Sulfur Dioxide (SO_2) Pollution Hotspots in South Africa: 2019-2020

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Executive summary

Sulfur dioxide (SO_2) is a colourless air pollutant that is invisible to the human eye, widespread and hazardous to human health. Breathing SO_2 increases the risk of health conditions, including stroke, heart disease, asthma, lung cancer, and premature death.

Globally, the single biggest source of SO_2 is from burning fossil fuels, including coal, oil, and gas. Elevated levels of SO_2 pollution can be found near coal-fired power plants, at oil refineries, and in areas that are dominated by heavy industry although this pollution can spread over vast areas.

For this Greenpeace[1] report, researchers used satellite data and a global catalogue of SO_2 emissions sources from the United States National Aeronautics and Space Administration (NASA) to detect emission hotspots. The data was analysed to identify source hotpots and emission trends. In South Africa, 97% of the SO_2 emissions identified are associated with coal combustion for power generation.

The findings reveal that South Africa's largest hotspot for SO_2 emission is Kriel in the Mpumalanga province and that this hotspot emits the most SO_2 of all hotspots in Africa. It is the largest hotspot associated with coal power worldwide.

Analysis indicates that global anthropogenic SO_2 emissions decreased by approximately 6% worldwide from 2018 to 2019. While South Africa experienced a decline in SO_2 emissions, bringing the country's SO_2 emissions to their lowest level on record, the SO_2 emissions are still on a dangerously high level. The causes of the 2019 decrease are temporary: reduction in coal-fired generation capacity due to maladministration led to the so-called "load shedding" that year. Stringent legislation is needed to ensure a sustainable decrease of SO_2 emissions in the future.

SO_2 emission data for 2020 is not yet available, but preliminary analysis of satellite observations of SO_2 in the atmosphere suggest that pollution in South Africa continued to fall through 2020. This is most likely because of a reduction in energy demand at South Africa's coal-fired power stations as a result of the COVID-19 pandemic. Despite this, SO_2 pollution remains dangerously high and thus poses a threat to the health of South Africans. SO_2 pollution can only be reduced sufficiently by permanently phasing out coal-burning industries.

Greenpeace urges:

- the South African Government to halt all investment in fossil fuels and shift to safer, more sustainable energy sources, such as wind and solar,
- Minister of Environment, Forestry and Fisheries, Barbara Creecy to strengthen SO_2 emissions standards by reinstating South Africa's 500 mg/Nm^3 minimum emission standard and applying flue gas pollution control technology at power plants, smelters, and other industrial SO_2 emitters,
- South Africa's National Air Quality Officer, Dr Thuli Khumalo, to enforce existing minimum emission standards,

[1] Within this report, "Greenpeace" refers to Greenpeace Africa, unless otherwise indicated.

- that no further postponement of compliance with minimum emission standards by Eskom and Sasol be granted by the South African Government and that coal-fired power stations or units that cannot comply with existing standards be decommissioned,
- the South African Government to implement an air pollution action plan for Mpumalanga, Johannesburg, Pretoria and all high priority areas that:
    - aligns with the World Health Organisation (WHO) Air Quality Guidelines for ambient air,
    - implements concrete measures and takes decisive action to improve the air quality in the regions and ensure compliance with South Africa's Minimum emission standard within the next five years, and
    - installs independent continuous emissions monitoring systems (CEMS) and receptor monitoring in the affected communities for different pollutants, making the data available to the public and informing decision making,
- Minister for Mineral Resources and Energy Gwede Mantashe to revise the commitments made in the Integrated Energy Plan and,
    - abandon plans for installing new coal-fired power stations of 1500 MW capacity scheduled for 2023 and 2027, and
    - increase uptake and implementation of renewable energy generation capacity through radical and deliberate policies and programmes,
- the South African Government to ensure the development of a comprehensive and inclusive Just Transition programme that moves the country away from the use of fossil fuels to cleaner and sustainable energy, and
- for the South African Government to hold carbon majors accountable for their emissions resulting from the use of fossil fuels by implementing and enforcing a carbon tax that will discourage carbon emissions.

It is encouraging that South Africa reduced its emissions in 2019, but nonetheless, SO_2 pollution continues to threaten the health of the South African population.

Contents

Introduction

When fossil fuels are burned, harmful substances are emitted into the air, which has grave impacts on both the climate and public health.[2,3] Each year, an estimated 23,000 people in South Africa die because of exposure to ambient air pollution, according to an estimate by the World Health Organization (WHO) based on 2016 data.[4] The WHO further estimates that the health impact attributable to air pollution leads to 712,000 years of life being lost and 740,000 life years when adjusted for impaired quality of life.[5,6] This means that each of these fatalities is on average deprived of 32 quality-adjusted life years. A 2020 study estimated that 13,000 of a total 23,000 air-pollution related fatalities in South Africa each year are due to air pollution from fossil fuel combustion and that air pollution costs the South African economy around 100 billion rand (6.3 billion USD) each year.[7]

Sulfur dioxide (SO_2) is one of many substances that pollute our air. It is a toxic gas that is released into the air when materials that contain sulfur are burned. Sulfur is found in all types of coal and oil resources. SO_2 is primarily emitted by industrial facilities that burn fossil fuels, either to generate electric power or to extract metal from ore (smelter). Other anthropogenic sources are locomotives, ships, and other vehicles or heavy equipment that burn fuel with a high sulfur content. The only significant natural source of SO_2 are volcanoes. Less than a third of the total SO_2 emitted to the atmosphere globally arises from volcanism. As there are no active volcanoes in South Africa, the relevance of volcanic SO_2 in the country is negligible.

SO_2 pollution leads to health impacts that result from both direct exposure to SO_2 as well as exposure to secondary pollutants which are created when SO_2 reacts with other chemicals in the air. An important secondary pollutant related to SO_2 is fine particulate matter[8] ($PM_{2.5}$). Exposure to SO_2 and $PM_{2.5}$ can lead to severe health problems. Acute symptoms following SO_2 exposure include a burning sensation in the nose, throat, and lungs; breathing difficulties; and harm to the respiratory system. Severe, chronic health impacts include dementia[9]; fertility problems[10]; reduced cognitive ability[11]; heart and lung disease; and premature death[12].

In addition to health impacts, every combustion process that emits SO_2 also releases substantial quantities of greenhouse gases into the atmosphere. Sources of SO_2 thus have

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[2] Ramanathan, V. Climate Change, Air Pollution, and Health: Common Sources, Similar Impacts, and Common Solutions. In: Al-Delaimy W., Ramanathan V., Sánchez Sorondo M. (eds) Health of People, Health of Planet and Our Responsibility. Springer, Cham. (2020). https://doi.org/10.1007/978-3-030-31125-4_5

[3] Perera, F. Pollution from Fossil-Fuel Combustion is the Leading Environmental Threat to Global Pediatric Health and Equity: Solutions Exist. *Int. J. Environ. Res. Public Health* 15(1), 16 (2017). https://doi.org/10.3390/ijerph15010016

[4] World Health Organization 2016, Global Health Observatory data repository, Deaths by country. Retrieved from https://apps.who.int/gho/data/node.main.BODAMBIENTAIRDTHS?lang=en on 2020-10-22.

[5] World Health Organization 2016, Global Health Observatory data repository, YLLs by country. Retrieved from https://apps.who.int/gho/data/node.main.BODAMBIENTAIRYLLS?lang=en on 2020-10-22.

[6] World Health Organization 2016, Global Health Observatory data repository, DALYs by country. Retrieved from https://apps.who.int/gho/data/node.main.BODAMBIENTAIRDALYS?lang=en on 2020-10-22.

