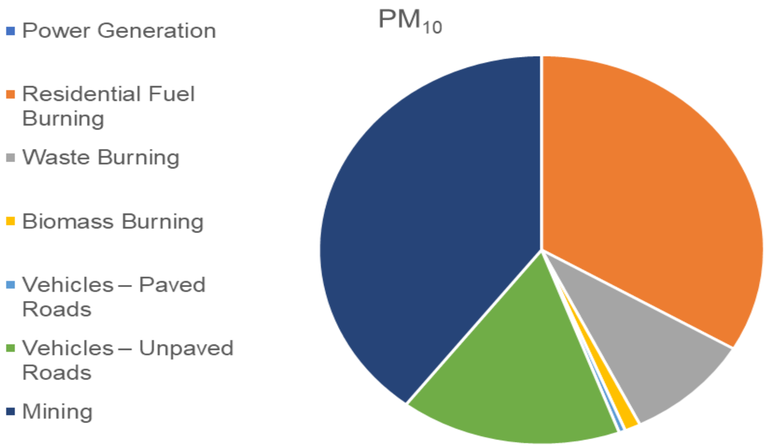
Eskom PMV Phase 2: Phola

Activity 5: Emissions Inventory

Activity 5.1: Phola Emissions Inventory for year 1



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1. STUDY BACKGROUND & OBJECTIVE

Phase 2 of Eskom's Air Quality Offset (AQO) programme focuses on Phola. Approximately 6,700 households in Phola will receive Eskom's AQO interventions aimed at reducing emissions from residential fuel burning. Eskom has included eight targeted AQO work package activities for Phola. In accordance with the scope of work, for Activity 5.1: Emissions Inventory for Year 1, Air Resource Management (ARM) shall estimate emissions from all major sources and use that information to develop a comprehensive emission inventory for Phola. The focus of this study is on the baseline (year 1) emissions inventory for Phola

2. STUDY METHODOLOGY

Emissions inventories provide source information that identifies the origin of the emissions. An example of a source would be a truck burning diesel fuel or a coal fired power plant. While you can see the emissions of some of the pollutants in the smoke coming out of the tail pipe or stacks, these sources actually emit a complex mixture of many pollutants.

Inventories may contain a variety of different source types, including both anthropogenic (related to human activity) or biogenic/natural (related to naturally occurring activity). Even forest fires are air pollutant sources that can be found in some emissions inventories. An inventory could be developed for a certain type of source (e.g., mobile sources) or could include all of the different source types in a region of interest.

In this study, an emission inventory was compiled for a number of source categories within the modelling domain (Phola), which includes:

1. Biomass Burning
2. Vehicles – Unpaved Roads
3. Vehicles – Paved Roads
4. Mining
5. Residential Fuel Burning
6. Residential Waste Burning
7. Industries

3. Study Results

In this study, the emission source categories include power generation, residential fuel burning, waste burning, biomass burning, vehicles travelling on paved roads, vehicles travelling on unpaved roads and mining. The emission inventory is presented in Table i and Table ii.

Table i: Emission Inventory for the Greater Phola Study Area

	Emission rate (tonnes/annum)				
Emission Source Category	**SO_2**	**NO_X**	**PM_{10}**	**$PM_{2.5}$**	**TPM**
Power Generation	1 184 740.46	862 755.33	209 216.17	92 539.93	12 877.82
Residential Fuel Burning	5 622.18	2 581.32	7 324.15	6 813.56	
Waste Burning	38.73	196.50	1 911.99	1 904.43	
Biomass Burning	247.63	54.09	2 550.06	2 451.40	3 666.53
Vehicles – Paved Roads	133.57	8 991.08	183.00	183.00	
Vehicles – Unpaved Roads	0.17	46.61	2 461.17	246.81	8 631.59
Mining			10 068.07	2 683.46	32 642.47
All Sources	1 190 782.75	874 624.93	233 714.61	106 822.59	57 818.41

Table ii: Emission Inventory for the Phola Study Area

	Emission rate (tonnes/annum)				
Emission Source Category	**SO_2**	**NO_X**	**PM_{10}**	**$PM_{2.5}$**	**TPM**
Power Generation					
Residential Fuel Burning	291.04	133.63	379.15	352.72	
Waste Burning	2.12	10.76	104.74	104.32	
Biomass Burning	1.27	0.28	13.12	12.61	18.87
Vehicles – Paved Roads	3.71	252.64	5.17	5.17	
Vehicles – Unpaved Roads	0.01	3.45	182.16	18.27	638.85
Mining			448.49	119.54	1 454.09
All Sources	298.17	400.76	1 132.83	612.63	2 111.81

3.1 Source Contribution Analysis

As each emission source category was simulated independently in the dispersion model, ARM was able to differentiate the air quality impact of these individual source categories in relation to the cumulative modelled impact.

