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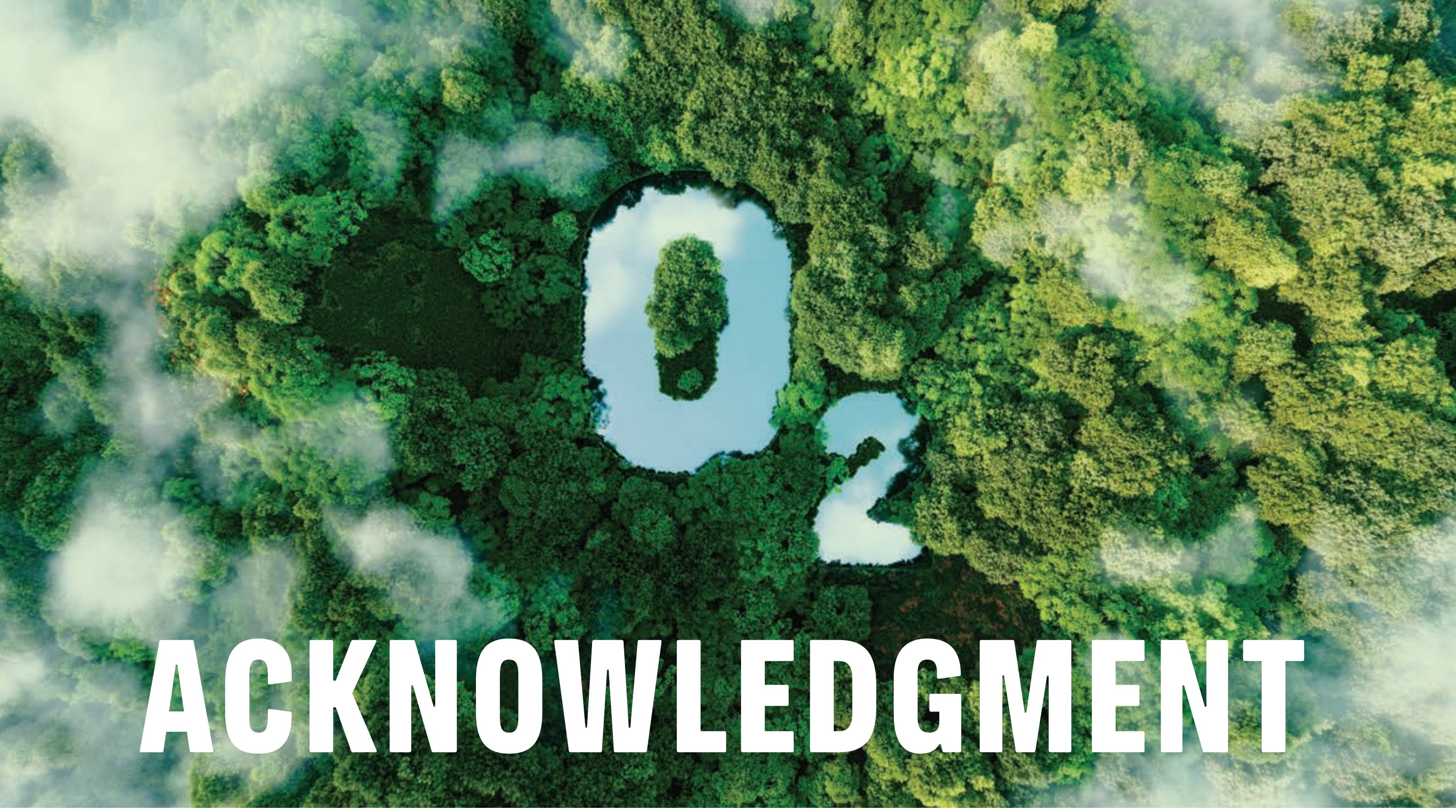
MAJOR AIR POLLUTERS IN AFRICA UNMASKED



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We would like to express our gratitude to:

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Executive Summary

This report investigates the biggest human-caused air pollution sources in Africa, especially those associated with major industrial and economic sectors and the fossil fuel industry. These emitters often have significant power and by reducing emissions could bring real benefits to affected communities.

Air pollution has vast consequences for public health in Africa, this report identifies major polluters and air pollution sources across the continent. It highlights the need for clean, renewable energy, an end to reliance on fossil fuels and combustion for energy and better regulation of air quality and emissions. These steps are critical for the well-being of people living in Africa and for the reduction of environmental injustices.

These steps are critical for the wellbeing of people living in Africa, and for the reduction of environmental injustices.

Air pollution in Africa frequently exceeds the levels recommended by the World Health Organisation, posing risks to public health. Poor air quality is a leading risk factor for deaths across Africa. However, many parts of Africa have little or no publicly available air pollution monitoring results. Therefore, this report examines emissions data to investigate African air pollution and expose major polluters.

Satellite datasets and databases of emissions can reveal the air pollutants which contribute to air quality problems in Africa, including emissions of nitrogen oxides, sulphur dioxide, non-methane volatile organic compounds and particles including black carbon. These pollutants are often closely linked to sectors responsible for significant fuel burning, and all contribute to fine particulate air pollution.

In this report, recently published satellite observations are investigated to identify Africa's biggest nitrogen dioxide and sulphur dioxide emission hotspots. Global and regional emission databases are interrogated to put these hotspots into context and to suggest which sectors and industries are the most polluting for different regions of Africa.

Key findings:

- Many of the emission hotspots identified align with thermal power plants, cement plants, metal smelters, industrial zones, or urban areas.
- Six of the world's ten largest nitrogen dioxide emission hotspots identified in this analysis were found in Africa, all of these are in South Africa.
- The ten largest nitrogen dioxide point sources identified in Africa are all thermal power stations, nine of which are in South Africa, the tenth is Azito and Vridi CIPREL (Compagnie Ivoirienne de Production d'Electricité) Power Plants in Côte d'Ivoire.
- Two of the world's ten largest sulphur dioxide emission hotspots identified in this analysis were found in Africa, and again, these are both in South Africa.
- Of the ten largest sulphur dioxide point sources identified in Africa, nine are thermal power stations and one is linked to a smelter complex in Mali. Four of the power plants are located in South Africa, two each in Morocco and Egypt, and one in Zimbabwe.
- In North Africa, emissions data suggests that the sector contributing most to nitrogen dioxide, volatile organic compounds and sulphur dioxide emissions is the energy sector. Fuel burning at home emits most black carbon.
- In West Africa, the sector contributing most to nitrogen dioxide and black carbon emissions is residential combustion. The energy sector emits most volatile organic compounds and sulphur dioxide emissions and these emissions are closely related to oil and gas infrastructure in Nigeria.

In East Africa, the sector contributing most to nitrogen dioxide and black carbon emissions is residential combustion, while the energy sector emits most volatile organic compounds and industry contributes most sulphur dioxide emissions.

In Central Africa, the sector contributing most to nitrogen dioxide, volatile organic compounds and black carbon emissions is residential combustion. Industry contributes most sulphur dioxide emissions. Poor air quality in this region has been attributed to waste burning, mining, and industrial practices such as mineral processing and cement manufacturing.

In Southern Africa, the sector contributing most to nitrogen dioxide, volatile organic compounds and sulphur dioxide emissions is the energy sector, whereas residential combustion contributes most black carbon emissions. Coal makes a very large contribution to fine particulate matter pollution. Waste burning is, both in residences and at dumps, an important factor contributing to black carbon emissions.

The United Nations project that the annual number of premature deaths linked to outdoor air pollution in Africa will rise from 930,000 in 2030 to 1.6 million in 2063.

Outdoor air pollution in Africa is projected to get worse unless prompt interventions are taken. Economic growth, population growth, unplanned urbanisation, and a lack of environmental regulation could exacerbate environmental and human health impacts. The United Nations Environment Programme's projection for the annual number of premature deaths linked to outdoor air pollution rises from 930,000 in 2030 to 1.6 million in 2063 (UNEP, 2022). Environmental regulations, including effective air quality and emissions regulations alongside significantly improved access to clean, renewable energy would help reduce inequalities and support the wellbeing of people living in Africa.

Effective solutions to Africa's air quality problems are already available. The report highlights several case studies:

- The work of environmental justice groups who used their constitutional rights to improve air quality management in Mpumalanga, South Africa.
- Malawi's "Solar Mamas" and Kobani, a company in Burundi, who bring solar energy to communities with no electricity grid.
- Young citizens embracing new technology to monitor their air quality.
- Community research in Kenya and Morocco used to hold polluters to account.
- Protest and legal action to prevent waste dumping and burning in Tunisia.

This report proposes nine actions that governments and legislators must take to address air pollutant emissions, particularly those from major industrial powers and the fossil fuel industry, to improve air quality in Africa:

1. To enact comprehensive laws for ambient air quality management and establish national air quality standards with the aim of achieving continuous improvement and air quality aligned with the science-based WHO guidelines.

2. To accelerate the development of air quality monitoring networks and strengthen existing ones to enhance estimates of population exposure to harmful air pollution. The most vulnerable communities should be prioritised. These networks must provide transparent, and timely access to data, with data reported in unambiguous physical units, at known locations, with good temporal resolution and direct online public access.

3. To monitor and report air pollutant emissions from facilities responsible for significant air pollution and to develop publicly available and independently verified pollutant release and transfer registers (PRTRs).

4. To improve access to clean, renewable energy for cooking with stronger policy actions for families in need. Governments should promote clean, renewable and affordable cooking solutions with evidence-based policies that avoid fossil and solid fuels, meet local cultural, social and gender needs and which are supported by adequate funds.

5 To urgently take steps to decrease reliance on coal, oil and gas power and make a just transition towards renewable energy, which benefits both people and the climate. While the transition towards a fully renewable system takes place, urgent action is needed to ensure the quality of fuels used in Africa meet the best international environmental standards, including for sulphur content.

6 The Mpumalanga region of South Africa stands out globally for its air pollutant emissions. The South African government should urgently and wholeheartedly implement the Highveld Priority Area Air Quality Management Plan, upholding the Pretoria High Court judgement of the 'Deadly Air' litigation. Exemptions related to already weak air pollution regulations in this region should not be considered, and coal-fired power stations reaching the end of their life should be decommissioned.

7 To take urgent steps to end oil and gas production, flaring and the use of fossil fuels in energy generation, and to achieve net-zero emissions by 2050.

8 To take stronger actions to reduce waste generation, prohibit the burning of waste, stop waste colonialism, and to provide access to effective means of waste management.

9 For African national governments, in collaboration with the international community and global north: to invest in sustainable, climate-friendly energy projects while phasing out environmentally harmful, high-emission industries that have negative impacts on public health and the climate.

CONTENTS

INTRODUCTION

Air pollution, specifically particulate matter (PM) pollution, is the second leading risk factor for death after malnutrition in Sub-saharan Africa, and the leading environmental risk factor for deaths in North Africa, posing a greater risk than unsafe water, lack of sanitation and hygiene (Murray et al 2020).

Recent reports have highlighted both dangerous pollution exposure and a vast burden of disease across the continent (e.g. IQAir 2023, HEI 2022, UNEP 2022, WHO 2023a,b). These impacts are compounded by injustices and disparities in pollution exposure, pollution monitoring and research.

Motivated to accelerate action at the root causes of these injustices, this work focuses on the nature and location of Africa's major air pollution sources, prioritising industrial scale pollution sources, especially fossil fuel pollution. The report asks, 'What are Africa's biggest air pollution sources?' It focuses on major human-made pollution sources, major industrial powers and the fossil fuel industry, while recognising those already making a difference and improving air quality.

This report considers emissions of nitrogen oxides (NO_2 and other oxides of nitrogen collectively known as NOx), sulphur dioxide (SO_2), non-methane volatile organic compounds (NMVOCs) and particles including black carbon (BC). These pollutants are often closely linked to sectors responsible for significant fuel burning. These pollutants all contribute to the production of 'secondary' particle pollution, fine particulate matter ($PM_{2.5}$), which is a leading risk factor for deaths in Africa. Once emitted into the air, exposure to each of these pollutants can be directly harmful to health.

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Africa's air quality

The World Health Organisation (WHO) has published guidelines and interim targets for pollutant concentrations (Table 1). The guidelines are informed by evidence of adverse health impacts in the scientific literature and are set such that pollution greater than that level would constitute an important risk to public health. The interim targets are designed to encourage cities, regions, and countries with high levels of air pollution to make progress towards cleaner air.

Table 1: WHO Air quality guidelines for selected pollutants (WHO 2021)

Pollutant	2021 Avg Time	2021 Interim Targets				Guideline
		1	2	3	4	
$PM_{2.5}$ (μg/m^3)	Annual	35	25	15	10	**5**
	24-hr (99th%ile)	75	50	37.5	25	**15**
NO_2 (μg/m^3)	Annual	40	30	20	-	**10**
	24-hr (99th%ile)	120	50	-	-	**25**
SO_2 (μg/m^3)	24-hr (99th%ile)	125	50	-	-	**40**

Average ambient $PM_{2.5}$ concentrations in Africa frequently exceed WHO guidelines (IQAir 2023). The WHO reports annually on locations that do and do not meet their guidelines. Their 2023 report - which uses the latest data from 2010-2019 - found that only 3% of the settlements, towns and cities assessed in the African region had air quality good enough to meet the annual average guideline for particulate matter. No settlements, towns or cities were below this guideline in the Eastern Mediterranean region[1] ($PM_{2.5}$ is assessed except when only PM_{10} data are available). In the African and Eastern Mediterranean region 0% and 2% of settlements, towns or cities were below the annual NO_2 guideline (WHO 2023a).

Despite the risk posed to public health, air quality is not sufficiently monitored across Africa. The WHO's 2023 Ambient Air Quality Database includes NO_2, $PM_{2.5}$ and PM_{10} monitoring data collected from government reports and websites, regional monitoring networks, the European Environment Agency, US embassies and scientific literature between 2010 and 2020. Data from these sources is only available for 14 countries within continental Africa (WHO 2023b). The IQAir 2022 World Air Quality Report additionally includes independently operated monitors, with 311 $PM_{2.5}$ monitors in Africa available to feed data into their report. These were located within just 19 of Africa's 54 countries (IQAir 2023, **Figure 1**).

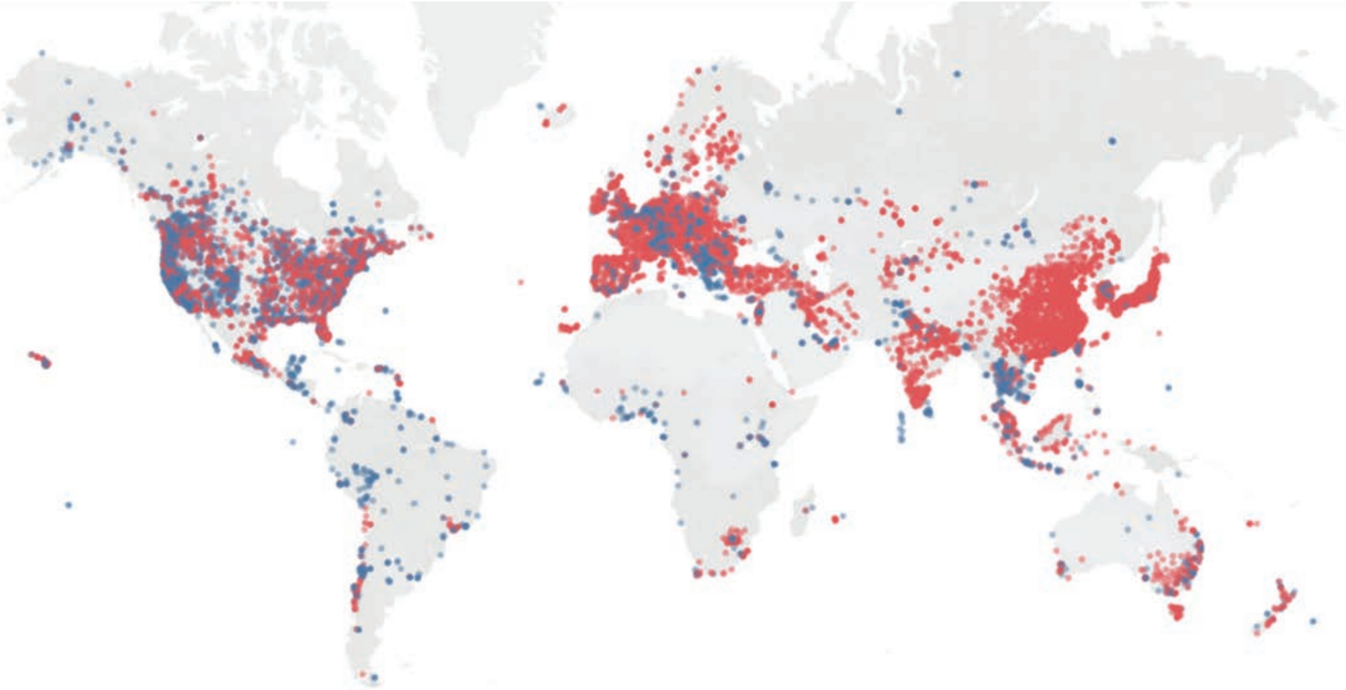

Figure 1. Illustration of the global distribution of $PM_{2.5}$ air quality monitoring stations. The stations shown are those included by IQAir in their World Air Quality Report 2022. Independently operated monitoring stations are represented by blue markers. Government stations are represented by red markers. Figure reproduced with kind permission of IQAir (IQAir 2023)

[1]The WHO's Eastern Mediterranean Region includes Djibouti, Egypt, Libya, Morocco, Somalia, Sudan, Tunisia and Yemen.


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It is difficult to specify what level of air pollution monitoring would be sufficient for each African nation. By way of an example, in each country of the EU, monitoring that can detect all breaches of air quality standards nationwide is required, and reporting must be done within 6 months (Larssen and Otto Hagen 1996). Such wide coverage can identify important areas for action, and can help reduce the number of communities, especially marginalised or vulnerable ones, that are overlooked. Extensive monitoring is not only undertaken in the Global North. For example, networks are operated in Colombia (Farrow et al 2021) and some regions in Africa have monitoring networks. The South African Air Quality Information System[2] provides data in major cities and some industrial areas.

Currently, national monitoring networks are the main basis for air quality data collection. The best means to rapidly address data gaps affecting large populations may be to develop systems that integrate different types of monitoring equipment, including low-cost sensors, satellite observation and research grade instruments (Martin et al 2019). These networks must provide transparent and timely access to data, with data reported in unambiguous physical units, at known locations, with good temporal resolution and direct online public access (Sawant et al 2022).

Air quality standards are an important policy mechanism that can drive reductions in air pollution and improve health (HEI 2022). In Africa, most countries lack national air quality standards. According to the First Global Assessment of Air Pollution Legislation (GAAPL) by the United Nations (UN) Environmental Programme (Misonne and Eloise 2021), and a review of air quality standards in eastern Mediterranean countries (Faridi et al 2023), only 19 out of the 54 African countries that are members of the UN have legislation containing ambient air quality standards. These countries are Algeria, Benin, Burkina Faso, Côte d'Ivoire, Egypt, Eswatini, Gambia, Ghana, Kenya, Mauritius, Morocco, Mozambique, Nigeria, Rwanda, Senegal, South Africa, Sudan, Tunisia and Tanzania (**Figure 2**).

[2]SAAQIS. South African Air Quality Information System. https://saaqis.environment.gov.za/

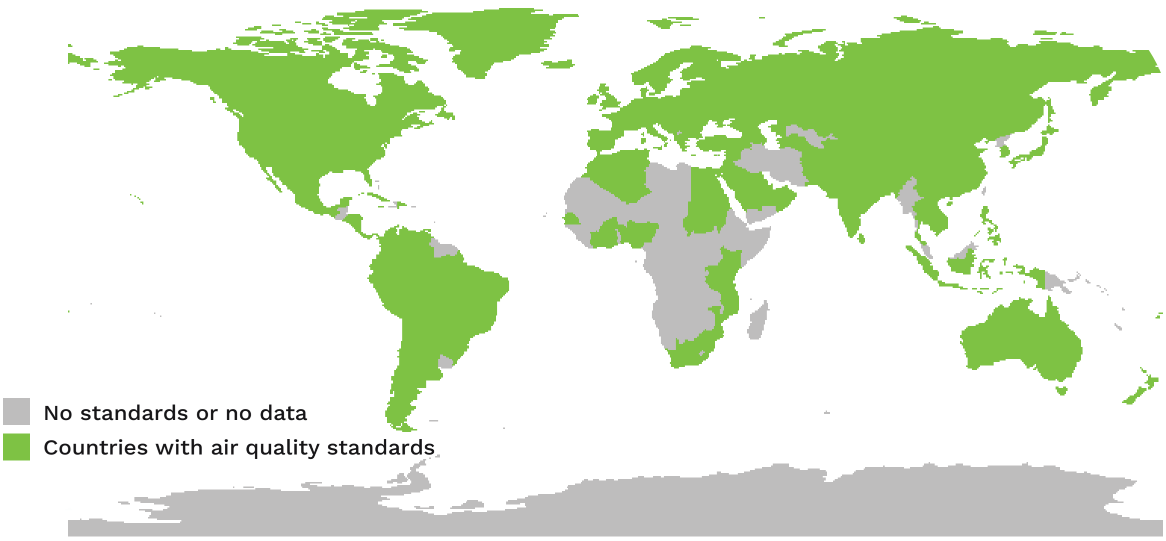

Figure 2. Countries with legislative instruments containing ambient air quality standards. (Misonne and Eloise 2021, Faridi et al 2023) Greenpeace is politically independent and does not take sides in territorial disputes. Boundaries on maps reflect legal requirements and/or the data source used.