[7] ibid.

[8] Particles with aerodynamic diameter of less than 2.5 μm.

[9] Wu, Y.-C. et al. Association between air pollutants and dementia risk in the elderly. *Alzheimers Dement. Amst. Neth.* 1(2), 220–228 (2015). https://doi.org/10.1016/j.dadm.2014.11.015

[10] Carré, J. et al. Does air pollution play a role in infertility?: A systematic review. *Environ. Health* 16, 82 (2017). https://doi.org/10.1186/s12940-017-0291-8

[11] Shehab, M.A. & Pope, F.D. Effects of short-term exposure to particulate matter air pollution on cognitive performance. *Sci. Rep.* 9, 8237 (2019). https://doi.org/10.1038/s41598-019-44561-0

[12] Cohen, A. J. et al. Estimates and 25-year trends of the global burden of disease attributable to ambient air pollution: an analysis of data from the Global Burden of Diseases Study 2015. *Lancet* 389(10082), 1907–1918 (2017). https://doi.org/10.1016/S0140-6736(17)30505-6

a negative direct effect on human health regionally as well as a negative long term impact on human wellbeing globally through their associated emissions of greenhouse gases, which drives global warming.

By documenting and understanding sources of SO_2 emissions, measures can be put in place to stop SO_2 pollution, reduce the health impacts of air pollution and expose the toxic consequences of fossil fuel use. This Greenpeace report investigates the sources and geographical distribution of the industries responsible for major SO_2 emissions in South Africa that have been identified by the United States National Aeronautics and Space Administration (NASA).

Methodology

Building on a global analysis[13] produced by the Centre for Research on Energy and Clean Air (CREA) and Greenpeace, this report presents a detailed investigation specific to South Africa. The analysis reveals SO_2 emission hotspots and trends using a satellite-derived global catalogue of SO_2 emissions sources from the United States National Aeronautics and Space Administration (NASA). Satellite data provides annually updated, near worldwide data coverage which can be used to detect and quantify major source locations of SO_2 and that is not reliant on emissions reporting on the ground. The regions and industry sectors responsible for major SO_2 emissions are identified in the NASA catalogue, and emissions trends are assessed through time. While the NASA catalogue provides global coverage, this report provides a specific focus on SO_2 emissions in South Africa.

OMI and MEaSUREs SO_2 emission catalogue

The amount of SO_2 in the atmosphere above a location on the Earth's surface (*column amount*) can be measured by instruments onboard Earth-orbiting satellites. The NASA Ozone Monitoring Instrument (OMI) is such a satellite-based device, which has been monitoring air quality from space since 2004 with high consistency. NASA's *Making Earth System Data Records for Use in Research Environments* (MEaSUREs) programme uses these measurements to detect and quantify SO_2 emissions of major source locations of SO_2 emissions across the globe (see **Box 1** for an explanation of how column amount relates to emissions).[14] These locations of high SO_2 emissions are referred to as *emission hotspots*. Because the technique does not rely on *a priori* knowledge of source locations, it can also detect new sources or those that are missing from other emission inventories. NASA's worldwide observation coverage makes it possible to identify emission hotspots in South Africa and worldwide (**Box 2**).[15]

The NASA MEaSUREs SO_2 emission source catalogue provides the geographical location and emission rate for hotspots in each calendar year. The catalogue groups the detected sources into four categories: one natural category (volcanoes) and three anthropogenic categories: power plant, oil and gas, and smelter. A complete list of all anthropogenic SO_2 emissions hotspots identified by OMI (NASA_Aura Satellite) can be found here[16]. In this report, the NASA category *power plant* is renamed *coal* in order to emphasise that the power plants in question are only coal-fired ones (and not those running on renewable or nuclear energy).

[13] Dahiya, S., Anhäuser, A., Farrow, A., Thieriot, H., Chanchal, A., & Myllyvirta, L. Global SO_2 emission hotspot database. Delhi: Center for Research on Energy and Clean Air & Greenpeace India. 48 pp. October 2020.
[14] National Aeronautics and Space Administration. MEaSUREs SO_2 source emission catalogue. Retrieved from https://so2.gsfc.nasa.gov/measures.html on Sept 14, 2020.
[15] Fioletov, V. E. et al. A global catalogue of large SO_2 sources and emissions derived from the Ozone Monitoring Instrument. *Atmos. Chem. Phys.* 16, 11497–11519 (2016). https://doi.org/10.5194/acp-16-11497-2016.
[16] https://bit.ly/3iyleQy

Box 1: What are SO_2 emissions and what is SO_2 column amount?

Emission rate:

The **emission** or **emission rate** describes the quantity of a pollutant (for example, SO_2) that is released into the atmosphere by a certain source within a certain time period. The most important sources for SO_2 emissions are coal-fired power stations, smelter sites, oil and gas industry installations, and volcanoes. Units of emission include 'kilograms per hour', 'kilotonnes per year', and 'megatonnes per year'. The quantity or 'emission (rate)' is only meaningful for *sources* of SO_2 and not for locations away from the sources.

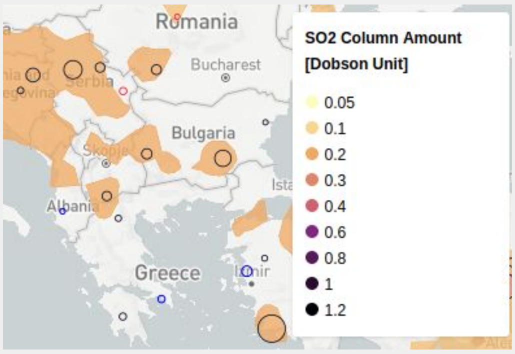
Column amount

The **boundary layer column amount,** which is abbreviated to **column amount**, is the total amount of an air pollutant that is present in the lowest layer of the Earth's atmosphere, known as the 'planetary boundary layer'[17]. For example, this could be all the SO_2 pollution that is found in the (virtual) column of air above a 1 km square area between the Earth's surface and the top of the boundary layer. The column amount is the quantity of pollutant that satellite instruments usually measure because those instruments make observations through the entire thickness of the atmosphere. Units for recording the quantity of air pollutants are 'kilograms per square metre' or the special unit, Dobson unit (DU). Because SO_2 sources are located at the Earth's surface, they emit into the boundary layer. In general, there is little vertical mixing from the boundary layer into the atmospheric layers above. The biggest part of the SO_2 pollution remains within the boundary layer before it is deposited or converts into other chemicals.

What is the relationship between emission rate and column amount?

Emitted pollutants are dispersed in the atmosphere and transported to locations away from the source through wind and turbulence before they are deposited or converted into other chemicals. Therefore, locations that are far from emission sources may also become polluted. In general, the air is more likely to be polluted in the proximity of an emission source than far away from it. On a map, emission sources are usually surrounded by an area with a high column amount of SO_2.

The raw column amount can be used as a proxy for emission, but it is important to note that the two are not the same thing. For example, a strong wind will blow pollution away from an emitting source, even if emissions are high. The area close to the source of the emissions could thus have a relatively low column amount. However, using annual mean emissions averages out most data anomalies caused by meteorological events such as high wind. On the map of annual mean emissions, virtually all hotspots are surrounded by areas with high column amounts of SO_2. An example is shown in the picture to the right. SO_2 emissions sources (circles) are surrounded by areas of high SO_2 column amount (shaded areas).



[17] The planetary boundary layer has a thickness of up to a few kilometers. The thickness varies depending on the time and global location. The planetary boundary layer is also known as the *atmospheric boundary layer*.

