLCP mitigation measure increasing the amount of manure going to composting, which has a higher emission factor for N_2O than solid storage, drylot and liquid slurry emissions (Intergovernmental Panel on Climate Change [IPCC] (2019).

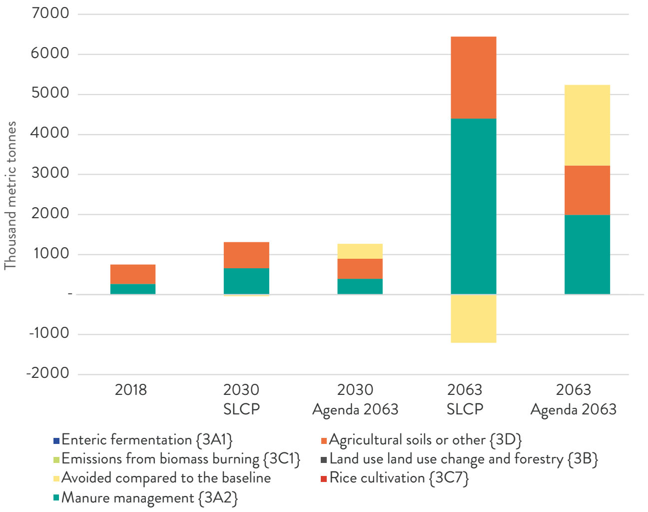

Figure 3.10 Nitrous oxide emissions from the agriculture, forestry and other land use sectors for the SLCP mitigation and Agenda 2063 scenarios, 2018, and 2030 and 2063, thousand metric tonnes.

Note: emissions avoided are calculated using baseline scenario values in 2030 and 2063 as appropriate.

3.2.6 MITIGATION IN THE LAND-USE CHANGE AND FORESTRY SECTOR

3.2.6.1 SITUATION IN THE LAND-USE AND FORESTRY SECTOR

LAND-USE CHANGE

A global modelling study on projected land-use change trajectories up to the 2050, driven by socioeconomic changes, i.e., population increase, economic growth and limited rises in agricultural productivity, showed that Africa will experience a 21 million plus hectares (ha) expansion of cropland (Schmitz *et al.* 2014). It is estimated that about 79 per cent of the new croplands in Africa will replace natural woody and herbaceous vegetation resulting in increased deforestation (Potapov *et al.* 2022). This conversion of land, from forests to croplands, will result in a net loss of C from biomass and soils to the atmosphere (Pellikka *et al.* 2018). The restoration of highly degraded tropical soils through forest establishment was reported to have reduced carbon emissions by 124, 127, and 158 tonnes of CO_2 eq/ha in Tanzania, Kenya and Uganda, respectively (Ambaw *et al.* 2020). Within already converted agricultural land, the potential for reversing the C loss and enhancing its sequestration exist. Climate-smart technologies such as agroforestry systems, reafforestation, cereal-legume rotations and reduced tillage, could significantly enhance C sequestration (Albrecht and Kandji 2003; Verchot *et al.* 2008; Ambaw *et al.* 2020; Giller *et al.* 2021).

REDUCED BURNING OF GRASSLANDS AND SAVANNAS

In grasslands and savannas fire is used by cattle farmers to stimulate new growth of nutritious grass, control ticks, suppress tree recruitment and control bush encroachment. Where burning is not managed correctly, however, farmers risk destroying feed, reducing long-term pasture quality and damaging infrastructure. For instance, a study conducted in Zimbabwe demonstrated that frequent burning resulted in the savanna being invaded by more alien plants relative to areas where fire was not used (Masocha *et al.* 2011). This implies that it may be prudent to reduce or manage burning. Early dry season burning, for example, has been shown to abate 37 per cent, or 64.2 million tonnes of CO_2eq/yr, of global savanna burning emissions (Lipsett-Moore *et al.* 2018).

REDUCED BURNING OF FORESTS

Unlike the benefits of fire in grasslands and savannas, forests are not adapted to fires and may take decades to recover (Zhou *et al.* 2019). In addition, fires used to open new cultivation areas cause degradation when uncontrolled (Hosonuma *et al.* 2012). Furthermore, other studies have shown that forests degradation increases vulnerability to fires, especially during dry periods (Dwomoh *et al.* 2019).

3.2.6.2 TREATMENT OF THE LAND-USE AND FORESTRY SECTOR

In this Assessment, the modelling of the SLCP mitigation and Agenda 2063 scenarios did not include measures to directly mitigate emissions related to land-use change, emissions reduction linked to reduced grassland and savanna burning, or forest burning. Several socioeconomic drivers influencing cropland expansion, discussed in Section 2.3.2, will probably result in a net loss of C from land-use change, which is not captured in the modelling. Open biomass burning was included in global modelling, as grassland, savanna and forestry burning, but it is not a source that is neatly classifiable as natural or anthropogenic since it is a natural process that is strongly influenced by humans. Also, a shift to improved pasture, increase feed quality and, consequently, livestock productivity was not included in the modelling although a shift will probably reduce savanna burning emissions.

Carbon dioxide and CH_4 emissions for land use, land-use change and forestry used in the baseline and mitigation scenarios, were taken from the World Research Institute's Climate Watch (WRI 2020) with projections to 2100. The WRI data, in turn, are based on the Global Change Assessment Model (GCAM) low-policy scenario (PNNL 2015).

3.2.7 MITIGATION IN THE WASTE SECTOR

3.2.7.1 OPPORTUNITIES IN THE WASTE SECTOR

Solid waste management is a sustainable development issue that cuts across socioeconomic activities and needs to be a political priority for Africa as improper waste management has severe health and environmental consequences. Although the amount of waste generated in Africa is small, relative to developed regions, the mismanagement of waste in Africa already impacts human and environmental health (Mebratu and Mbandi 2022).

In 2015, urban Africa generated 124 million tonnes of waste and this was projected to increase to 244 million tonnes per year by 2025. The average composition of MSW in sub-Saharan Africa is estimated to be 57 per cent organic waste; 13 per cent plastics; 9 per cent paper or cardboard; 4 per cent glass; 4 per cent metal, with the remaining 13 per cent being other materials; however, the composition varies across the continent (UNEP 2018).

The first ten-year (2014–2023) plan for Agenda 2063 includes commitments for improving living standards across Africa, with the primary waste goal being for cities to recycle at least 50 per cent of the waste they generate (UNEP 2018). It is, however, difficult to develop coherent strategies and effective waste management services as there is no baseline data on current waste management and recycling.

WAYS TO MINIMIZE WASTE PRODUCTION AND INNOVATION IN SANITATION IN URBAN AREAS

About 62 per cent of urban population in Sub-Saharan Africa live in slum areas dominated by uncontrolled, informal spatial development, without access to essential water, sanitation or waste management systems. Thus, improvements in waste management services and, more broadly, of urban slums are core challenges to be addressed in the coming decades (UN Habitat, 2014).

The most important way of improving the situation is to reduce the amount of waste generated through changing consumption patterns which, together with economic activity, generate various types of waste that must be appropriately managed to ensure a decent standard of life for all urban residents. Waste prevention is the most desirable option in the waste management hierarchy; it is an important goal and a guiding principle of future waste strategies (UNEP 2015). There are two different ways to attain prevention:

i. quantitative prevention comprises measures that reduce the quantities of substances, materials and products that become waste; and
ii. qualitative prevention which seeks to eliminate the use of specific hazardous substances in materials and products that become waste, thereby directly improving environmental performance.

A determined political drive can play a role in establishing a robust zero waste goal in line with other multilateral environmental agreements, including the Agenda 2063 Implementation Plan (2014-2023) and the SDGs to bring about positive changes for the environment and communities. Waste prevention and reuse can also reduce the financial, social and environmental costs associated with waste collection and disposal (UNEP 2015).

Efforts by development partners have aimed to decouple resource use and environmental impacts from manufacturing growth through improved energy, water and materials efficiency. This has led to the development of national cleaner-production centres that contribute to improved environmental performance and resource efficiency of enterprises. Waste prevention, however, is a concept that is still in its infancy in Africa (UN-Habitat 2014).

Source separation of waste is not common in African cities and towns, nor is it mandatory, whereas it is an essential requirement in most high-income countries. Keeping different waste items separate at the point of generation ensures that dry recyclable waste remains clean and uncontaminated by other waste streams. Organic waste should be separated at the point of generation for composting rather than being added to landfills. Increasing segregation at source is a critical component of any programme and should include the informal sector in mainstream waste management. This would improve both their working conditions and livelihoods (Mebratu and Mbandi 2022).

Collection and source segregation plans need to be adapted to the African context and the opportunities for social innovations identified. In Africa, where municipalities struggle to implement collection services, informal collectors, small-scale entrepreneurs and private businesses, who have stepped in to provide the service, should be encouraged. Indeed, the informal waste sector is very effective and efficient in collecting waste, particularly valuable, recyclable materials. There is growing consensus that the informal sector must be considered when improving waste management systems in developing countries, as it covers areas in which it is difficult for official contractors to operate (UNEP 2018; Mebratu and Mbandi 2022).

INCREASED SOLID WASTE RECYCLING

The global waste sector is undergoing a paradigm shift, with waste being increasingly considered as a secondary resource within the vision of a circular global economy (Mebratu and Mbandi 2022). The circular economy emphasizes keeping resources in use for as long as possible through reuse, recycling and materials recovery (UNEP 2018). It aims to retain the intrinsic value of waste as a resource and unlock the associated economic and social benefits available through increased waste recovery and recycling. In Africa, however, opportunities to develop the concept of waste as a secondary resource are still largely unexplored. Considering that more than 90 per cent of waste generated in Africa is recyclable, but only 4 per cent currently is, typically by marginalized informal reclaimers, the potential for waste recycling in many African countries needs to receive serious attention (UNEP 2018).

There is a high potential for effective recycling initiatives using organic waste as animal feed, composting material and biofuels. In addition, there are opportunities to recycle non-organic waste such as paper and glass. There is a need to establish formal recycling systems and for municipalities to recycle as part of their waste management services (Mebratu and Mbandi 2022).

The large, very active informal and highly functional waste sector in Africa should be formalized. Labour-intensive collection and sorting of secondary resources could create many direct jobs and even more related indirect employment opportunities at higher pay levels (Mebratu and Mbandi 2022).

Unlocking the above social and economic opportunities from waste requires a combination of an enabling governance environment and the development of local and regional value chains to create demand for end-of-life products. It also requires bridging the service- and value-chains, thereby diverting waste from dumping and landfilling to value-added opportunities. Advanced policy instruments such as extended producer responsibility schemes could play a role in developing local recycling businesses in Africa (Bass 2017). In addition, the private sector could provide municipalities with additional income to cope with the rising quantities of end–of–life products entering municipal solid waste.

The waste management value chain, which includes the collection, treatment, reuse, recycling and final disposal of various waste streams, provides economic opportunities for the private sector to become an effective partner in environmental management, given an enabling environment for private sector investment in waste management activities (Mebratu and Mbandi 2022). Furthermore, processing capacity and markets for recycled materials must be developed on the African continent, supported by all African states.

The lack of advanced waste management methods, supported by appropriate technologies, means that there are very few alternative practical uses for solid waste in Africa (Mebratu and Mbandi 2022). Furthermore, where alternative technologies exist, they tend to be expensive relative to dumping or landfilling and are thus a less attractive option. Tipping fees at landfills, if charged at all, tend to be artificially low since many municipal landfill sites are not designed and operated according to engineered sanitary landfill standards. Higher capital and operating costs associated with sanitary landfilling would drive up costs and make alternative waste treatment options more attractive.

In addition to the economic opportunities associated with secondary resources, several social opportunities could be realized both by prevention and by diverting waste from landfill to reuse, recovery and recycling. These social opportunities include job creation, poverty alleviation, enterprise development, entrepreneurship and women's empowerment. Furthermore, micro, and SMEs are vital in waste management. A major challenge public authorities face is creating an enabling environment for SMEs to enter the waste management industry and thereby increase employment potential and productivity (UNEP 2018).

Given the large, active informal waste sector in Africa, opportunities also exist to improve waste pickers' livelihoods and working conditions by integrating this informal sector into the waste and secondary resources economy (Mebratu and Mbandi 2022). If implemented sustainably, this will also create environmental benefits, such as improved resource efficiency, environmental quality, and the maintenance of ecosystem services (UNEP 2018). It is crucial to ensure that the social opportunities created by treating waste as a secondary resource are realized locally and regionally on the African continent. This creates an opportunity for the waste sector to contribute to achieving the SDGs, particularly the targets for SDG 1 No poverty, SDG 5 Gender equality and SDG 8 Decent work and economic growth.

REDUCED BURNING OF SOLID WASTE

Open burning of waste is widely practised across Africa. It provides a means of reducing the volume of accumulated waste where collection services do not exist. Typical emissions associated with the open burning of waste include dioxins, polycyclic aromatic hydrocarbons, BC, highly toxic carcinogens and potent SLCPs (UNEP 2015).

Open burning is often the result of a lack of awareness of alternative disposal options, high poverty levels, a lack of regulation or, when it does exist, enforcement. Eliminating uncontrolled open dumping of waste and diverting organic waste away from landfill to alternative waste treatment technology, such as composting and anaerobic digestion, could significantly benefit the continent, including by reducing GHG emissions (Mebratu and Mbandi 2022).

Social instruments could raise people's awareness and influence, and change attitudes and behaviour, with or without the government's direct participation as legislation on waste burning does not exist in some countries, and where it does exist, it either has not been implemented or enforced.

METHANE CAPTURE FROM LANDFILL SITES

Methane is considered one of the most important GHGs, with a global warming potential more than 25 times higher than CO_2. It is also explosive at concentrations of 5–15 per cent. One of the sources of GHG emissions across the African continent is the CH_4 produced from the anaerobic decomposition of organic waste at landfill sites. It is estimated that Africa emits 1–7 per cent of the world's total CH_4 emissions (UNEP 2018).

The UNFCCC (1992) calls on parties to the agreement to manage waste and not cause harm to human health or the environment. The most important way to mitigate CH_4 emissions from landfills or dumpsites is to reduce the amount of waste generated and not recycled or reused so that less waste finds its way to landfill sites. In addition, organic waste should be separated and sent for composting rather than being added to landfill sites. Effective management of formal landfill sites, as well as getting rid of informal dumpsites, are critical ways of managing CH_4 production.

In addition, there has been an increasing focus on gas flaring at landfill sites as a way of counteracting the accumulation of CH_4. Incineration is an alternative method for heating waste in the presence of air at 850°C, through which the wastes is converted into CO_2, water with the non-combustible materials remaining as a solid residue (bottom ash). The heat generated can be used for other practical applications such as electricity and heat generation. Several cities in Africa, including in Ethiopia, Kenya, Nigeria and South Africa, have been piloting the conversion of heat generated from waste into electricity (UNEP 2018).

An estimated 1 125 petajoules (PJ) of energy could have been produced through landfill gas recovery and incineration from the waste generated in Africa in 2012. This energy potential is significant considering that the primary energy supply in Africa in 2010 was about 29 308 PJ. Thus, potential electricity production from waste generated in Africa in 2012 was estimated at 62.5TWh, or 9.5 per cent of the total African electricity consumption of 661.5 TWh in 2010 (Mwangomo 2018).

While the energy potential of organic waste, including industrial biomass, is significant for Africa, using technologies such as landfill gas recovery and anaerobic digestion), the high moisture content of the waste means that traditional thermal waste-to-energy technologies such as incineration should be carefully considered and should be based on comprehensive waste characterization studies.

The Clean Development Mechanism was a mechanism agreed to in the Kyoto Protocol (2007), which was meant to allow for the flow of climate finance to projects that aim to reduce GHG emissions. The financing has been used in several gas flaring projects at landfill sites across the continent. In addition, it is an essential source of financing for private companies involved in these projects.

INCREASED USE OF WASTEWATER FOR INDUSTRY AND AGRICULTURE

Wastewater treatment aims to remove biodegradable organic compounds, suspended and floatable material, nutrients and pathogens (African Development Bank *et al.* 2020). The criteria for wastewater treatment intended for reuse in irrigation, however, differ considerably. While the pathogens should be removed to the maximum possible extent, some of the biodegradable organic matter and most of the nutrients available in the raw wastewater need to be maintained

The resuse of treated wastewater is considered a beneficial and attractive option because it eliminates the need for more costly and complicated wastewater treatment processes; in particular, removing nutrients, nitrogen and phosphorus is unnecessary. Potential non-agricultural uses for treated wastewater include industrial cooling, landscape irrigation, firefighting and for flushing toilets in non-residential buildings.