The air pollution health burden

Exposure to air pollution is the second leading risk factor for death in Africa.

Few air pollution health impact studies have been conducted in Africa compared with other geographies; analysis of the academic literature suggests that there have been no epidemiological studies assessing long-term exposure to particulate matter air pollution and mortality for African populations (Greenstone and Hasenkopf 2023). This analysis identified 24 such studies for populations in Asia, and 60 in Europe, the US and Canada.

However, using epidemiological data from other regions, alongside African demographic and air quality data, it is possible to estimate the burden of disease from air pollution in Africa. Such analysis suggests that exposure to air pollution is the second leading risk factor for death in Africa (HEI 2022), and in the event that World Health Organisation guidelines were achieved, significant gains in life expectancy could be achieved (**Figure 3**). In Central, East, Southern, West and North Africa life expectancy increases are projected to have been as large as 2.9 years (Democratic republic of the Congo), 2.7 years (Rwanda), 1.8 years (Lesotho), 1.8 years (Nigeria) or 1.3 years (Egypt) respectively had WHO guidelines been met in 2021 (Greenstone and Hasenkopf 2023).

Wearable Tech and Youth: Bridging Data Gaps and Advocating for Clean Air

Image Credits: Twitter/ X @UrbanBetter

There exists a substantial gap in air quality data across Africa, with many African cities lacking comprehensive air quality information. In response to this pressing issue, the Cityzens for Clean Air campaign, a part of the UrbanBetter Cityzens initiative, embarked on an endeavour to collect air quality data and identify local pollution sources.

The campaign harnessed the potential of wearable sensors, leveraging technology to address the data deficit. Through a bespoke mobile application, citizen scientists participated by capturing multimedia data—photos, audio, video, and text—alongside geolocation data.

Central to the initiative was the active engagement of young people aged 18 to 35 in three prominent African cities: Cape Town, Accra, and Lagos. Adopting a citizen science approach, these youth were designated as "Run Leaders." They were assigned specific running routes organized to encompass diverse socio-economic areas within the cities. Between July and September 2022, these citizen scientists embarked on their 5-10km running routes. Accompanied by over 200 co-runners, they collectively covered significant ground.

The culmination of their efforts was showcased at the COP27 meeting in Egypt, presented through various sessions in the Youth and Health Pavilions.

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Country level gain in life expectancy if WHO $PM_{2.5}$ Guideline is met (AQLI)

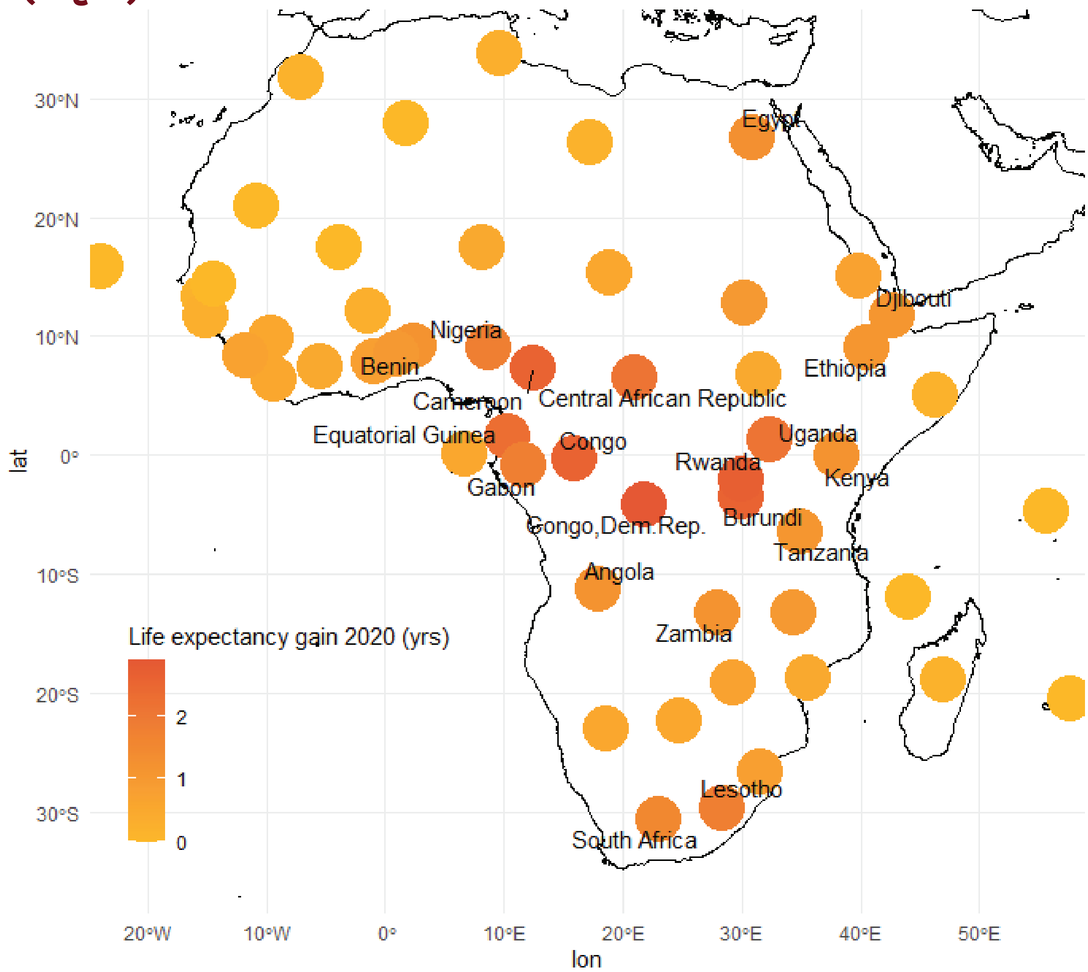

Figure 3. Gain in life expectancy that could be expected if WHO Guidelines had been met in 2021 (Greenstone and Hasenkopf 2023)

Estimates on the number of premature deaths that can be attributed to air pollution vary according to the pollutants considered, pollution sources included and methodological decisions made by the authors. In 2022, the Health Effects Institute reported that air pollution contributed to an estimated 1.1 million deaths in Africa, with 63% linked to exposure to household air pollution (HEI, 2022). Farrow et al (2020) estimated 89,000[3] deaths in Africa due to fossil fuel-related NO_2, O_3 and $PM_{2.5}$ in 2019, while Leliveld et al (2019) estimated mortality in 2015 from all $PM_{2.5}$ exposure and from fossil fuel-related $PM_{2.5}$ exposure to be 956,000[4] and 67,000[5] respectively. An analysis by Vohra et al (2021) used an approach which accounted for the varying toxicity of different types of particulate matter. This work estimated 194,000[6] premature deaths in Africa due to fossil fuel-related $PM_{2.5}$ in 2012. The wide range of estimates is due to a lack of epidemiological data in places with very high

[3] 95% confidence interval: 131,000 to 58,000
[4] 95% confidence interval: 1,145,000 to 751,000
[5] 95% confidence interval: 79,000 to 54,000
[6] 95% confidence interval: 457,000 to −237,000

$PM_{2.5}$ concentrations (> 50 μg m^{-3}); the uncertainty increases because mortality estimates need to be extrapolated from studies that looked at lower pollutant concentrations. Country-level mortality estimates from these studies are presented in **Figure 4** and Appendix **Figures A1-A2**.

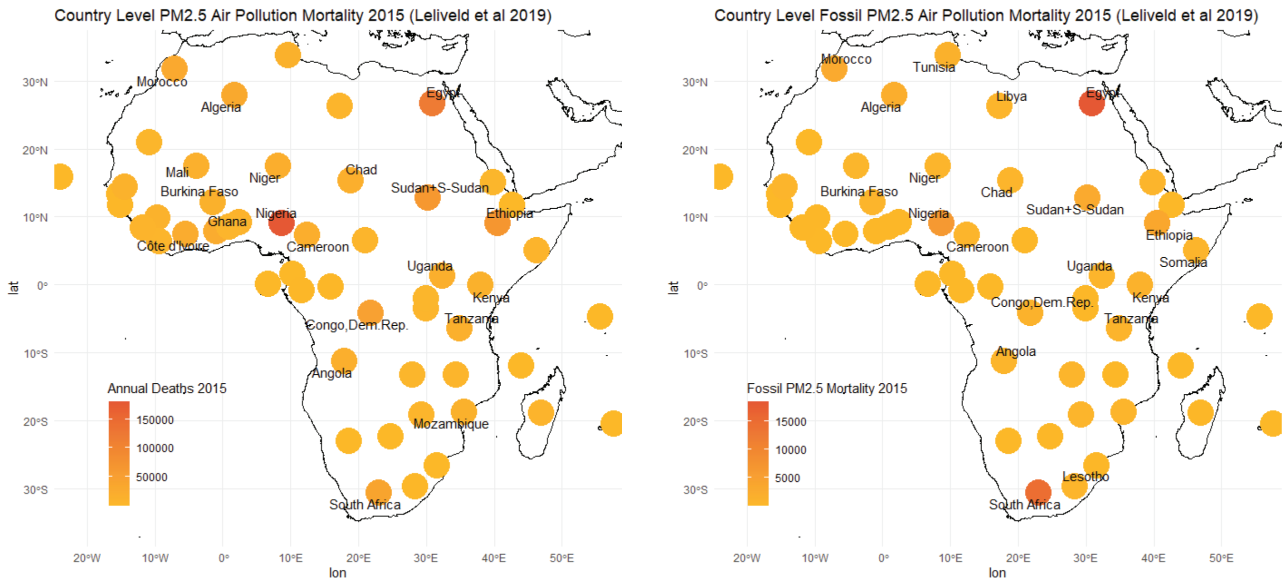

Figure 4: Estimated country-level mortality attributable to $PM_{2.5}$ pollution (Left) and Fossil Fuel $PM_{2.5}$ pollution (Right) for 2015 (Leliveld et al 2019)

While these assessments vary in magnitude, all agree that **a large number of premature deaths occur annually in Africa as a result of air pollution exposure. Egypt, Nigeria and South Africa are found to have large disease burdens**, including when only fossil fuel sources are considered in several studies (Leliveld et al 2019, Vohra et al 2021). When adjusting for country population, the North African states, South Africa and its neighbours have the highest fossil fuel-related air pollution mortality rates (**Figure 5**). Disease burden estimates where windblown dust is an important pollutant, such as in western Sub-Saharan Africa might be too high. Wind-blown dust is potentially less toxic than other sources (Lin et al. 2019; Meng et al. 2019; U.S. Environmental Protection Agency 2019; WHO 2013).

A large number of premature deaths occur annually in Africa as a result of air pollution exposure.

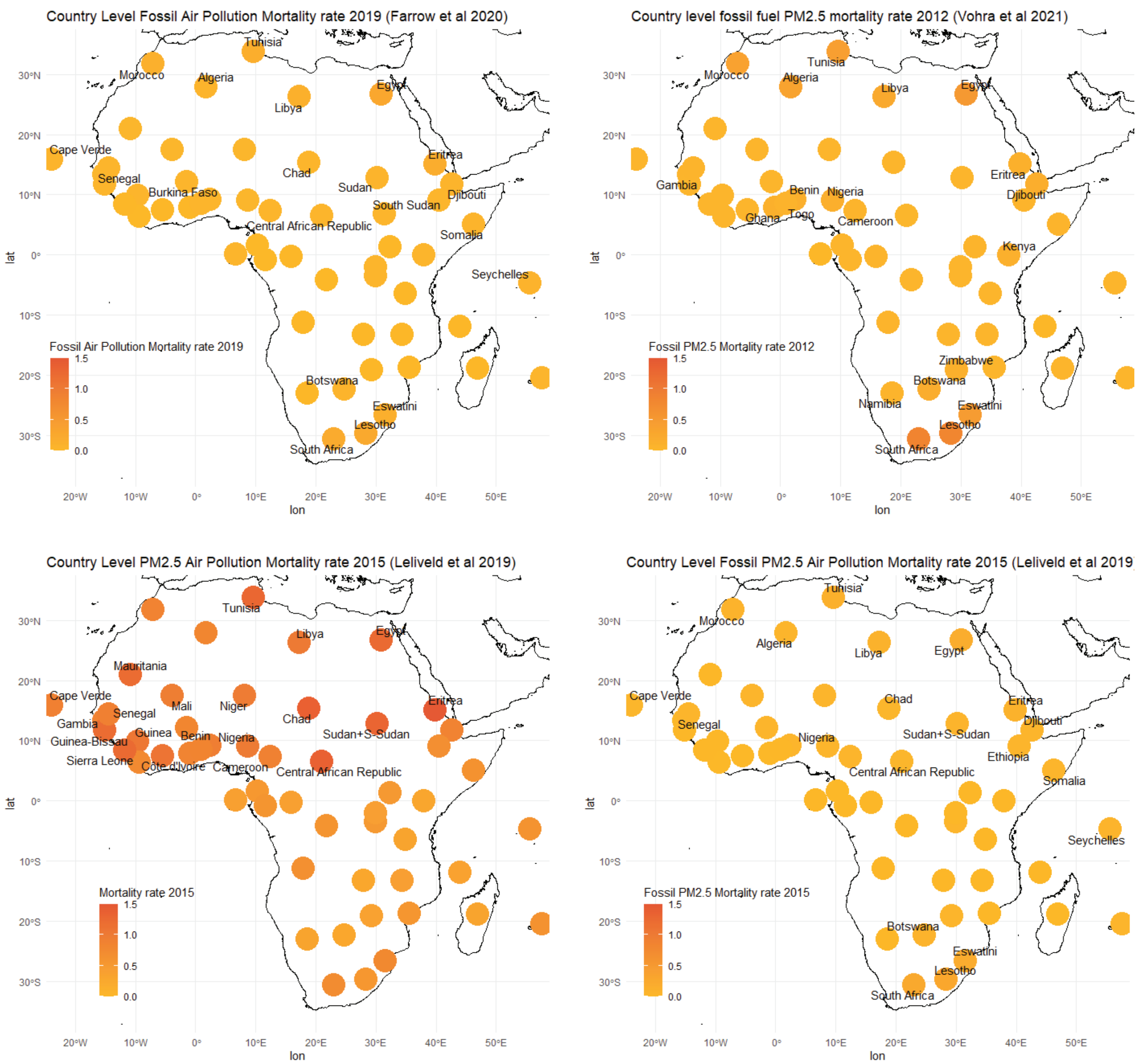

Figure 5: Estimated country-level mortality rates per 1,000 people for fossil fuel NO_2, ozone and $PM_{2.5}$ in 2019 (Top left, Farrow et al 2020), attributable to fossil fuel $PM_{2.5}$ pollution in 2012 using updated concentration response functions (top right, Vohra et al 2021) and in 2015 for total (bottom left) and fossil fuel (bottom right) $PM_{2.5}$ exposure (Leliveld et al 2019).

Outdoor air pollution in Africa is projected to get worse unless prompt interventions are made. The United Nations Environment Programme's projection for the annual number of premature deaths linked to outdoor air pollution rises from 930,000 in 2030 to 1.6 million in 2063 (UNEP, 2022). Economic growth, population growth, unplanned urbanisation, and a lack of environmental regulation could exacerbate environmental and human health impacts. Environmental regulations, including air quality and emissions regulations, alongside improved access to clean, renewable energy, could help reduce inequalities and improve the wellbeing of people living in Africa.

Household Air Pollution

This report investigates major human-made pollution sources and important polluting industries in Africa. It focuses on the air quality challenges posed by major industrial powers and the fossil fuel industry. However, an important type of air pollution across Africa responsible for health impacts is that generated by households.

Large proportions of households use solid fuel for cooking, 95% in East Africa, 83% in West Africa, 77% in Central Africa, 32% in Southern Africa and 13% in North Africa. These proportions are falling, but the number of people exposed to solid fuel emissions in their homes continues to increase in some countries (HEI 2022). The total amount of biofuel burned in residences has grown in east, west, southern and central African countries. It is now the major source of carbonaceous particulate emissions, CO and NMVOCs (Keita et al 2021).

Burning coal, wood, dung, agricultural residues, and kerosene among other fuels in people's homes may account for 63% of deaths attributable to air quality in Africa annually. Sadly it is newborns and children under the age of five who are often most vulnerable to domestic air pollution, in part because of the time they spend at home (HEI 2022). The elderly are also vulnerable to the worst impacts of indoor air pollution, and they often carry childcare burdens requiring them to be at home.

Most families do not have access to clean, renewable energy for cooking. Stronger policy actions are needed to provide access to clean fuels for families in need. Governments should promote clean, renewable and affordable cooking solutions with evidence-based policies that meet local cultural, social and gender needs and which are supported by adequate funds (UN, 2018).

Ultimately, access to affordable, clean, decentralised electricity and energy sovereignty would go a long way towards reducing household reliance on fossil and solid fuels.

WHAT ARE THE BIGGEST SOURCES OF AIR POLLUTION IN AFRICA?

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Sources of air pollution in Africa share many commonalities with the rest of the world, but there are important differences on continental, country and local scales in source types and the contribution each source makes.

In South Africa energy production alone contributes 23% of the $PM_{2.5}$ burden.

For example, the Health Effects Institute reported in 2022 that the contribution of solid biofuels to particulate pollution is small in North Africa relative to Africa south of the Sahara. In southern Africa, fossil fuel use contributes a relatively large proportion of fine particles, at 40%. In South Africa energy production alone contributes 23% of the $PM_{2.5}$ burden.

Important pollution sources in Africa can be both natural, human-made or a combination. Human-made sources include burning of solid fuels, fossil fuel energy production, industry including mining, transport, agricultural activities, and waste burning. Natural and semi-natural sources include wildfires, sea-salt and windblown dust (HEI 2022).

Air Pollution a Violation of Constitutional Rights: Major Victory for Mpumalanga Communities in Deadly Air Case, South Africa

Environmental justice group groundWork and Mpumalanga community organisation Vukani, represented by the Center for Environmental Rights as their attorney, achieved a significant victory in the landmark 'Deadly Air' litigation launched in 2019.

In the judgement delivered in the Pretoria High Court in March 2022, Judge Colleen Collis recognized the unhealthy air quality in South Africa's Mpumalanga Highveld as a violation of residents' constitutional right to an environment that does not jeopardise their health and well-being.

Furthermore, the court ordered the government to establish regulations for the implementation and enforcement of the Highveld Priority Area Air Quality Management Plan. Judge Collis determined that Environment Minister Barbara Creecy has a legal obligation to enact these regulations and that her delay in formulating and initiating the regulations to enact the Highveld Plan was "unreasonable."

The HPA is home to 12 of Eskom's coal-fired power stations, and Sasol's coal-to-liquid fuels refinery, situated in Secunda, all supplied by numerous coal mining operations.

Despite the passage of more than 15 months since the judgement, actual measures that could significantly mitigate air pollution and benefit the communities residing in the Highveld region are yet to be implemented on the ground.

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Satellite Data

Ground-level air pollution monitoring is sparse in many regions of Africa, but observations of air quality from satellites can help fill the gaps. Satellites can monitor where there is no directly measured data. For example NASA's satellite-based Moderate Resolution Imaging Spectroradiometer (MODIS) can be used to observe dust in the Earth's atmosphere, while the Ozone Monitoring Instrument (OMI), Ozone Mapping and Profiler Suite (OMPS), and European Space Agency's Tropomi instrument provide data on air pollutants like NO_2 and SO_2.

These space-based observations can estimate the amount of a pollutant in the atmosphere above points on the Earth's surface. This measurement is called the Column Amount. Column Amount is not a measurement of the concentration close to ground level or the amount of pollution being emitted. Instead, these data have to be interpreted to estimate concentrations or emissions. Satellite data are limited by data resolution noise and artefacts, and only large sources are easily detected and reliably quantified.

Such satellite data have been used to reveal the earth's largest sources of mineral dust, which during the northern hemisphere summer are Middle Eastern and North African deserts (Chappell et al 2023) and to show that there are major air pollution hotspots over the Mpumalanga area of South Africa where coal is mined and burned for energy. These methods do not rely on a priori knowledge of source locations, meaning that they can detect new sources or those that are missing from other data sources.