Box 2: MEaSUREs explained in a nutshell

MEaSUREs is a catalogue developed by NASA that lists annual SO_2 emissions of human-made and natural sources with global coverage. It takes actual wind into account for its emission estimates. It uses a technique based on a comparison of upwind and downwind SO_2 column amounts to make a quantitative estimate of emissions rates for each hotspot. The results have been validated by comparing the emission estimates by MEaSUREs against reliable *in situ* measurements in the United States and the European Union (EU).[18,19]

Limitations of satellite-based SO_2 observations and emission estimates

Data coverage

Satellite-based approaches for detecting and quantifying major point sources of SO_2 provide almost continuous worldwide data coverage. However, the quality of the measurements is limited by a number of factors, including spatial resolution, measurement noise, and artefacts, observation geometry, snow, ice, and cloud cover. Only large SO_2 sources are thus detected and quantified reliably; sources that emit less than ~50 kt/yr tend to have large relative uncertainties.[20] NASA estimates that sources emitting less than 30 kt/yr are not reliably detected at all and that the MEaSUREs catalogue accounts for about half of all known anthropogenic SO_2 emissions worldwide.[21] The detection ratio is about 50±15% for most large countries and regions across the world.[22] Therefore, the MEaSUREs dataset can be used to estimate and compare regional emission trends.

Data uncertainty

The precision of emission estimates varies from one hotspot to another. Uncertainty in the underlying satellite data increases in the high latitudes, reducing confidence in estimates for hotspots in these regions, but this has little impact in South Africa. For some hotspots with relatively low emissions, catalogue estimates of the emission amount have uncertainty ranges that are as large as the value itself, rendering values of this individual source almost meaningless. However, where South African and other country totals are presented, all hotspots listed in the catalogue are taken into account; it is assumed that the uncertainty ranges given by NASA is meaningful even for small emission values and the errors between

[18] Fioletov, V. et al. Multi-source SO_2 emission retrievals and consistency of satellite and surface measurements with reported emissions. *Atmos. Chem. Phys.* 17, 12597–12616 (2017). https://doi.org/10.5194/acp-17-12597-2017
[19] Fioletov, V. et al. Multi-Satellite Air Quality Sulfur Dioxide (SO_2) Database Long-Term L4 Global V1, Greenbelt, MD, USA, Goddard Earth Science Data and Information Services Center (GES DISC) (2019). Accessed Sept 23, 2020. https://doi.org/10.5067/MEASURES/SO2/DATA403
[20] See full hotspot list in the main report.
[21] Fioletov, V. E. et al. A global catalogue of large SO_2 sources and emissions derived from the Ozone Monitoring Instrument. *Atmos. Chem. Phys.* 16, 11497–11519 (2016). https://doi.org/10.5194/acp-16-11497-2016
[22] Ibid.

different hotspots are not correlated (no systematic error). This way, relatively precise values can be retrieved for country totals even if the data for the individual sources are rather noisy.

The quality of OMI sensor measurements is decreased in an area called the South Atlantic Anomaly (SAA), where high-energy charged particles in the atmosphere are trapped by the Earth's magnetic field.[23] The SAA affects a part of South America and the southern Atlantic Ocean. As a consequence, the emissions data for Argentina, Brazil, Chile, Peru, Bolivia, Paraguay, and Uruguay (the latter three are completely absent in the data set) cannot claim the same accuracy and completeness that prevail in other regions of the world. NASA advises to treat data from the SAA region with caution and we, therefore, recommend that comparisons should not be made with South Africa.

Concentration analysis in 2020

Global emissions data for 2020 has not yet been made available by the NASA MEaSUREs project. However, the raw OMI column amount data which is used by MEaSUREs to retrieve the emissions is available in near-real-time.

In order to make the first inquiry into 2020 emissions trends, SO_2 column amount measurements are used as an indicator of SO_2 emissions. For each of the hotspots, we computed the average SO_2 column amount in a 50 km radius around that hotspot. As explained above, this simple approach does not provide a direct indication of SO_2 emissions (**Box 1**). Nevertheless, analysis of observed SO_2 column amounts from 2020 can help to identify the most recent trends in SO_2 air pollution. The raw observations are cleaned by applying the same filters that are used in the NASA MEaSUREs methodology to estimate the anthropogenic SO_2.[24]

[23]Zhang, Y. et al. Continuation of long-term global SO_2 pollution monitoring from OMI to OMPS. *Atmos. Meas. Tech*. 10, 1495–1509 (2017). https://doi.org/10.5194/amt-10-1495-2017

[24] Fioletov, V. E. et al. A global catalogue of large SO2 sources and emissions derived from the Ozone Monitoring Instrument. *Atmos. Chem. Phys.* 16, 11497–11519 (2016). https://doi.org/10.5194/acp-16-11497-2016

Results and analysis

South Africa

The MEaSUREs catalogue lists five SO_2 emission hotspots in South Africa: Kriel, Matimba, Majuba, Lethabo, and Palabora (**Fig. 1**). All of them are of anthropogenic origin. Combined, they emitted about 1,200 kt of SO_2 in 2019 (**Table 1**).

Figure 1: *Locations of the five South African SO_2 emission hotspots detected by MEaSUREs. Circle sizes scale with 2019 emissions of each hotspot. They do not indicate the spatial extent of the hotspots. Political borders from the GADM project.[25] Name, location, and population (indicated by font size) of populated places from GeoNames.[26] Relief from Natural Earth.[27]*

[25] GADM. (2018). Retrieved from https://gadm.org/download_world.html on 2019-08-15.
[26] GeoNames (2020). Retrieved from http://download.geonames.org/export/dump/cities15000.zip on 2020-10-26. Population number manually corrected where obviously wrong and noticed.
[27] Natural Earth (2020). 1:10m Gray Earth with Shaded Relief, Hypsography, and Flat Water. Retrieved from https://www.naturalearthdata.com/downloads/10m-raster-data/10m-gray-earth/ on 2020-10-26.

Table 1: Emissions of the five SO_2 hotspots detected in South Africa by MEaSUREs. Comparison of 2019 to the previous year. Data source: NASA MEaSUREs.

Hotspot	Source	Emissions (kt) (with 95%-confidence range)		Change (with 95%-confidence range)	
		2018	2019	absolute (kt)	relative
South Africa		**1389 (±93)**	**1187 (±83)**	**-202 (±125)**	**-15% (±8%)**
Kriel	Coal	591 (±71)	504 (±60)	-87 (±93)	-15% (±14%)
Matimba	Coal	358 (±44)	362 (±44)	4 (±62)	1% (±17%)
Majuba	Coal	215 (±30)	149 (±24)	-67 (±39)	-31% (±15%)
Lethabo	Coal	177 (±24)	135 (±21)	-42 (±32)	-24% (±16%)
Palabora	Smelter	47 (±17)	37 (±17)	-10 (±24)	-22% (±46%)

The Kriel hotspot in Mpumalanga is the largest SO_2 emission hotspot in South Africa (**Table 1, Fig. 2**). It incorporates a cluster of power stations in Nkangala including Duvha, Kendal, and Kriel coal-fired power stations. There are 12 coal-fired power stations in the Mpumalanga province, located just 100-200 km from South Africa's largest populated area, Gauteng City region, posing a significant health threat to local residents.

South Africa's combined SO_2 emissions dropped by approximately 15% in 2019 compared to the previous year (**Table 1**), reaching an all-time low in the 15-year period where OMI observations are available (**Fig. 3**). However there has been little overall change in South Africa's SO_2 emissions across the 15-year record, and emissions remain significant. This is in contrast to the global trend of substantial emission reductions.