For agriculture, treated wastewater can be mixed with fresh water and used to grow non-food crops such as cotton, flax and trees. A bonus is that the nutrients in the wastewater reduce the need for applying chemical fertilizers, thereby reducing costs and environmental problems associated with the run-off of such chemicals. Meanwhile, many contaminants in the effluent, including suspended solids, nitrogen, phosphorus, heavy metals, bacteria, viruses and other microorganisms, are reduced or removed through an inexpensive process.

The increasing demand for domestic water due to population growth, improvement in living standards and the growing industrial sector will increase the total amount of wastewater available for reuse as an important source. The major issues include public health and environmental hazards and technical, institutional, socio-cultural and sustainability aspects.

About 25–30 per cent of irrigation water returns to drains. If reused, this relatively high volume needs continuous monitoring and evaluation of its environmental impacts, especially on soils, cultivated crops and human health.

WIDE PROVISION OF SANITATION – WITH METHANE CAPTURE

To manage sludge from human and animal waste, public-private partnerships can be established to support the adoption of sludge exhaustion technologies and/or waste-to-energy systems. Biogas systems, for example, involve anaerobic waste treatment to produce biogas to supplement energy requirements for various purposes (Kemausuor *et al.* 2018). This system has a dual effect of providing supplemental energy to the population while reducing the release of hazardous gases resulting from the disposal of such wastes into the atmosphere. Such measures should fully consider designs that are easily adapted to the realities of slums and other informal settlements

UN-Habitat has been working with local governments and communities on waste management approaches that are participatory and all-inclusive; tailor-made to local conditions; innovatively designed with low-cost equipment that is, preferably, developed locally to ensure the availability of after-sales services within the target region; and incorporates income generation to encourage the full involvement of local communities in job creation (Africa Clean Cities Platform, 2022).

3.2.7.2 MODELLING APPROACH IN THE WASTE SECTOR

For the waste sector, emissions are estimated for 1960–2019 to account for the historic accumulation of solid waste in landfill sites, which determine the CH_4 emission levels in future years. The future scenarios are extended to 2063, but also provide results in terms of mitigation of SLCP, GHG and air pollutant emissions for 2030 as an intermediate point, which is aligned with both the SDGs and the Paris Agreement.

The modelling analysis includes two sub-sectors of the waste sector. The MSW sub-sector, for which CH_4 emissions from landfill sites, and GHG, SLCP and air pollutant emissions associated with waste incineration and the open burning of waste were estimated (Table 3.5); and the liquid waste sub-sector, for which CH_4 emissions from domestic wastewater were estimated.

Table 3.5 Overview of emission sources covered in waste modelling

SOURCE SECTOR	POLLUTANT
MSW	CH_4
LIQUID WASTE	CH_4
WASTE BURNING	BC, CH_4, CO, NH_3, NMVOC, N_2O, NO_x, OC PM, SO_2

To develop the different scenarios for the waste sector, six mitigation measures were modelled in total and their aims and targets discussed in a consultation session with African stakeholders before they were implemented in the modelling of the different scenarios. Two measures were included in the SCLP mitigation scenario and four in the Agenda 2063 scenario (Table 3.6).

Table 3.6 Mitigation measures in the waste sector, near-term (2030) and 2063 assumptions used in the modelling and links to Agenda 2063 priority areas

MEASURE	DESCRIPTION	NEAR-TERM ASSUMPTIONS (2030)	2063 ASSUMPTIONS	SCENARIO	RELEVANT AGENDA 2063 PRIORITY AREAS
WASTE					
W1. SOLID WASTE DISPOSAL	Implementation of best practise landfill management to reduce open burning of waste and methane capture at landfills	Only change will be in formal landfills - in those, a 75% reduction of waste burning and a 60% methane capture. No change to dumps or residential	All formal landfills continue to have 75% implementation of reduced burning and 75% methane capture.	SLCP	1. Modern and liveable habitats and basic quality services 2. Health and nutrition
W2. LIQUID WASTE	Methane capture at wastewater treatment plants	Methane capture on all existing wastewater treatment plants (up to 60% by 2030)	Methane capture on all existing wastewater treatment plants	SLCP	Sustainable consumption and production patterns
W3. SOLID WASTE DISPOSAL	Implement waste collection and the development of formal landfill sites	No change from the baseline	All waste is collected and any disposal to land is to formal landfills. Implementation starts in 2030.	Agenda 2063	1. Modern and liveable habitats and basic quality services 2. Health and nutrition
W4. SOLID WASTE DISPOSAL	Diversion of organic waste to composting or biogas	30% of organic waste going to landfill is composted or converted to biogas	90% of organic waste going to landfill is composted or converted to biogas	Agenda 2063	Renewable energy
W5. SOLID WASTE DISPOSAL	Reduce organic waste generation	Reduction equivalent to reduced food waste (see measure A6 on food waste)	Reduction equivalent to reduced food waste (see measure A6 on food waste)	Agenda 2063	Sustainable consumption and production patterns
W6. LIQUID WASTE	Universal access to improved water and sanitation services	No change from baseline. Change starts in 2030.	All urban areas connected to a sewage treatment plants that have methane treatment and capture. Assume that different systems will be developed in rural areas which will have low methane generation.	Agenda 2063	1. Modern and liveable habitats and basic quality services 2. Health and nutrition

SHORT-LIVED CLIMATE POLLUTANT MITIGATION SCENARIO MEASURES

- **W1: Implementation of best practise landfill management to reduce open burning of waste, and methane capture at landfills.** For the solid waste, the mitigation measure that was chosen was an implementation of the best practices for landfill management to reduce the open burning of waste and increase and/or introduce CH_4 capture. Both a 2030 and a 2063 target were set for the specific measure. For the 2030 target, the mitigation measure reflects a 75 per cent decrease in the amount of waste that is burned at formal landfill sites, and a 60 per cent CH_4 capture. The 2063 target reflects the same 75 per cent decrease in the percentage of waste burned in formal landfills and an increase in the CH_4 capture to 75 per cent.
- **W2: methane capture at wastewater treatment plants.** For liquid waste, the mitigation measure that was chosen was CH_4 capture at wastewater treatment plants. A target of CH_4 capture at all existing wastewater treatment plants was set for 2063, with up to 60 per cent implementation by 2030.

AGENDA 2063 SCENARIO MEASURES

- **W3: Implement waste collection and the development of formal landfill sites**. The aim and target for this measure is that all waste is collected and any disposal to land is at formal landfills by 2063. Implementation of this measure starts in 2030.
- **W4: Diversion of organic waste to composting or biogas**. 30 per cent and 90 per cent of organic waste going to landfill is composted or converted to biogas by 2030 and 2063, respectively.
- **W5: Reduce organic waste generation**. Reduction equivalent to reduced food waste (measure A6), i.e., modelling assumes that through technological advances and behavioural changes, food waste will be completely eliminated by 2063.
- **W6: Universal access to improved water and sanitation services.** For this mitigation measure, all urban areas are connected to a sewage treatment plants that have CH_4 treatment and capture by 2063, starting in 2030. The modelling assumed that different systems will be developed in rural areas which will have low CH_4 generation.

LINKS TO AGENDA 2063 – THE AFRICA WE WANT

Each of the waste-sector measures in the SLCP mitigation and Agenda 2036 scenarios are directly linked to the Agenda 2063 priorities (Table 3.6). Improved waste management contributes to the modern and liveable habitats and basic quality services priority and relates to the implementation of policies for the growth of urban waste-recycling industries. They also contribute to the health and nutrition priority and to the promotion of programmes to combat communicable and non-communicable diseases. Measure W4, diversion of organic waste to composting or biogas, could also contribute to renewable energy goals.

THE EFFECT OF IMPLEMENTING MEASURES IN THE WASTE SECTOR

The measures indicated under the SLCP mitigation and Agenda 2063 scenarios have been chosen to mitigate emissions of all key GHGs, air pollutants and SLCPs related to the waste sector. In both scenarios, the emissions reductions are related to and driven by changes in key variables, such as the population and GDP values, the rate of waste generation, waste composition and waste disposal.

Figure 3.11 shows that in 2030, the SLCP mitigation and Agenda 2063 measures related to reducing waste burning (Table 3.6) resulted in a 27 per cent and 38 per cent reduction in BC emissions respectively compared to the baseline. In 2063, the proportions of BC emissions reductions were modelled to be about 43 and 90 per cent for the SLCP mitigation and Agenda 2063 scenarios respectively. Emissions of $PM_{2.5}$ are also reduced by the SLCP mitigation and Agenda 2063 measures related to reducing waste burning by 12–25 per cent by 2030 and 30–88 per cent by 2063 (Figure 3.12).

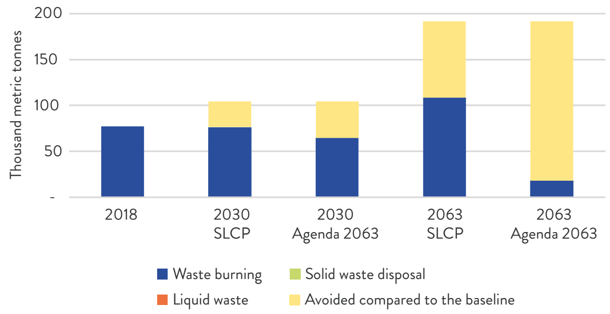

Figure 3.11 Black carbon emissions from the waste sector for the SLCP mitigation and Agenda 2063 scenarios, 2018, and 2030 and 2063, thousand metric tonnes.

Note: emissions avoided are calculated using baseline scenario values in 2030 and 2063 as appropriate.

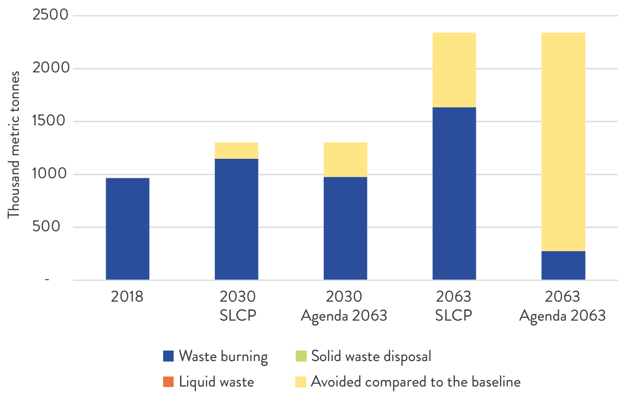

Figure 3.12 Fine particulate matter ($PM_{2.5}$) emissions from the waste sector for the SLCP mitigation and Agenda 2063 scenarios, 2018, and 2030 and 2063, thousand metric tonnes.

Note: emissions avoided are calculated using baseline scenario values in 2030 and 2063 as appropriate.

Methane emissions are also reduced by measures related to reduced waste burning but also by solid and liquid waste management (Figure 3.13). Overall, the SLCP mitigation and Agenda 2063 measures (Table 3.6) reduce CH_4 emissions by 50 and 53 per cent by 2030 and 49 and 79 per cent by 2063 respectively, with the solid waste disposal and liquid waste measures having the greatest effect.

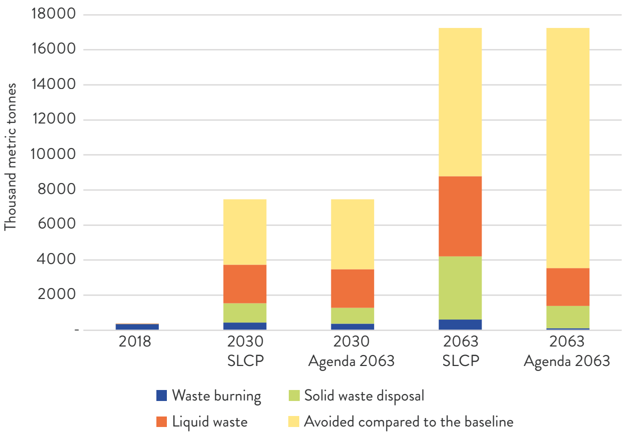

Figure 3.13 Methane emissions from the waste sector for the SLCP mitigation and Agenda 2063 scenarios, 2018, and 2030 and 2063, million metric tonnes.

Note: emissions avoided are calculated using baseline scenario values in 2030 and 2063 as appropriate.

3.3 RESULTS OF MODELLING THE SHORT-LIVED CLIMATE POLLUTANT MITIGATION AND AGENDA 2063 SCENARIOS

MAIN MESSAGES

- Greenhouse gas emissions could be drastically reduced if concurrent action is taken to reduce emission of SLCPs.
- The 37 measures generated by this Assessment can cut CO_2 emissions by 55 per cent in 2063 compared to the baseline scenario. This would involve implementation of measures in the transport sector (32 per cent of the total reduction), industry (14 per cent of the total reduction), electricity generation (48 per cent of the total reduction), by using renewable sources (solar, wind, hydro, and geothermal), with smaller contributions the residential and commercial services.
- By 2063, CH_4 emission reductions of 74 per cent are projected from implementing measures in: agriculture (74 per cent of the total reduction), oil and gas extraction and charcoal production (16 per cent of total reduction), waste management (9 per cent of total reduction), with smaller contributions from the transport, residential and commercial measures.
- Emissions of the greenhouse gas N_2O could also be reduced by 40 per cent by 2063 compared to the baseline, mainly from implementing measures in the agricultural sector.
- There are also significant co-benefits through the reduction of SLCPs, such as BC and HFCs, and air pollutants such as $PM_{2.5}$, OC, NOx, SO_2, NH_3, CO, and NMVOCs. Some of these pollutant emissions, such as CH_4, CO, NOx, and NMVOCs, contribute to producing O_3 pollution in the troposphere which has significant health, crop, and climate impacts.

3.3.1 EFFECT OF SHORT-LIVED CLIMATE POLLUTANT MITIGATION AND AGENDA 2063 SCENARIOS ON GREENHOUSE GAS EMISSIONS

The implementation of all 37 mitigation measures included in this Assessment results in a 62 per cent reduction in GHG emissions in 2063 compared to the baseline scenario (Table 3.7). The SLCP mitigation scenario results in only modest reductions in GHG emissions, with a 20 per cent reduction compared to the baseline scenario.