3.2.1 SO_2

As illustrated in Figure i, the source contribution analysis indicates that residential fuel burning, and power generation are the main contributors to ambient SO_2 levels in the Phola Airshed. Ambient contributions from waste burning, biomass burning and vehicles on paved and unpaved roads are much smaller in comparison.

It is however noted that other large industries (petrochemical, metallurgical, etc.) were excluded from the modelling simulation due to data policy privacy issues. However, an analysis of the ambient air quality monitoring data indicates that SO_2 displays a typical industrial signature with increased SO_2 concentrations just around midday due to the break-up of an elevated inversion layer, in addition to the development of daytime convective conditions causing the plume to be brought down to ground level and relatively close to the point of release from tall stacks. This confirms the additional impact of other tall stack sources in the Phola airshed.

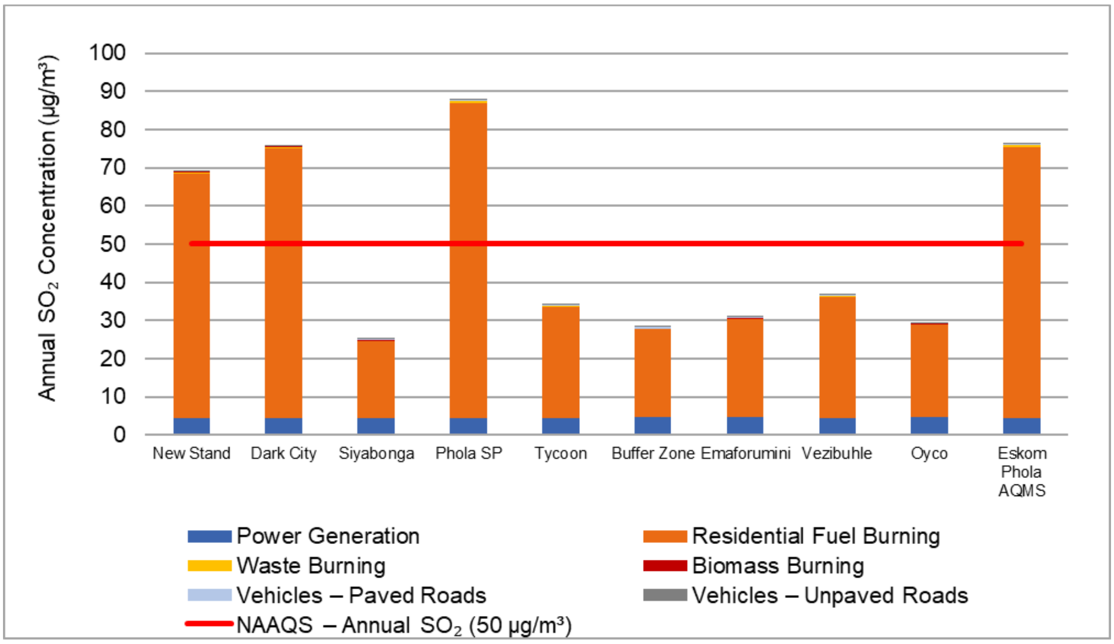

Figure i: Stacked bar graph representing model predicted annual SO_2 ambient concentrations in µg/m³ at discrete receptors for the six emission source categories

3.2.2 NO_2

As illustrated in Figure ii, the source contribution analysis indicates that residential fuel burning and vehicles on paved roads are the main contributors to ambient NO_2 levels in the Phola Airshed. Ambient contributions from power generation, waste burning, biomass burning and vehicles on unpaved roads are much smaller in comparison. This is further supported by the analysis of the ambient data which clearly shows that elevated NO_2 levels are conditioned by both rush-hour traffic and the contribution of residential fuel burning in winter.