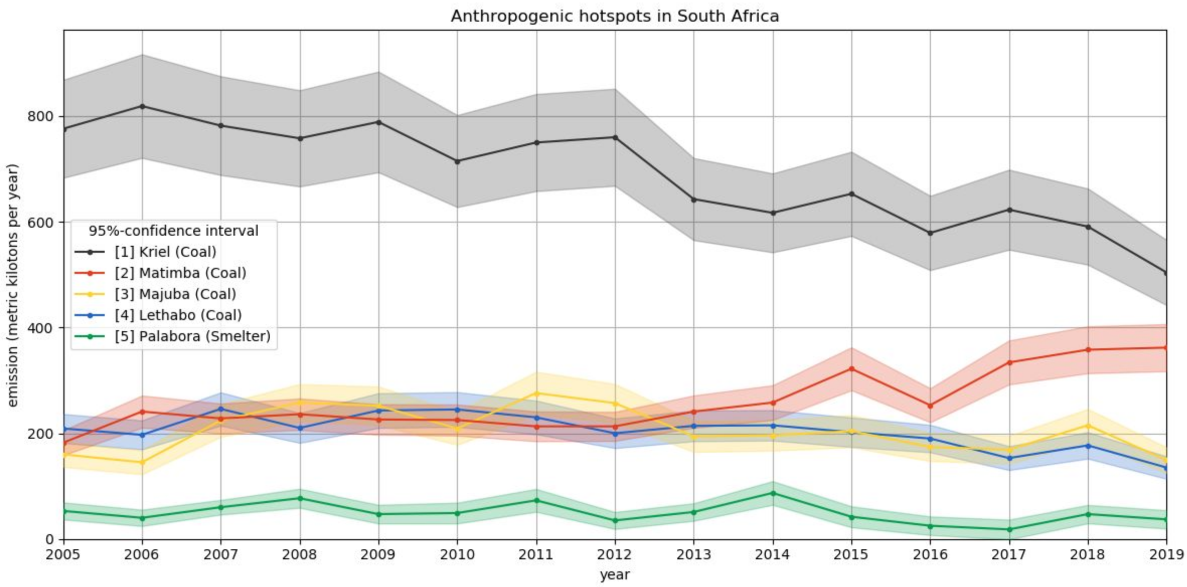


Figure 2: 2005 to 2019 SO_2 emissions in hotspots detected in South Africa by MEaSUREs (emissions in kilotonnes per year). Data source: NASA MEaSUREs.

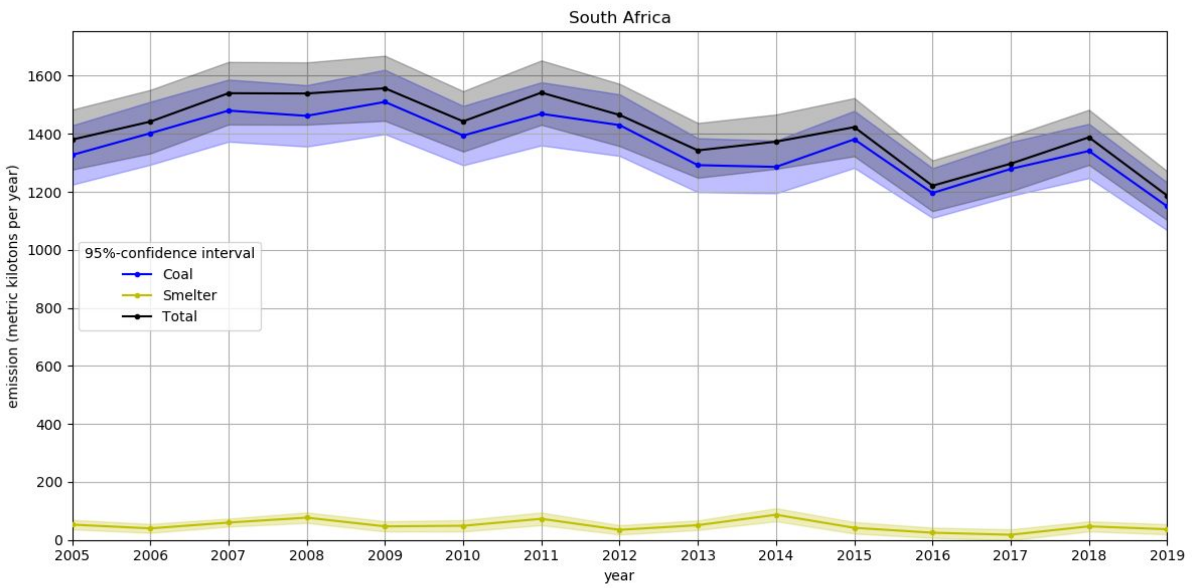


Figure 3: *Contributions of industry sectors to total SO_2 emissions from 2005 to 2019 in South Africa (kilotonnes per year). Data source: NASA MEaSUREs.*

SO_2 emission reduction in 2019

The 2019 decline in SO_2 emissions was due to a combination of (a) a reduction in electricity demand and (b) maladministration manifesting in a lack of planning, corruption and inadequately qualified personnel.

- Countrywide electricity load reduction was experienced in 2019. This resulted in a rotational and intended electrical power shutdown over different parts of the distribution regions[28], commonly referred to as *load-shedding*[29] - also known as rolling blackouts.
- Furthermore, unplanned maintenance and associated plant shutdowns and/or breakdowns lead to a reduction in actual plant capacity in 2019 as compared to previous years.[30]

The combination of these two factors led to a reduction in coal combustion in 2019. However, this decline in SO_2 emissions was not due to a concerted effort to improve air quality but rather a side-effect of reduced operating capacity, which cannot be counted on to persist into the future. For a lasting improvement in air quality, legal measures to tighten emission limits are needed so that emissions are reduced permanently with no danger of return.

[28] Retief, Hanlie, (2019), 'Eskom is captured': Jan Oberholzer on wet coal, sabotage and stage 6 desperation, City Press, retrieved from https://www.news24.com/citypress/News/eskom-is-captured-jan-oberholzer-on-wet-coal-sabotage-and-stage-6-desperation-20191216 on 2020-11-16

[29] Eskom, *What is load shedding?* Retrieved from https://loadshedding.eskom.co.za/LoadShedding/Description on 2020-11-13

[30] Kimberly City Info (2019). *Eskom energy availability factor plunge to new record low.* Retrieved from https://www.kimberley.org.za/eskom-energy-availability-factor-plunge-new-record-low/ on 2020-11-13.

Global Context

Human-made sources constituted more than two-thirds (68%) of total global SO_2 emissions in 2019 according to the MEaSUREs catalogue (**Fig. 4**). These sources of SO_2 are found in locations that have high fossil fuel consumption (coal burning, oil refining and combustion) or host smelter sites. The principal natural source of SO_2 emissions is volcanic activity. In South Africa there are no active volcanoes, meaning that SO_2 air pollution in South Africa is dominated by human-made emissions.

Worldwide, 36%, 21%, and 12% of anthropogenic SO_2 emissions identified by the MEaSUREs catalogue are associated with locations dominated by either coal combustion for power generation, oil and gas installations, or smelters, respectively (**Fig. 4, Table 2**). In South Africa, 97% of the SO_2 emissions identified by the MEaSUREs catalogue are associated with coal combustion for power generation. Smelter activity makes up the remaining 3% of emissions.

In contrast to the global picture, where a mixture of source sectors contribute to human-made SO_2 emissions, it is the coal power sector that dominates in South Africa.