Table 3.7 Emissions of greenhouse gases, short-lived climate pollutants and air pollutants in the baseline, short-lived climate pollutant mitigation and Agenda 2063 scenarios

SCENARIO	POLLUTANT	UNITS	2018	2030	2030 % REDUCTION VS BASELINE	2063	2063 % REDUCTION VS BASELINE
BASELINE	GHGs	Billion metric tonnes CO_2-eq	4.15	5.41		14.16	
SLCP MITIGATION	GHGs	Billion metric tonnes CO_2-eq	4.15	4.76	12.0	11.36	19.7
AGENDA 2063	GHGs	Billion metric tonnes CO_2-eq	4.15	4.13	23.7	5.44	61.6
BASELINE	CO_2	Million Metric Tonnes	2459.4	3024.2		6698.5	
SLCP MITIGATION	CO_2	Million Metric Tonnes	2459.4	2971.5	1.7	6153.5	8.1
AGENDA 2063	CO_2	Million Metric Tonnes	2459.4	2798.3	7.5	3035.0	54.7
BASELINE	CH_4	Million Metric Tonnes	48.4	69.1		207.8	
SLCP MITIGATION	CH_4	Million Metric Tonnes	48.4	48.1	30.4	123.1	40.8
AGENDA 2063	CH_4	Million Metric Tonnes	48.4	35.6	48.5	53.9	74.0
BASELINE	HFCs	Million Metric Tonnes CO_2-eq	91.1	66.2		157.0	
SLCP MITIGATION	HFCs	Million Metric Tonnes CO_2-eq	91.1	56.0	15.4	2.7	98.3
AGENDA 2063	HFCs	Million Metric Tonnes CO_2-eq	91.1	56.0	15.4	2.7	98.3
BASELINE	BC	Million Metric Tonnes	1225.3	1401.2		2737.7	
SLCP MITIGATION	BC	Million Metric Tonnes	1225.3	1011.7	27.8	1181.5	56.8
AGENDA 2063	BC	Million Metric Tonnes	1225.3	986.0	29.6	742.1	72.9
BASELINE	OC	Million Metric Tonnes	3621.4	4343.2		8094.2	
SLCP MITIGATION	OC	Million Metric Tonnes	3621.4	2897.4	33.3	3779.5	53.3
AGENDA 2063	OC	Million Metric Tonnes	3621.4	2731.2	37.1	1933.4	76.1
BASELINE	$PM_{2.5}$	Million Metric Tonnes	7.7	10.0		18.6	
SLCP MITIGATION	$PM_{2.5}$	Million Metric Tonnes	7.7	6.6	34.3	8.5	54.0
AGENDA 2063	$PM_{2.5}$	Million Metric Tonnes	7.7	6.2	37.8	4.5	75.8
BASELINE	NOx	Million Metric Tonnes	9.7	15.5		51.6	
SLCP MITIGATION	NOx	Million Metric Tonnes	9.7	11.6	25.0	17.9	65.3
AGENDA 2063	NOx	Million Metric Tonnes	9.7	11.0	29.0	10.6	79.5
BASELINE	SO_2	Million Metric Tonnes	5.5	7.0		20.5	
SLCP MITIGATION	SO_2	Million Metric Tonnes	5.5	6.6	5.3	17.9	12.5
AGENDA 2063	SO_2	Million Metric Tonnes	5.5	5.8	17.2	6.5	68.1
BASELINE	NH_3	Million Metric Tonnes	9.0	13.2		47.3	
SLCP MITIGATION	NH_3	Million Metric Tonnes	9.0	10.4	21.4	28.3	40.2
AGENDA 2063	NH_3	Million Metric Tonnes	9.0	7.8	41.0	15.7	66.9
BASELINE	NMVOCs	Million Metric Tonnes	42.5	55.7		111.3	
SLCP MITIGATION	NMVOCs	Million Metric Tonnes	42.5	37.3	33.0	45.2	59.4
AGENDA 2063	NMVOCs	Million Metric Tonnes	42.5	36.0	35.3	29.2	73.7
BASELINE	CO	Million Metric Tonnes	129.7	172.1		377.8	
SLCP MITIGATION	CO	Million Metric Tonnes	129.7	116.6	32.2	135.5	64.1
AGENDA 2063	CO	Million Metric Tonnes	129.7	112.1	34.8	83.8	77.8

The majority of the GHG emissions reductions occur from the implementation of the Agenda 2063 measures (Figures 3.14–3.16).

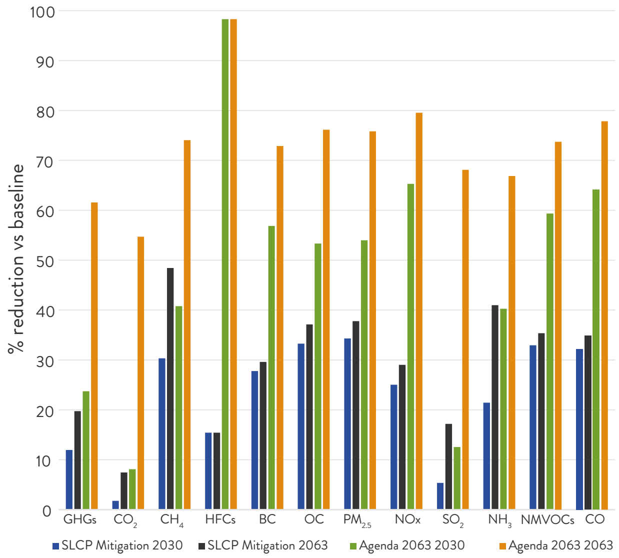

Figure 3.14 Reduction in greenhouse gas, short-lived climate pollutant and air pollutant emissions for the short-lived climate pollutant and Agenda 2063 mitigation scenarios relative to the baseline, 2030 and 2063, per cent

In all scenarios, total African GHG emissions have increased in 2063 compared to 2018 (Table 3.7), reflecting substantial increases in population and economic growth, but GHG emissions per person and per unit of GDP have decreased substantially, highlighting a substantially lower GHG emission intensity in the Agenda 2063 scenario compared with the baseline.

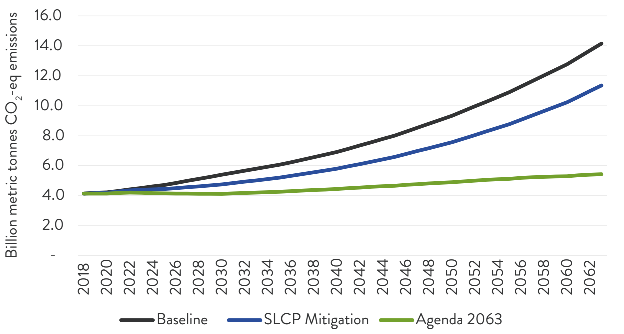

Figure 3.15 Greenhouse gas emissions pathways for the baseline, short-lived climate pollutant and Agenda 2063 mitigation scenarios, 2018–2062, billion metric tonnes of carbon dioxide equivalent.

The SLCP mitigation scenario results in only small reductions in CO_2 emissions, because the SLCP mitigation measures either are not implemented in major CO_2 emissions source sectors or the measure does not target CO_2 reductions, for example, the vehicle emissions standards.

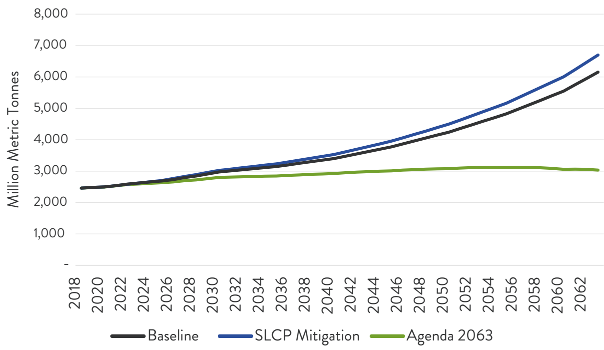

Figure 3.16 Carbon dioxide emission pathways for the baseline, short-lived climate pollutant and Agenda 2063 mitigation scenarios, 2018–2062, million metric tonnes.

Substantially larger CO_2 emissions reductions occur from the implementation of the Agenda 2063 scenario. Due to the Agenda 2063 measures being largely implemented after 2030, the CO_2 reductions in 2030 are relatively small (Figure 3.17a), with the majority of the reductions occurring after 2030 (Figure 3.17b).

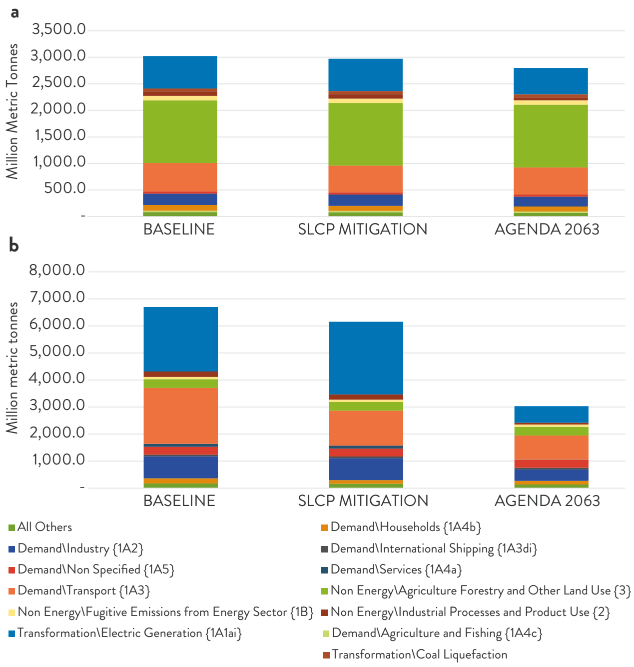

Figure 3.17 Carbon dioxide emissions disaggregated by major emissions sources, a) 2030, and b) 2063, million metric tonnes.

While emissions are reduced across all sectors, electricity generation is the largest single source of CO_2 emissions in 2063 in the baseline scenario, and the combination of energy efficiency and electricity generation from renewable sources results in the largest reduction in CO_2 emissions in the electricity generation sector.

3.3.2 EFFECT OF THE SHORT-LIVED CLIMATE POLLUTANT MITIGATION AND AGENDA 2063 SCENARIOS ON SHORT-LIVED CLIMATE POLLUTANT EMISSIONS

There are substantially larger reductions in SLCPs in both the SLCP mitigation and Agenda 2063 scenario compared to GHGs overall, allowing for the fact that CH_4 is both an SLCP and a GHG. Implementation of all mitigation measures could avoid 74 per cent of 2063 CH_4 emissions compared to the baseline scenario (Table 3.7). Approximately half of this reduction is achieved from the SLCP mitigation measures, and half from more development-oriented Agenda 2063 measures related to food waste and diet (Figure 3.18; Table 3.4).

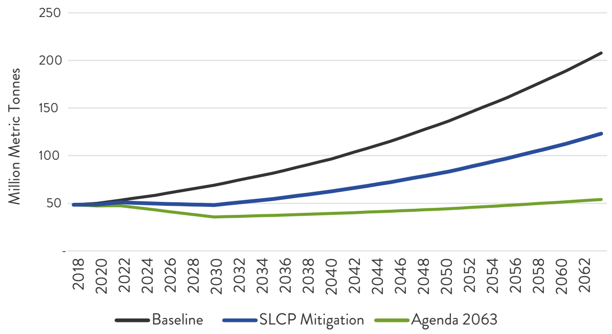

Figure 3.18 Methane emissions pathways for baseline, short-lived climate pollutant and Agenda 2063 mitigation scenarios, 2018–2062; million metric tonnes

Agriculture is the largest source of CH_4 emission in all scenarios, and implementation of mitigation measures in agriculture results in the greatest absolute reduction in CH_4 emissions across sectors (Figure 3.19).

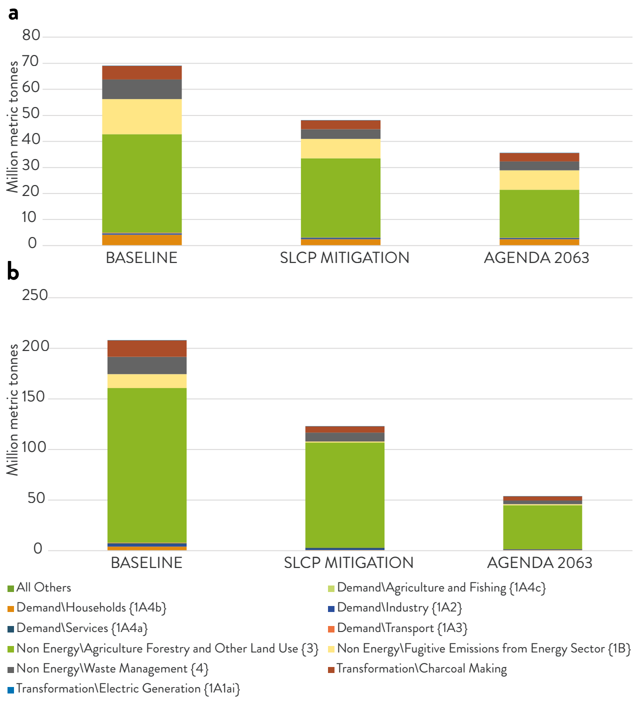

Figure 3.19 Methane emissions disaggregated by major emissions source, in a) 2030, and b) 2063, million metric tonnes.

Waste, fossil fuel production and charcoal production are the other major sources of CH_4 and are all substantially reduced from the implementation of the measures included in the SLCP mitigation scenario. Methane emissions could be substantially reduced by 2030 by the Agenda 2063 scenario, with almost 50 per cent lower CH_4 emissions in 2030 compared to the baseline scenario.

Approximately half of all BC emissions across Africa come primarily from the residential sector (Figures 3.20; 3.21). Therefore, mitigation measures that result in a switch to more efficient or clean fuels for cooking have the largest impact on them. The emissions could be reduced by almost one third by 2030 from implementation of the SLCP mitigation scenario, largely due to reductions in the household sector (Figure 3.21). More substantial falls in BC emission after 2030 occur due to further reductions in the household sector related to the efficiency of appliances, as well as mitigation across other sectors, especially transport.

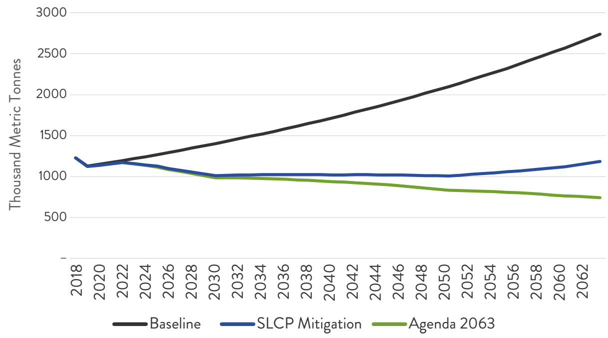

Figure 3.20 Black carbon emissions pathways for the baseline, short-lived climate pollutant mitigation and Agenda 2063 scenarios, 2018–2062, thousand metric tonnes.

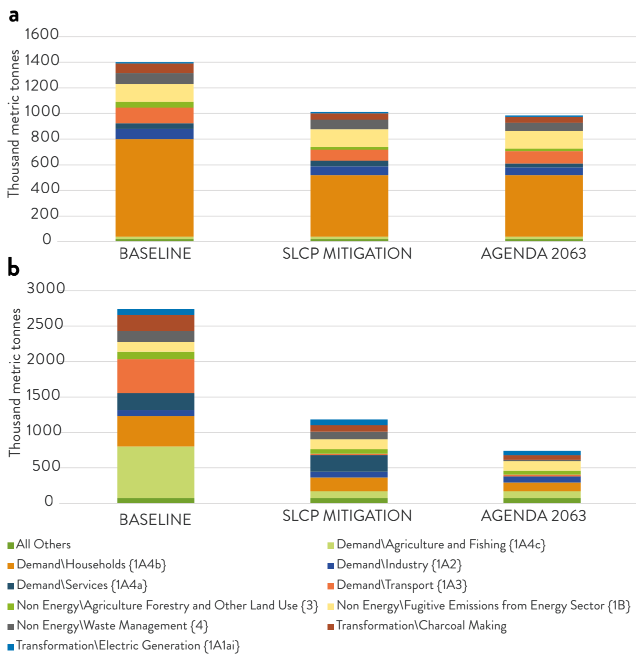

Figure 3.21 Black carbon emissions disaggregated by major emissions source, a) 2030, and b) 2063, thousand metric tonnes.

In this Assessment, HFC emissions are reduced through implementation of the Kigali Amendment to the Montreal Protocol, which outlines specific timelines for the phasedown of HFC consumption. By 2063, there is a 98 per cent reduction in HFC emissions in the SLCP mitigation scenario compared to the baseline, reflecting the full implementation of the Kigali Amendment (Table 3.7, Figure 3.14).

3.3.3 EFFECT OF SHORT-LIVED CLIMATE POLLUTANT MITIGATION AND AGENDA 2063 SCENARIOS ON AIR POLLUTANT EMISSIONS

Other air pollutants are emitted from many of the same sources as SLCPs and GHGs, such as, respectively, BC and CO_2. The implementation of the SLCP mitigation and Agenda 2063 scenarios, therefore, results in substantial reductions in other air pollutants such as $PM_{2.5}$, and NO_x (Figure 3.14). Similar reductions in PM pollutants, for example, $PM_{2.5}$ and OC, are achieved as for BC, due to the large overlap in sources (Figure 3.22). The implementation of the SLCP Mitigation and Agenda 2063 scenarios can, therefore, reduce PM by more than 70 per cent in 2063 compared to the baseline (Table 3.7), and it is reductions in emissions from the household sector that are responsible for the majority of the reductions (Figure 3.23).