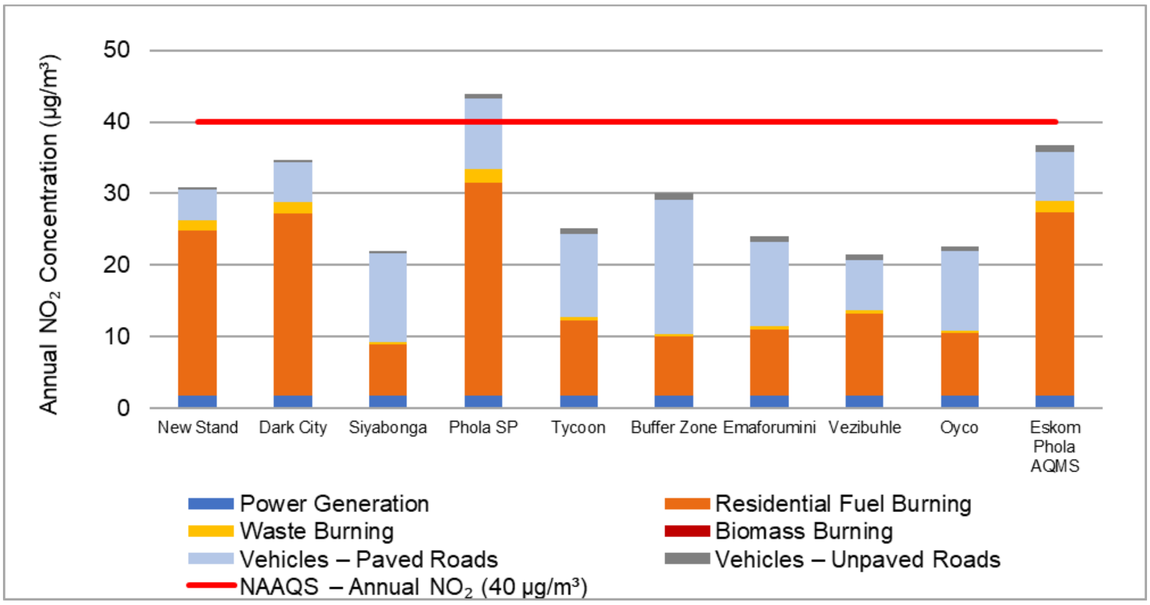

Figure ii: Stacked bar graph representing model predicted annual NO_2 ambient concentrations in µg/m³ at discrete receptors for the six emission source categories

3.2.3 PM (PM_{10} and $PM_{2.5}$)

As illustrated in Figures iii & iv, the source contribution analysis indicates that residential fuel burning and vehicles on unpaved roads have the most significant air quality impact on ambient PM_{10} levels in the Phola Airshed while residential fuel burning have the most significant air quality impact on ambient $PM_{2.5}$ levels in the Phola Airshed.