Nitrogen Dioxide (NO_2)

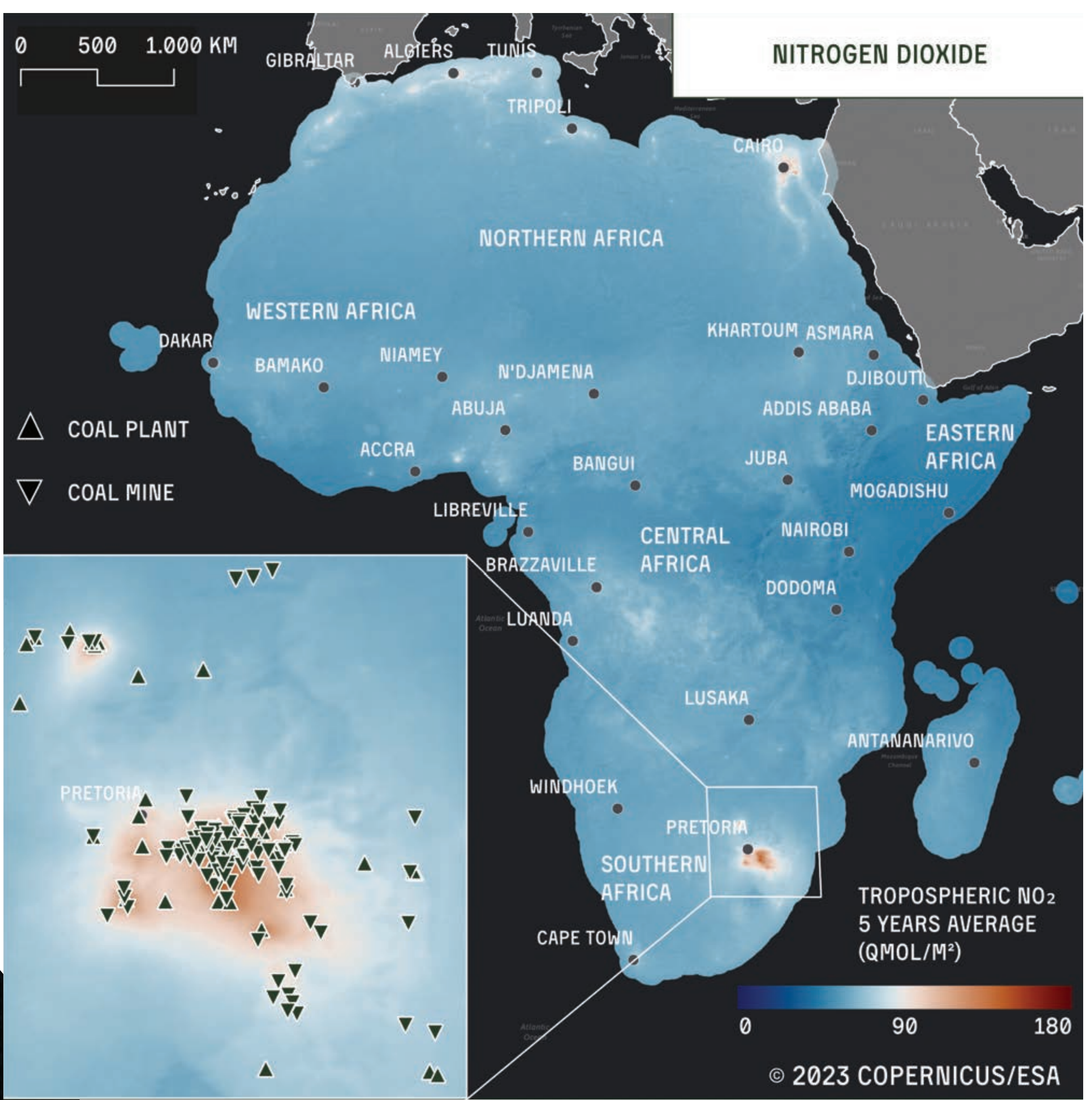

Figure 6. Satellite observed NO_2 (mol/m^2) the TROPOMI satellite instrument 2018-2023 mean (Sources: van Geffen et al 2019, 2022, Global Coal Plant Tracker 2023; Interative map developed using Google Earth Engine and available at https://peatfires-153915.projects.earthengine.app/view/afrs5#-timelapse=Show%20timelapse;aoi=all;)

NO_2 is a harmful air pollutant which is created by virtually all combustion processes including in fossil fuels power plants, petrol and diesel car engines, or wildfires. It provides a signature from locations where large amounts of fuel are burned that can be detected from space (**Figure 6**), preventing large pollution sources from going undetected. NO_2 can also react with other chemicals in the atmosphere and cause particulate matter pollution.

Beirle et al (2023) used data from the TROPOMI satellite instrument (van Geffen et al 2019, 2022) spanning May 2018 to Nov 2021 to catalogue NO_2 emissions from 1139 major point sources. Many of the locations identified in the analysis align with thermal power plants, cement plants, metal smelters, industrial zones, or urban areas. **Of the ten largest point source emitters identified world wide, six are located in Africa, all of which are in South Africa, Figure 7-8). The ten largest point sources identified in Africa are all thermal power stations, nine of which are in South Africa** and owned by Eskom Holdings SOC Ltd, a public utility that has the government of South Africa as its sole shareholder. The tenth is the area around Azito OCGT (Open-cycle gas turbine) and Vridi CIPREL OCGT Power Plants in Côte d'Ivoire (Table 2, Figure 7).

Of the ten largest point source emitters identified world wide, six are located in Africa, all of which are in South Africa.

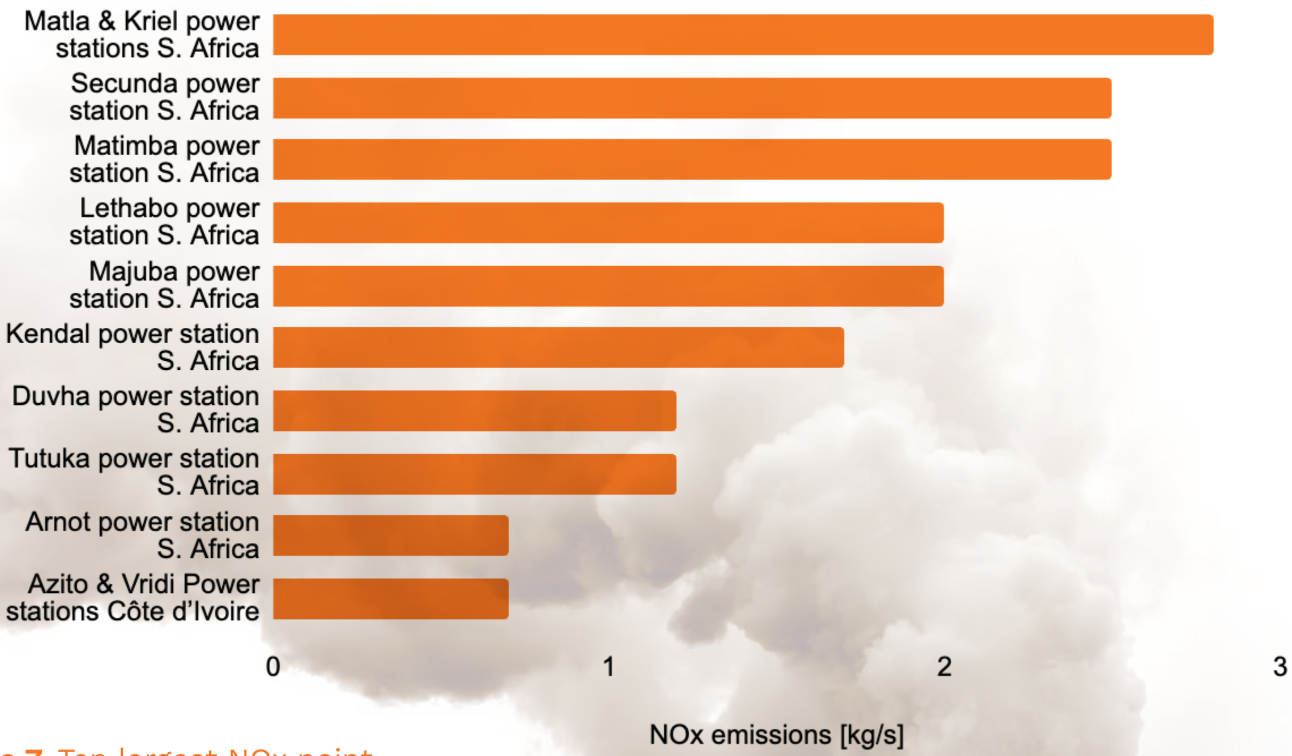

Figure 7. Ten largest NOx point sources, May 2018 to November 2021 (Beirle et al 2023)

Table 2. Africa's ten largest NOx point sources, May 2018 to November 2021

Rank	Point sources aligned with satellite observed hotspots (Power plants)	Country	NOx emissions [kg/s]
1	Matla coal-fired power station; Kriel power station Owned by Eskom Holdings	South Africa	**2.8**
2	Secunda Coal to Liquids (CTL) power station Owned by Sasol	South Africa	**2.5**
3	Matimba coal-fired power station Owned by Eskom Holdings	South Africa	**2.5**
4	Lethabo coal-fired power station Owned by Eskom Holdings	South Africa	**2.0**
5	Majuba coal-fired power station Owned by Eskom Holdings	South Africa	**2.0**
6	Kendal coal-fired power station Owned by Eskom Holdings	South Africa	**1.7**
7	Duvha coal-fired power station Owned by Eskom Holdings	South Africa	**1.2**
8	Tutuka coal-fired power station Owned by Eskom Holdings	South Africa	**1.2**
9	Arnot coal-fired power station Owned by Eskom Holdings	South Africa	**0.7**
10	Sources including Azito OCGT gas fired power plant and Vridi CIPREL OCGT gas fired Power plant	Côte d'Ivoire	**0.7**

Sources: Emissions and locations, Beirle et al 2023; Fuel and ownership, Eskom 2023., Azito Energie 2015., Ciprel 2023., Sasol 2023.

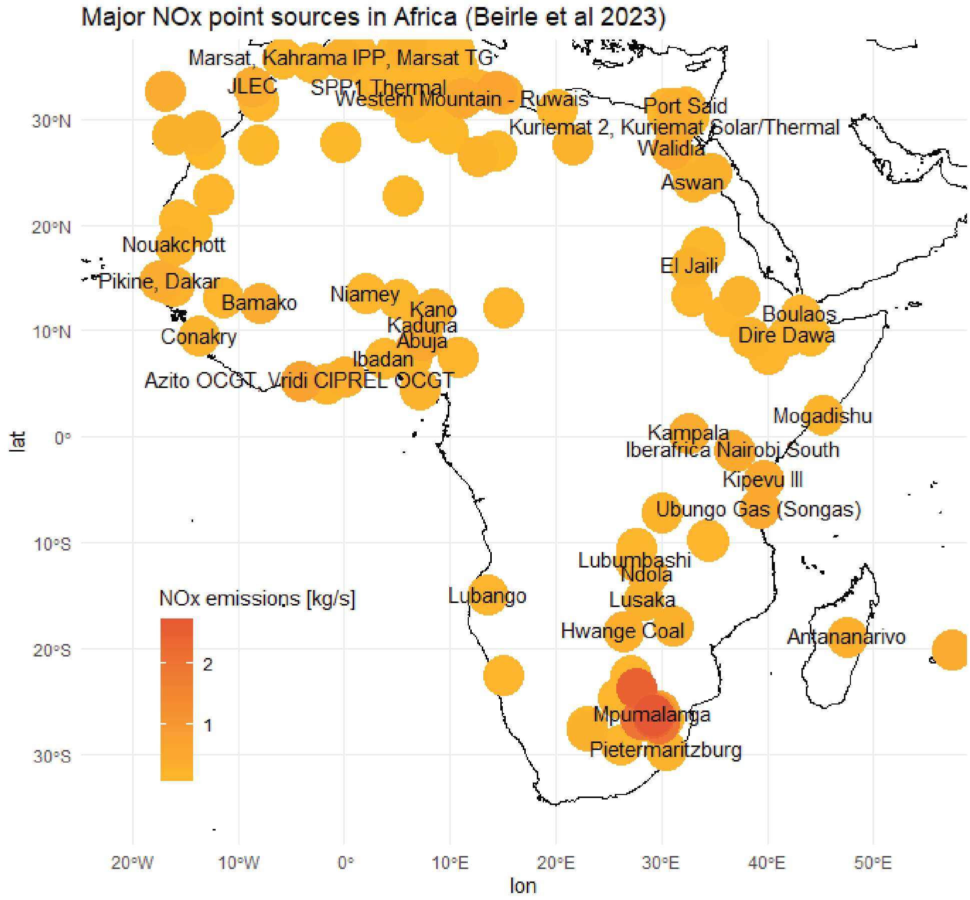

Figure 8. African NOx point sources, May 2018 to November 2021 (Beirle et al 2023). Names and attributions shown are provided by Beirle et al (2023), for clarity not all point sources are named.

Sulphur Dioxide (SO_2)

SO_2 is produced by burning and processing of materials that contain sulphur, including by oil and gas infrastructure, in coal power stations and during the processing of some mineral ores. SO_2 reacts with other substances to form harmful compounds, such as sulphuric acid, sulphurous acid and sulphate particles. It is therefore a cause of acid rain and particulate matter pollution.

Globally, human-caused emissions of SO_2 are much greater than those from natural sources such as volcanoes, meaning that like NO_2, SO_2 provides a signature that can be detected from space and used to identify locations where large amounts of sulphurous fuel are burned such as in coal and oil power plants, industrial facilities, and vehicles (**Figure 9**).

The United States National Aeronautics and Space Administration (NASA) publishes a catalogue of SO_2 emission hotspots each year (Fioletov et al 2023). Version 2 of the global catalogue, the current version, uses data sourced from the Ozone Monitoring Instrument (OMI), Ozone Mapping and Profiler Suite (OMPS), and TROPOspheric Monitoring Instrument (TROPOMI) satellite spectrometers. The catalogue groups SO_2 sources into four categories, one natural category 'volcanoes' and three anthropogenic categories, ‘power plant’, ‘oil and gas’, and ‘smelter’. The catalogue covers the period of 2005–2021 and includes a total of 759 continuously emitting point sources. Two of the ten largest SO_2 emission hotspots identified are in Africa, both in South Africa. The only larger sources are the Norilsk smelter in Russia, two oil and gas facilities in Iran and two in Mexico. Among the hotspots identified in the analysis, there are 23 human-made sources in the African continent, the majority of which are power plant sources (**Figure 10** and **Figure 11**).

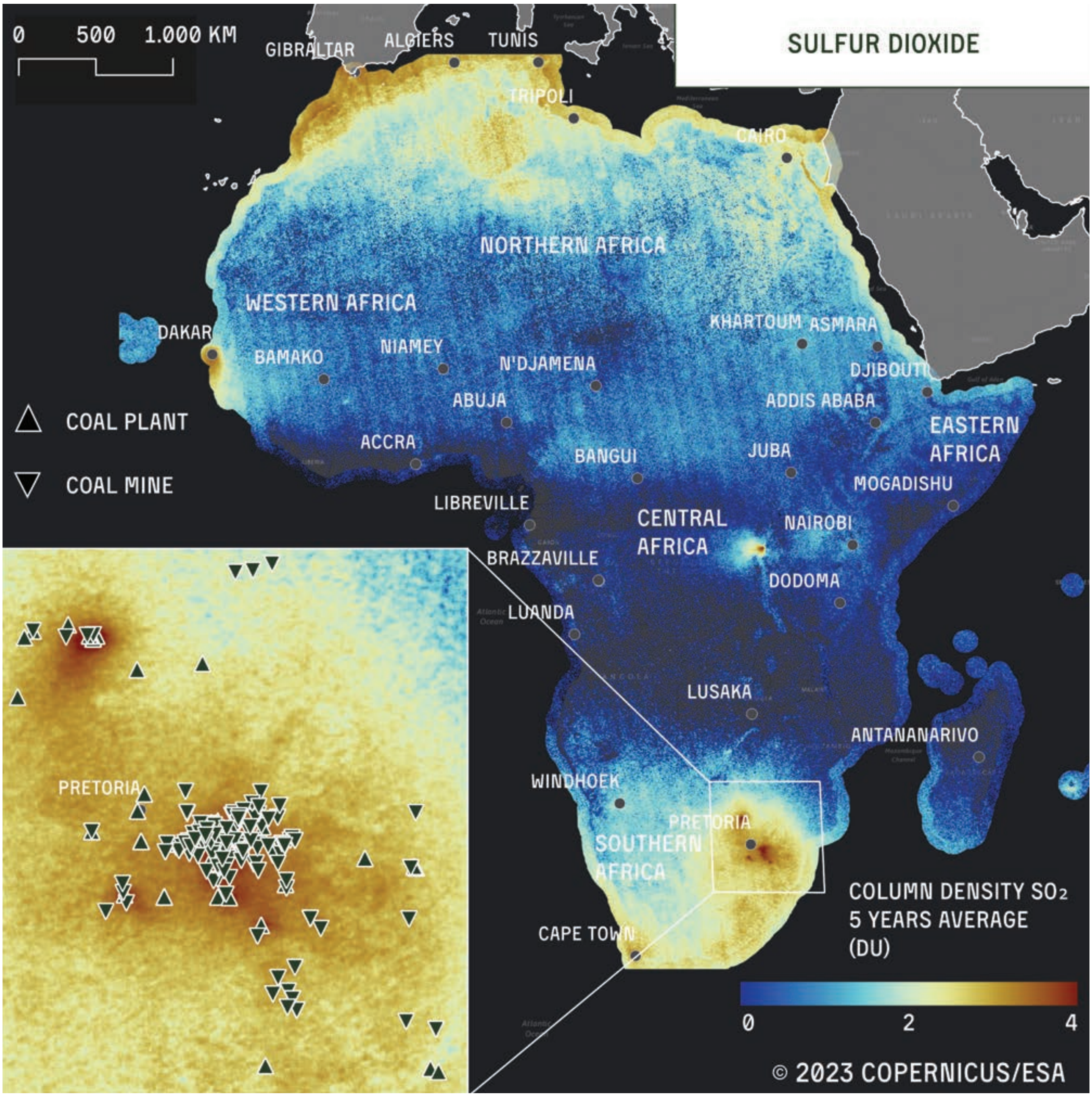

Figure 9. Satellite observed SO_2 (DU), the TROPOMI satellite instrument 2018-2023 mean (Sources: van Geffen et al 2019, 2022, Global Coal Plant Tracker 2023; Interactive map developed using Google Earth Engine and available at https://peatfires-153915.projects.earthengine.app/view/afrs5#timelapse=Show%20timelapse;aoi=all;)

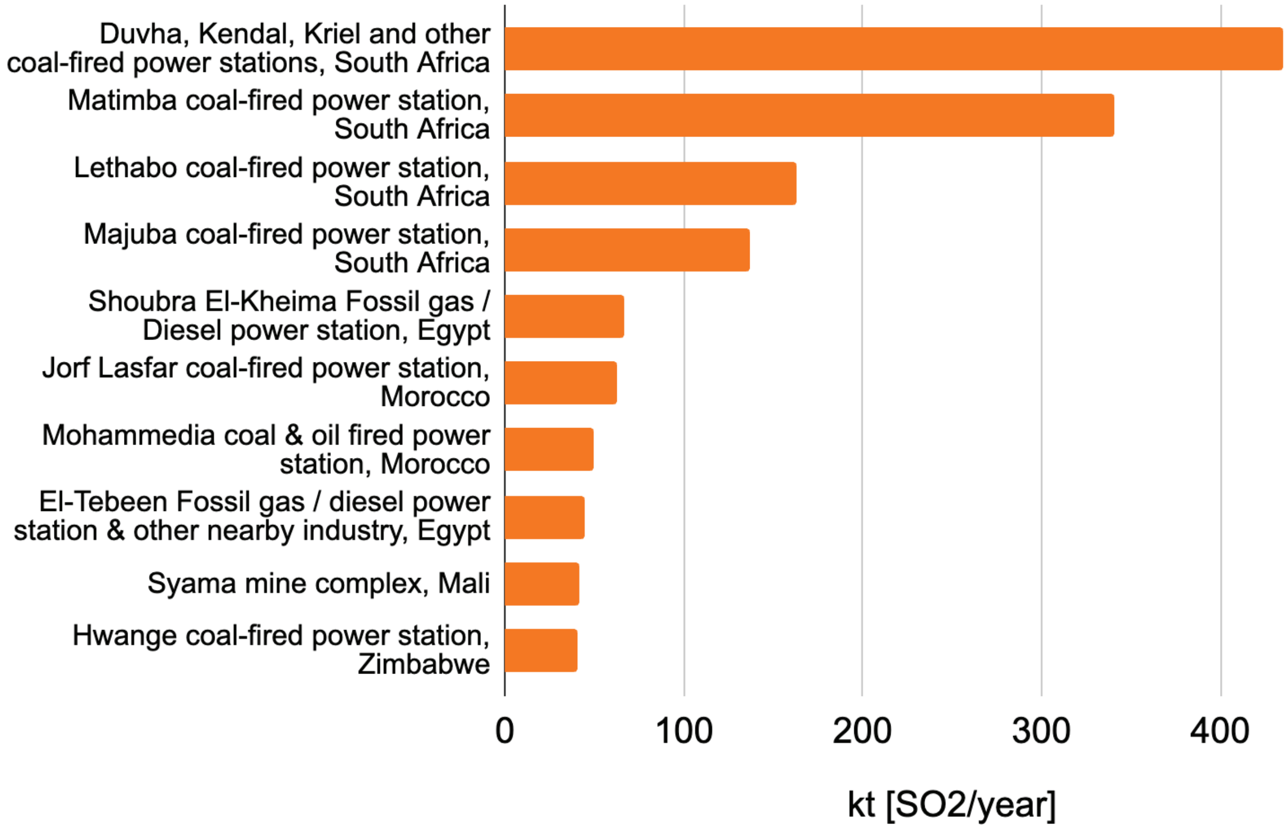

Figure 10. Major African SO_2 point sources, 2022 (Fioletov et al 2023)