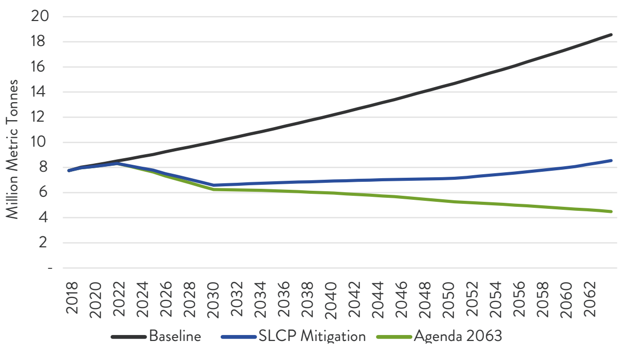

Figure 3.22 Fine particulate matter ($PM_{2.5}$) emissions pathways for baseline, short-lived climate pollutant mitigation and Agenda 2063 scenarios, 2018–2062, million metric tonnes.

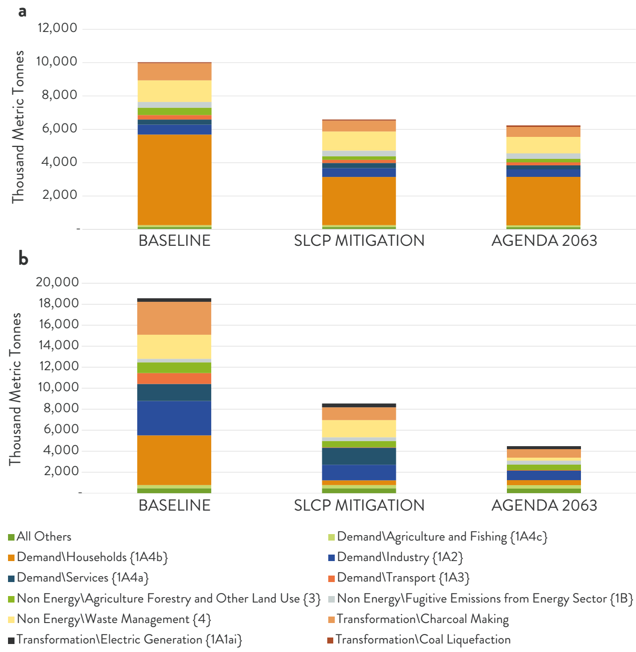

Figure 3.23 Fine particulate matter ($PM_{2.5}$) emissions disaggregated by major emissions source, a) 2030, and b) 2063, thousand metric tonnes

Nitrogen oxides emissions are emitted predominantly from the transport sector, and, therefore, the mitigation measures targeting transport included in the SLCP mitigation and Agenda 2063 scenarios are effective at reducing NO_x emissions (Figures 3.24 and 3.25).

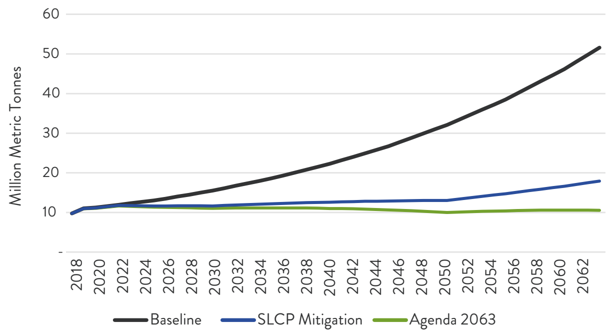

Figure 3.24 Nitrogen oxides emissions pathways for the baseline, short-lived climate pollutant mitigation and Agenda 2063 scenarios, 2018–2062, million metric tonnes

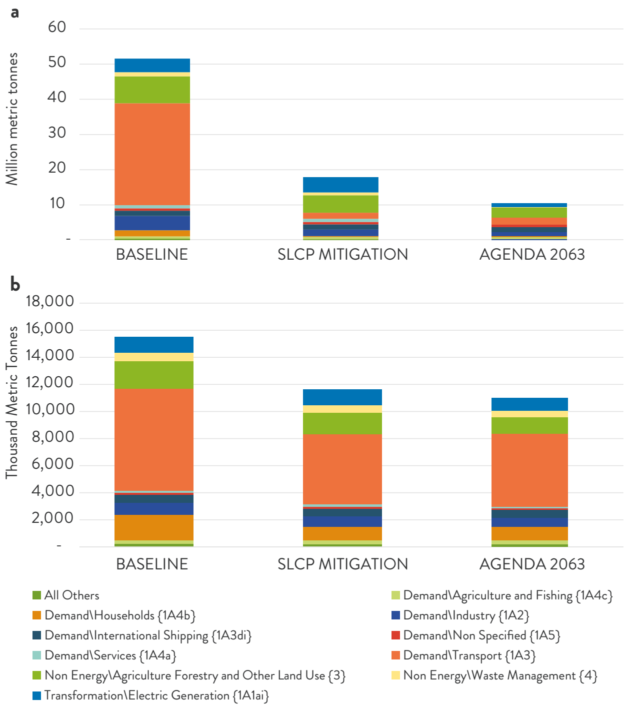

Figure 3.25 Nitrogen oxides emissions disaggregated by major emissions source, a) 2030, and b) 2063, thousand metric tonnes

3.4 BENEFITS FOR AIR QUALITY AND CLIMATE CHANGE UPON IMPLEMENTATION OF THE SHORT-LIVED CLIMATE POLLUTANT MITIGATION AND AGENDA 2063 INTERVENTIONS

MAIN MESSAGES

HUMAN HEALTH

- The emission reductions that could be achieved by the 37 measures are estimated to prevent about 180,000 premature deaths per year by 2030 and 800,000 deaths per year by 2063 from outdoor air pollution in comparison to the baseline scenario.
- Fine particulate matter pollution ($PM_{2.5}$) can be significantly reduced under the SLCP Scenario, and further reduced under the Agenda 2063 Scenario, across the five major regions of Africa, bringing values closer to the WHO Air Quality guideline.
- Tropospheric ozone (O_3), the other main pollutant affecting human health in Africa, and for ozone attributable deaths, can also be significantly reduced by the measures.
- The Assessment's SLCP measures would also prevent 20,000 household (indoor) air pollution-related premature deaths per year by 2030 and 80,000 per year by 2063, corresponding to a 12 and 53 per cent reduction in premature death in those years, respectively.
- Household air quality benefits would decrease the impact on vulnerable populations most affected by air pollution exposure: children, women, people with underlying chronic conditions, and the elderly in the household environment.
- In addition to the many harmful effects of air pollution on human health, there is emerging evidence of negative effects of air pollution on cognitive function, especially for children, that could also be reduced by the recommended measures.

CLIMATE CHANGE BENEFITS FOR AFRICA

Implementing the 37 measures has the potential to:

- Reduce regional climate change in Africa, lessening further land degradation and desertification and improving food production and quality.
- Reduce changes in local precipitation patterns compared to a situation where there is no change in policy. For example, the Assessment projects there will be reduced drying in the Sahel and West Africa in June–August and potentially also in southern parts of Africa in December-February due in part to reduced air pollution.
- Lead to a modest but widespread reduction in annual average warming across Northern and Central Africa. There are also reductions in seasonal warming, with the most significant avoided increases in temperature during the winter months in Northern (December-February) and southern Africa (June–August).
- Increase yield gains for crops across Africa: rice (approximately 1 per cent), maize (approximately 4 per cent), soy (approximately 6 per cent) and wheat (approximately 11 per cent in East Africa). These yield gains are due to reduced warming, changes in precipitation, and reduced concentrations of ozone resulting from the implementation of the measures across Africa. These gains outweigh small yield decreases due to reduced carbon dioxide concentrations in the atmosphere, and the net changes will also benefit ecosystems and forests.
- Reduce the burdens of several climate-sensitive food-, water-, and vector-borne diseases that are projected to increase with higher temperatures, assuming no additional adaptation.

- Achieve direct adaptation benefits, for example, as well as reducing CH_4 emissions, adopting the alternate wetting and drying measure for rice growing can have the co-benefit of reducing irrigation water consumption as well as help control mosquitoes.

3.4.1 CLIMATE CHANGE BENEFITS OF THE SHORT-LIVED CLIMATE POLLUTANT MITIGATION AND AGENDA 2063 SCENARIOS

Under the Agenda 2063 scenario, Africa-wide average surface temperatures are indistinguishable from the baseline scenario through 2050, with a suggestion of a very small departure thereafter (Figure 3.26). The weak sensitivity of Africa-wide temperatures to the mitigation of African emissions under the Agenda 2063 scenario relative to the baseline is indicative of the dominant role of GHG emissions from the rest of the world as Africa emits only a small fraction of GHGs, as well as the counteracting impacts of reduced levels of cooling aerosols (mostly sulphate) and GHGs.

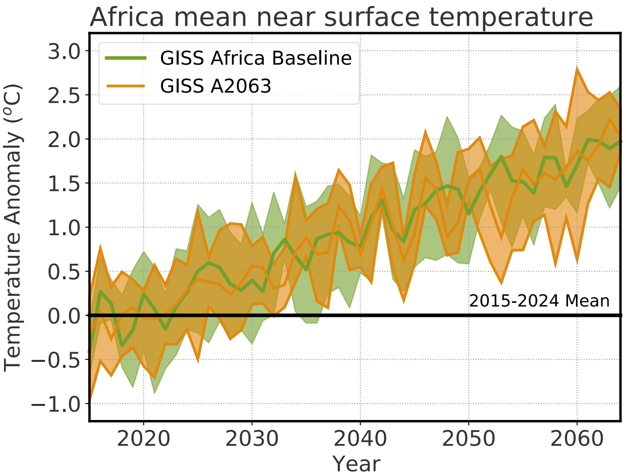

Figure 3.26 Africa, mean annual average surface air temperature in the GISS-E2.1-G model for the baseline and Agenda 2063 scenarios, 2015–2063, degrees centigrade.

Note: solid lines show the ensemble mean whereas shaded areas show the range across the ensemble (n=5). Anomalies are calculated relative to the 2015–2024 mean.

At a regional scale, there are statistically significant temperature responses to the Agenda 2063 scenario over Africa relative to the baseline by the 2050s. Specifically, there is a widespread reduction in warming across northern and central Africa (Figure 3.27c). Seasonally, the avoided warming is greatest during the local winter months in northern (December–February, Figure 3.27f) and southern Africa (June–August, Figure 3.27i). Small areas around Morocco and Madagascar show increased warming associated with large-scale oceanic changes, as is the small area of cooling at the southwest tip of southern Africa, and as such are likely to be model specific and are thus considered less robust as only one climate model was used.

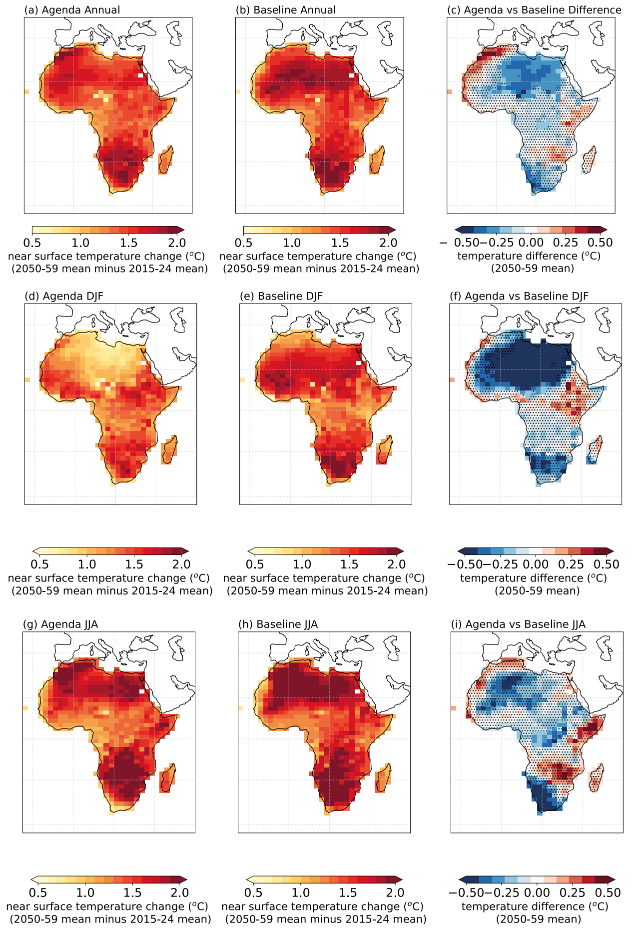

Figure 3.27 Africa, average surface air temperature changes in the GISS-E2.1-G model for the Agenda 2063 simulations (a, d and g), the baseline simulations (b, e and h) for 2050-2059 relative to 2015-2024, and the difference between the 2050-59 means for Agenda 2063 and the baseline (c, f and i) for the annual average (top row), December–February (middle row) and June–August (bottom row).

Note: stippling indicates the differences are not statistically significant (95 per cent confidence) across the ensemble.

Unsurprisingly, the climate impacts were the entire world to act to mitigate emissions rather than Africa alone would be much larger, with much greater values of avoided warming extending across virtually every area under a sustainability, low-emissions focused world (Figure 3.28).

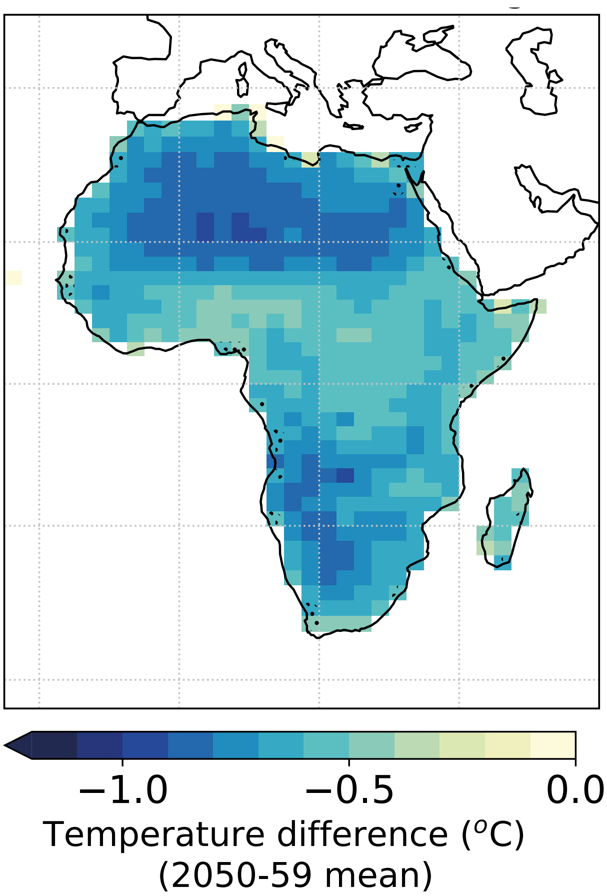

Figure 3.28 Africa, annual average surface air temperature differences under the sustainability, low-emissions focused scenario SSP1_2.6 relative to the SSP3_7.0 scenario, 2050–2059, degrees centigrade.

Note: results are multi-model means over the CMIP6 models with stippling indicating the differences are not statistically significant (95 per cent confidence).

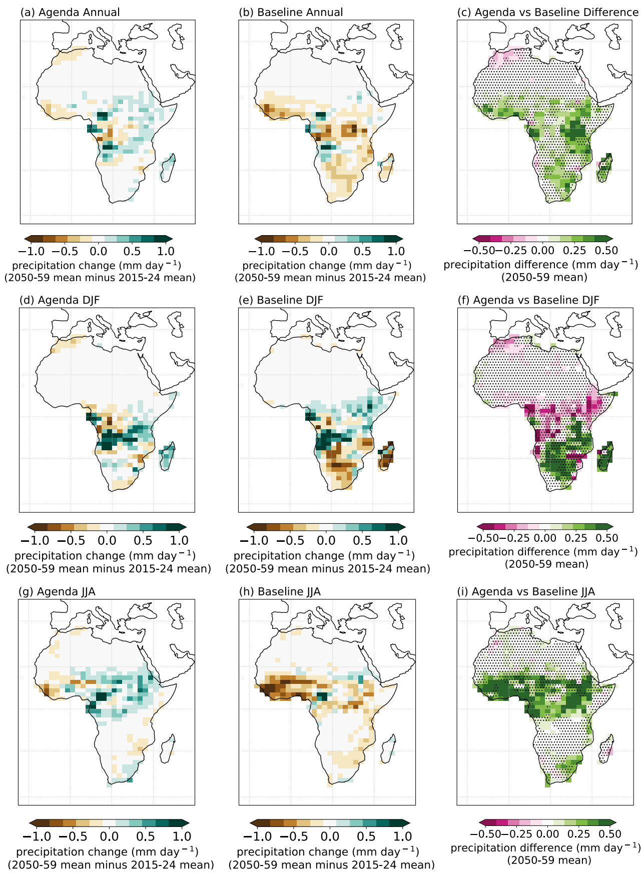

Figure 3.29 Africa, seasonal average precipitation changes in the GISS-E2.1-G model for the Agenda 2063 simulations (a, d and g), the baseline simulations (b, e and h) for 2050-2059 relative to 2015-2024, and their difference (c, f and i) for annual average (top) December-February (middle) and June–August (bottom).