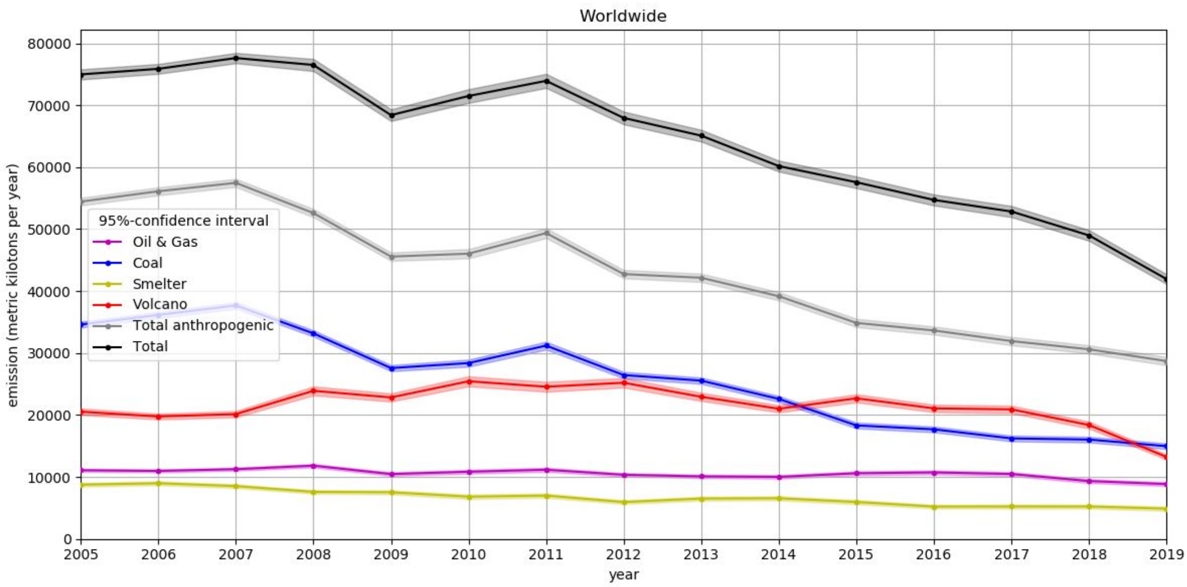


Figure 4: *Global contributions of major industry sectors and natural sources (volcanoes) to total SO_2 emissions from 2005 to 2019 (in kilotonnes per year). Data source: NASA MEaSUREs.*

Table 2: *Global contributions of major industry sectors and natural sources (volcanoes) to total SO_2 emissions in 2018 and 2019 (in kilotonnes per year). Data source: NASA MEaSUREs.*

	SO_2 emissions in 2018 & 2019 (kt).		The proportion of Total (%)	
Source	**World Wide**	**South Africa**	**World Wide**	**South Africa**
Coal	14,972	1,150	52	97
Oil & Gas	8,850	0	31	0
Smelter	4,883	37	17	3
Total	28,705	1,187	-	-

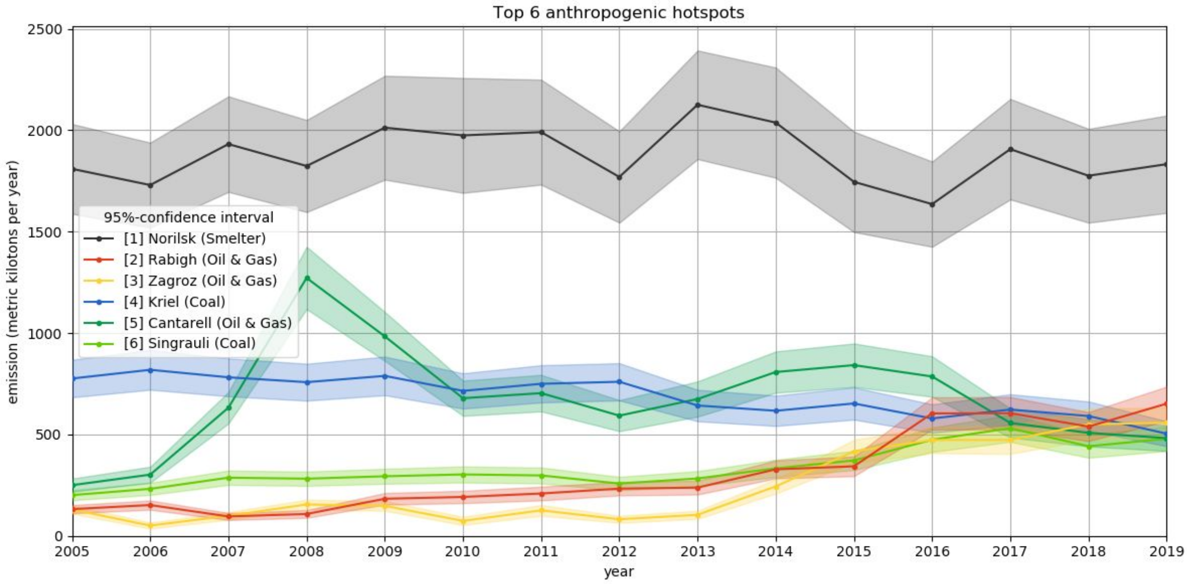


Figure 5: *The contributions of the six largest anthropogenic SO_2 emissions sources from 2005 to 2019 (in kilotonnes per year). Data source: NASA MEaSUREs.*

South Africa's largest SO_2 emission hotspot by annual emission amount is the Kriel hotspot in Mpumalanga. This hotspot is the largest on the entire African continent and the largest hotspot driven by coal combustion worldwide. It has been persistently within the world's top four SO_2 emission hotspots regardless of industry type over the entire NASA MEaSUREs 15-year record (**Fig. 5**).

The Norilsk smelter site in Russia is the largest anthropogenic SO_2 emission hotspot in the world. It is the only hotspot to have continually had more annual SO_2 emissions than Kriel. In 2019 the Rabigh (Saudi Arabia) and Zagroz (Iran) oil and gas hotspots emitted more SO_2 into the atmosphere than Kriel for the first time in the NASA MEaSUREs data (**Fig. 5**). Kriel and Matimba are among the world's top 10 hotspots of anthropogenic SO_2 emissions (**Table 3**).

South Africa had the 7th-highest SO_2 country-total emissions globally in 2019, as detected by MEaSUREs (**Table 4**). South Africa's per capita SO_2 emissions were 20.3 kt per million inhabitants, which is four and a half times that of India (4.4 kt/million people), the world's territory with the greatest emissions in absolute terms. South Africa emits five and a half times the global average per capita SO_2 emission (3.7 kt/million people).