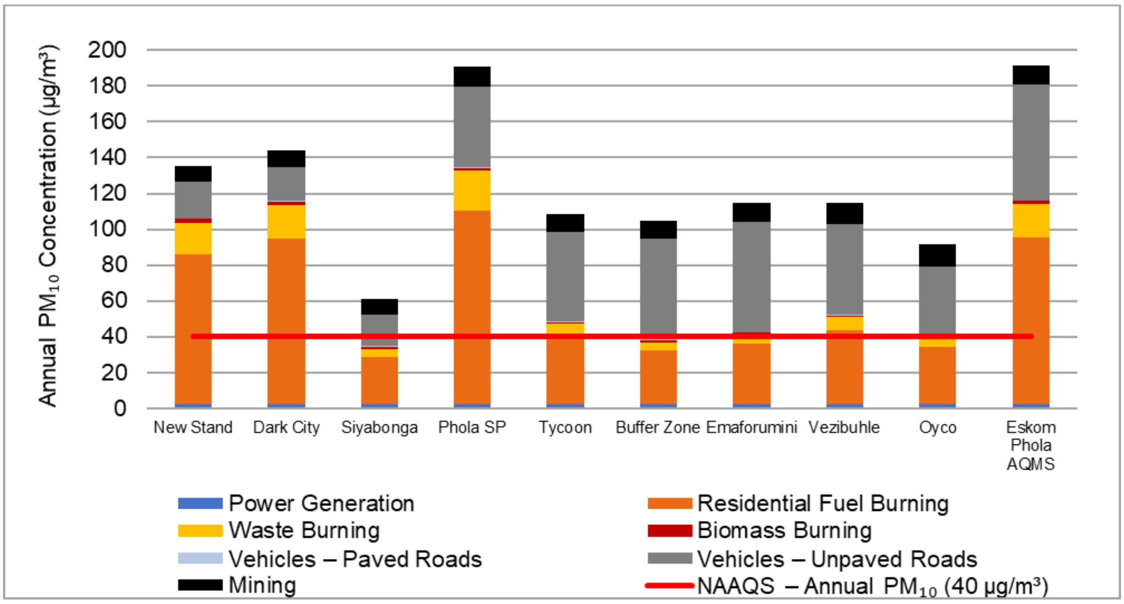

Figure iii: Stacked bar graph representing model predicted annual PM_{10} ambient concentrations in µg/m³ at discrete receptors for the seven emission source categories

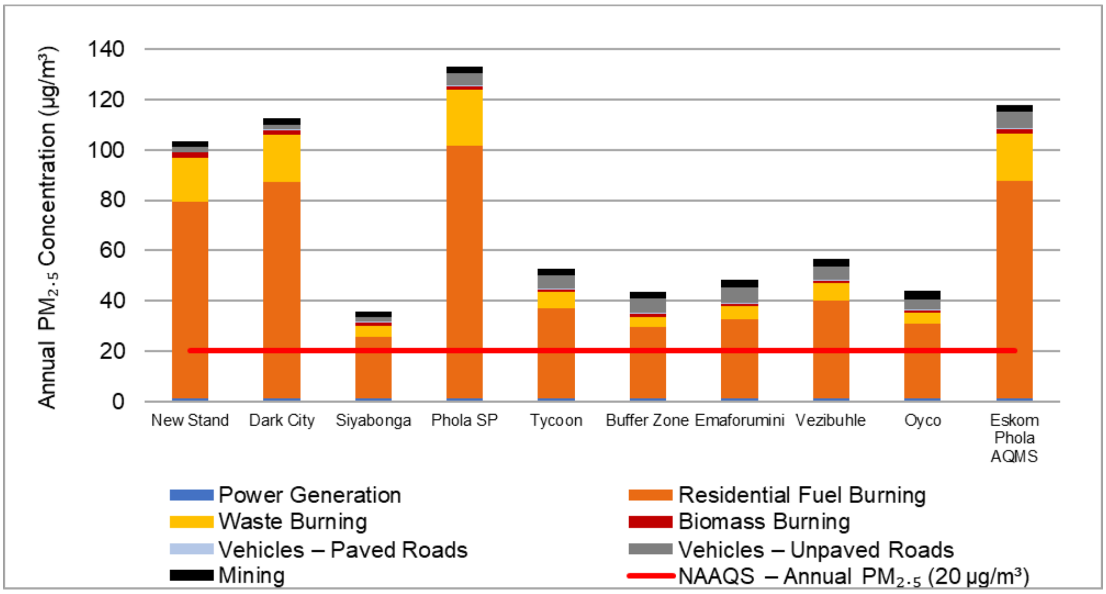

Figure iv: Stacked bar graph representing model predicted annual $PM_{2.5}$ ambient concentrations in µg/m³ at discrete receptors for the seven emission source categories

1. INTRODUCTION

1.1 AIR QUALITY OFFSETS GUIDELINE

An environmental offset is an action(s), designed to compensate for a negative environmental impact of resource use, a discharge, emission, or other activity. The Department of Environment, Forestry & Fisheries (DEFF) defines air emission offsets as an intervention, or interventions, specifically implemented to counterbalance the adverse and residual environmental impact of atmospheric emissions in order to deliver a net ambient air quality benefit within, but not limited to, the affected Airshed where ambient air quality standards are being or have the potential to be exceeded and whereby opportunities and need for offsetting exist (Notice 333 of 2016).