Note: stippling indicates the differences are not statistically significant (95 per cent confidence) across the ensemble.

Turning to precipitation, the Agenda 2063 emissions reductions strongly mitigate the drying projected under the baseline scenario (Figure 3.29h) in West, East and Central Africa during June-August (Figure 3.29i) and in Southern Africa during December-February (Figure 3.29f). Projected changes in annual mean precipitation are weaker than projected changes in seasonal precipitation (Figure 3.29c).

Westervelt *et al.* (2018) show how regional aerosol changes can cause local precipitation shifts and how those responses vary greatly across models. It is also difficult to separate the impacts of aerosol and GHG changes on precipitation, with the aerosol portion of changes, which may be especially important in the Sahel, likely to be fairly uncertain relative to the GHG-induced portion since aerosols can either supress or enhance precipitation both locally and remotely depending on background conditions (e.g. Yakubu and Chetty, 2022). For context, the modelling baseline results (section 2.61) show that the drying in West Africa and increased precipitation in East Africa in boreal winter along with the drying of Southern Africa in boreal summer (austral winter i.e. June through August) are robust features of the response to a warming planet, with the GISS model generally falling near the mean across the CMIP6 models but with a somewhat larger drying over W Africa (in both magnitude and areal extent) (Almazroui, *et al.* 2020).

3.4.2 OUTDOOR AIR POLLUTION BENEFITS UNDER THE SHORT-LIVED CLIMATE POLLUTANT MITIGATION AND AGENDA 2063 SCENARIOS

3.4.2.1 FINE PARTICULATE MATTER EXPOSURE AND PREMATURE MORTALITY

The Assessment modelled the projected trends in $PM_{2.5}$ exposure under the three scenarios for the five African regions (see Section 2.6.2 for methodology). The modelling projections for annual population-weighted $PM_{2.5}$ concentrations show that exposure to $PM_{2.5}$ can be significantly reduced under the SLCP mitigation scenario, and further reduced under the Agenda 2063 scenario, across the five major regions of Africa, bringing values closer to the WHO Air Quality Interim Targets (Figure 3.30a) It should be noted that the WHO guideline value of 5 µg/m³ annual average is not met in any year modelled in any region, but under the Agenda 2063 scenario considerable progress can be made in all regions. By 2063 the cleanest outdoor air in Africa is projected to be in Southern Africa, with an annual average under 10 µg/m³, and the most polluted in West Africa, where interim Target 1, 35 µg/m³ annual average, is only met in mid-century (Figure 3.30a).

The spatial extent of the projected absolute and relative changes in annual mean $PM_{2.5}$ concentrations for the modelling time periods 2015-2024 and 2050-2059 can be seen in Figure 3.30b and c. The higher $PM_{2.5}$ concentrations in Northern and Western African regions, which persist until the end of the modelling period in 2059, can be seen in both the SLCP and Agenda 2063 scenarios. This phenomenon is caused largely by Saharan dust, which mostly has natural causes and, in some areas, increases by the end of the modelling period due in part to climate change-induced increases in surface winds (Figure 3.30 b,c). In parts of Northern, Western, Central and Southern Africa the comparison between the Agenda 2063 and the baseline scenarios for the period 2050-2059 shows marked improvement in air quality in both the SLCP and Agenda 2063 scenarios, especially the latter.

Figure 3.31 shows a comparison of exposure projections across six CMIP6 models to give an idea of the uncertainty associated with results from a single model (Shindell *et al.* 2022). The GISS model used in this Assessment is one of the six in the multi-model analysis (Shindell *et al.* 2022). The $PM_{2.5}$ exposure and the difference between the high and low emissions scenarios in the GISS model are systematically slightly low relative to the multi-model. This indicates that the modelling results for the Assessment scenarios, based on this model alone, are likely to provide a conservative estimate of the PM reductions that would be achieved by following either the SLCP or Agenda 2063 scenarios.

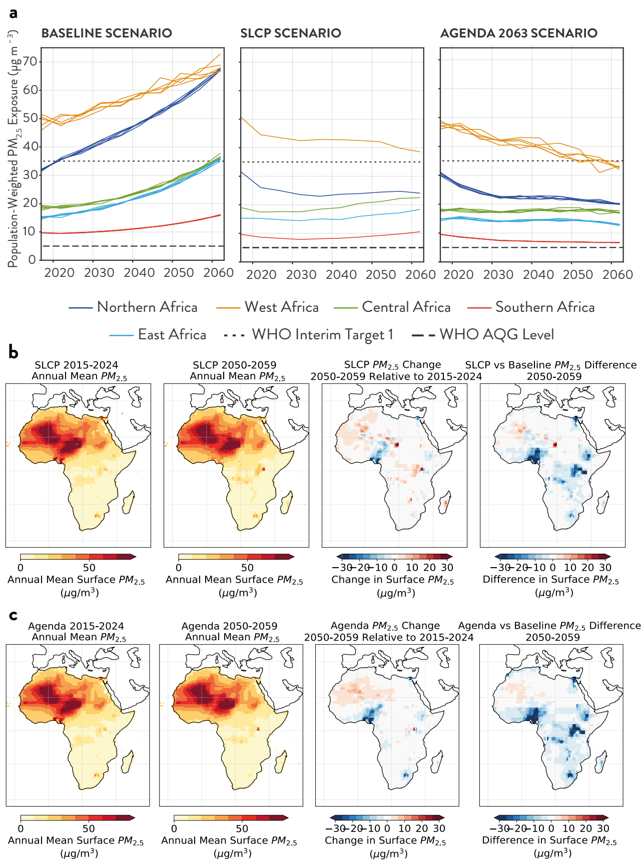

Figure 3.30 Africa, (a) regional annual population-weighted $PM_{2.5}$ (micrograms per cubic metre) exposure under the baseline, SLCP and Agenda 2063 scenarios for the five regions shown in Table 4.1 in Chapter 4, 2018–2062.;(b) and (c) spatial extent of absolute and relative changes in annual mean PM2.5 concentrations (micrograms per cubic metre) projected for 2015–2024 and 2050–2059 modelling periods for the (b) SLCP and (c) Agenda 2063 mitigation scenarios.

Note: the lines show the ensemble means. The graphs also show the WHO Air Quality Guideline (5 µg/m³ annual average) and interim Target 1 (35 µg/m³ annual average);.

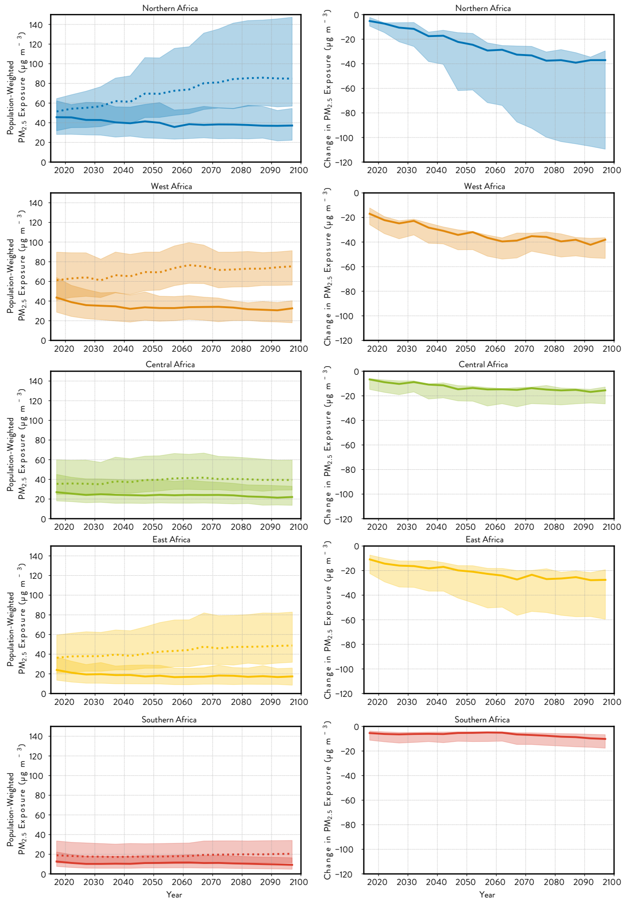

Figure 3.31 Population-weighted annual mean ambient $PM_{2.5}$ exposures in the African regions projected by CMIP6 models under SSP3_7.0 (dotted lines) and SSP1_2.6 (solid lines) (left column; μg m^{-3}) and the difference in exposure between these scenarios (right column; μg m^{-3}). These projections include changes in population. The solid lines show the multi-model means and the shaded area shows the full range across the 6 available models. Figure from Shindell *et al.* (2022).

This Assessment also examined $PM_{2.5}$-related mortality in these scenarios (Figure 3.32). These scenarios include projected changes in population, baseline mortality rates, and $PM_{2.5}$ exposure. Here the analysis of $PM_{2.5}$-related mortality follows the methodology described in Shindell *et al.* (2022) to make the results comparable, with the exception of a slight modification to the definition of $PM_{2.5}$ (now using all sea-salt smaller than 2.5 microns as calculated by the GISS model rather than the fixed fraction of total sea-salt, and not including any weight of water as ground-monitors were reported as dry aerosol mass). In all regions, the SLCP scenario reduces premature mortality by 2030, and even more so by 2063 compared to the baseline, with the Agenda 2063 scenario delivering the largest benefits by 2063 (Figure 3.32).

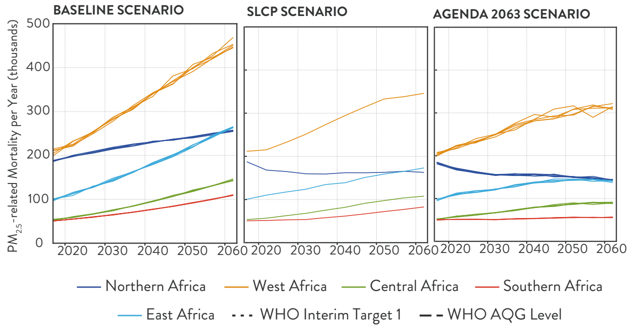

Figure 3.32 Regional premature deaths (thousands per year) associated with annual mean, ambient $PM_{2.5}$ exposure under the baseline, SLCP and Agenda 2063 scenarios, including projected changes in population and vulnerability under those scenarios. The lines show the individual ensemble member results for each region.

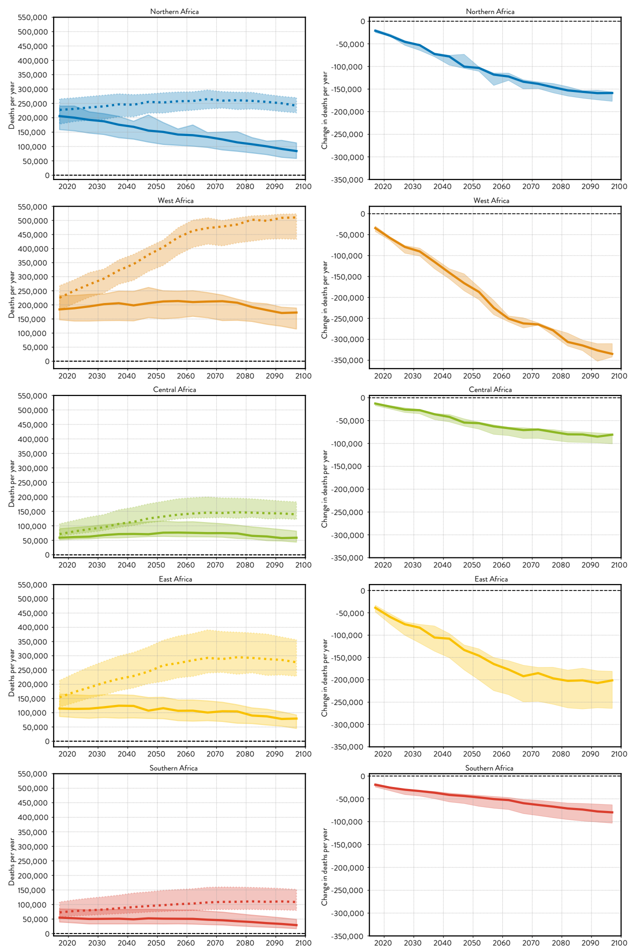

Figure 3.33 Regional premature deaths associated with $PM_{2.5}$ exposure in the African regions projected by CMIP6 models under SSP3_7.0 (dotted lines) and SSP1_2.6 (solid lines) (left column; μg m^{-3}) and the difference between those (right column; μg m^{-3}) including projected changes in population under those scenarios. The solid lines show the multi-model means and the shaded area shows the full range across the 6 available models. Figure from Shindell *et al.* (2022).

The Assessment analysis shown in Figure 3.32 is similar to the analysis of $PM_{2.5}$-related mortality using the CMIP6 models (Figure 3.33) and shows that the benefits of Africa following the Agenda 2063 scenario provide a large portion of the avoided $PM_{2.5}$-related mortalities seen when the entire world acts (the SSP1_2.6 scenario relative to the SSP3_7.0 scenario; Shindell *et al.* 2022).

3.4.2.2 TROPOSPHERIC OZONE EXPOSURE AND PREMATURE MORTALITY

In addition to $PM_{2.5}$, tropospheric ozone (O_3) is the other main air pollutant affecting human health in Africa. This assessment also modelled the outdoor O_3 exposure for the five different African regions and estimated associated premature mortality in the populations of these regions (see section 2.6.2 for methodology). Figure 3.34(a) shows the projections of population-weighted exposure to the annual average of daily maximum 8-hour average ozone in the five regions for the baseline, SLCP, and Agenda 2063 scenarios.

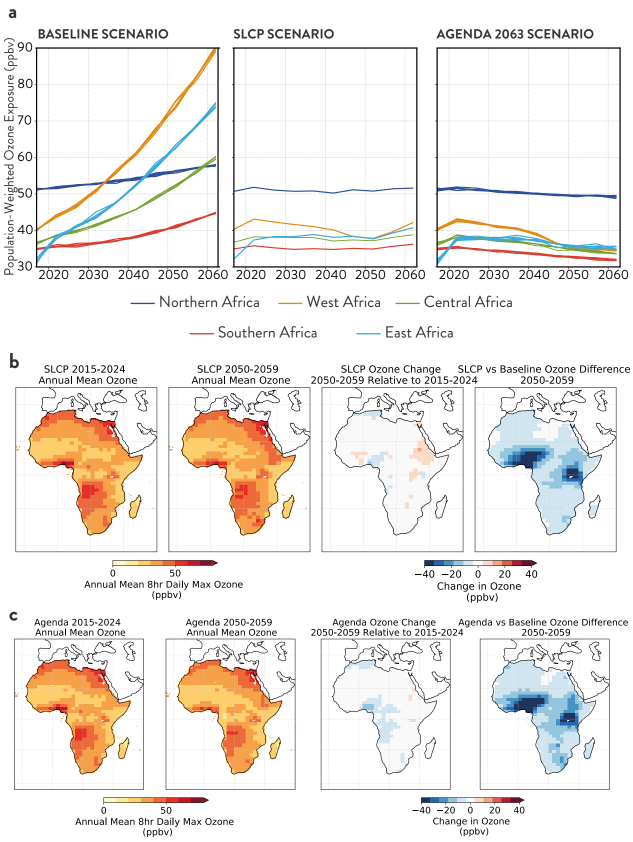

Figure 3.34 (a) Regional daily maximum 8-hour average O_3 exposure for the five different African regions (ppbv) under the baseline, SLCP and Agenda 2063 scenarios for the five regions shown in Table 4.1 in Chapter 4. The lines in (a) show the individual ensemble member results for each region. (b,c) Spatial extent of absolute and relative changes in daily maximum 8-hour average O_3 exposure projected for the 2015-2024 and 2050-2059 modelling periods for the SLCP (b) and Agenda 2063 (c) scenarios.