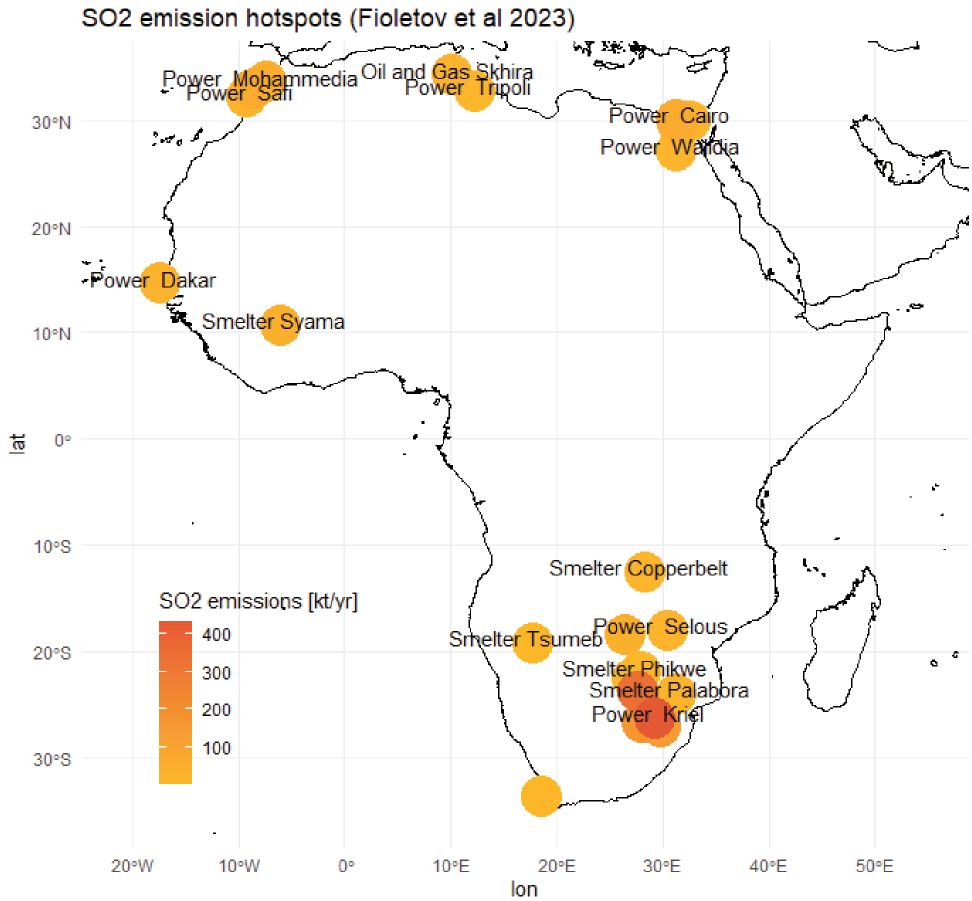

Figure 11. Major SO_2 point sources, natural and human-made (Fioletov et al 2023). Source types and names are provided by Fioletov et al (2023); for clarity not all point sources are named.

Table 3. Africa's ten largest SO_2 point sources, 2022

Rank	Point sources aligned with satellite observed hotspots (Power plants & smelters)	Country	SO_2 emissions [kt/year]
1	Duvha, Kendal, Kriel coal-fired power stations Owned by Eskom Holdings Other power plants	South Africa	**435.4**
2	Matimba coal-fired power plant Owned by Eskom Holdings	South Africa	**341.1**
3	Lethabo coal-fired power plant Owned by Eskom Holdings	South Africa	**163.1**
4	Majuba coal-fired power plant Owned by Eskom Holdings	South Africa	**137.1**
5	Shoubra El-Kheima Fossil gas / Diesel power plant Owned by Cairo Electricity Production Company	Egypt	**66.9**
6	Jorf Lasfar coal-fired power plant Owned by TAQA Morocco, a subsidiary of Abu Dhabi National Energy Company	Morocco	**62.9**
7	Mohammedia coal & oil fired power plant Owned by the Office National de l'Electricité et de l'Eau Potable (ONEE)	Morocco	**49.8**
8	El-Tebeen Fossil gas / Diesel power plant Owned by Cairo Electricity Production Company Other nearby industry	Egypt	**44.7**
9	Syama mine complex Owned by Resolute and the government of Mali	Mali	**41.6**
10	Hwange coal-fired power plant Owned by Zimbabwe Electricity Supply Authority (ZESA)	Zimbabwe	**40.4**

Sources: Emissions and locations, Fioletov et al 2023; Fuel and ownership, Eskom 2023., Cairo Electricity Production Company 2023., TAQA Morocco 2022., Office National de l'Electricité et de l'Eau Potable (ONEE) 2014., Global Energy Monitor 2023., Resolute 2023.

Of the 10 largest SO_2 emission hotspots in Africa, four are in South Africa. These hotspots, align with coal-based power plants owned by Eskom Holdings SOC Ltd, a public utility with the government of South Africa as

its sole shareholder. Two are in Egypt, two are in Morocco, and Mali and Zimbabwe each have one hotspot (**Table 3**). In North Africa the catalogue includes hotspots aligned with sources in Egypt, Libya, Morocco and Tunisia. In Egypt, these are associated with Shoubra El Khiema Power Plant, Suez thermal power plant, industry including power and steel plants in El-Tebeen and Asyut El Waleedeya power plant. In Libya and Morocco the hotspots are associated with Tripoli, Mohammedia, Jorf Lasfar, and Safi power plants. In Tunisia emissions from oil and gas at Skhira are aligned with the hotspot. In West Africa the catalogue includes Syama smelter in Mali, and power plants in Dakar. In East Africa the catalogue includes smelters in Zambia's copperbelt, as well as Selous and Hwange power plants in Zimbabwe. In southern Africa the catalogue includes three smelters in Botswana, South Africa and Namibia; South Africa's power plants of Matimba, Kriel, Lethabo, Majuba and Ankerlig, and Morpule power plant in Botswana.

Of the six SO_2 South African hotspots listed, only Kriel has a long term trend of declining emissions. Notably, emissions of SO_2 in the hotspot corresponding to Palabora, a large copper mine, smelter, and refinery complex increased by 220% between 2021 and 2022 although longer term trends are stable. The complex, managed by Palabora Mining Company in the Limpopo Province of South Africa, shows little change in emissions over longer time periods (**Figure 12**).

Of the 10 largest SO_2 emission hotspots in Africa, four are in South Africa.

In North Africa emissions identified by Fioletove et al (2023) show no clear long-term trends (**Figure 13**). Out of the 4 listed sources in Egypt, three of them - namely, Shoubrah El-kheima power plant; El-Tebeen Steel Factory; and Suez Power plant - experienced a considerable increase in SO_2 emissions of 63%, 40%, and 20%, respectively, in 2022 compared to 2021 data. A power plant in Tripoli, Libya, also increased emissions by 24%. On the other hand, Asyut El Waleedeya power plant saw a decline of 28% in SO_2 emissions. Last year in Morocco two SO_2 hotspots showed a decline. Safi Power plant demonstrated a substantial decline of 67%, and Jorf Lasfar (JLEC) Thermal power plant saw a decline of 19% in SO_2 emissions compared to 2021 data. However, Mohammedia coal power plant showed an increase of 54% in SO_2 emissions over the same period.

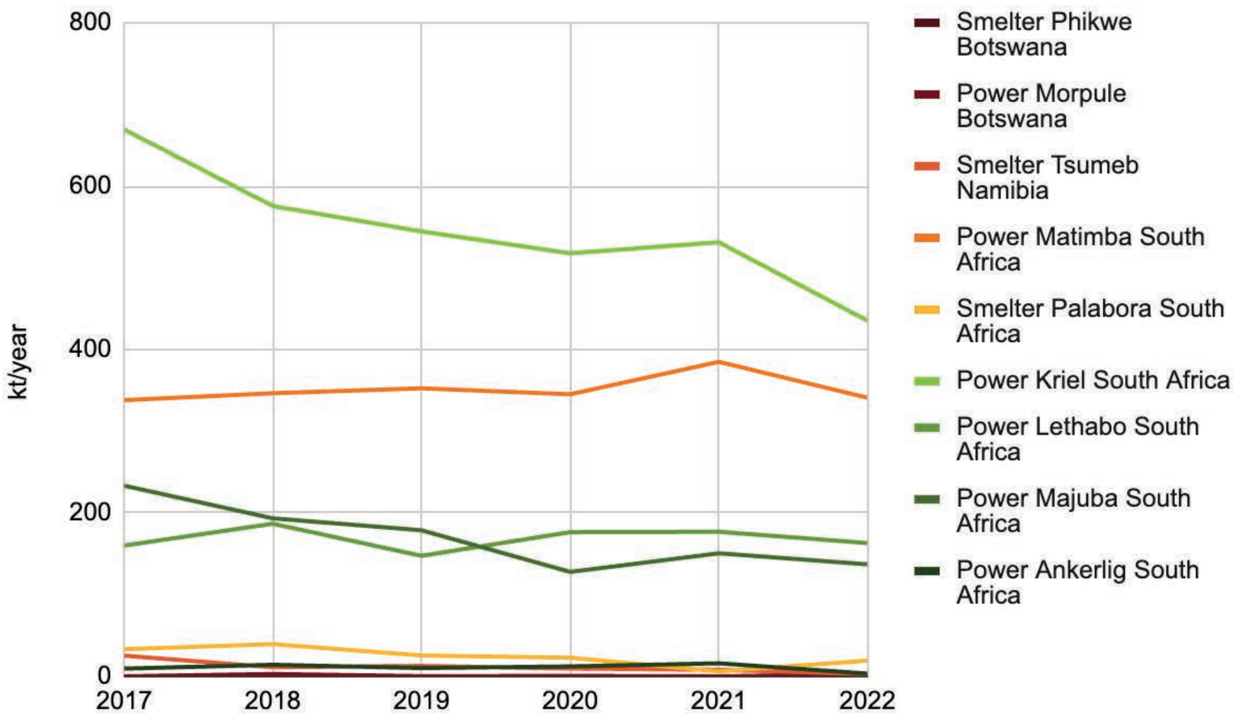

Figure 12. Estimated annual emission of SO_2 for major sources in Southern Africa (Fioletov et al 2023)

The estimated emissions from Fioletove et al (2023) for other SO_2 hotspots in East and West Africa have increasing trends (**Figure 14**). There is significant year-on-year variation, for example locations with increased emissions in 2022 compared to 2021 data include Syama gold mine smelter in Mali with a rise of 15%, Hwange power plant in Zimbabwe with a rise of 43%, and the Selous power plant in Zimbabwe with a rise of 39%. On the contrary the satellite-estimated emission for Morupule power plant in Botswana was 2.5 kt in 2022 compared to none in 2021. Similarly, Phikwe Nickel and copper mine and smelter in Botswana showed emissions of 0.1 kt in 2022, compared to none in 2021.

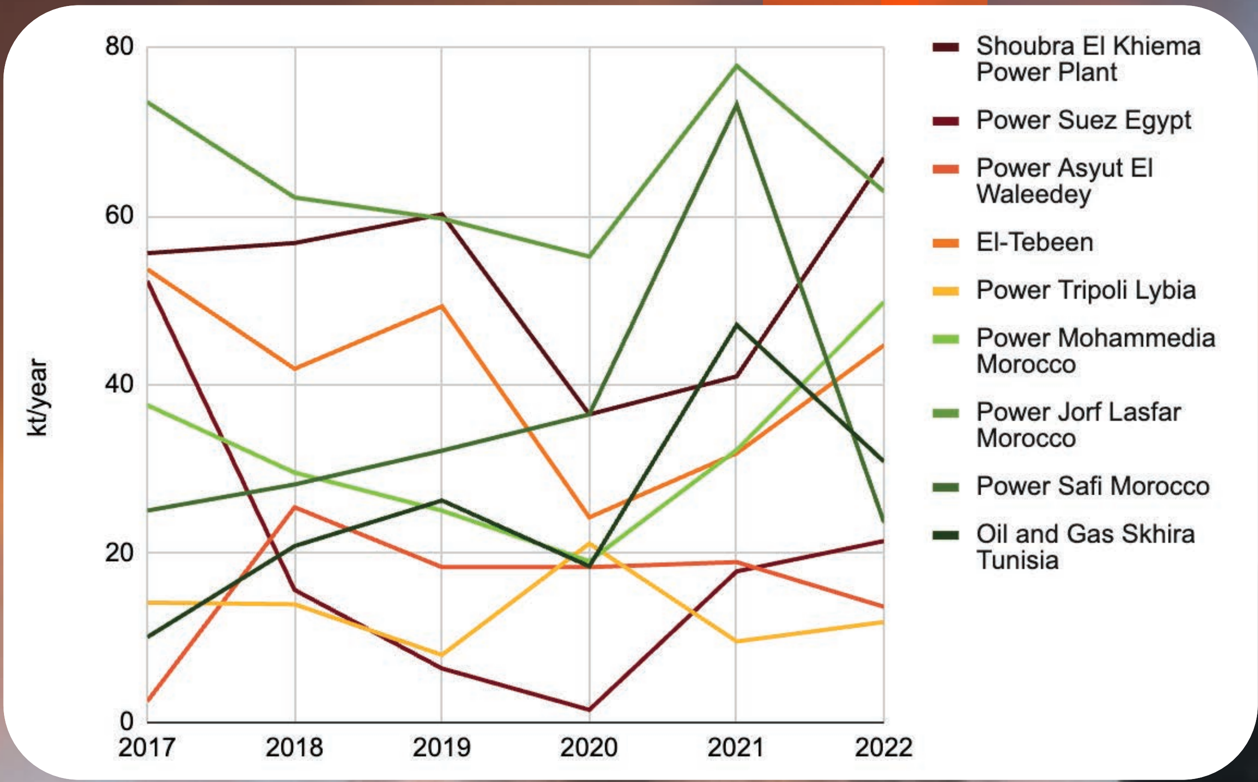

Figure 13. Estimated annual emission of SO_2 for major sources in North Africa (Fioletov et al 2023)

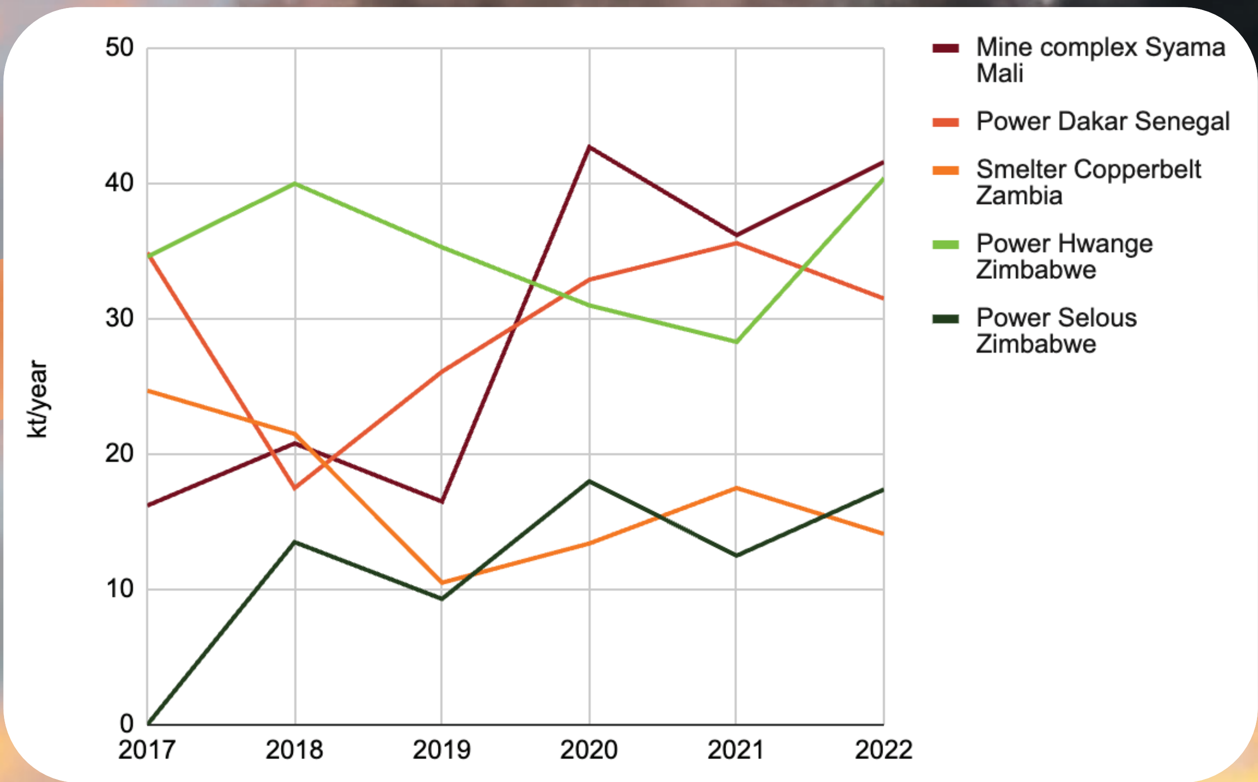

Figure 14. Estimated annual emission of SO_2 for major sources in East and West Africa (Fioletov et al 2023)

Emissions Inventories

Satellite data are ideal for finding and identifying large point sources of air pollution. Other information is needed to identify smaller or distributed sources and how much each of these contributes. Therefore, researchers build databases, called ‘emissions inventories’, to explore the many different types of pollution source.

Emissions Inventories

Inventories can have global or local extent. They usually quantify emissions, include different source sectors, map emission locations, and track changes over time. Many inventories are developed ‘bottom-up’ by taking activity data (such as the amount of fuel used in a country) and multiplying this information by an emissions factor (the pollution emitted per unit of fuel). Some inventories are developed ‘top-down’ by taking estimates of total emissions and disaggregating them to different sources. Emissions are sometimes adjusted and scaled to ensure consistency between different input datasets or years. The emissions are mapped across each country or region, according to maps of population density, road networks or power plant locations for example. In Africa, assumptions often have to be made where there is no information on fuel use, or the technology or the regulations that might affect emissions factors.

Global emission inventories include:

- the Hemispheric Transport of Air Pollution (HTAP v3) inventory (Crippa, 2023)
- the Emissions Database for Global Atmospheric Research (EDGAR) (European Commission, 2022, IEA, 2019),
- the Community Emissions Data System (CEDS) (Hoesly et al. 2018, McDuffie et al 2020), and, among others,
- the Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) inventory (Ammann et al 2011).

South Africa, Nigeria and the North African nations are large NOx emitters.

The CEDS inventory combines regional and national-level inventories and multiple fuel uses within one consistent framework. For example, CEDS incorporates activity and emission input data from sources such as EDGAR and GAINS as well as local inventories to produce global emissions that are consistent through time and aligned with current local data (Hoesly et al., 2018). CEDS' use of local inventories has the benefit of incorporating local knowledge. Local data can include sources that are often missing in global inventories, such as the use of diesel and petrol generators. It can also provide local emissions factors. This is important because local emission rates may vary, for example if vehicles or oil and gas flares are more or less well regulated than assumed by the database developers.

Therefore, a recent version of CEDS, CEDS_GBD-MAPS (McDuffie et al 2020), is used for the analysis in this report. It is global in extent and includes pollutants particularly relevant for air pollution and health, namely the $PM_{2.5}$ precursors CH_4, NH_3, NOx, SO_2, and non-methane volatile organic compounds (NMVOCs), along with BC and organic carbon. Alongside the global CEDS database, an Africa-specific inventory, the DACCIWA inventory (Keita et al 2021), is also analysed below.

The CEDS_GBD-MAPS inventory includes Agriculture (non-combustion sources only, excludes open fires), Energy (power generation, transformation and extraction), Industry (combustion and non-combustion processes), On-Road Transportation, Off-Road/Non-Road Transportation (rail, domestic navigation, other), Residential Combustion, Commercial Combustion, Other Combustion, Solvents, Waste (disposal and handling) and International Shipping. It does not include emissions from open fires or aircraft. Alongside these sectors, CEDS_GBD-MAPS categorises emissions by fuel type. The types included are Total Coal Combustion (hard coal + brown coal + coal coke), Solid Biofuel Combustion, and Liquid Fuel (light oil + heavy oil + diesel oil) plus Fossil Gas Combustion.

Air pollutant emissions in the DACCIWA inventory for BC, OC, NOx, CO, SO_2 and NMVOCs increased across Africa over recent decades (Keita et al 2021). The energy sector is the biggest contributor to SO_2 (54%) and NOx (29%) emissions. Traffic is the second largest NOx emitting sector, while industry is the second largest SO_2 emitting sector (Keita et al 2021). The DACCIWA and CEDS_GBD-MAPS databases find that Southern Africa and North Africa are Africa's biggest emitting regions for SO_2 and NOx. These regions have large industrial and power plant sources compared to Africa's other regions (Keita et al 2021). In West and East Africa traffic and domestic emissions are the largest sectors respectively (Keita et al 2021). **Figure 15** shows that South Africa, Nigeria and the North African nations are large NOx emitters, while SO_2 emissions are also dominated by South Africa and the power plant and smelter sites identified in the previous section. Sulphur levels in fuels are regulated in many countries worldwide. This leads to reduced SO_2 and particulate emissions, including from road traffic. High levels of sulphur are found in fuels in many African nations (UNEP, 2023). Urgent action is needed to ensure fuels used in Africa meet the best international standards while working towards a fully renewable system.