1.2 ESKOM'S APPROACH TO AIR QUALITY OFFSETS

DEFF's Air Quality Offset Guideline has shaped and informed Eskom's Air Quality Offsets Implementation Plan. This Plan has been based on a scientific process of feasibility studies, testing and demonstration, and on consultation with key stakeholders. Figure 1-1 illustrates the concept schedule for the phased implementation of Eskom's air quality offsets.

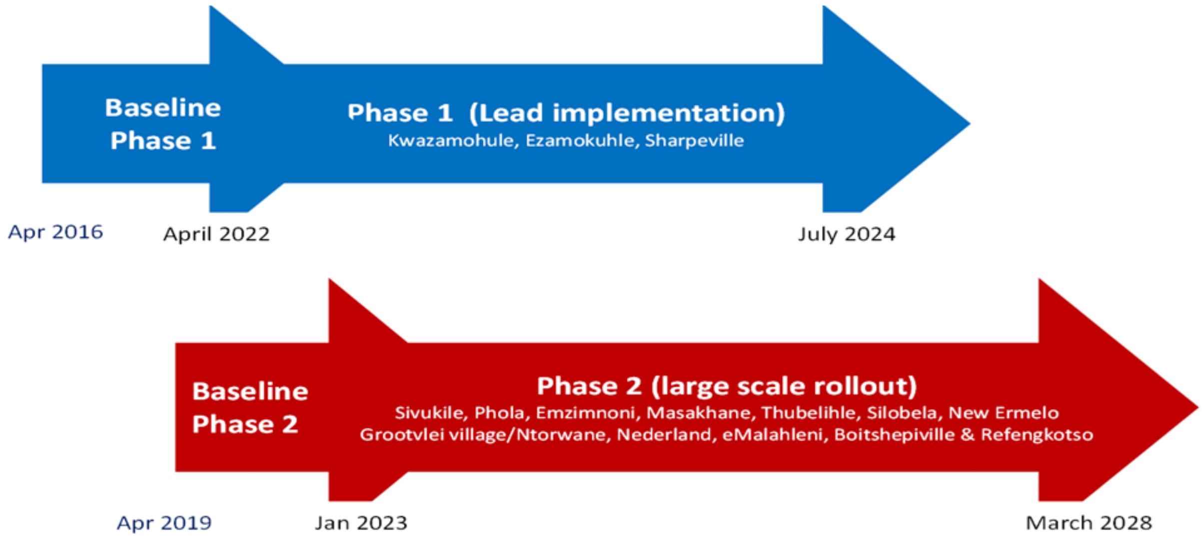

Figure 1-1: Concept Schedule for the implementation of Eskom's air quality offsets (Matimolane, 2023)

Eskom has adopted the phased approach (Figure 1-2) herein to increase the probability of success and to ensure that learnings from early phases are incorporated into the large-scale roll-out. (Matimolane, 2020).