Changes in projected ozone exposure are similar to those of $PM_{2.5}$ over time (Figure 3.30(a)), with both scenarios reducing exposure but with Agenda 2063 reducing exposure the most by 2063. Spatially, the hotspots for current and projected total exposures are in Northern, Western, Central and Southern Africa, whereas the biggest reductions are projected to occur in both scenarios in Western and Eastern Africa (Figure 3.34(b) and (c). In Northern Africa, ozone exposure stays at around 50 ppbv in both scenarios out to 2063, indicating that emissions reductions do not lead to substantial decreases in ozone exposure in this region (Figure 3.3.4(a)).

The human health benefits, in terms of reduced premature mortality associated with reduced exposure to $PM_{2.5}$ and ozone, are qualitatively similar, with those associated with $PM_{2.5}$ being larger (Figures 3.32 and 3.35).

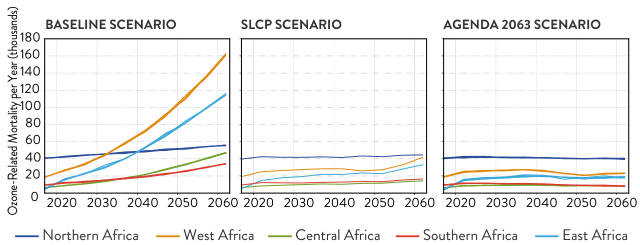

Figure 3.35 Regional premature deaths (thousands per year) associated with annual average daily maximum 8-hour average O_3 exposure under the baseline, SLCP and Agenda 2063 scenarios, including projected changes in population and vulnerability under those scenarios. The lines show the individual ensemble member results for each region.

3.4.2.3 ESTIMATION OF PREMATURE MORTALITY ASSOCIATED WITH OUTDOOR FINE PARTICULATE MATTER AND OZONE EXPOSURE MODELLED IN THIS ASSESSMENT

Across all regions in Africa, the simulations show that around 180 000 (± 45 000) outdoor air pollution-related premature deaths per year will be avoided by 2030, of which about 140 000 (± 35 000) are due to reduced $PM_{2.5}$ exposure and around 40 000 (± 13 000) are due to reduced O_3 exposure, if the recommended measures under the Agenda 2063 scenario are implemented. By 2063 the number of avoided premature deaths increases to about 800 000 (± 200 000) per year, of which around 480 000 (± 120 000) are attributable to reduced $PM_{2.5}$ exposure and about 320 000 (± 100 000) to reduced O_3 exposure. These reductions in air pollution-attributable premature deaths represent decreases of 20 and 50 per cent for 2030 and 2063, respectively, relative to the baseline scenario.

3.4.3 INDOOR AIR POLLUTION BENEFITS UNDER THE SHORT-LIVED CLIMATE POLLUTANT MITIGATION AND AGENDA 2063 SCENARIOS

Over one third of the total number of premature deaths from household air pollution in Africa were estimated to be infant deaths, with the remainder premature adult ones (Figure 3.36).

Despite an increasing population across Africa, in the baseline scenario the gradual transition of households to the use of cleaner fuels, and a reduction in baseline mortality rates, especially for children, results in a reduction in the number of premature deaths attributable to household air pollution. By 2063, the number of premature deaths attributable to household air pollution is estimated to have reduced by 40 per cent compared to 2018 levels. The dramatic reduction in infant mortality rates is estimated to reduce child mortality from household air pollution by 79 per cent in 2063 compared to 2018 levels.

However, the SLCP mitigation scenario, with steeper transitions to cleaner fuels, results in a substantially larger reduction in the health burden compared to the baseline scenario. In 2030, 20 000 premature deaths could be avoided from implementation of the SLCP mitigation scenario, and 80 000 in 2063, corresponding to a 12 per cent and 53 per cent reduction in disease burden in 2030 and 2063, respectively.

In 2063, 12 000 extra infant and 70 000 adult premature deaths could be avoided through implementation of the SLCP mitigation scenario measures. Regional trends are discussed in Section 4.5.3.

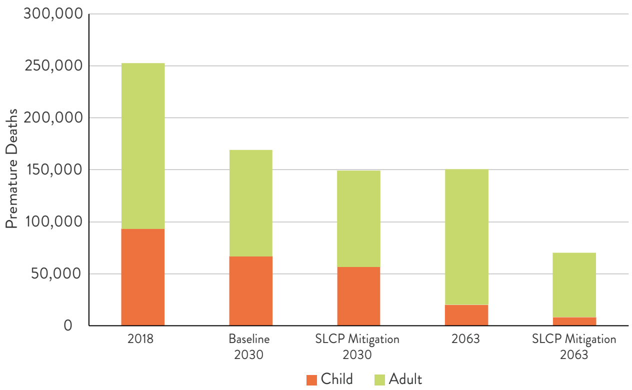

Figure 3.36 Premature deaths attributable to household air pollution from solid fuel combustion for the baseline and short-lived climate pollutant mitigation scenarios disaggregated by age, Africa, 2018, 2030 and 2063, thousands

3.4.4 BENEFITS FOR CROP YIELDS OF THE SHORT-LIVED CLIMATE POLLUTANT MITIGATION AND AGENDA 2063 SCENARIO MEASURES AT A CONTINENTAL SCALE

Under the SLCP mitigation and Agenda 2063 scenarios, O_3 and CO_2 concentrations, and particularly temperatures and rainfall changes vary regionally across Africa (Section 3.4.1). Figure 3.37 shows net yield gains in response to changes in temperature, precipitation and concentrations of O_3 and CO_2. There are yield gains for rice, maize and soy of around 1, 4 and 6 per cent respectively under the Agenda 2063 scenario, but no clear trend for wheat (Figure 3.37). There is a similar trend under the SLCP mitigation scenario but to a lesser extent, showing the relative benefit of also implementing the behavioural change related measures under the Agenda 2063 scenario. These gains compare with yield losses of roughly 7, 19, 7 and 15 per cent for maize, rice, soy and wheat respectively in the baseline (Section 2.6.4).

For the relative changes in the four crops, it is a complicated picture. Maize has a relatively large benefit, in part because, as a C4 plant, it is not very sensitive to CO_2 and so the O_3 reductions are not offset as much by CO_2 as they are for the other three crops assessed in the baseline (i.e. rice, soy and wheat). Wheat is especially sensitive to temperature in the tropics, and since the mitigation measures do not affect temperature much (Section 3.4.1) there is not a large benefit. Nothing in particular stands out about rice, but it seems that the CO_2, temperature and O_3 effects largely cancel one another out, so the net impact is small, whereas they do not offset each other so neatly for soy. Each crop has different temperature, O_3, precipitation and CO_2 sensitivities, as described in Shindell *et al.* (2019) and based primarily on the meta-analysis of Challinor *et al.* (2014) for meteorological variables and CO_2 and on Van Dingenen *et al.* (2009) for ozone. These can lead to substantial differences in the net impact despite the small differences in any given factor that go into the evaluation of the net impact. Uncertainties associated with variability in the climate and O_3 across the five ensemble simulations are fairly small, so that most of the projected yield changes are statistically significant with respect to that source of uncertainty (Figure 3.37).

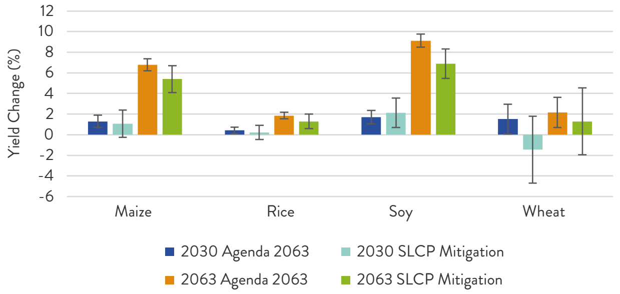

Figure 3.37 Simulated maize, rice, soy and wheat yield gains relative to baseline under the Agenda 2063 scenario by 2030 (blue) and 2063 (orange) and the short-lived climate pollutant mitigation scenario by 2030 (light blue) and 2063 (green) in response to changes in ozone, carbon dioxide, temperature and precipitation, Africa, per cent.

Note: uncertainty bars reflect the variability in the climate and O_3 across the five ensemble simulations completed for the baseline scenario and indicate when the modelled changes are statistically significant. There is additional uncertainty in the CO_2 concentration response to CO_2 emissions and in the crop impact-response functions that is not included here. Only one run was carried out for the SLCP mitigation scenario, so it has large error bars relative to the five model runs under the Agenda 2063 scenario, hence some of the changes in the SLCP mitigation scenario are not significant. Data from the GISS-E2.1-G simulations.

3.4.5 ADAPTATION TO CLIMATE CHANGE AND IMPLICATIONS OF DIFFERENT EMISSION SCENARIOS FOR THE REQUIRED ADAPTATION

HEALTH SECTOR ADAPTATION

Until about 2050, the burdens of several climate-sensitive food-, water-, and vector-borne diseases are projected to increase with higher temperatures, assuming no additional adaptation. The distribution and intensity of the transmission of malaria is expected to decrease in some areas and increase in others, with rises projected mainly along the current edges of its geographic distribution in endemic areas of Africa (Trisos *et al.* 2022). The risk of dengue will increase, with a larger spatio-temporal distribution in Africa (Trisos *et al.* 2022). Temperature increases will also lead to a higher incidence of mental illness as well as heat stress with the onset and severity determined by many other factors, such as age, geography, seasonality and temperature levels, that drive exposure (Section 1.3.3). Section 3.4.1 shows that, in terms of increasing temperatures as a result of climate change, increases projected by this Assessment and the IPCC Working Group 1 (IPCC 2021) are heavily influenced by emissions outside of Africa, making adaptation planning a priority for the continent.

For precipitation, the influence of climate change on rainfall patterns is more uncertain and the required adaptation response will vary by region (Section 3.4.1). Building climate-resilient health systems will require multi-sectoral, multi-system and collaborative efforts at all governance scales. A framework for public health adaptation to climate change in Africa was endorsed by African ministers of health in 2011 (WHO ROA 2011). During UNFCCC's COP26, the WHO launched its strategy for building resilient and low carbon health systems, a comprehensive guide to building adaptation plans that is available online for member states. It broadly covers strategies for financing health systems, strengthening health workforces, building resilience of health infrastructure, and strengthening surveillance and emergency response systems. By May 2022, 19 of the 47 WHO's African member states had committed to building resilient and sustainable low carbon health systems while 22 had developed Health National Adaptation Plans (H-NAPs).

Furthermore, the influence of climate change on air quality is likely to have an impact on levels of O_3 and possibly PM which affect human health (Section 1.3.3.1) and crop yields (Section 1.3.2), and so should be considered when developing adaptation strategies.

ADAPTING AGRICULTURE AND LAND-USE SECTORS

This Assessment shows that climate change and air pollution are major threats to agricultural productivity in Africa, affecting major such crops as maize, rice, soy, and wheat (section 2.6.4), and the implementation of measures under the SLCP mitigation and Agenda 2063 scenarios are estimated to result in crop-yield benefits of 1–6 per cent depending on the crop (Section 3.4.4).

Some of the measures also have direct adaptation benefits, for example, the agricultural measure aimed at reducing CH_4 emissions through the implementation of AWD for flooded rice (Measure A4, Table 3.4) is a water-saving technology that farmers can apply to reduce their irrigation water consumption in rice fields without decreasing their yields; there is also the added advantage that AWD is similar to, but not the same as, the intermittent irrigation used to control mosquitoes (CGIAR 2020).

Under UNFCCC'a KJWA, the AGNES called for rapid scaling up of tested climate-smart agricultural technologies and best practices compatible with specific agricultural systems on the continent (AGNES 2020). However, as noted in section 1.3.6.2, to 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). According to AGNES (2020), while climate-smart technologies may address productivity, adaptation/resilience and mitigation to different degrees, food security has to increase during the shift to more integrated practices (GACSA 2014). The AGNES report highlights a few key areas that resonate with this Assessment.

- Practices that reduce GHG emissions whilst improving the yield of livestock – through, for example, measures to improve genetics and forage – could have a positive impact on farmers' yields and incomes. These relate to the agricultural measures to increase productivity of livestock, reduce the emissions intensity of meat and dairy production, and increase the digestibility of feed to reduce CH_4 emissions from enteric fermentation (Measures A1 and A2, Table 3.4).
- Integrated soil fertility management using inorganic and organic fertilizers relates to the agricultural measures to switch to manure management systems with lower CH_4 and N emissions (Measures A3, Table 3.4).

Another important consideration for adapting agriculture and land-use practices is alternative land-use management to reduce the burning of savanna and grasslands as well as crop residues. In this Assessment, only the elimination of open burning of agricultural residues was modelled (Section 3.2.5.2; Measure A5, Table 3.4). The treatment of land-use change and the forestry sector is discussed in Section 3.2.6.2.

3.5 IMPLICATIONS OF AGENDA 2063 INTERVENTIONS FOR AFRICA'S DEVELOPMENT PRIORITIES

MAIN MESSAGES

PARIS AGREEMENT ON CLIMATE CHANGE

- Implementing the recommended measures could contribute substantially to keeping global emissions within limits that are compatible with 1.5°C and 2°C scenarios. This is particularly true for mitigating methane emissions, especially in the near term.
- Given Africa's development path, the Assessment found that Africa is likely to emit more than half of the global greenhouse gas emissions consistent with a 1.5°C scenario by 2050. This is the case if Africa follows the baseline and the rest of the world is limiting emissions consistent with achieving the Paris Agreement under the most optimistic circumstances, emphasizing the critical importance of implementing the 37 measures across Africa.
- If countries outside Africa are to help limit warming to 1.5°C, they need to drastically reduce their own emissions, to help Africa avoid the worst impacts of climate change and reduce the cost of adaptation.

AGENDA 2030 AND THE SDGS

- The recommended measures align closely with the goals and targets of the SDGs. Thirty five of the 37 recommended measures relate closely to SDG 11: Make cities and human settlements inclusive, safe, resilient, and sustainable and SDG 12: Ensure sustainable consumption and production patterns. Other measures align with SDG 7: Affordable and clean energy, household energy measures relate to SDG 5: Gender equality, and the greenhouse gas reductions from all the measures relate to SDG 13: Climate action.

3.5.1 IMPLICATIONS FOR THE ACHIEVEMENT OF THE PARIS AGREEMENT

The 2015 Paris Agreement includes the goal of limiting global temperature increases to "*well below 2 °C*", and to pursue "*efforts to limit the temperature increase to 1.5 °C above pre-industrial levels*". The Paris Agreement commits Parties to submit NDCs every five years to achieve these collective goals. All African countries have signed the Paris Agreement, and all but two countries have ratified it – Eritrea and Libya signed the Agreement in 2016 but are yet to ratify it. As a result, 53 African countries have submitted NDCs, outlining their commitment to reducing GHGs, as well as adaptation, financing, technology transfer and capacity-building priorities.

The contribution of Africa to climate change is currently very small compared to other regions (Table 3.8). In 2018, Africa was estimated to emit 4 per cent of total global CO_2 emissions, 13 per cent of global CH_4 emissions, and 12 per cent of global N_2O emissions (Crippa *et al.* 2021). The IPCC's 6th Assessment Report and Special Report on 1.5 °C of warming both emphasize the need for rapid reductions in GHG emissions, achieving net-zero CO_2 emissions between 2050 and 2055 to limit global temperature increases to 1.5 °C (50 per cent probability), and between 2070–2075 to limit global temperature increases to below 2 °C. In other GHGs, scenarios that limit global temperature increases to 1.5 °C, CH_4 is reduced by

33 per cent in 2030 and 50 per cent in 2050. Table 3.9 shows the global GHG emissions emitted in 2030 and 2050 in scenarios evaluated in the IPCC's 6th Assessment Report that were consistent with limiting global temperature increases to less than 1.5 °C and 2 °C. The global GHG emissions in these scenarios allow comparison with the GHG emission results for Africa in this Assessment (Table 3.10).