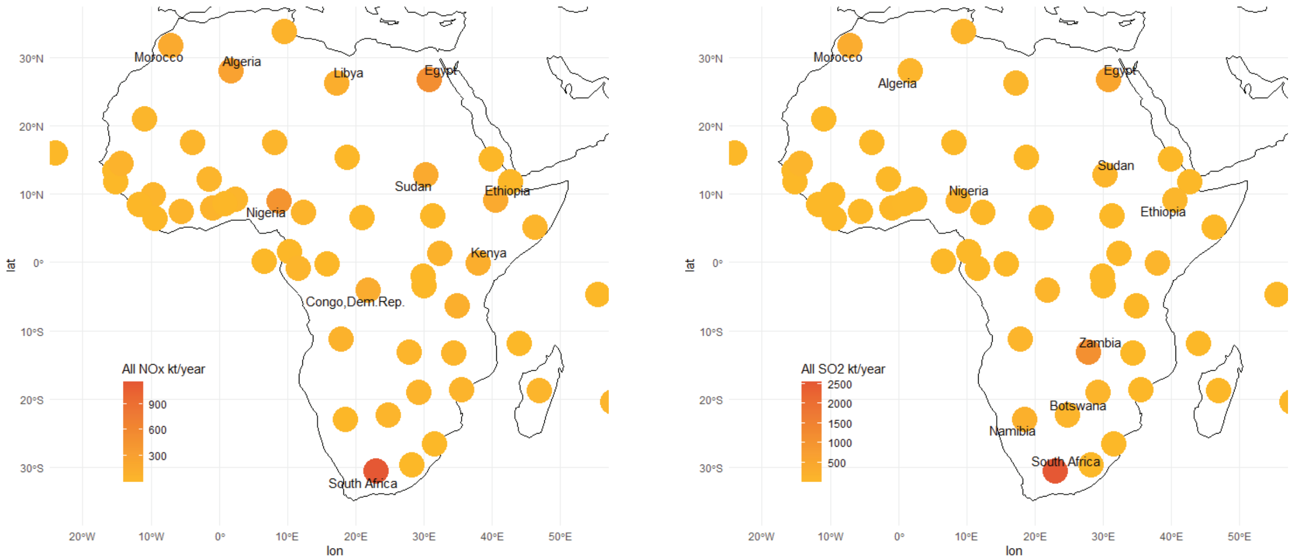

Figure 15. Estimated NOx and SO_2 emissions for 2017 aggregated by country (McDuffie et al 2020)

Global NMVOC emissions are strongly influenced by Africa, due to the residential and energy sectors. Africa is home to significant oil and gas production sites, such as those in the Niger delta. These oil and gas operations are particularly large NMVOCs emitters. Flaring and fugitive emissions from oil and gas, alongside residential burning, contribute to West Africa being the highest emitting region for BC and NMVOCs (Figure 16, McDuffie et al 2020, Keita et al 2021). Some emissions from flaring are reducing as a result of the Global Gas Flaring Reduction initiative (GGFR) (Keita et al 2021). Open waste burning is also an important source of BC and NMVOC emissions (Keita et al 2021).

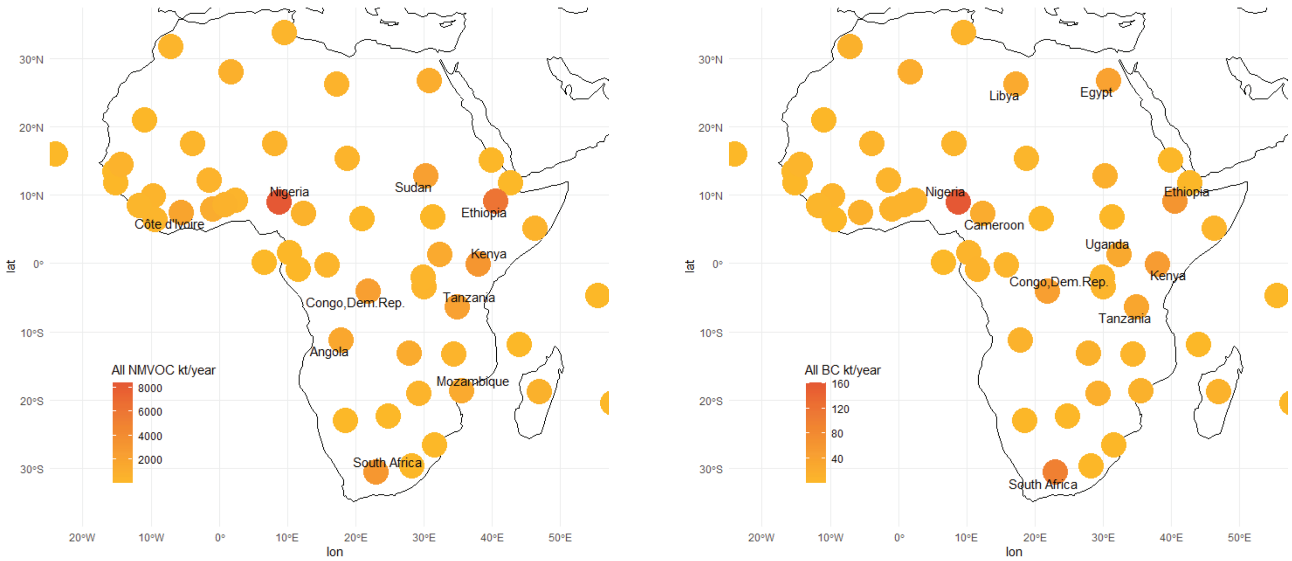

Figure 16. Estimated NMVOC and BC emissions for 2017 aggregated by country (McDuffie et al 2020)

Agareb "I Am Not a Dump" People's Movement

Citizens of Agareb, a small village in the governorate of Sfax, Tunisia (North Africa), have for 5 years led a campaign to protest about the waste dump installed in their village that has passed its capacity and its legitimate period of use.

The dump, which contains household, medical, and other types of waste, has become a serious source of health issues and air pollution. The burning in the dump releases a toxic smell that becomes unbearable for the surrounding community.

A people's movement was formed in 2016 called Agareb is Not a Dump!, in response to the rejection of authorities taking serious measures to shut down the dump permanently and put an end to the environmental crisis that they are facing,

The people of Agareb have always felt that they were paying the price in order for the rest of the Tunisian population to breathe clean air.

After leading a series of peaceful protest actions and after losing a young citizen from the village who lost his life due to police violence to suppress the protest, the movement decided that the only way to get to their goal was by going to court.

In 2021, after a long judicial journey, the people of Agareb finally received a court decision that acknowledged the necessity to shut down the dump immediately. The decision was executed on September 27, 2021.

Although the dump is no longer in use, people in Agareb still feel affected by the damages that the dump has caused to their environment and to their health and are still fearful of any attempt to reopen the dump again.

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Inkyfada.com, Web Address, accessed on 15th October 2023

Image Source: ftdes.net

The Black Dust

The residents of Kenitra, Morocco, were grappling with a black dust issue they believed to be related to a nearby industrial power station. Suspecting the power station, fueled by heavy fuel oil, as a significant source of particulate emissions including fly ash and soot, they were concerned about adverse health effects such as respiratory and cardiovascular diseases, an elevated risk of cancer, aggravation of existing health conditions, and developmental effects on children. $PM_{2.5}$ pollution causes not only health issues but also environmental problems like haze, reduced visibility, and harm to ecosystems and water quality.

Taking action, the residents initiated the collection of scientific evidence on the composition of the black dust. In August 2022, two samples were obtained from rooftops and sent to the UK's Greenpeace Research Laboratories. The analysis aligned with fly ash from heavy fuel oil combustion, providing the community with crucial evidence to engage with authorities and the plant, asserting their right to a healthy environment via scientifically supported demands.

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Greenpeace Research Laboratories Analytical Results 2022-05: 14 pp. Analysis of settled dust particles from the city of Kenitra, Morocco. Available at https://www.greenpeace.to/greenpeace/?page_id=2058

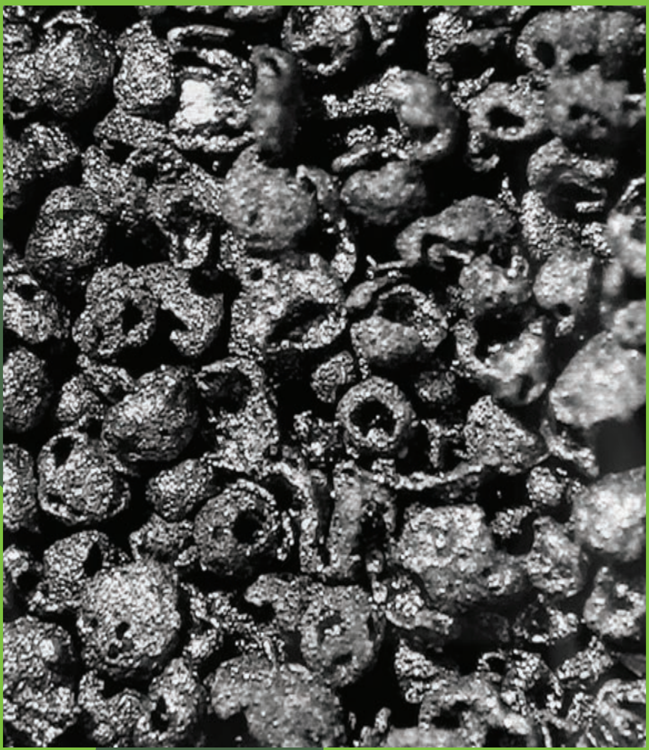
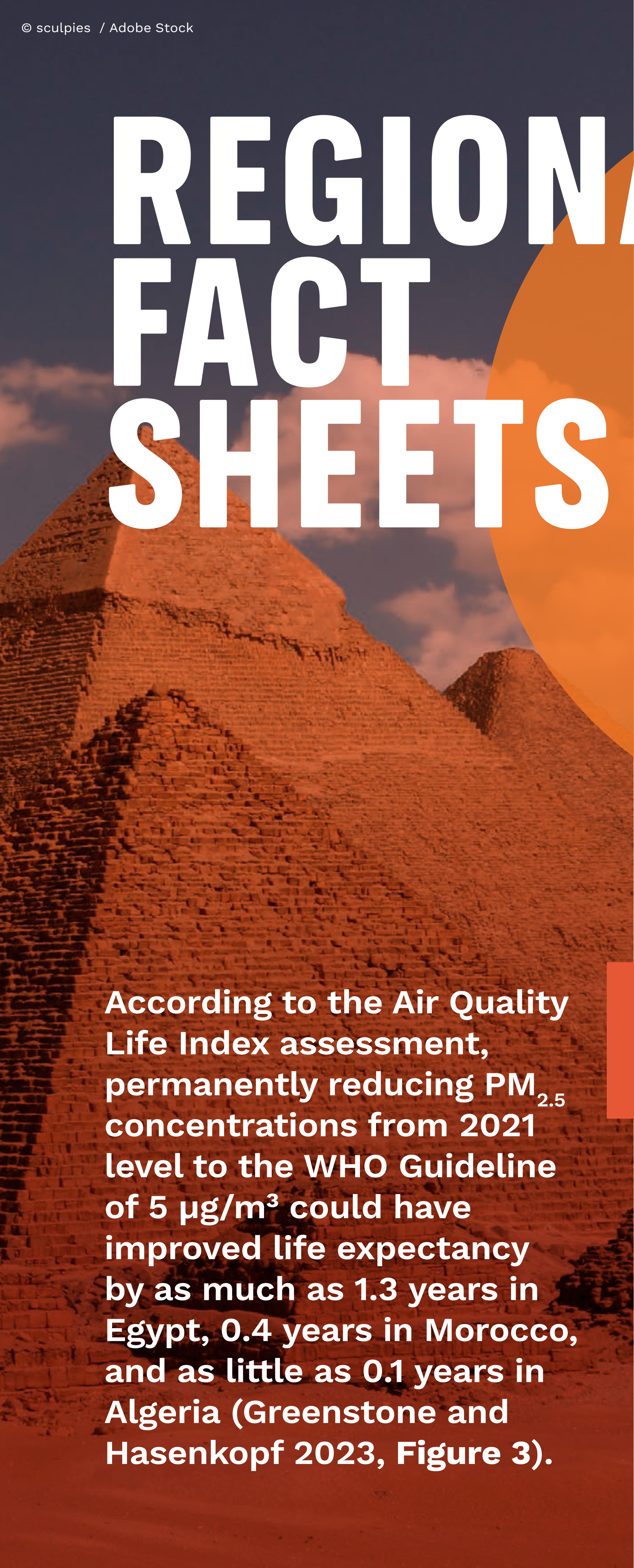


Image credit: Greenpeace International



REGIONAL FACT SHEETS

According to the Air Quality Life Index assessment, permanently reducing $PM_{2.5}$ concentrations from 2021 level to the WHO Guideline of 5 μg/m³ could have improved life expectancy by as much as 1.3 years in Egypt, 0.4 years in Morocco, and as little as 0.1 years in Algeria (Greenstone and Hasenkopf 2023, Figure 3).

North Africa

Algeria, Egypt, Libya, Morocco and Tunisia

Estimates of premature mortality relating to $PM_{2.5}$, specifically fossil fuel-related $PM_{2.5}$, and other fossil fuel air pollutants all identify the largest mortality rate in this region to be in Egypt (Leliveld 2019, McDuffie et al 2021, Vohra et al 2021, Farrow et al 2020, **Figure 4** and

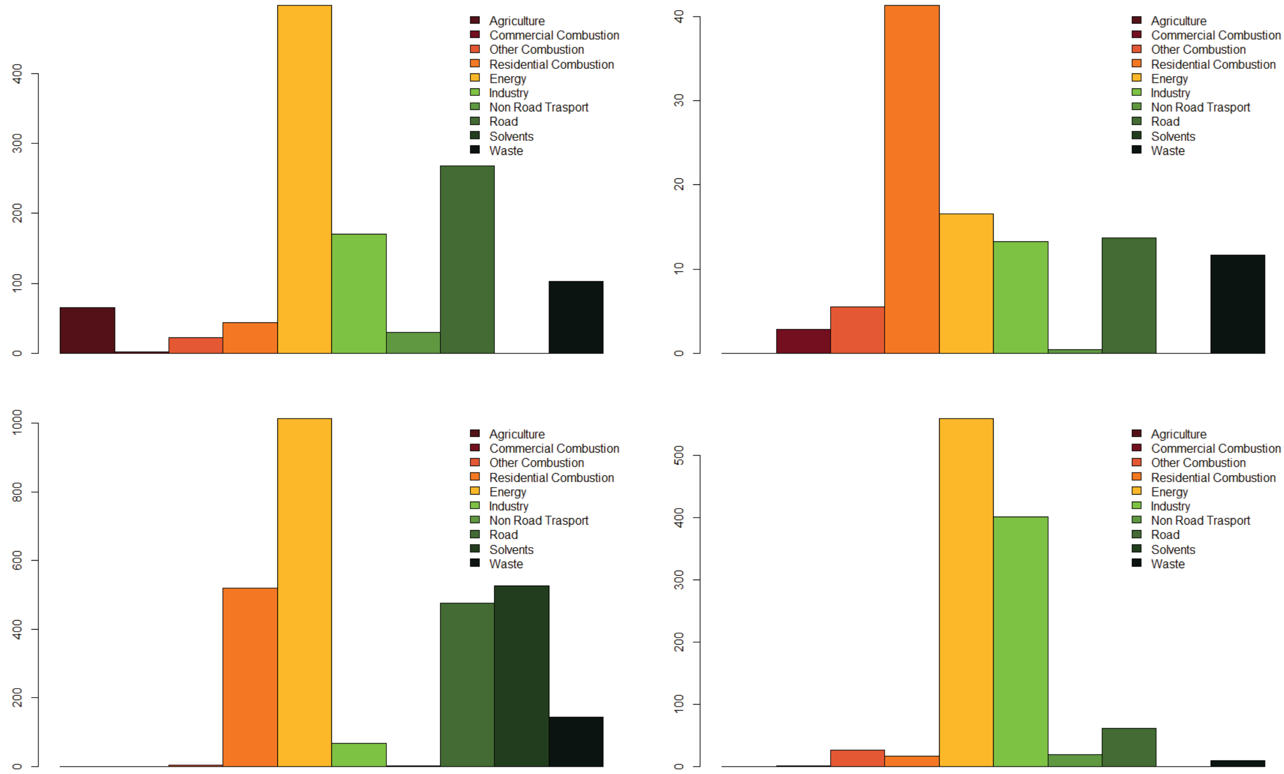


Figure 17. Sector contributions to NOx, BC, NMVOC, and SO_2 emissions in the CEDS-GBD_MAPS emission inventory for the year 2017 in North African countries (McDuffie et al 2020)

Appendix **Figures A1-A2**). Countries with large and small populations can be compared on the basis of mortality rates per 1000 inhabitants. Egyptian mortality rates for all $PM_{2.5}$ and fossil $PM_{2.5}$ air pollution have been estimated for 2019 to have been 1.2 and 0.19 per 1000 people respectively (Leliveld 2019). This compares to 0.78 and 0.05 for Africa as a whole in that year.

In North Africa the sector contributing most to NOx, NMVOC and SO_2 emissions in the CEDS database is the energy sector. Residential combustion (excluding waste) emits most BC (**Figure 17**, **Appendix 1**). The World Bank reports that Algeria and Libya are in the world's top 10 countries for oil and gas flaring; such flares are likely to contribute to the energy sector emissions for this region (World Bank, 2022).

The Moroccan Ministry of Environment, Mines, and Sustainable Energy (MEMSD) produces a national emission inventory (Moroccan Ministry of Environment, Mines, and Sustainable Energy, 2018, Saidi 2023). This locally developed emissions inventory potentially provides local insights not available in countries where no national inventory has been developed. The MEMSF inventory attributes most $PM_{2.5}$ emissions to residential sources, followed by road sources. As in the CEDS_GBD-MAPS database it identifies road transport as an important NMVOC emission source. Morocco is also home to the Safi coal-fired power plant. Greenpeace Southeast Asia has previously estimated the plant's air pollution could contribute to between 30-88 premature deaths annually (Son et al 2019).

Faridi et al (2022) assessed particulate matter source apportionment literature in countries across parts of North Africa, the east Mediterranean and MiddleEast region. Of the countries included in the assessment, they could not identify studies in Djibouti, Libya, Somalia, Sudan, or Tunisia. The work identified large differences across the region, with dust contributing most to $PM_{2.5}$ in Egypt, while in Morocco, nearly 53% of ambient $PM_{2.5}$ was attributed to industries, 35% to dust and 13% to traffic.

While in Morocco, nearly 53% of ambient $PM_{2.5}$ was attributed to industries.

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West Africa

Benin, Burkina Faso, Cameroon, Côte d’Ivoire, Gambia, Ghana, Guinea, Guinea-Bissau, Liberia, Mali, Mauritania, Niger, Nigeria, Senegal, Sierra Leone, Togo

According to the Air Quality Life Index assessment, permanently reducing $PM_{2.5}$ concentrations from 2021 level to the WHO Guideline of 5 µg/m³ could have improved life expectancy by as much as 2.5 years in Cameroon, 1.8 years in Nigeria, and as little as 0.1 years in Senegal (Greenstone and Hasenkopf 2023, Figure 3).

Estimates of premature mortality relating to $PM_{2.5}$, specifically fossil fuel $PM_{2.5}$, and other fossil fuel air pollutants all identify the highest mortality rates in this region to be in Nigeria (Leliveld 2019, McDuffie et al 2021, Vohra et al 2021, Farrow et al 2020, Figure 4 and Appendix Figures A1-A2). Countries with large and small populations can be compared on the basis of mortality rates per 1000 inhabitants. Nigerian mortality rates for all $PM_{2.5}$ and fossil $PM_{2.5}$

air pollution have been estimated for 2019 to have been 0.99 and 0.04 per 1000 people respectively (Leliveld 2019). This compares to 0.78 and 0.05 for Africa as a whole in that year.

In West Africa the sector contributing most to NOx and BC emissions in the CEDS database is residential combustion; the energy sector emits most NMVOCs and SO_2 emissions (**Figure 18**, **Appendix 1**).

Looking specifically at Nigeria, Okedere (et al 2021) identified gas flaring, petroleum product refining, gas power plants, transportation, manufacturing, land use changes, and waste as well as domestic cooking, bush burning and agriculture as key pollution sources. Nigeria's energy sector and its oil and gas industry are responsible for large amounts of flaring. This is the result of development practices in the 1960s and 1970s when there was limited demand for fossil gas and environmental standards were not stringent. With no market for the gas produced as a byproduct of oil wells, flares were installed as a disposal method. Decades later Nigeria continues to flare large volumes of fossil gas (Anejionu et al 2015). Gas is now used in electricity generation alongside hydro power (Sonibare, 2010).