Table 3: *The top 10 anthropogenic SO_2 emission hotspots. Data source: NASA MEaSUREs (partially renamed and/or reclassified).*

Rank	Hotspot	Country / Region	Source type	Emissions 2019 (kt) (95%-confidence interval)		
				best estimate	low estimate	high estimate
1	Norilsk	Russia	Smelter	1,833	1,598	2,068
2	Rabigh	Saudi Arabia	Oil & Gas	652	569	735
3	Zagroz	Iran	Oil & Gas	558	484	632
4	**Kriel**	**South Africa**	**Coal**	**504**	**443**	**564**
5	Cantarell	Mexico	Oil & Gas	482	420	544

6	Singrauli	India	Coal	479	420	538
7	Reforma/Cactus	Mexico	Oil & Gas	415	349	481
8	Ilo	Peru	Smelter	414	338	489
9	**Matimba**	**South Africa**	**Coal**	**362**	**319**	**406**
10	Al Doha	Kuwait	Oil & Gas	351	307	395

Table 4: *Top 10 emitter countries of anthropogenic SO_2 (kt) in 2019, estimated by MEaSUREs.*

Rank	Country / Region	2019 anthropogenic SO_2 emissions (kt) (95%-confidence interval)		
		best estimate	low estimate	high estimate
-	**worldwide**	**28,704**	**28,050**	**29,358**
1	India	5,953	5,768	6,138
2	Russia	3,362	3,335	3,717
3	China	2,156	2,044	2,344
4	Saudi Arabia	1,910	1,874	2,027
5	Mexico	1,873	1,849	1,998
6	Iran	1,746	1,708	1,858
7	**South Africa**	**1,187**	**1,167**	**1,270**
8	Turkey	1,072	1,072	1,157
9	USA	823	814	1,025
10	Kazakhstan	760	657	863

Worldwide, a robust trend of decreasing anthropogenic SO_2 emissions can be observed in the NASA MEaSUREs database. This trend is not apparent in South Africa, however. South Africa's annual SO_2 emissions have varied between 1,200 and 1,600 kt for the past 15 years (**Fig. 3**). The gradual downward trend in South African SO_2 emissions is much slower than that seen globally. South Africa's population growth is higher than the global average. However, the contrast between rates of SO_2 emission reduction remains even after adjustment for differences in population growth. Even when comparing annual per capita emissions rather than absolute emissions, SO_2 emission reductions in South Africa are slow relative to the global average (**Fig. 6**). South Africa's relative decrease in per capita SO_2 emissions is less than half of that of the rest of the world.

Both the global and South African trends reveal that action is needed to accelerate the reduction of SO_2 emission. At current rates of improvement, South Africa can expect substantial SO_2 emissions for decades to come.

Figure 6: *Per capita SO_2 emissions relative to 2005-2019 average for South Africa and the rest of the world. Emissions have been divided by annual UN population data (past and future projection)[31] and normalised to their 2005-2019 averages. Future extrapolations show 95% prediction confidence intervals (shaded areas) and central values (dashed lines) for linear regressions of the data.*

[31] United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019, Online Edition. Rev. 1.

Interactive pollution map

A worldwide interactive map showing the raw OMI SO_2 column amounts together with the locations of the SO_2 emission sources listed in the NASA catalogue is available at energyandcleanair.github.io/202008_hotspots/ (see **Box 1** for the difference between column amount and emission rate). **Fig. 7** shows a screenshot of the map.

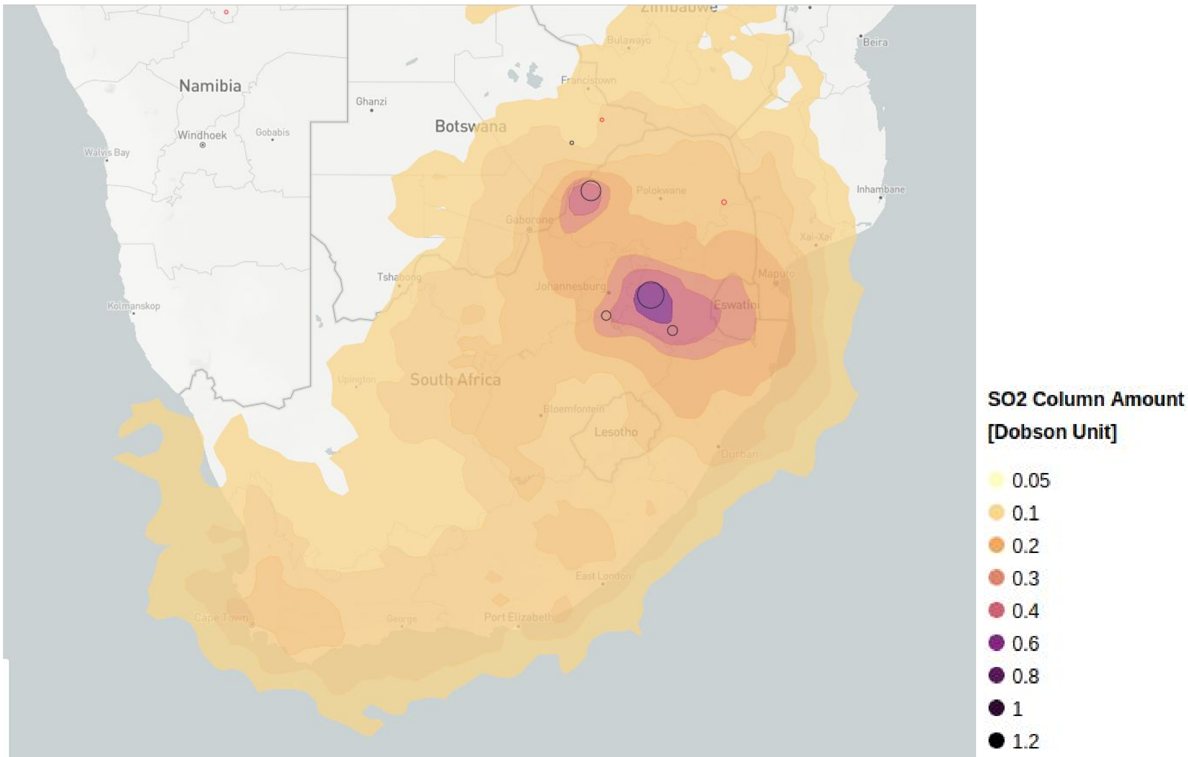


Figure 7: *Column amount of SO_2 detected by the Ozone Monitoring Instrument (OMI) sensor in 2019 over South Africa. A worldwide interactive map can be found at https://energyandcleanair.github.io/202008_hotspots/.*

2020 trends (OMI data)

In 2020, the COVID-19 pandemic dramatically altered daily life in many regions of the world, including South Africa. As a result of physical distancing measures, there was a substantial reduction in global demand for energy and electricity in the first half of 2020. The reduction in energy demand resulted in improved air quality in many locations where the demand for energy from fossil fuels was reduced. In Europe for instance, power generation from coal fell by 37%, and measures to prevent the spread of SARS-CoV-2[32] led to as much as a 40% reduction in the average level of nitrogen dioxide (NO_2) pollution according to a recent analysis.[33]

[32] *Severe acute respiratory syndrome coronavirus 2*, the pathogen which caused COVID-19
[33] Myllyvirta, L. & Thieriot, H. 11,000 air pollution-related deaths avoided in Europe as coal, oil consumption plummet. CREA (2020). Retrieved from https://energyandcleanair.org/wp/wp-content/uploads/2020/04/CREA-Europe-COVID-impacts.pdf on 2020-09-23.

MEaSUREs estimates of SO_2 emissions are not yet available for 2020. In this section, we rely on SO_2 column amounts around emission hotspots measured by OMI as an indirect proxy for emissions themselves (see **Box 1** in the Methodology section for the difference between SO_2 emissions and SO_2 column amounts).

SO_2 changes around anthropogenic hotspots between 2019 and 2020 are the result of changes in emissions and environmental factors such as seasonality. A 365-day running average of column amounts was calculated for major SO_2 emitting territories, eliminating the effects of seasonality and allowing comparison between the two years (**Fig. 8**).

On a global scale, SO_2 column amounts show a decrease in 2020 relative to 2019. However, interannual variability and the effects of changing weather prevent us from attributing the observed decreases to the COVID-19 pandemic with certainty.