Comparison of the global GHG emissions consistent with achieving the Paris Agreement's temperature limits and Africa's projected GHG emissions shows that currently Africa makes a small contribution to global GHG emissions. As the permissible global GHG emissions to limit global temperatures to 1.5 or 2 °C reduces, however, Africa's projected emissions become a substantially larger fraction of global ones. Limiting global temperature increases to 1.5 °C, for example, requires global GHG emissions to fall so that fewer than 9 billion tonnes of GHG emissions are emitted in 2050. In the baseline scenario in this Assessment, Africa's GHG emissions alone exceed this 2050 1.5 °C-compatible level. Implementation of the measures in the SLCP mitigation scenario would still result in Africa emitting more than 80 per cent of the permissible global GHG emissions. Full implementation of all measures within this Assessment's Agenda 2063 scenario would still result in Africa emitting 54 per cent of the global GHG emissions in the 1.5 °C scenario.

For individual GHGs, Africa is projected to emit a substantially larger fraction of global CO_2 that can be emitted if global temperature increases are to be limited to 1.5 °C in all the scenarios included in this Assessment. To limit global temperature increases to 2 °C, Africa is projected to emit over one third of the permissible CO_2 emissions under the Agenda 2063 scenario. For CH_4, baseline emissions projections in 2050 for Africa are 80 per cent of those permissible in the 1.5 °C temperature-limit scenario but reduce to only 26 per cent if all the measures in the Agenda 2063 scenario are implemented.

The necessary reductions in GHG emissions to achieve the Paris Agreement, and the projected changes in GHG emissions across Africa, imply that, by the middle of the 21st Century:

1. Africa cannot follow a baseline emissions pathway without exceeding the global GHG emission level that is consistent with limiting global temperature increases to well below 1.5 °C;
2. in the most ambitious mitigation scenario implemented in this Assessment, Africa will emit more than half of the permissible global GHG emissions consistent with a 1.5 °C temperature limit;
3. implementing the mitigation measures included in this study, particularly the CH_4-focused mitigation measures, can make a substantial contribution to keeping global emissions within limits compatible with 1.5 °C and 2 °C of warming;
4. it is imperative that countries outside of Africa implement substantial reductions in their GHG emissions to allow for the possible pathway to achieve 1.5 °C, and to compensate for Africa's increasing share of GHG emissions;
5. additional mitigation measures implemented in Africa, over and above those modelled in this study, could further contribute to limiting global GHG emissions to within 1.5 °C-compatible levels.

Table 3.8 Historic greenhouse gas emissions for Africa and the world

EMISSION	LOCATION	UNITS	YEAR	EMISSIONS	SOURCE
CARBON DIOXIDE	Africa	Million metric tonnes	2018	1,385 (excluding Forestry and Other Land Use)	This Assessment
CARBON DIOXIDE	Africa	Million metric tonnes	2018	1,464 (excluding Forestry and Other Land Use)	EDGAR
CARBON DIOXIDE	Global	Million Metric tonnes	2018	37,687	EDGAR
METHANE	Africa	Million metric tonnes	2018	48.4	This Assessment
METHANE	Africa	Million metric tonnes	2018	50.5	EDGAR
METHANE	Global	Million metric tonnes	2018	375	EDGAR
NITROUS OXIDE	Africa	Million metric tonnes	2018	0.90	This Assessment
NITROUS OXIDE	Africa	Million metric tonnes	2018	1.13	EDGAR
NITROUS OXIDE	Global	Million metric tonnes	2018	9.16	EDGAR
GHGS	Africa	Million metric tonnes	2018	4,147	This Assessment
GHGS	Africa	Million metric tonnes	2018	3,277	EDGAR
GHGS	Global	Million Metric tonnes	2018	51,363	EDGAR

Table 3.9 Greenhouse gas emissions for Africa – IPCC projections for 2030 and 2050

EMISSION	LOCATION	UNITS	YEAR	EMISSIONS	SOURCE
GHGS	Global	Million metric tonnes CO_2-eq	2030 2050	31,000 9,000	IPCC AR6 WGIII Table 3.2 Scenario: Below 1.5°C with no or limited overshoot
GHGS	Global	Million metric tonnes CO_2-eq	2030 2050	44,000 20,000	IPCC AR6 WGIII Table 3.2 Scenario: Likely below 2°C
GHGS	Global	Million metric tonnes CO_2-eq	2030 2050	50,000 28,000	IPCC AR6 WGIII Table 3.2 Scenario: Below 2°C
CARBON DIOXIDE	Global	Million metric tonnes	2030 2050	24,532 671	IPCC Special Report on 1.5 degrees warming Scenario: 1.5°C scenario with no or limited overshoot
METHANE	Global	Million metric tonnes	2030 2050	226 169	IPCC Special Report on 1.5 degrees warming Scenario: 1.5°C scenario with no or limited overshoot
NITROUS OXIDE	Global	Million metric tonnes	2030 2050	8.575 8.127	IPCC Special Report on 1.5 degrees warming Scenario: 1.5°C scenario with no or limited overshoot
CARBON DIOXIDE	Global	Million metric tonnes	2030 2050	27,434 9,248	IPCC Special Report on 1.5 degrees warming Scenario: Below 2°C
METHANE	Global	Million metric tonnes	2030 2050	270 194	IPCC Special Report on 1.5 degrees warming Scenario: Below 2°C
NITROUS OXIDE	Global	Million metric tonnes	2030 2050	9.087 8.599	IPCC Special Report on 1.5 degrees warming Scenario: Below 2°C

Table 3.10 Greenhouse gas emissions for Africa – future projections 2030, 2050 and 2063

EMISSION	LOCATION	UNITS	YEAR	EMISSIONS
GHGS	Africa	Million metric tonnes CO_2-eq	2030	Baseline: 5,479; SLCP: 4,762; Agenda 2063: 4,127
GHGS	Africa	Million metric tonnes CO_2-eq	2050	Baseline: 9,496; SLCP: 7,566; Agenda 2063: 4,897
GHGS	Africa	Million metric tonnes CO_2-eq	2063	Baseline: 14,418; SLCP: 11,361; Agenda 2063: 5,440
CARBON DIOXIDE	Africa	Million metric tonnes	2030	Baseline: 3,053; SLCP: 3,008; Agenda 2063: 2,797
CARBON DIOXIDE	Africa	Million metric tonnes	2050	Baseline: 4,546; SLCP: 4,367; Agenda 2063: 3,082
CARBON DIOXIDE	Africa	Million metric tonnes	2063	Baseline: 6771; SLCP: 6421; Agenda 2063: 3022
METHANE	Africa	Million metric tonnes	2030	Baseline: 69.1; SLCP: 48.1; Agenda 2063: 35.6
METHANE	Africa	Million metric tonnes	2050	Baseline: 136.2; SLCP: 83.3; Agenda 2063: 44.2
METHANE	Africa	Million metric tonnes	2063	Baseline: 207.7; SLCP: 123.1; Agenda 2063: 53.9
NITROUS OXIDE	Africa	Million metric tonnes	2030	Baseline: 1.46; SLCP: 1.46; Agenda 2063: 1.04
NITROUS OXIDE	Africa	Million metric tonnes	2050	Baseline: 3.4; SLCP: 3.7; Agenda 2063: 2.1
NITROUS OXIDE	Africa	Million metric tonnes	2063	Baseline: 5.6; SLCP: 6.6; Agenda 2063: 3.4

3.5.2 IMPLICATIONS FOR ACHIEVEMENT OF THE AGENDA 2030 SUSTAINABLE DEVELOPMENT GOALS

The 37 measures modelled in this Assessment under the SLCP mitigation and Agenda 2063 scenarios align closely with the goals and targets of the Agenda 2030 SDGs, as shown in Tables 3.11–3.15 and Annex 3.1 . Most noticeably, all but two of this Assessment's measures cover SDG 11 Sustainable cities and communities and 12 Responsible consumption and production.

TRANSPORT SECTOR

The eight measures modelled in the transport sector relate to six different SDGs. These measures are strongly associated with SDG 3, in particular the targets to reduce premature, maternal and under-5 mortality, as well as with SDG 7, Affordable and clean energy (Annex 3.1).

Table 3.11 The transport measures modelled in this Assessment and how they link to the Sustainable Development Goals and their targets. The colour signifies that the measure is related to the associated Sustainable Development Goal and the number signifies how many targets it relates to within that goal

MEASURE DESCRIPTION	SUSTAINABLE DEVELOPMENT GOAL																	NUMBER OF SDG TARGETS THE MEASURE RELATES TO
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Electric			4				2	1	1		3	2						13
Public Transport			3				2	1			3	1						10
Non-Motorized Transport			4					1	1		3	1						10
Switch Freight from Road to Rail			4				1	1	1		3	1						11
Advanced Emissions Controls for Road Vehicles			3				1				3	2						9
Hybrid Vehicles			1				2	3			2	2						10
Rail Electrification							2	3	1		2	2						10
Road Freight Electrification			4				2	1	1		3	2						13

RESIDENTIAL SECTOR

The five measures modelled for the residential sector under the SLCP mitigation and Agenda 2063 scenarios closely link to SDGs 3 Good health and well-being, 4 Quality education, 7 Affordable and clean energy and 8 Decent work and economic growth. Clean lighting and clean cookstoves relate to 18 and 17 different SDG targets, respectively. Every measure for the residential sector accords with the SDG target 8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10 Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead (Annex 3.1).

Table 3.12 Residential sector measures modelled in this Assessment and how they link to the Sustainable Development Goals and their targets. The colour signifies that the measure is related to the associated Sustainable Development Goal and the number signifies how many targets it relates to within that goal

MEASURE DESCRIPTION	SUSTAINABLE DEVELOPMENT GOAL																	NUMBER OF SDG TARGETS THE MEASURE RELATES TO
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Efficient Air Conditioning							1	1			2	1						5
Clean Lighting	2		3	4	1		2	1	1		3	1						18
Efficient Refrigeration							1	1			2	1						5
Clean Cookstoves	2		3	3	1		2	1	1		3	1						17
Other household energy efficiency							1	1			2	1						5

OTHER ENERGY SECTOR MEASURES

The energy sector, along with the other sectors modelled in this Assessment, has strong links with SDG 7 Affordable and clean energy and 8 Decent work and economic growth. A key measure to highlight in this sector is E3 Industrial energy efficiency, as this links to seven different targets within SDG 9 Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.

Table 3.13 The energy sector measures modelled in this Assessment and how they link to the Sustainable Development Goals and their targets. The colour signifies that the measure is related to the associated Sustainable Development Goal and the number signifies how many targets it relates to within that goal

MEASURE DESCRIPTION	SUSTAINABLE DEVELOPMENT GOAL																	NUMBER OF SDG TARGETS THE MEASURE RELATES TO
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Transmission and Distribution Loss Reduction		1	3				2	5	1		2	2						16
Efficient Charcoal Making			3				2	3			2	1						11
Industrial Energy Efficiency			3				3	3	7		2	2						20
Service Sector Energy Efficiency				3			1	2	1		3	4						14
Post-Combustion Emission Controls in Industry								3	5		1	2						11
Coal Methane Capture							2	3			1	1						7
Oil and Gas Methane Emissions							2	5			1	1						9
Reduce Demand for Cement			3					1	6		3	4						17
CCS in Carbon Intensive Industries and Electric Generation							1		1		1	2						5
Renewable Electric Generation (Solar, Wind, Geothermal, Hydropower)			3				2	3	1		2	2						13
Industrial processes and product use (IPPU) - HFCs								1			1	3						5

AGRICULTURAL SECTOR

The agricultural sector modelling links to 10 different SDGs. The specific mitigation measure A5 Eliminating open burning of waste links to 28 different SDG targets, the most of all the measures modelled in this Assessment, closely followed by A6 Reducing food waste at point of consumption and A1 Increase productivity of livestock herd to reduce emissions intensity of meat and dairy (Table 3.14). The agricultural sector, unlike others, links to SGD 15 Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

Table 3.14 The agricultural sector measures modelled in this Assessment and how they link to the Sustainable Development Goals and their targets. The colour signifies that the measure is related to the associated Sustainable Development Goal and the number signifies how many targets it relates to within that goal

MEASURE DESCRIPTION	SUSTAINABLE DEVELOPMENT GOAL																	NUMBER OF SDG TARGETS THE MEASURE RELATES TO
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Increase productivity of livestock herd to reduce emission intensity of meat and dairy		5	3			2		3		1	1	4			6			25
Increase digestibility of feed to reduce methane emissions from enteric fermentation		5	2			2				1		4						14
Switch to manure management systems with lower methane and nitrogen emissions		3	3				1	5		1	1	3						17
Implementation of alternate wetting and drying for flooded rice	1	5	2			2		1		2		3						16
Eliminate open burning of agricultural residues	1	5	3			2	1	1		2	3	4			6			28
Reduce food waste at point of consumption	1	4	3			2		3	5		2	5			1			26
Shift in diets to reduce red meat consumption and increase plant-based protein sources		3	3					1		1	2	3			6			19

WASTE SECTOR

Every measure in the waste sector directly relates to SDG 8 Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all, and to targets 8.1–8.5 (Annex 3.1). As well as this, all measures relate to SDG 6 Ensure availability and sustainable management of water and sanitation for all. The measure W5 Reduce organic waste generation spans seven SDGs and relates to 20 different targets.

Table 3.15 Waste sector measures modelled in this Assessment and how they link to the Sustainable Development Goals and their targets. The colour signifies that the measure is related to the associated Sustainable Development Goal and the number signifies how many targets it relates to within that goal

MEASURE DESCRIPTION	SUSTAINABLE DEVELOPMENT GOAL																	NUMBER OF SDG TARGETS THE MEASURE RELATES TO
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	
Implementation of best practise landfill management to reduce open burning of waste, and methane capture at landfills			3			2		5	1		2	4						17
Methane capture at wastewater treatment plants						4	1	5	1		2	3						16
Implement waste collection and development of formal landfill sites			3			2		5	1		2	4						17
Diversion of organic waste to composting or biogas			3			2	1	5			2	5						18
Reduce organic waste generation	1	3	3			2		5			2	4						20
Universal access to improved water and sanitation services						4	1	5	1		2	3						16

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ANNEX 3.1 LIST OF SDG GOALS, TARGETS AND INDICATORS WHICH RELATE TO THE MEASURES MODELLED BY THE ASSESSMENT

MEASURE DESCRIPTION	SDG1	SDG2	SDG3	SDG4	SDG5	SDG6	SDG7	SDG8	SDG9	SDG 10	SDG 11	SDG 12	SDG 13	SDG 14	SDG 15	SDG 16	SDG 17
Electric			3.1 3.2 3.4 3.6				7.1 7.b	8.4	9.1		11.2 11.6 11.b	12.2 12.6					
Public Transport			3.1 3.2 3.4				7.3 7.b	8.4			11.2 11.6 11.b	12.2					
Non-Motorized Transport			3.1 3.2 3.4 3.6					8.4	9.1		11.2 11.6 11.b	12.2					
Switch Freight from Road to Rail			3.1 3.2 3.4 3.6				7.1	8.4	9.1		11.6 11.b	12.2 12.6					
Advanced Emissions Controls for Road Vehicles			3.1 3.2 3.4				7.1				11.2 11.6 11.b	12.2 12.6					
Hybrid Vehicles			3.6				7.1 7.3	8.4			11.2 11.b	12.2 12.6					
Rail Electrification							7.3 7.b	8.1 8.2 8.4	9.1		11.2 11.b	12.1 12.6					
Road Freight Electrification			3.1 3.2 3.4 3.6				7.1 7.b	8.4	9.1		11.2 11.6 11.b	12.2 12.6					
Efficient Air Conditioning							7.3	8.4			11.6 11.b	12.2					
Clean Lighting	1.1 1.2		3.1 3.2 3.4	4.1 4.2 4.5 4.6	5.4		7.1 7.b	8.4	9.1		11.1 11.6 11.b	12.2					
Efficient Refrigeration							7.3	8.4			11.6 11.b	12.2					
Clean Cookstoves	1.1 1.2		3.1 3.2 3.4	4.1 4.2 4.5	5.4		7.1 7.b	8.4	9.1		11.1 11.6 11.b	12.2					
Other household energy efficiency							7.3	8.4			11.6 11.b	12.2					
Transmission and Distribution Loss Reduction		2a	3.1 3.2 3.4				7.3 7.b	8.1 8.2 8.3 8.4 8.5	9.1		11.6 11.b	12.2 12.6					
Efficient Charcoal Making			3.1 3.2 3.4				7.3 7.b	8.1 8.2 8.4			11.6 11.b	12.6					
Industrial Energy Efficiency			3.1 3.2 3.4				7.1 7.3 7.b	8.1 8.2 8.4	9.1 9.2 9.3 9.4 9.5 9.a 9.b		11.6 11.b	12.2 12.6					
Service Sector Energy Efficiency				4.1 4.2 4.a			7.3	8.4 8.9	9.1		11.3 11.6 11.b	12.2 12.6 12.7 12.b					
Post-Combustion Emission Controls in Industry								8.1 8.2 8.4	9.2 9.4 9.5 9.a 9.b		11.b	12.2 12.6					
Coal Methane Capture							7.3 7.b	8.1 8.2 8.4			11.b	12.6					