Nigeria features in the top 10 flaring countries worldwide.

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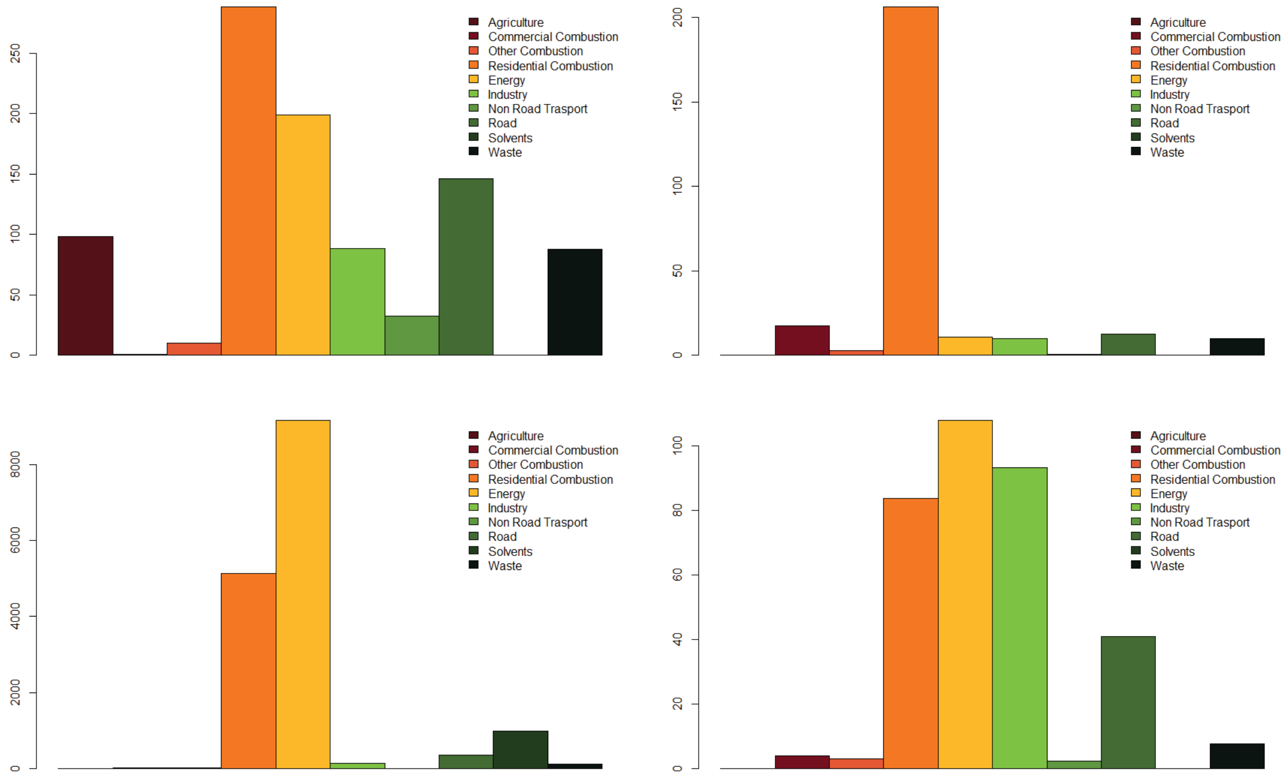

Figure 18. Sector contributions to NOx, BC, NMVOC, and SO_2 emissions in the CEDS-GBD_MAPS emission inventory for the year 2017 in West African countries (McDuffie et al 2020)

Nigeria features in the top 10 flaring countries worldwide (World Bank, 2022). Although flaring has reduced nationally, there are many small oil fields where flaring remains a serious issue. Nigeria is Africa's largest producer and exporter of crude oil, and these exports power many motorbikes in neighbouring countries (Assamoi and Liousse, 2010, Keita et al 2021). For example, traffic is identified as a large contributor to BC emissions in Benin where there are a high number of two-wheeled vehicles (Keita et al 2021).

East Africa

Burundi, Djibouti, Eritrea, Ethiopia, Kenya, Malawi, Mozambique, Rwanda, Somalia, South Sudan, Sudan, Tanzania, Uganda, Zambia and Zimbabwe

According to the Air Quality Life Index assessment, permanently reducing $PM_{2.5}$ concentrations from 2021 level to the WHO Guideline of 5 µg/m³ could have improved life expectancy by as much as 2.7 years in Rwanda, 1.1 years in Malawi, and as little as 0.6 years in Sudan (Greenstone and Hasenkopf 2023, **Figure 3**).

Estimates of premature mortality relating to $PM_{2.5}$, specifically fossil fuel $PM_{2.5}$, and other fossil fuel air pollutants all identify the largest mortality rate in this region to be in Ethiopia (Leliveld 2019, McDuffie et al 2021, Vohra et al 2021, Farrow et al 2020 **Figure 4** and Appendix **Figures A1-A2**). Countries with large and small populations can be compared on the basis of mortality rates per 1000 inhabitants. Higher mortality rates are projected in Djibouti and Eritrea (**Figure 5**).

In East Africa the sector contributing most to NOx and BC emissions in the CEDS database is residential combustion; the energy sector emits most NMVOCs and industry contributes most SO_2 emissions (**Figure 19**, Appendix 1).

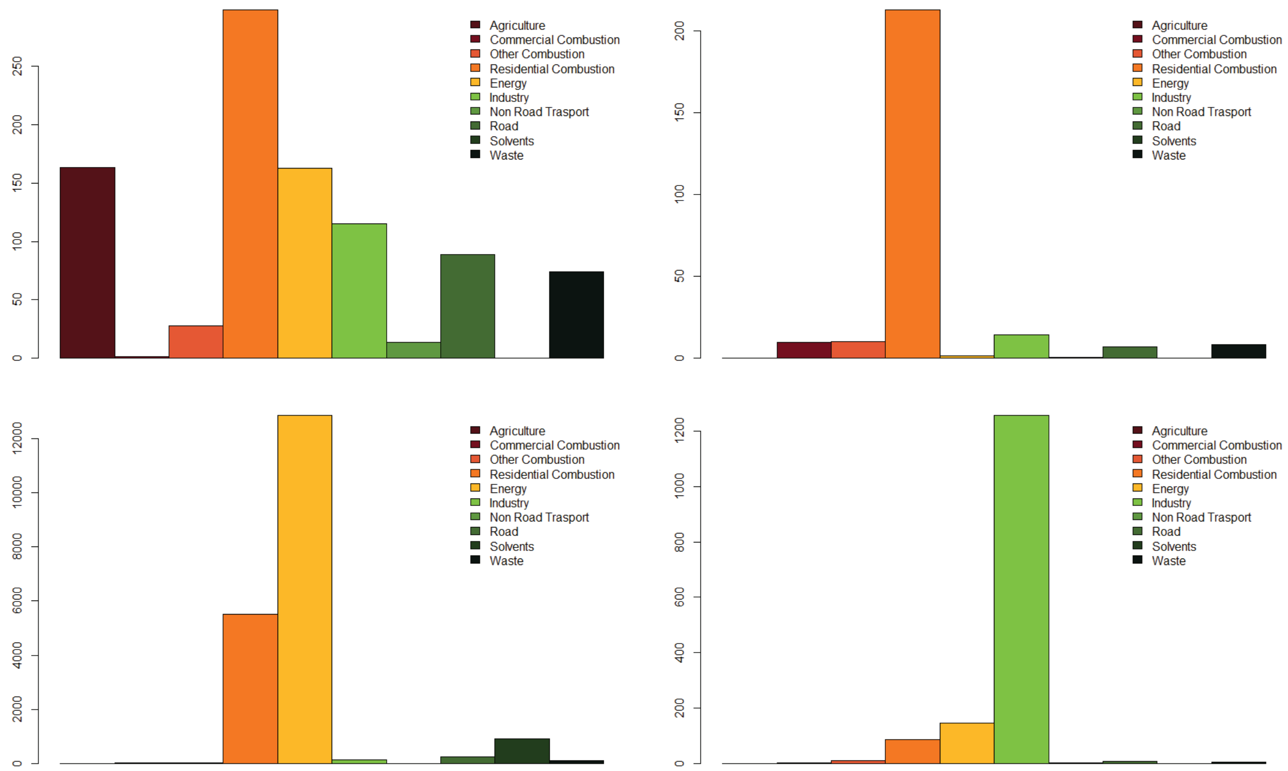

Figure 19. Sector contributions to NOx, BC, NMVOC, and SO_2 emissions in the CEDS-GBD_MAPS emission inventory for the year 2017 in East African countries (McDuffie et al 2020)

Empowering African Communities Through Solar Solutions

In Malawi, a country in southeastern Africa where only 10% of the population is connected to the power grid, we find a narrative of change. A group known as the "Solar Mamas" is driving transformation in this energy landscape. These determined Malawian women have undergone training in solar energy installation and repair. Their efforts have illuminated 200 households in villages around Malawi's capital, Lilongwe, bringing much-needed light to these communities. Notably, schools are now well-lit, enabling students to attend classes in the early morning and evening hours. Moreover, the skills acquired by the Solar Mamas have become a source of income, as they are compensated for installing and repairing solar equipment.

Even though none of the women had traditional education, they were selected by the charity Voluntary Service Overseas (VSO) to train in India to become solar engineers through a remarkable initiative by Barefoot College International in Tilonia, in India's Rajasthan state. Their journey exemplifies how knowledge, empowerment, and sustainable energy solutions are catalysts for positive change in Africa and beyond.

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VSO Ireland, Web Address, accessed on 15th October 2023

Image Credit: VSO Ireland at vso.ie


Image Credit: Kobani.org

Brightening Burundi: Kobani's Solar-Powered Rural Electrification

The stark reality remains that, as of 2021, around 43% of Africa's population, equivalent to approximately 600 million people, lacked access to electricity. In sub-Saharan Africa alone, 590 million individuals were living without electricity, according to the International Energy Agency. Amid these challenges, solar power emerges as a promising solution that communities across Africa can rely on.

Kobani, a renewable energy service company, has taken up the mission of rural electrification in Burundi on a scale that ensures economic viability. By closely collaborating with the Energy Ministry of the Burundian government, local communities, and financial institutions, Kobani utilises well-tested and continually evolving implementation solutions. This approach ensures that access to electricity comes at a cost lower than traditional substations, making it both affordable and dependable. Kobani is currently executing a pilot project in Giharo, Rutana province, under a community energy cooperative plan. This initiative utilises 14.4 kWp of solar photovoltaic technology paired with 27 kWh of Cegasa LFP batteries and SMA inverters. Kobani is demonstrating that access to energy need not be prohibitively expensive.

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Central Africa

Central African Republic, Chad, Congo, Democratic Republic of the Congo, Equatorial Guinea and Gabon

According to the Air Quality Life Index assessment, permanently reducing $PM_{2.5}$ concentrations from 2021 level to the WHO Guideline of 5 µg/m³ could have improved life expectancy by as much as 2.9 years in the Democratic Republic of the Congo, 2 years in the Central African Republic, and as little as 0.6 years in Chad (Greenstone and Hasenkopf 2023, **Figure 3**).

Estimates of premature mortality relating to $PM_{2.5}$, specifically fossil fuel $PM_{2.5}$, and other fossil fuel air pollutants all identify the largest mortality rate in this region to be in the Democratic Republic of the Congo or Chad (Leliveld 2019, McDuffie et al 2021, Vohra et al 2021, Farrow et al 2020 **Figure 4** and Appendix **Figures A1-A2**). Countries with large and small populations can be compared on the basis of mortality rates per 1000 inhabitants. Relatively high mortality rates are projected in the Central African Republic (**Figure 5**).

Relatively high mortality rates are projected in the Central African Republic.

In Central Africa the sector contributing most to NOx, NMVOC and BC emissions in the CEDS database is residential combustion. Industry contributes most SO_2 emissions (**Figure 20**, Appendix 1). Poor air quality in this region has been attributed to waste burning, mining, and industrial practices such as mineral processing and cement manufacturing (Greenstone and Hasenkopf 2023).

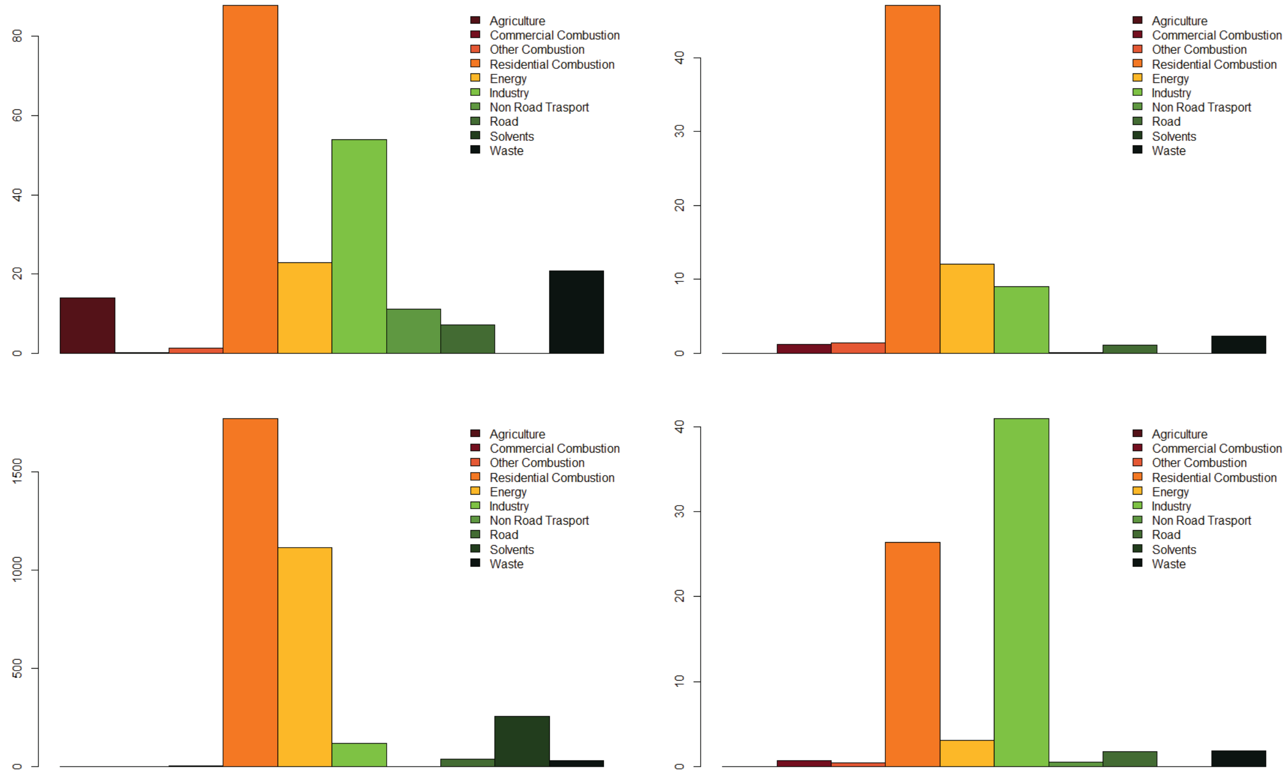

Figure 20. Sector contributions to NOx, BC, NMVOC, and SO_2 emissions in the CEDS-GBD_MAPS emission inventory for the year 2017 in Central African countries (McDuffie et al 2020)

Southern Africa

Angola, Botswana, Lesotho, Namibia, South Africa and Eswatini

According to the Air Quality Life Index assessment, permanently reducing $PM_{2.5}$ concentrations from 2021 level to the WHO Guideline of 5 µg/m³ could have improved life expectancy by as much as 1.8 years in Lesotho, 1.6 years in South Africa, and as little as 0.7 years in Namibia (Greenstone and Hasenkopf 2023, **Figure 3**).

Estimates of premature mortality relating to $PM_{2.5}$, specifically fossil fuel $PM_{2.5}$, and other fossil fuel air pollutants all identify the largest mortality rate in this region to be in South Africa (Leliveld 2019, McDuffie et al 2021, Vohra et al 2021, Farrow et al 2020 **Figure 4** and Appendix **Figures A1-A2**). Countries with large and small populations can be compared on the basis of mortality rates per 1000 inhabitants. Relatively high mortality rates are projected in South Africa, Lesotho and Eswatini (**Figure 5**).

In Southern Africa the sector contributing most to NOx, NMVOC and SO_2 emissions in the CEDS database is the energy sector. Coal constituted over

70% of total energy supply in South Africa in 2020 (IEA 2022). Residential combustion contributes most BC emissions (**Figure 21**, Appendix 1). These pollutants contribute to $PM_{2.5}$ formation. At the national level, South Africa and Eswatini both have very large contributions to $PM_{2.5}$ relating to coal (McDuffie et al 2021, Appendix 1). Waste burning, both in residences and at dumps, is an important factor contributing to BC emissions in South Africa, alongside emissions from industry, energy, traffic and flaring (Keita et al 2021).

Much of these air pollution impacts and drivers are related to the Highveld region in South Africa, which is known for industrial activities, mining operations, and coal-fired power plants. Consequently South Africa is the country emitting the highest amount of SO_2, with roughly 62% of the total African SO_2 emissions (Keita et al 2021).

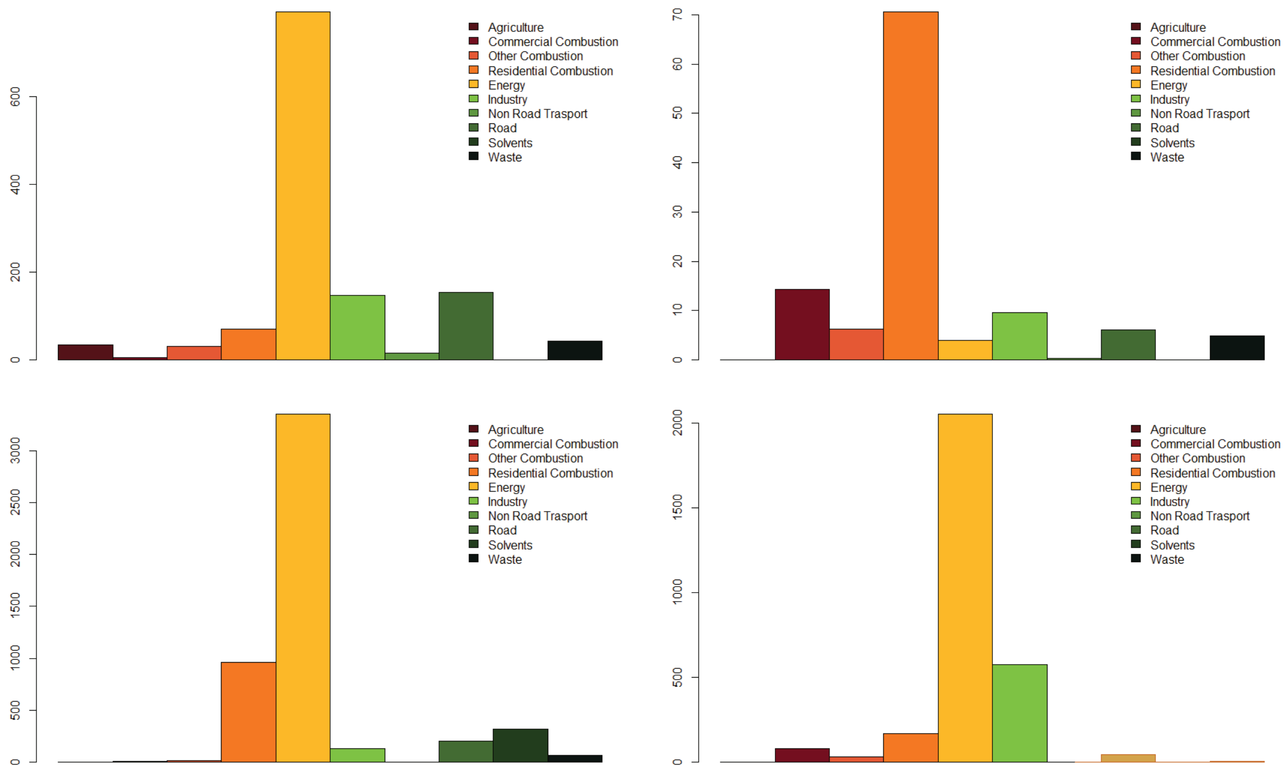

Figure 21. Sector contributions to NOx, BC, NMVOC, and SO_2 emissions in the CEDS-GBD_MAPS emission inventory for the year 2017 in Southern African countries (Mc-Duffie et al 2020)

CONCLUSIONS

This report highlights the major sources of air pollution and the biggest air pollutant emitters in Africa. These pollution emissions cause a serious impact on health and the environment. The report calls for urgent collective action at all levels to address the issue.

Exposure to air pollution in Africa is associated with a vast public health impact and is a major contributor to premature deaths. The report has identified major point-source polluters, including fossil fuel power plants, smelters and oil and gas production infrastructure. It highlights the need for clean, renewable energy, an end to reliance on fossil fuels and combustion for energy and better regulation of air quality and emissions. These steps are critical for the wellbeing of people living in Africa and for the reduction of environmental injustices.