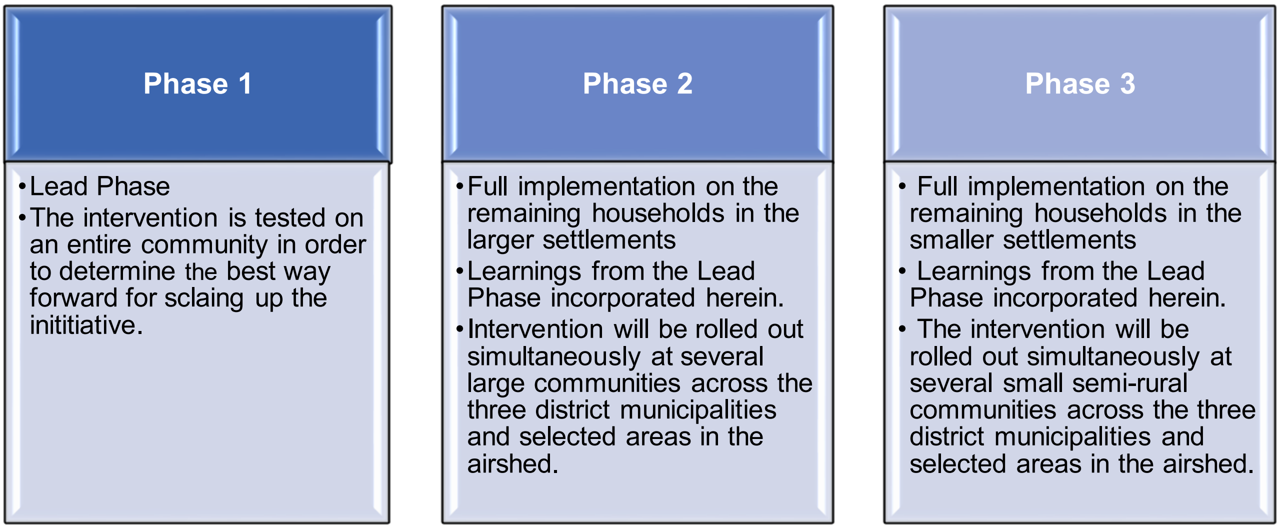

Figure 1-2: Eskom's Phased approach to the rollout of air quality offset interventions (Matimolane, 2020).

Eskom's air quality offsets programme is designed to reduce human exposure to harmful levels of air pollution by reducing emissions from local sources, like domestic coal burning and waste burning. Thus, air quality offsets can improve ambient air quality in low-income communities in the vicinity of Eskom's power stations. Eskom's air quality offsets programme is designed to reduce human exposure to harmful levels of air pollution by reducing emissions from local sources, like domestic coal burning and waste burning. Thus, air quality offsets can improve ambient air quality in low-income communities in the vicinity of Eskom's power stations.

1.3 ESKOM'S PLANNING, MONITORING AND VERIFICATION (PMV) PROJECT

As part of phase 2 of the Eskom's air quality offset (AQO) programme, Phola is the main focus of Kendal Power Station's Air Quality Offset Intervention. Phola has an estimated population of 31, 885 (based on 2011 census). The estimated number of households earmarked to receive AQO intervention is 6700.

For Eskom's PMV Phase 2 Project, interventions to reduce household emissions from domestic coal/wood burning will be rolled out in Phola, located in the Mpumalanga Highveld. For formal dwellings the intervention will be a thermal insulation retrofit and an electricity starter pack and installation. Air Resource Management (ARM) (Pty) Ltd has been appointed by Eskom to support in the Planning monitoring and Verification (PMV) services of Air Quality Offset Phase 2 Project for a period of four (4) years at Phola in the Mpumalanga Province. The overall objective of Eskom's AQO Phola PMV study is to assist with the planning of the offset interventions to minimize implementation risk, increase practical and scientific knowledge, and develop and refine monitoring, reporting and verifications processes. To achieve this, Eskom has included eight targeted work package activities (Table 1-1: Eskom Phola PMV StudyTable 1-1) for Phola.

Table 1-1: Eskom Phola PMV Study

Activity no.	Description	Year 1	Year 2	Year 3	Year 4
1.	**Ethical clearance**	Initial report	Update report	Update report	Update report
2.	**Area intelligence**	Inception	Year 2 report (Less in-situ assessment & fuel survey)	Year 3 report (Less in-situ assessment & fuel survey)	Year 4 report
3.	**Household survey (baseline)**	Initial report			Year 4 report
4.	**Ambient Air Quality Monitoring**	Initial report	Year 2 report	Year 3 report	Year 4 report
5.	**Emission inventory**	Initial report	Year 2 report	Year 3 report	Year 4 report
6.	**Air quality modelling**	Initial report	Year 2 report	Year 3 report	Year 4 report
7.	**Project effectiveness review**	Initial report	Year 2 report	Year 3 report	Year 4 report
8.	**Database and Reporting**	Initial report	Year 2 report	Year 3 report	Year 4 report

1.4 Scope of Work

In accordance with the scope of work, for *Activity 5.1: Emissions Inventory for Year 1*, ARM shall estimate emissions from all major sources and use that information to develop a comprehensive emission inventory for Phola.

This will be done by compiling a comprehensive emission inventory for a number of emission source categories which include power generation, residential fuel burning, waste burning, biomass burning, vehicles travelling on paved roads, vehicles travelling on unpaved roads and mining.