Oil and Gas Methane Emissions							7.3 7.b	8.1 8.2 8.3 8.4 8.5			11.b	12.6					
Reduce Demand for Cement			3.1 3.2 3.4					8.4	9.1 9.2 9.4 9.5 9.a 9.b		11.6 11.b	12.1 12.2 12.5 12.6					
CCS in Carbon Intensive Industries and Electric Generation							7.b		9.1		11.b	12.2 12.6					
Renewable Electric Generation (Solar, Wind, Geothermal, Hydropower)			3.1 3.2 3.4				7.2 7.b	8.3 8.4 8.5	9.1		11.6 11.b	12.2 12.6					
Industrial processes and product use (IPPU) - HFCs								8.4			11.b	12.1 12.2 12.6					
Increase productivity of livestock herd to reduce emission intensity of meat and dairy		2.1 2.2 2.3 2.4 2.a	3.1 3.2 3.4			6.3 6.5		8.3 8.4 8.5		10.1	11.6	12.1 12.2 12.3 12.6			15.1 15.2 15.5 15.8 15.9 15.a		
Increase digestibility of feed to reduce methane emissions from enteric fermentation		2.1 2.2 2.3 2.4 2.a	3.2 3.4			6.4 6.5				10.1		12.1 12.2 12.3 12.6					
Switch to manure management systems with lower methane and nitrogen emissions		2.3 2.4 2.a	3.1 3.2 3.4				7.1	8.1 8.2 8.3 8.4 8.5		10.1	11.6	12.1 12.2 12.6					
Implementation of alternate wetting and drying for flooded rice	1.5	2.1 2.2 2.3 2.4 2.a	3.2 3.4			6.4 6.5		8.4		10.1 10.7		12.1 12.2 12.6					
Eliminate open burning of agricultural residues	1.5	2.1 2.2 2.3 2.4 2.a	3.1 3.2 3.4			6.4 6.5	7.1	8.4		10.1 10.7	11.5 11.6 11.b	12.1 12.2 12.3 12.6			15.1 15.2 15.5 15.8 15.9 15.a		
Reduce food waste at point of consumption	1.5	2.1 2.2 2.3 2.4	3.1 3.2 3.4			6.3 6.5		8.1 8.3 8.4	9.2 9.4 9.5 9.a 9.b		11.6 11.b	12.1 12.2 12.3 12.5 12.6			15.1		
Shift in diets to reduce red meat consumption and increase plant-based protein sources		2.3 2.4 2.a	3.1 3.2 3.4					8.4		10.1	11.6 11.b	12.1 12.2 12.6			15.1 15.2 15.5 15.8 15.9 15.a		
Implementation of best practise landfill management to reduce open burning of waste, and methane capture at landfills			3.1 3.2 3.4			6.3 6.5		8.1 8.2 8.3 8.4 8.5	9.1		11.6 11.b	12.1 12.2 12.4 12.6					
Methane capture at wastewater treatment plants						6.2 6.3 6.4 6.5	7.1	8.1 8.2 8.3 8.4 8.5	9.1		11.6 11.b	12.1 12.2 12.6					
Implement waste collection and development of formal landfill sites			3.1 3.2 3.4			6.3 6.5		8.1 8.2 8.3 8.4 8.5	9.1		11.6 11.b	12.1 12.2 12.4 12.6					
Diversion of organic waste to composting or biogas			3.1 3.2 3.4			6.3 6.5	7.1	8.1 8.2 8.3 8.4 8.5			11.6 11.b	12.1 12.2 12.3 12.4 12.6					
Reduce organic waste generation	1.5	2.1 2.2 2.4	3.1 3.2 3.4			6.3 6.5		8.1 8.2 8.3 8.4 8.5			11.6 11.b	12.1 12.2 12.4 12.6					
Universal access to improved water and sanitation services						6.2 6.3 6.4 6.5	7.1	8.1 8.2 8.3 8.4 8.5	9.1		11.6 11.b	12.1 12.2 12.6					

GOAL 1. END POVERTY IN ALL ITS FORMS EVERYWHERE

1.1 By 2030, eradicate extreme poverty for all people everywhere, currently measured as people living on less than $1.25 a day

1.2 By 2030, reduce at least by half the proportion of men, women and children of all ages living in poverty in all its dimensions according to national definitions

1.5 By 2030, build the resilience of the poor and those in vulnerable situations and reduce their exposure and vulnerability to climate-related extreme events and other economic, social and environmental shocks and disasters

GOAL 2. END HUNGER, ACHIEVE FOOD SECURITY AND IMPROVED NUTRITION AND PROMOTE SUSTAINABLE AGRICULTURE

2.1 By 2030, end hunger and ensure access by all people, in particular the poor and people in vulnerable situations, including infants, to safe, nutritious and sufficient food all year round

2.2 By 2030, end all forms of malnutrition, including achieving, by 2025, the internationally agreed targets on stunting and wasting in children under 5 years of age, and address the nutritional needs of adolescent girls, pregnant and lactating women and older persons

2.3 By 2030, double the agricultural productivity and incomes of small-scale food producers, in particular women, indigenous peoples, family farmers, pastoralists and fishers, including through secure and equal access to land, other productive resources and inputs, knowledge, financial services, markets and opportunities for value addition and non-farm employment

2.4 By 2030, ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality

2.a Increase investment, including through enhanced international cooperation, in rural infrastructure, agricultural research and extension services, technology development and plant and livestock gene banks in order to enhance agricultural productive capacity in developing countries, in particular least developed countries

GOAL 3. ENSURE HEALTHY LIVES AND PROMOTE WELL-BEING FOR ALL AT ALL AGES

3.1 By 2030, reduce the global maternal mortality ratio to less than 70 per 100,000 live births

3.2 By 2030, end preventable deaths of newborns and children under 5 years of age, with all countries aiming to reduce neonatal mortality to at least as low as 12 per 1,000 live births and under-5 mortality to at least as low as 25 per 1,000 live births

3.4 By 2030, reduce by one third premature mortality from non-communicable diseases through prevention and treatment and promote mental health and well-being

3.6 By 2020, halve the number of global deaths and injuries from road traffic accidents

GOAL 4. ENSURE INCLUSIVE AND EQUITABLE QUALITY EDUCATION AND PROMOTE LIFELONG LEARNING OPPORTUNITIES FOR ALL

4.1 By 2030, ensure that all girls and boys complete free, equitable and quality primary and secondary education leading to relevant and effective learning outcomes

4.2 By 2030, ensure that all girls and boys have access to quality early childhood development, care and pre-primary education so that they are ready for primary education

4.5 By 2030, eliminate gender disparities in education and ensure equal access to all levels of education and vocational training for the vulnerable, including persons with disabilities, indigenous peoples and children in vulnerable situations

4.6 By 2030, ensure that all youth and a substantial proportion of adults, both men and women, achieve literacy and numeracy

4.a Build and upgrade education facilities that are child, disability and gender sensitive and provide safe, non-violent, inclusive and effective learning environments for all

GOAL 5. ACHIEVE GENDER EQUALITY AND EMPOWER ALL WOMEN AND GIRLS

5.4 Recognize and value unpaid care and domestic work through the provision of public services, infrastructure and social protection policies and the promotion of shared responsibility within the household and the family as nationally appropriate

GOAL 6. ENSURE AVAILABILITY AND SUSTAINABLE MANAGEMENT OF WATER AND SANITATION FOR ALL

6.2 By 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations

6.3 By 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally

6.4 By 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity

6.5 By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate

GOAL 7. ENSURE ACCESS TO AFFORDABLE, RELIABLE, SUSTAINABLE AND MODERN ENERGY FOR ALL

7.1 By 2030, ensure universal access to affordable, reliable and modern energy services

7.2 By 2030, increase substantially the share of renewable energy in the global energy mix

7.3 By 2030, double the global rate of improvement in energy efficiency

7.b By 2030, expand infrastructure and upgrade technology for supplying modern and sustainable energy services for all in developing countries, in particular least developed countries, small island developing States and landlocked developing countries, in accordance with their respective programmes of support

GOAL 8. PROMOTE SUSTAINED, INCLUSIVE AND SUSTAINABLE ECONOMIC GROWTH, FULL AND PRODUCTIVE EMPLOYMENT AND DECENT WORK FOR ALL

8.1 Sustain per capita economic growth in accordance with national circumstances and, in particular, at least 7 per cent gross domestic product growth per annum in the least developed countries

8.2 Achieve higher levels of economic productivity through diversification, technological upgrading and innovation, including through a focus on high-value added and labour-intensive sectors

8.3 Promote development-oriented policies that support productive activities, decent job creation, entrepreneurship, creativity and innovation, and encourage the formalization and growth of micro-, small- and medium-sized enterprises, including through access to financial services

8.4 Improve progressively, through 2030, global resource efficiency in consumption and production and endeavour to decouple economic growth from environmental degradation, in accordance with the 10Year Framework of Programmes on Sustainable Consumption and Production, with developed countries taking the lead

8.5 By 2030, achieve full and productive employment and decent work for all women and men, including for young people and persons with disabilities, and equal pay for work of equal value

8.9 By 2030, devise and implement policies to promote sustainable tourism that creates jobs and promotes local culture and products

GOAL 9. BUILD RESILIENT INFRASTRUCTURE, PROMOTE INCLUSIVE AND SUSTAINABLE INDUSTRIALIZATION AND FOSTER INNOVATION

9.1 Develop quality, reliable, sustainable, and resilient infrastructure, including regional and trans-border infrastructure, to support economic development and human well-being, with a focus on affordable and equitable access for all

9.2 Promote inclusive and sustainable industrialization and, by 2030, significantly raise industry's share of employment and gross domestic product, in line with national circumstances, and double its share in least developed countries

9.3 Increase the access of small-scale industrial and other enterprises, in particular in developing countries, to financial services, including affordable credit, and their integration into value chains and markets

9.4 By 2030, upgrade infrastructure and retrofit industries to make them sustainable, with increased resource-use efficiency and greater adoption of clean and environmentally sound technologies and industrial processes, with all countries taking action in accordance with their respective capabilities

9.5 Enhance scientific research, upgrade the technological capabilities of industrial sectors in all countries, in particular developing countries, including, by 2030, encouraging innovation and substantially increasing the number of research and development workers per 1 million people and public and private research and development spending

9.a Facilitate sustainable and resilient infrastructure development in developing countries through enhanced financial, technological and technical support to African countries, least developed countries, landlocked developing countries and small island developing States

9.b Support domestic technology development, research and innovation in developing countries, including by ensuring a conducive policy environment for, inter alia, industrial diversification and value addition to commodities

GOAL 10. REDUCE INEQUALITY WITHIN AND AMONG COUNTRIES

10.1 By 2030, progressively achieve and sustain income growth of the bottom 40 per cent of the population at a rate higher than the national average

10.7 Facilitate orderly, safe, regular and responsible migration and mobility of people, including through the implementation of planned and well-managed migration policies

GOAL 11. MAKE CITIES AND HUMAN SETTLEMENTS INCLUSIVE, SAFE, RESILIENT AND SUSTAINABLE

11.1 By 2030, ensure access for all to adequate, safe and affordable housing and basic services and upgrade slums

11.2 By 2030, provide access to safe, affordable, accessible and sustainable transport systems for all, improving road safety, notably by expanding public transport, with special attention to the needs of those in vulnerable situations, women, children, p

11.3 By 2030, enhance inclusive and sustainable urbanization and capacity for participatory, integrated and sustainable human settlement planning and management in all countries

11.6 By 2030, reduce the adverse per capita environmental impact of cities, including by paying special attention to air quality and municipal and other waste management

11.b By 2020, substantially increase the number of cities and human settlements adopting and implementing integrated policies and plans towards inclusion, resource efficiency, mitigation and adaptation to climate change, resilience to disasters, and development

GOAL 12. ENSURE SUSTAINABLE CONSUMPTION AND PRODUCTION PATTERNS

12.1 Implement the 10-Year Framework of Programmes on Sustainable Consumption and Production Patterns, all countries taking action, with developed countries taking the lead, taking into account the development and capabilities of developing countries

12.2 By 2030, achieve the sustainable management and efficient use of natural resources

12.3 By 2030, halve per capita global food waste at the retail and consumer levels and reduce food losses along production and supply chains, including post-harvest losses

12.4 By 2020, achieve the environmentally sound management of chemicals and all wastes throughout their life cycle, in accordance with agreed international frameworks, and significantly reduce their release to air, water and soil in order to minimize thei

12.5 By 2030, substantially reduce waste generation through prevention, reduction, recycling and reuse

12.6 Encourage companies, especially large and transnational companies, to adopt sustainable practices and to integrate sustainability information into their reporting cycle

12.b Develop and implement tools to monitor sustainable development impacts for sustainable tourism that creates jobs and promotes local culture and products

GOAL 15. PROTECT, RESTORE AND PROMOTE SUSTAINABLE USE OF TERRESTRIAL ECOSYSTEMS, SUSTAINABLY MANAGE FORESTS, COMBAT DESERTIFICATION, AND HALT AND REVERSE LAND DEGRADATION AND HALT BIODIVERSITY LOSS

15.1 By 2020, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains and drylands, in line with obligations under international agreements

15.2 By 2020, promote the implementation of sustainable management of all types of forests, halt deforestation, restore degraded forests and substantially increase afforestation and reforestation globally

15.5 Take urgent and significant action to reduce the degradation of natural habitats, halt the loss of biodiversity and, by 2020, protect and prevent the extinction of threatened species

15.8 By 2020, introduce measures to prevent the introduction and significantly reduce the impact of invasive alien species on land and water ecosystems and control or eradicate the priority species

15.9 By 2020, integrate ecosystem and biodiversity values into national and local planning, development processes, poverty reduction strategies and accounts

15.a Mobilize and significantly increase financial resources from all sources to conserve and sustainably use biodiversity and ecosystems

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_4	methane

CI	confidence interval
CMIP	Coupled Model Intercomparison Project
CMIP6	Sixth Coupled Model Intercomparison Project
CO	carbon monoxide
CO_2	carbon dioxide
CO_2-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 (109 watts)
GWh	gigawatt hours
GWP	Gridded Population of the World
HFC	hydrofluorocarbon
H_2O	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^2	square metre
m^3	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 (106 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
NH3	ammonia
NH4	ammonium
NIR	New Industrial Revolution
NMT	non-motorised transport
NMVOC	non-methane volatile organic compound
NO	nitric oxide
N_2O	nitrous oxide
NO_2	nitrogen dioxide
NO_x	nitrogen oxides
NREL	National Renewable Energy Laboratory
NSB	national standards body
O_x	containing oxygen

O_3	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 (O3) monitoring instrument
PCFV	Partnership for Clean Fuels and Vehicles
PIDA	Programme for Infrastructure Development in Africa
PIQ	performance intelligence quotient
PM	particulate matter
PM_1	very fine particulate matter (with a diameter of less than 1 micron)
$PM_{2.5}$	fine particulate matter (with a diameter of less than 2.5 microns)
PM_{10}	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_2	sulphur dioxide
SSP	shared socioeconomic pathway
TAREA	Tanzania Renewable Energy Association
TROPOMI	Tropospheric Monitoring Instrument
TSP	total suspended particulates
TW	terawatt (1012 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


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