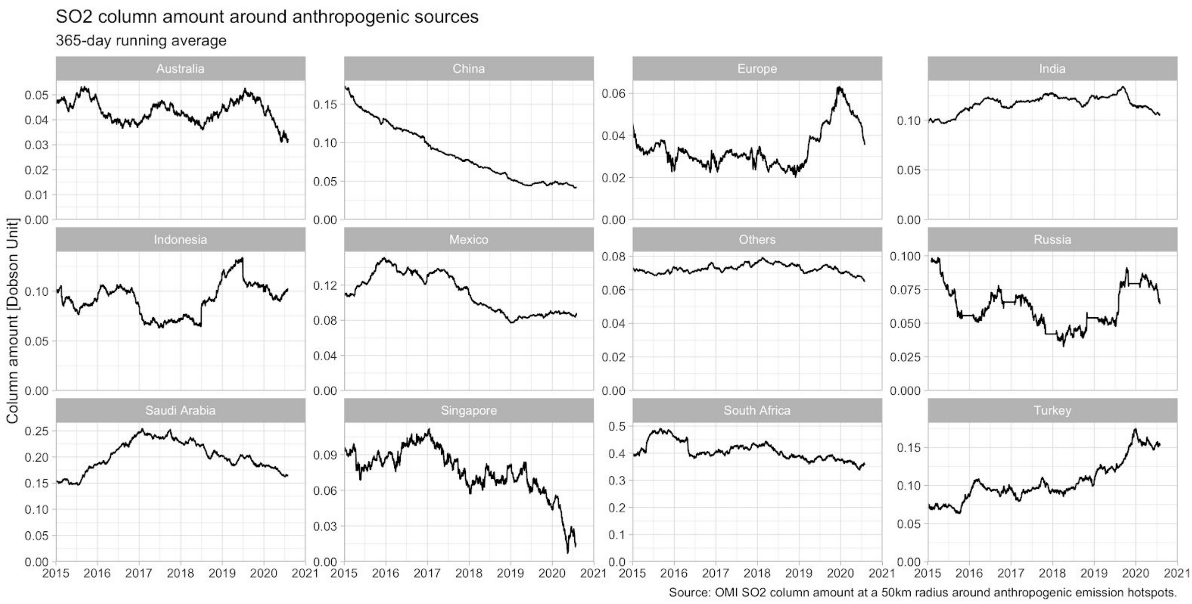


Figure 8: *365-day running average of SO_2 column amounts within 50 km around anthropogenic sources from 2015–2020 in countries and regions that have large emissions.. 'Others' refers to all other countries and regions combined—data source: OMI.*

The column amounts shown in **Fig. 8** must be interpreted with caution and serve only as an indication of actual SO_2 emissions. Significant SO_2 column amount reductions are observed at the beginning of 2020 in Australia, Europe, Russia, and Singapore. It is possible that these reductions result from the measures to manage the COVID-19 crisis. In contrast, such measures seem to have had little effect on SO_2 emissions in South Africa. The SO_2 column amount reductions identified between 2019 and 2020 most likely result from several factors, and not only the COVID-19 crisis.

South African SO_2 emissions are predominantly the result of coal combustion for electricity generation, with only 3% of annual emissions associated with smelter operations. Analysis of the difference in SO_2 column amount between 2019 and 2020 for South African hotspots shows that different hotspots may have responded differently to the crisis. SO_2 column amounts at the Palabora SO_2 emission hotspot, which is associated with smelter operations have shown the largest decrease in 2020 (**Fig. 9**). A 365-day running average of SO_2 column amounts indicates that levels are close to 40% lower than they were in 2019. The reduction is less pronounced at SO_2 emission hotspots associated with coal power, with SO_2 column amounts at Majuba and Malima decreasing 20% year-on-year while SO_2 column amounts at the Lethabo hotspot increased by 30%. SO_2 column amounts at Kriel, the largest SO_2 emission hotspot in South Africa, were relatively constant compared to 2019.

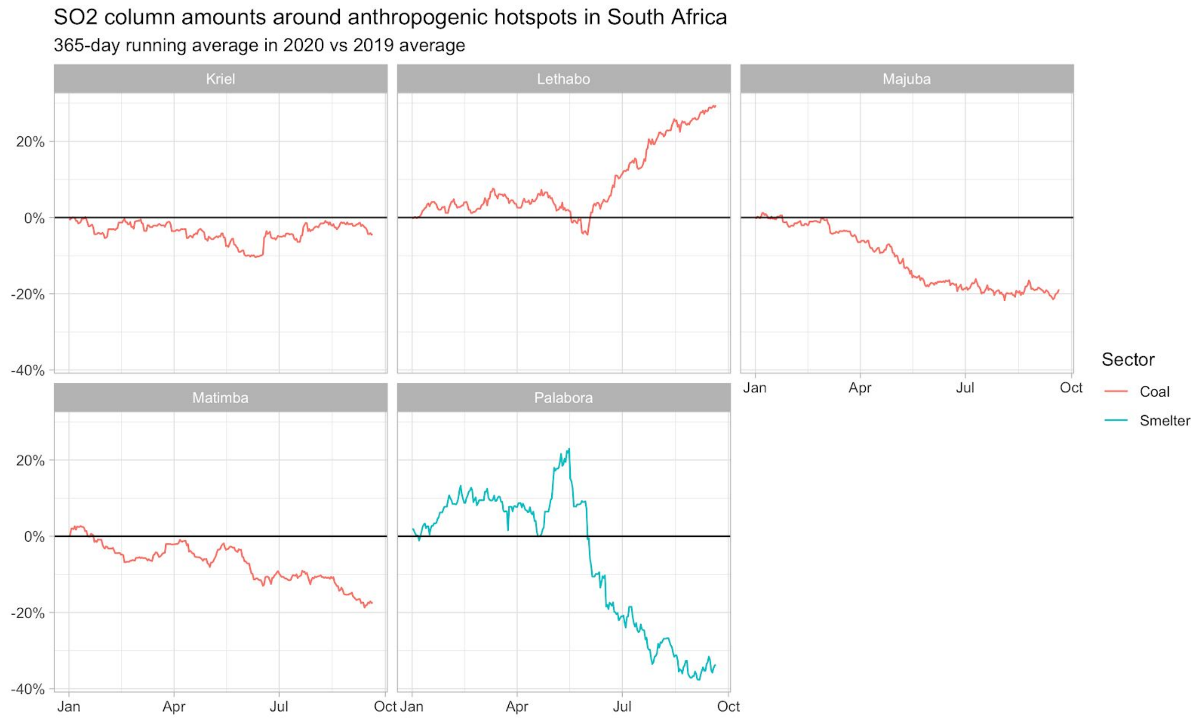


Figure 9: *The 2020 to 2019 anomaly using a 365-day running average of SO_2 column amounts for South Africa. Data source: OMI.*

Despite the continuing emission of SO_2 by the coal power sector in South Africa, the South African government relaxed SO_2 emission regulations for coal power stations in 2020. The change which doubled the permitted emission rate took effect on 1 April 2020.[34] Weakening SO_2 emission standards is a direct concession to the country's power utility companies Eskom and Sasol (synfuel company) who called it "costly" to comply with the regulations around SO_2.[35]

The way forward

Fossil fuel combustion leads to the release of SO_2 and other hazardous pollutants into the air, water, and land ecosystems. Pollution degrades ecosystems and has adverse impacts on human health, causing or worsening a host of long-term health conditions and premature deaths. This Greenpeace report has identified major SO_2 emission hotspots in South Africa, all of which are related to fossil fuel combustion. Fossil fuel combustion is a

[34] Vlavianos, C. 'SA government gazettes approval for air pollution increases.' Greenpeace Africa press release on March 30, 2020. Available at: https://www.greenpeace.org/africa/en/press/9221/sa-government-gazettes-approval-for-air-pollution-increases/ [accessed Sept. 23, 2020].