The report studied satellite observations to identify Africa's largest NO_2 and SO_2 emission hotspots. It analysed global and regional emission databases to contextualise these hotspots and suggest which sectors and industries are the most polluting in various regions of Africa. All of the pollutants studied can be harmful, but they also contribute to particulate matter pollution which is particularly important for health impacts.

The pollutant emissions discussed often occur where there are severe gaps in the collection and availability of air pollution data and often in countries where air pollution legislation and air quality standards are either absent or inadequate.

Pollutant emissions result in significant numbers of premature deaths in Africa. Egypt, Nigeria and South Africa are consistently found to have large disease burdens. It is in these nations where mortality linked to fossil fuel air pollution is greatest.

Pollutant emissions result in significant numbers of premature deaths in Africa.

Satellite observations unmask Africa's largest point sources of pollution. Between May 2018 and November 2021, out of the ten largest NOx point sources globally, the top five were power plants in South Africa. Four were owned by Eskom, the state's largest power generation utility, one by Sasol. Among the ten largest SO_2 emission hotspots in Africa identified by NASA between 2005 to 2021, four are in South Africa, two are in Egypt, two are in Morocco and Mali and Zimbabwe each have one hotspot. South Africa's hotspots are substantial enough to rank among the top 50 anthropogenic sources globally.

Analysis of global and regional emissions inventories suggests that air pollutant emissions, including BC, NOx, CO, SO_2 and NMVOCs, have increased across Africa over recent decades. Southern Africa and North Africa emerge as Africa's biggest emitting regions for SO_2 and NOx. These regions host substantial industrial and power plant sources compared to other African regions. In West and East Africa, traffic and household emissions are important sectors. Notably, South Africa, Nigeria and North African nations are significant NOx emitters, largely from the fossil fuel energy industry including coal, oil and gas facilities. SO_2 emissions are primarily dominated by South Africa's power plants.

This report has highlighted major sources and emitters of air pollutants. It also presents case studies illustrating how communities are actively combating air pollution through diverse means such as legal action, new technology and collective community efforts. Despite the challenges, sustainable change is attainable through the appropriate use of technology, holding governments accountable, and active community engagement.

Outdoor air pollution in Africa is projected to get worse unless prompt interventions are taken. Economic growth, population growth, unplanned urbanisation, and a lack of environmental regulation could exacerbate environmental and human health impacts. Environmental regulations, including air quality and emissions regulations alongside improved access to clean, renewable energy, would help reduce inequalities and support improved wellbeing for people living in Africa.

Based on the analysis, we recommend the following measures that governments and legislators must take to address air pollutant emissions from major polluters in Africa:

1. All African countries should enact comprehensive laws for ambient air quality management and establish national air quality standards with the aim of achieving continuous improvement and air quality aligned with the science-based WHO guidelines.

2. To accelerate the development of air quality monitoring networks and strengthen existing ones to enhance estimates of population exposure to harmful air pollution. The most vulnerable communities should be prioritised. These networks must provide transparent and timely access to data, with data reported in unambiguous physical units, at known locations, with good temporal resolution and direct online public access.

3. In addition to free and public air quality data, measures must be taken to monitor and report air pollutant emissions. Sectors and industrial facilities responsible for significant air pollutant emissions must be required to report their emissions. Publicly

available and independently verified pollutant release and transfer registers (PRTRs) should be established so that progress on emissions reduction can be monitored and polluters can be held to account.

The Stench is No More. Community Action Triumphs Over Air Pollution in Syokimau, Kenya

Syokimau is a middle-income neighbourhood in Machakos County, close to Kenya's capital, Nairobi. The community found itself grappling with multiple factories, including a steel mill, a cement manufacturing plant, and an asphalt factory, that emitted thick fumes into the air.

The situation was dire. Many residents resorted to keeping their windows shut and preventing their children from playing outside due to the fear of falling sick.

Despite initial complaints to the authorities and unsuccessful attempts at the National Environment Tribunal, the residents found a powerful ally in Code for Africa. In 2019, the organisation supplied low-cost sensors to help investigate the extent of the pollution. The collected data were made available on a public website for anyone to access, sparking a wave of awareness.

The residents launched a strategic social media campaign, sharing real-time data from the sensors and tagging various authorities, which caught the attention of leaders who had previously ignored their pleas.

The media amplified the campaign's voice, reporting on the residents' fight against air pollution. As a result, the environmental officials were finally spurred into action. They conducted inspections of the factories, engaged with community members, and issued an order for the steel mill to shut down until effective air filters were installed.

The impact was tangible. The sensors recorded significantly lower pollution levels, marking a victory for the community. The once-persistent stench and heavy fumes disappeared, and the rate of children falling ill from chest infections began to decrease.

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Citizen TV Kenya, Youtube Web Address, accessed on 26th October 2023

4

Indoor and household air pollution is closely associated with negative health burdens, often driven by limited access to clean, renewable energy for cooking. Stronger policy actions are needed to provide access to clean fuels for families in need. Governments should promote clean, renewable, and affordable cooking solutions with evidence-based policies that avoid fossil and solid fuels, meet local cultural, social and gender needs, and which are supported by adequate funds.

5

Coal burning for electricity generation and low quality fuel use are closely linked to major air pollutant emission sources in this report. Urgent steps need to be taken to decrease reliance on coal, oil and gas power and make a just transition towards renewable energies, which benefits both people and the climate. While the transition towards a fully renewable system takes place, urgent action is needed to ensure the quality of fuels used in Africa meet the best international environmental standards, including for sulphur content.

6

The Mpumalanga region of South Africa stands out globally for its air pollutant emissions. The South African government should urgently and wholeheartedly implement the Highveld Priority Area Air Quality Management Plan, upholding the Pretoria High Court judgment of the 'Deadly Air litigation'. Exemptions related to the already weak air pollution regulations in this region should not be considered, and coal-fired power stations reaching the end of their life should be decommissioned.

7

Fossil oil and gas infrastructure and electricity generation are linked to significant air pollutant emissions. Such processes are often linked to international oil and gas companies. Urgent steps need to be taken to end oil and gas production, flaring and the use of fossil fuels in energy generation, and to achieve net-zero emissions by 2050.

8

Waste burning and poor waste management is closely associated with air pollutant emissions in many of Africa's regions. Stronger actions are needed to reduce waste generation, prohibit the burning of waste, stop waste colonialism, and to provide access to effective means of waste management.

9

For African national governments, in collaboration with the international community and global north: to invest in sustainable, climate-friendly energy projects while phasing out environmentally harmful, high-emissions industries that have negative impacts on public health and the climate.

GLOSSARY

air pollutant
An unwanted substance found in the air in the form of a solid particle, a liquid droplet or a gas. The substance may be hazardous, harmful to human health if inhaled or damaging to the environment. Prominent examples are $PM_{2.5}$, NOx and SO_2.

air quality guideline
A guideline for the pollutant concentration, issued by the WHO. Pollutant concentrations above the guideline value are shown to be harmful to human health. According to the WHO, there is no safe level of particulate pollution, meaning any reduction in pollution will result in public health benefits. Harmful impacts for gaseous pollutants have been shown on pollution levels below these guidelines.

BC
Black carbon
Black carbon refers to sooty particles emitted by combustion processes including from fossil fuels.

CIPREL
Compagnie Ivoirienne de Production d'Electricité / Ivorian Company of Electricity Production

DU
Dobson units describe the amount of a trace gas in the entire thickness of the atmosphere above a particular point on the Earth's surface. It imagines that all the trace gas above that point is in a layer just above the ground, at standard temperature and pressure. The thickness of the layer can be used to describe the gas's abundance in increments of 0.01 millimetres.

emission limit
The maximum allowed emission concentration (or sometimes emission rate) for a specific station. It can be prescribed by national standards, environmental permit conditions (which can be based on national standards but can also be looser or stricter) or some other legal regulation.

emission rate
The amount of a pollutant that is emitted per unit time by a specific power station (e.g. 100 kg/hour). In some cases, this is used instead of the emission concentration as a measure of how polluting the coal-burning power station is.

exceedance — A period of time when the concentration of an air pollutant is greater than the appropriate air quality guideline. Not to be confused with: excess pollution

fossil fuel — A general term for hydrocarbon fuels including oil, gas and coal that are geological in origin and were produced by the decomposition of fossilised plant and animal remains. Fossil fuels contribute to climate change and air pollution when they are used.

fossil gas — Also known as 'natural gas' or 'methane gas'. It is a type of fossil fuel composed of a mixture of hydrocarbons, principally methane.

NMVOC — Non-methane volatile organic compound. Carbon containing compounds that readily evaporate, but excluding methane. Some NMVOCs are known carcinogens.

NO — Nitrogen monoxide. A trace gas that is produced in all combustion processes. It converts from and to NO_2.

Synonym: nitric oxide

NO_2 — Nitrogen dioxide. A trace gas that is produced in all combustion processes. It converts from and to NO. The amount of NO_2 in the atmosphere is commonly used as a proxy to assess the health impact of the whole NOx group.

NOx — Nitrogen oxides. A generic term for NO and NO_2, a group of trace gases that are harmful to human health.

OCGT — Open-cycle gas turbine. A type of gas fired power plant, which uses gas combustion to power turbines without recovering waste heat. This makes the technology less efficient than designs that use waste heat for heating or extra power generation.

$PM_{2.5}$ — Fine particulate matter / fine particles. Solid particles with aerodynamic diameter less than 2.5μm (i.e. small dust particles). They are so small that they can pass from the lungs into the bloodstream, affecting the entire cardiovascular system and causing a range of health impacts. Due to their small size, the particles stay airborne for a long time and can travel hundreds or thousands of kilometres. Fossil fuel combustion emits $PM_{2.5}$ directly, as fly ash and other unburned particles, and contributes to $PM_{2.5}$ indirectly through emissions of gaseous pollutants (particularly SO_2 and NOx) which form $PM_{2.5}$ in the atmosphere. $PM_{2.5}$ is harmful to human health and thus an air pollutant.

PRTR	Pollutant release and transfer register. A database of potentially hazardous chemical substances or pollutants released to air, water and soil and transferred off-site for treatment or disposal by industrial sites and other sources.
SO_2	Sulphur dioxide. Sulphur dioxide is a trace gas produced by industrial processing of materials that contain sulphur, including burning coal in power stations and processing of some mineral ores. Anthropogenic sources of SO_2 far exceed all natural sources even when accounting for volcanic activities. Sulphur dioxide reacts with other substances to form harmful compounds, such as sulphuric acid (H_2SO_4), sulphurous acid (H_2SO_3) and sulphate particles and it is therefore a cause of acid rain and particulate matter pollution.
Waste colonialism	Where waste and pollution contribute to the domination of one group in their homeland by another group. Typically the term describes the transboundary movement of waste from areas of privilege and affluence to areas with lower economic status and influence.
WHO	World Health Organization
µg	Microgram. A millionth of a gram (about the mass of an ant's antennae).

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APPENDIX 1. COUNTRY-LEVEL DATA

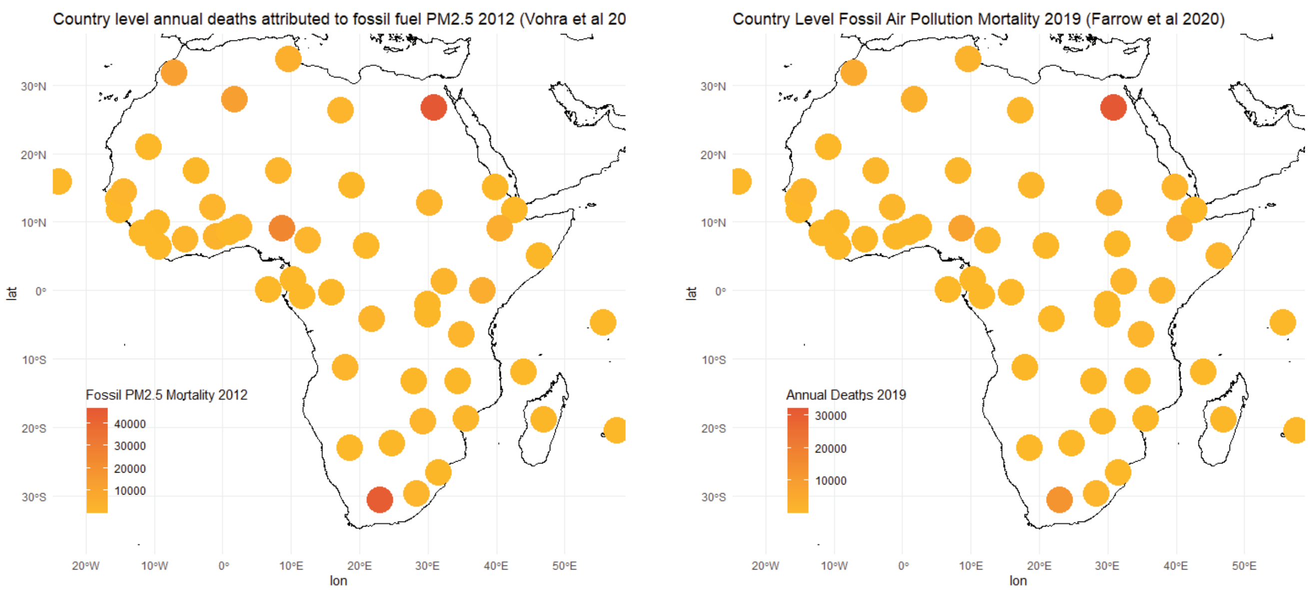

Figure A1: Estimated country-level mortality attributable to fossil fuel $PM_{2.5}$ pollution in 2012 using updated concentration response functions (left) (Vohra et al 2021) and in 2019 using a more conservative methodology (right) (Farrow et al 2020). Both identify nations where fossil fuel particulate matter causes the largest number of premature deaths.

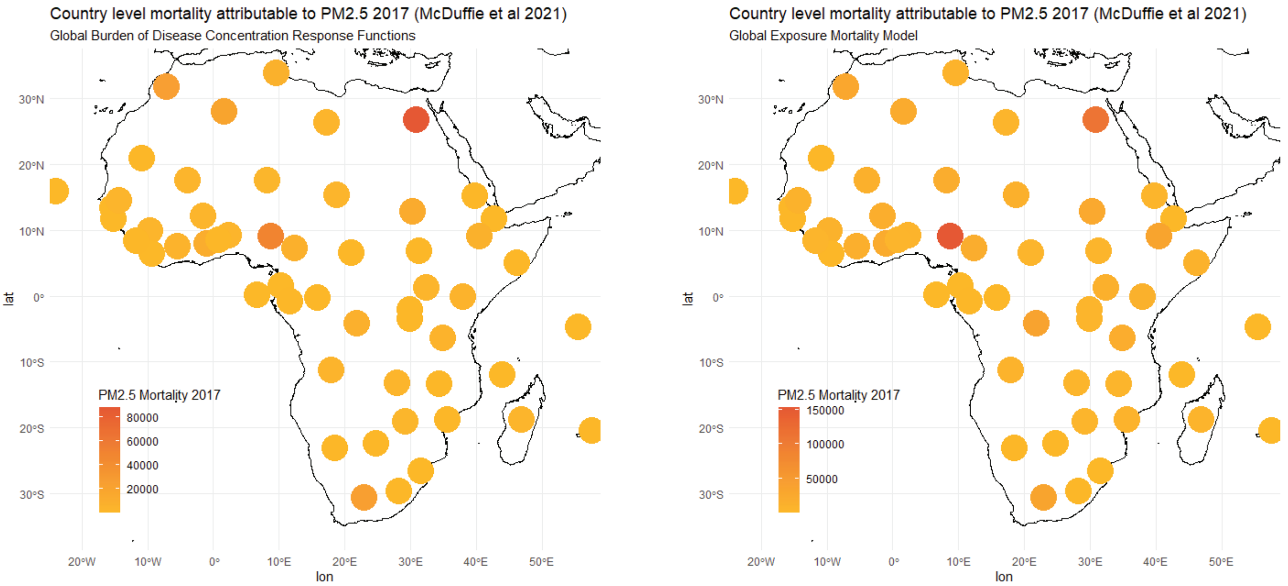

Figure A2: Estimated country-level mortality attributable to $PM_{2.5}$ air pollution in 2017 (McDuffie et al 2021) derived using Global Burden of Disease (GBD) concentration response functions (left) and Global Exposure Mortality Model functions (GEMM) (right). GEMM includes more recent observational data as well as data on type 2 diabetes, preterm births, and low birth weights. GBD is partly informed by data including household air pollution and second-hand smoke exposure, while GEMM only includes studies of ambient $PM_{2.5}$.

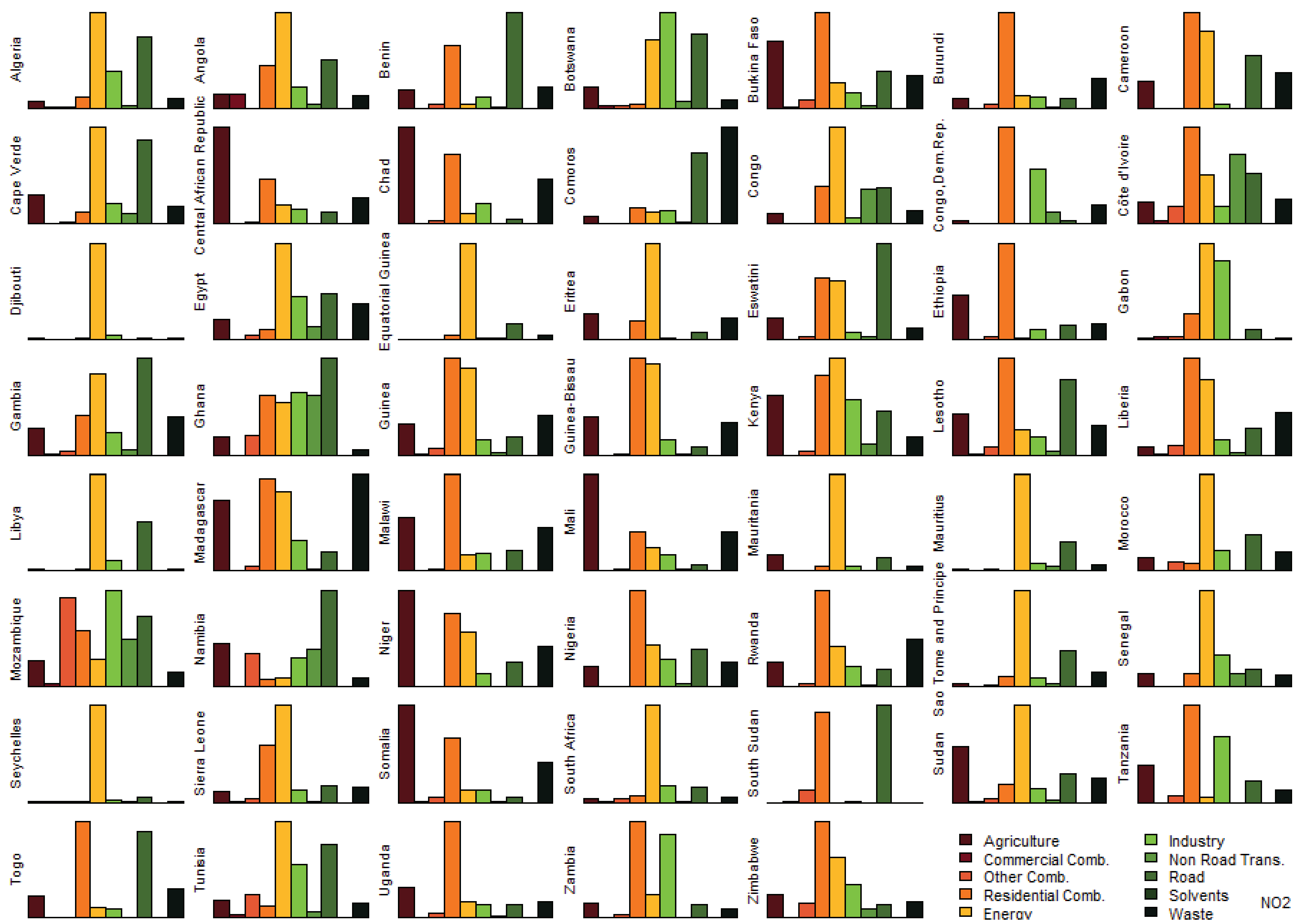

Figure A3. Relative contribution of source sectors to NO_2 emissions by country in the CEDS_GBD-MAPS inventory (McDuffie et al 2020)