2. GENERAL DESCRIPTION OF AREA

2.1 LOCATION

The township of Phola lies approximately 4 km north of the town of Ogies within the Emalahleni Local Municipality, Nkangala District Municipality in the Mpumalanga Province, South Africa (Figure 2-1). According to the Census 2011 data, Phola has an area of 6.35 km^2 with a population of 31,885 (5,024.24 per km^2) and has 8,913 households (1,404.46 per km^2) (StatsSA, 2012).

Figure 2-1: Locality Map for Phola

3. EMISSIONS INVENTORY

Air pollution can negatively impact both public health and the environment. These pollutants are generated by human activities such as vehicle use, industrial operations, and agricultural practices, as well as by natural events such as wildfires. Emissions inventories provide a foundation for understanding and addressing air pollution. The identification of existing sources of emissions is fundamental to the assessment of the potential for cumulative impacts and synergistic effects given the existing operations and their associated emissions.

Generally, an emissions inventory describes the sources of emissions for a given air pollutant, or pollutants, and how much of each pollutant is emitted by each source. More precisely, an emissions inventory is a comprehensive listing of:

- specific air pollutants;
- emitted by specific sources;
- within a given geographic area;
- over a given time-period;
- indicating the quantity of the pollutant(s) emitted.

Emissions inventories are fundamental to air quality management because they provide information that can be used to identify, quantify and prioritise pollutants for reductions, emissions sources and geographic areas of focus.

The key elements that make up an emissions inventory are the:

- Pollutants;
- Sources;
- Geographic information;
- Temporal information;
- Emissions quantities.

Emissions inventories can be focused on a single pollutant, such as mercury, a certain "type" of pollutant, like hazardous air pollutants, or multiple pollutant types, such as a combination of hazardous air pollutants, criteria/priority pollutants and greenhouse gases.

Emissions inventories provide source information that identifies the origin of the emissions. An example of a source would be a truck burning diesel fuel or a coal fired power plant. While you can see the emissions of some of the pollutants in the smoke coming out of the tail pipe or stacks, these sources actually emit a complex mixture of many pollutants.

Inventories may contain a variety of different source types, including both anthropogenic (related to human activity) or biogenic/natural (related to naturally occurring activity). Even forest fires are air pollutant sources that can be found in some emissions inventories. An inventory could be developed for a certain type of source (e.g., mobile sources) or could include all of the different source types in a region of interest.

Inventories can cover a small geographic area, such as the area encompassing a specific chemical plant, to a town that may have multiple sources of emissions, to a district municipality, a province, a country or even the entire globe. Within each geographic area, inventories can also have different discernible details (or spatial resolution). For example, an inventory may provide national, provincial or even finer resolution

The time-period covered by most emissions inventories is typically a calendar year (i.e., emissions released from January 1 through December 31), because most activity data (such as the amount of fuel used) is available on an annual basis. These inventories are referred to as annual inventories. However, some inventories may cover shorter periods of time, such as a season, a month or even a day. Shorter time periods help to accurately reflect a more specific time-period for a location.

In addition to the time-period covered by the emissions inventory, there may be information reflecting the temporal variability of the emissions within the inventory time-period. Inventories may provide seasonal, monthly, daily or even hourly variation data for some sources to accurately reflect the temporal variation in emissions. For example, some facilities may operate continuously throughout the year, while others only operate during certain hours of the day or during certain seasons of the year. In addition, the activity levels of fires, residential wood combustion, some mobile sources and agricultural operations are strongly dependent upon the time of day and/or season of the year.

Emission quantities refer to the unit that is used to express the emission inventory. This may vary depending on the spatial scale or temporal variability of the inventory. Common quantities that are used include tonne / annum, or grams / second.

In this study, an emission inventory was compiled for a number of source categories within the modelling domain of Phola, which includes:

1. Power Generation
2. Residential Fuel Burning
3. Residential Waste Burning
4. Biomass Burning
5. Vehicles – Paved Roads
6. Vehicles – Unpaved Roads
7. Mining

3.1 Power Generation

3.1.1 Introduction

Coal has traditionally dominated the energy supply sector in South Africa. Presently, about 80 percent of South Africa's primary energy needs are provided by coal. Through 2032, South Africa is projected to continue generating the majority of its electricity from traditional thermal power sources, primarily coal-fired generation. Approximately 95% of the electricity used in South Africa and 45% of the electricity used in Africa is produced by Eskom (ITA, 2024).