[35] Ms Creecy, B. D. Ministry of Forestry, Fisheries and the Environment. Republic of South Africa. Letter to Ms Kate Handley. July 20, 2020. Available at: https://drive.google.com/file/d/1nekGK0_CFh10EwjIdodUVCk-64oN-Q-y/view

dominant driver of air pollution and the principal cause of the climate emergency. Consequently, these two urgent crises share many of the same solutions.

As one of the top SO_2 emitters in the world (mostly resulting from the burning of coal), South Africa must immediately stop investing in fossil fuels and shift to safer, more sustainable sources of energy such as solar and wind energy. Meanwhile, it must apply stringent legal measures to reduce emissions of existing coal-fired power stations and end the practise of granting exemptions to major SO_2 emitters such as Eskom and Sasol.

South Africa's emission standards for SO_2 are currently among the worst on the planet (**Table 5**). They are seven times laxer than those of India and about 10-20 times worse than in China, the European Union, and the United States. Requiring the installation of state-of-the-art flue-gas desulphurisation would capture more than 99% of the SO_2 in a wet flue-gas desulphurisation process.[36,37] This would serve as an easy first step to cleaner air and substantially reduce impacts on human health.

Therefore, Greenpeace urges the South African Government to halt all fossil fuel investment. South Africa's minimum emission standard of 500 mg/Nm^3[38] must be reinstated and be appropriately enforced, to achieve cleaner air. There must be no further postponement of the requirement to comply with minimum emission standards by Eskom and Sasol, and coal-fired power stations or units that cannot comply with the existing standards must be decommissioned. Existing power plants, smelters, and other industrial SO_2 emitters must be fitted with flue gas pollution control technology.

The South African Government must implement an air pollution action plan for Mpumalanga, Johannesburg, Pretoria and all high priority areas. The action plan must align with the World Health Organisation (WHO) Air Quality Guidelines for ambient air,[39] and implements concrete measures and takes decisive action to improve air quality and to ensure compliance with South Africa's Minimum emission standard within the next five years. The action plant must ensure independent continuous emissions monitoring systems (CEMS) and receptor monitoring in communities is installed for different pollutants, making this data available to the public to inform decision making.

Minister for Mineral Resources and Energy Gwede Mantashe must revise the commitments made in the Integrated Energy Plan and abandon plans for installing new coal-fired power stations of 1500 MW capacity scheduled for 2023 and 2027. Instead, the minister must ensure increased uptake and implementation of renewable energy generation capacity through radical and deliberate policies and programmes.

The South African Government must ensure the development of a comprehensive and inclusive Just Transition programme that moves the country away from the use of fossil fuels, to cleaner and sustainable energy. Carbon majors must be held accountable for their emissions resulting from the use of fossil fuels by implementing and enforcing a carbon tax that will discourage carbon emissions.

[36] Poullikkas, A. Review of Design, Operating, and Financial Considerations in Flue Gas Desulfurization Systems. *Energy Technol. Policy* 2(1), 92-103 (2015). https://doi.org/10.1080/23317000.2015.1064794

[37] Carpenter, A. M. Low water FGD technologies. IEA Clean Coal Centre (2019). Available at: https://usea.org/sites/default/files/112012_Low%20water%20FGD%20technologies_ccc210.pdf [accessed Sept. 23, 2020].

[38] Normalised to 101.325 kPa and 273.15 K_2

[39] World Health Organization. WHO Air quality guidelines for particulate matter, ozone, nitrogen dioxide and sulfur dioxide: global update 2005: summary of risk assessment. No. WHO/SDE/PHE/OEH/06.02. World Health Organization, 2006.

As society prepares to recover from the COVID-19 pandemic, it becomes even more important to direct funds spent on energy sources towards renewable energy. In 2020, fossil fuels have become an outdated energy source. Any new fossil fuel investment risks becoming a stranded asset, as the world inevitably moves on to more economical and climate-friendly technologies.

***Table 5**. National emission standards for SO_2 for large coal-fired power stations (mg/Nm^3)*[40]

Country/ Region	Old Stations/Units		New Stations/Units	
China[41,42]	Rest of the country	200	"Ultra Low Emission" standards to be adopted by 2020 (already applies to new units)	35
	Key regions	50		
India[43]	Units commissioned until 2003	600	Units commissioned after 2017	100
	Units commissioned 2004-2016	200		
USA[44]	Power stations commissioned after 1997-2011	160	New power stations after 2011	60
	Power stations commissioned between 1978-1996	640		
EU[45]	PC Pulverized combustion boilers[46] Capacity ≥ 300 MW	10-130	PC Pulverized combustion boilers Capacity ≥ 300 MW	10-75
	Fluidised bed boiler Capacity ≥ 300 MW	20-180	Fluidised bed boiler Capacity ≥ 300 MW	10-75
South Africa[47]	**Built before 2010, decommissioned before 2030**	**4760**	**Built after 2025**	**680**
	Built before 2025, decommissioned after 2030[48,49]	**until 2025: 4760 after 2025: 1000**		

[40] Converted from other units as required. Most countries normalise flue gas oxygen content to 6% or 7%, and temperature to 0°C or 25°C; this makes a difference of less than 10% and has not been harmonised. South Africa uses reference oxygen content of 10% which has been converted to 6% to allow comparison.
[41] Standardization Administration of China. Emission standard of air pollutants for thermal power plants. GB 13223-2011. Available at : http://english.mee.gov.cn/Resources/standards/Air_Environment/Emission_standard1/201201/W020110923324406748154.pdf
[42] Ministry of Ecology and Environment of China. The work plan for "Ultra Low Emission" standards of coal power plants. Available at: https://www.mee.gov.cn/gkml/hbb/bwj/201512/W020151215366215476108.pdf
[43]MoEF&CC. The Gazette of India: Extraordinary. Part II, Section 3, Sub-section (ii) S.O. 3305(S). New Delhi 2016. Available at: http://moef.gov.in/wp-content/uploads/2017/08/Thermal_plant_gazette_scan.pdf
[44] Electronic Code of Federal Regulations. Available at: http://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr60_main_02.tpl [accessed Sep. 24, 2020]
[45] The European Commission. *Official Journal of the European Union* L212/1, 31 July 2017. Available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32017D1442&from=EN [accessed Sep. 24, 2020] to enter into force on 17.08.2021.
[46] Coal is ground into fine particles and then injected with heated combustion air through a number of burners into the lower part of the furnace. Particles burn in suspension and release heat which is transferred into the steam cycle.
[47] Listed Activities and Associated Minimum Emission Standards Identified in terms of Section 21 of the National Environmental Management: Air Quality Act, 2004 (Act 39 of 2004). Available at: https://www.environment.gov.za/sites/default/files/gazetted_notices/nemaqa_listofactivities_g33064gon248_0.pdf
[48] At 10% O_2, 273 K and 1 atmosphere (approximately 1367 mg/Nm^3 at 6% O_2).
[49] Msimang, A., Bradfield, C., and Vermaak M., (2020), *Revised Minimum Emission Standards Provide Relief For Major Sulphur Dioxide (SO_2) Emitters*, retrieved from https://www.bowmanslaw.com/insights/environmental-law/revised-minimum-emission-standards-provide-relief-for-major-sulphur-dioxide-so2-emitters/ on 2020-11-13.

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