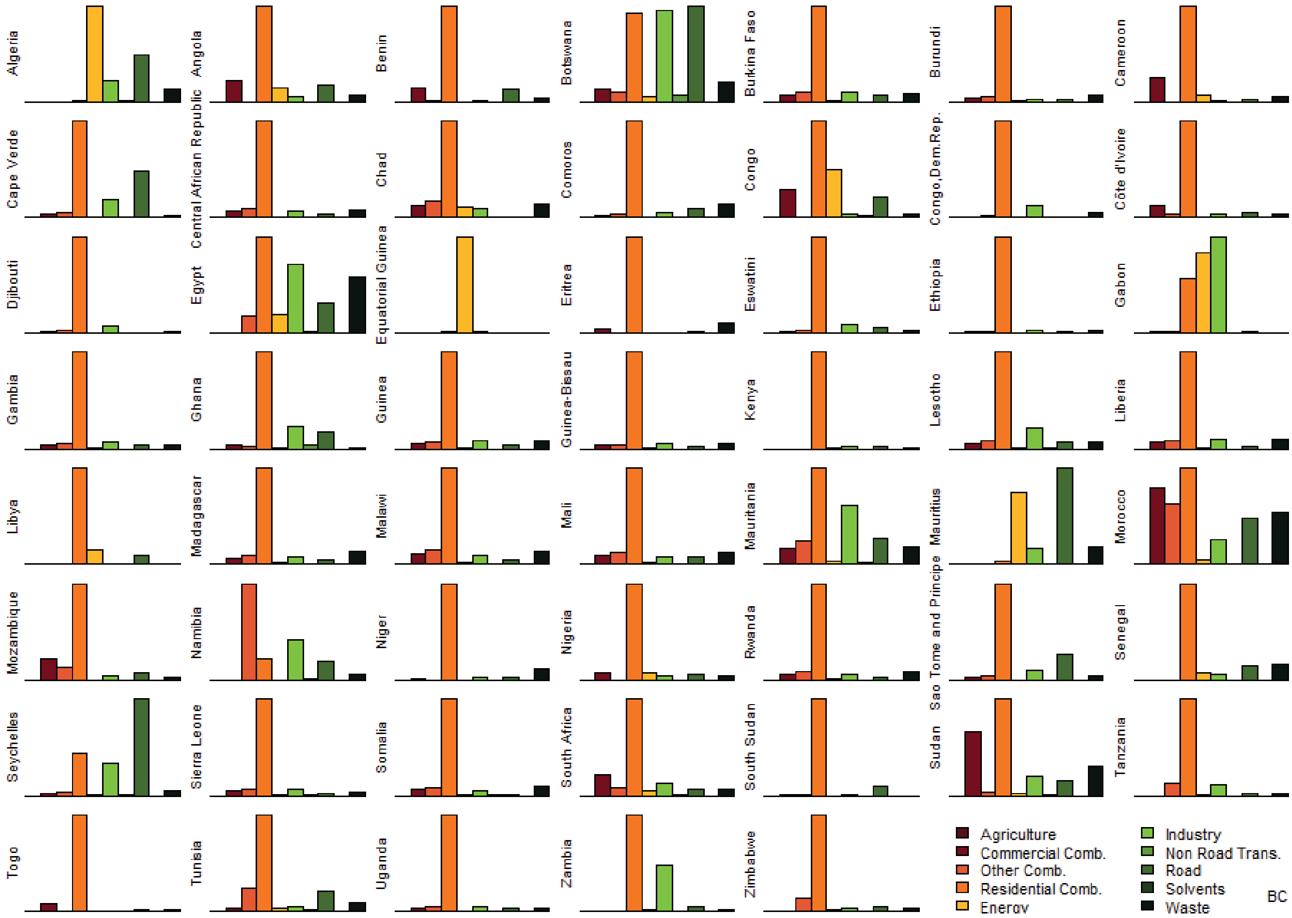

Figure A4. Relative contribution of source sectors to BC emissions by country in the CEDS_GBD-MAPS inventory (McDuffie et al 2020)

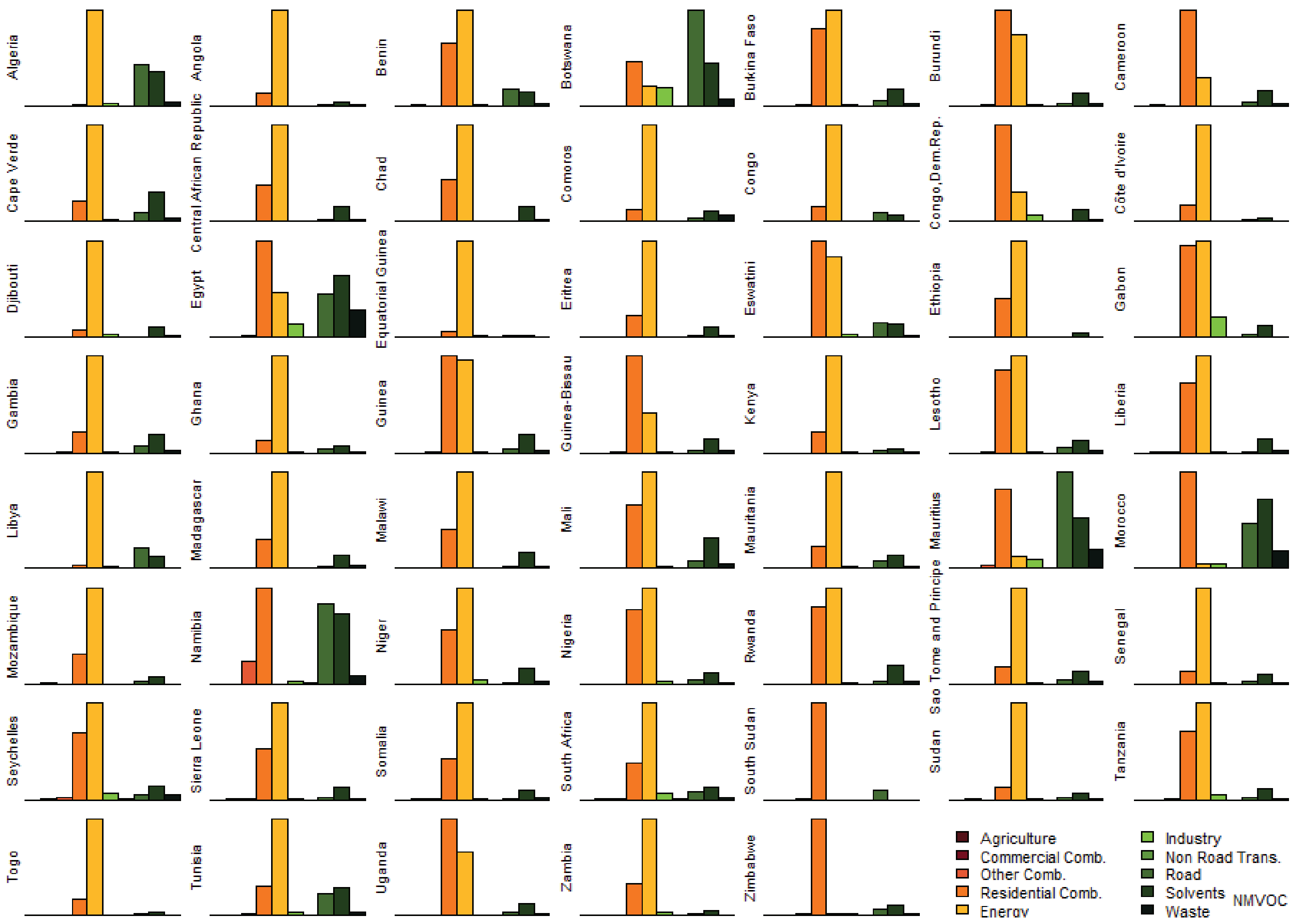

Figure A5. Relative contribution of source sectors to non-methane volatile organic compound emissions by country in the CEDS_GBD-MAPS inventory (McDuffie et al 2020)

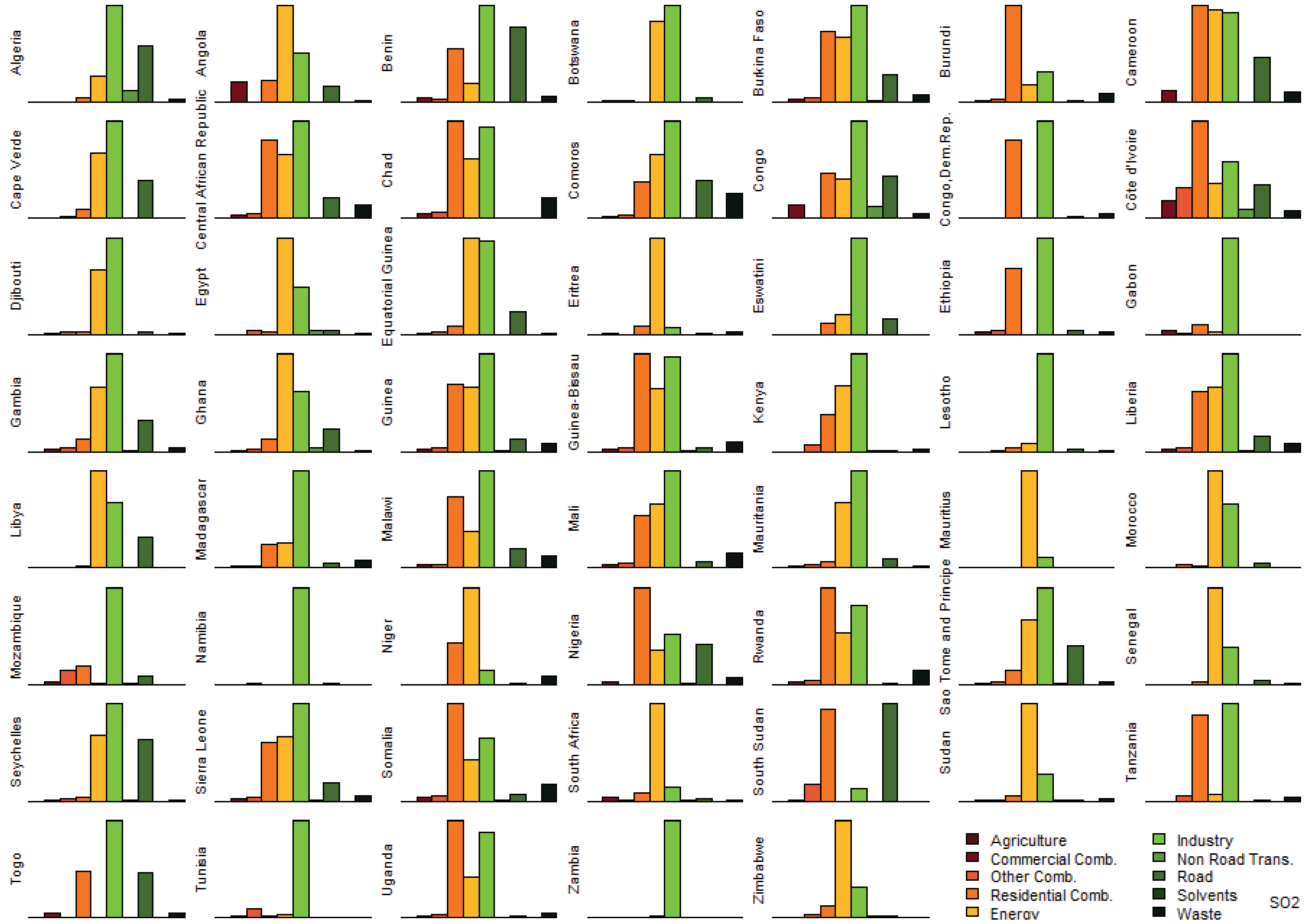

Figure A6. Relative contribution of source sectors to SO_2 emissions by country in the CEDS_GBD-MAPS inventory (McDuffie et al 2020)

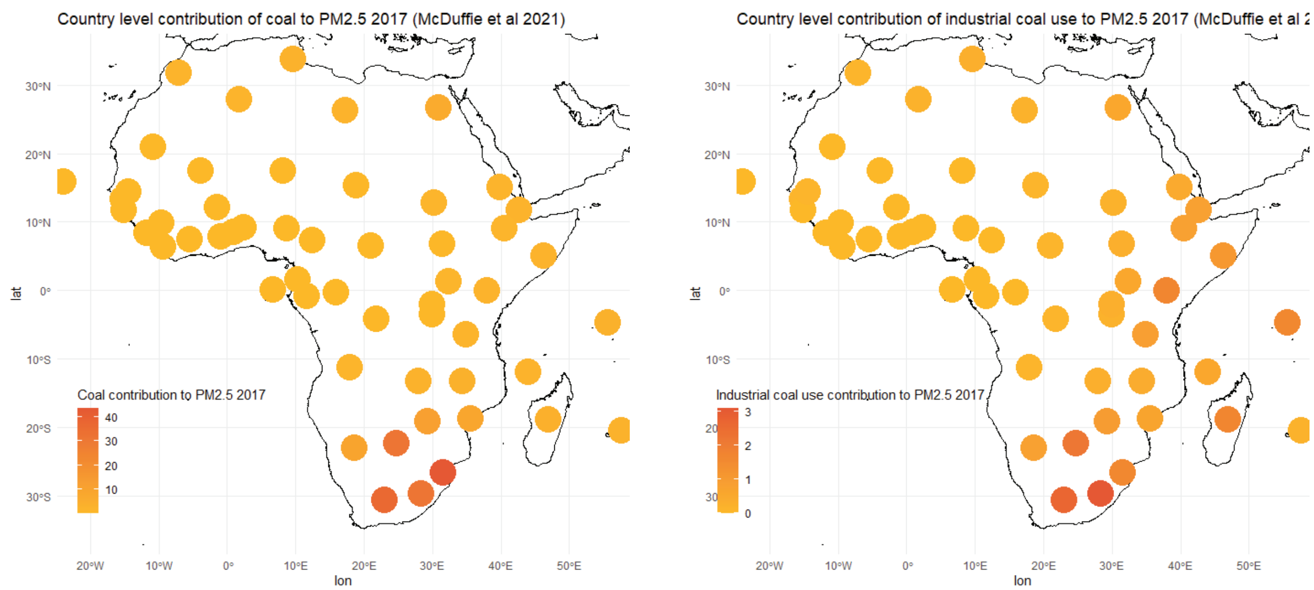

Figure A7. Contribution of source sectors to $PM_{2.5}$ concentrations by country in 2017, for all coal use and industrial coal use (McDuffie et al 2021)

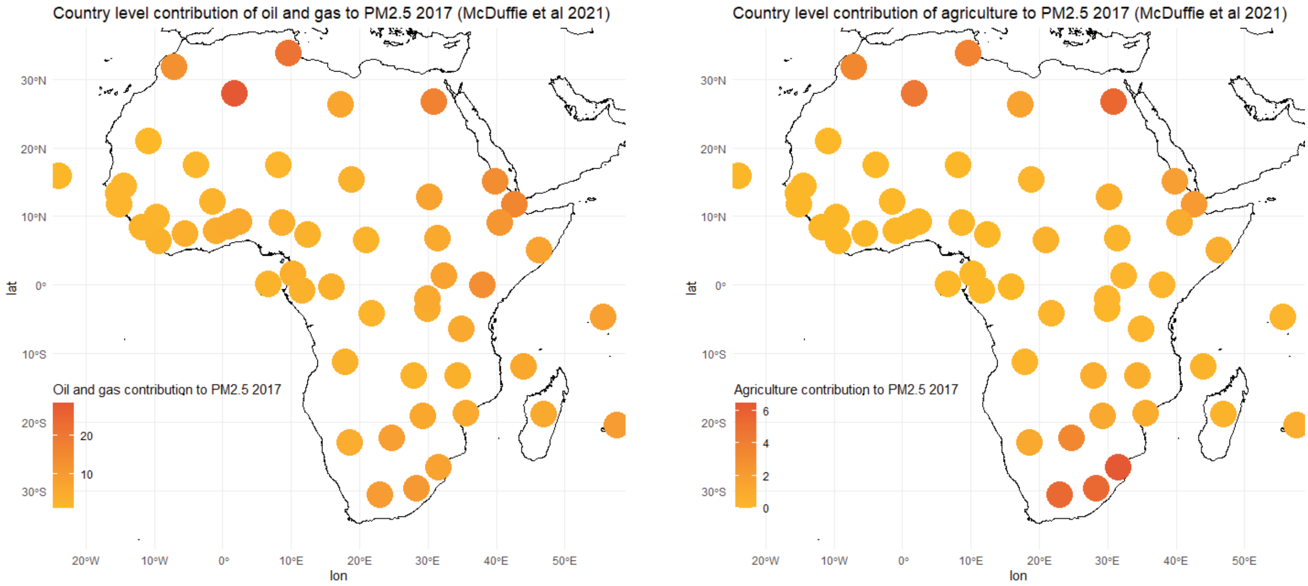

Figure A8. Contribution of source sectors to $PM_{2.5}$ concentrations by country in 2017, for oil and gas, and agriculture (McDuffie et al 2021)

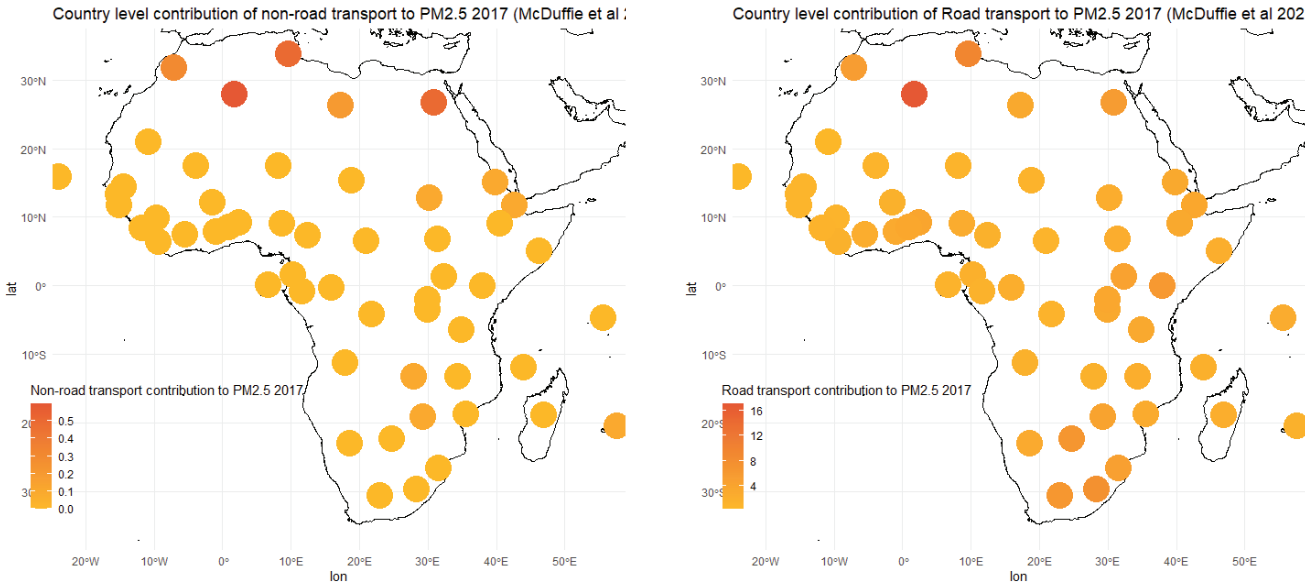

Figure A9. Contribution of source sectors to $PM_{2.5}$ concentrations by country in 2017, for non-road transport and road transport (McDuffie et al 2021)

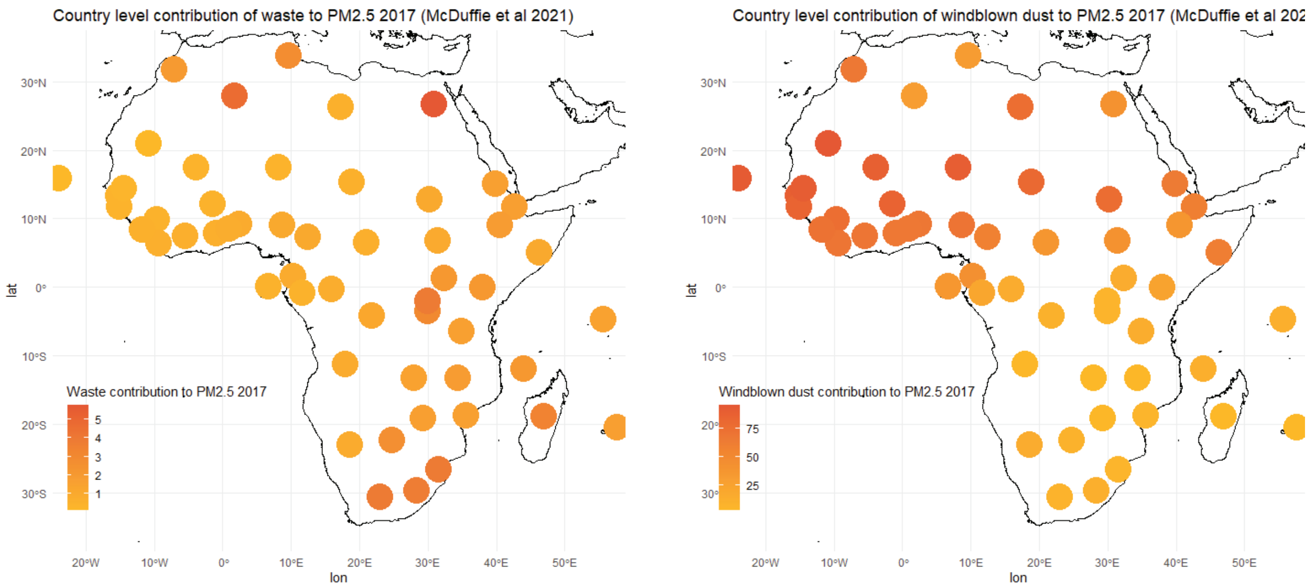

Figure A10. Contribution of source sectors to $PM_{2.5}$ concentrations by country in 2017, for waste and wind-blown dust (McDuffie et al 2021)

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