3.1.2 Emission Inventory

In this study, emissions from Eskom's Duvha Power Station, Kendal Power Station, Kriel Power Station, Kusile Power Station and Matla Power Station were included. The emission inventory for the five power stations which accounts for stacks, coal yards and ash dump emissions is compiled using data provided by Eskom. The emission inventory for the five power stations is presented in Table 3-1 and Table 3-2; and location of the stations is shown in Figure 3-1.

Table 3-1: Stack parameters and emission rates for the Eskom Power Station Stacks

Source	Height (m)	Diameter (m)	Exit Temp (K)	Exit Velocity (m/s)	SO_2 (t/a)	NO_X (t/a)	PM_{10} (t/a)	$PM_{2.5}$ (t/a)
Duvha Power Station								
Stack 1	300	12.47	403	27	133 273	71 056	5 457	2 728
Stack 2	300	12.47	403	27	133 273	71 056	5 457	2 728
Sub-total					**266 546**	**142 113**	**10 914**	**5 457**
Kendal Power Station								
Stack 1	275	13.51	399	24	174 895	67 870	39 963	17 584
Stack 2	275	13.51	399	24	174 895	67 870	39 963	17 584
Sub-total					**349 790**	**135 740**	**79 927**	**35 168**
Kriel Power Station								
Stack 1	213	14.3	403	19	138 113	118 381	23 407	10 299
Stack 2	213	14.3	403	19	138 113	118 381	23 407	10 299
Sub-total					**276 226**	**236 761**	**46 814**	**20 598**
Kusile Power Station								
Stack 1	220	15.4	323	18	21 281	24 940	737	368
Stack 2	220	15.4	323	18	21 281	24 940	737	368
Sub-total					**42 562**	**49 880**	**1 474**	**737**
Matla Power Station								
Stack 1	213	14.3	397	22.9	124 808	149 131	31 825	14 003
Stack 2	275	12.47	397	30.1	124 808	149 131	31 825	14 003
Sub-total					**249 617**	**298 262**	**63 649**	**28 006**
All Power Stations								
TOTAL					**1 184 740**	**862 755**	**202 777**	**89 965**

Table 3-2: Emission rates for the Eskom Power Station Coal Yards and Ash Dumps

Power Station	Source	Emission Basis	TPM (t/a)	PM_{10} (t/a)	$PM_{2.5}$ (t/a)
Duvha Power Station	Coal Yard	Materials Handling (quantity-based)	0.70	0.33	0.05
		Wind Erosion (surface area-based)	47.71	23.86	9.54
	Ash Dump	Materials Handling (quantity-based)	0.02	0.01	0.00
		Wind Erosion (surface area-based)	4 211.00	2 105.50	842.20
		Sub-total	**4 259.43**	**2 129.70**	**851.79**
Kendal Power Station	Coal Yard	Materials Handling (quantity-based)	1.80	0.85	0.13
		Wind Erosion (surface area-based)	93.38	46.69	18.68
	Ash Dump 1	Materials Handling (quantity-based)	0.15	0.07	0.01
		Wind Erosion (surface area-based)	1 524.87	762.43	304.97
	Ash Dump 2	Materials Handling (quantity-based)	0.02	0.01	0.00
		Wind Erosion (surface area-based)	798.01	399.01	159.60
		Sub-total	**2 418.22**	**1 209.06**	**483.39**
Kriel Power Station	Coal Yard	Materials Handling (quantity-based)	2.99	1.41	0.21
		Wind Erosion (surface area-based)	39.31	19.65	7.86
	Ash Dump	Materials Handling (quantity-based)	0.06	0.03	0.00
		Wind Erosion (surface area-based)	1 739.21	869.61	347.84
		Sub-total	**1 781.58**	**890.71**	**355.92**
Kusile Power Station	Coal Yard	Materials Handling (quantity-based)	0.64	0.30	0.05
		Wind Erosion (surface area-based)	32.79	16.40	6.56
	Ash Dump	Materials Handling (quantity-based)	0.40	0.19	0.03
		Wind Erosion (surface area-based)	1 204.65	602.33	240.93
		Sub-total	**1 238.49**	**619.21**	**247.56**
Matla Power Station	Coal Yard	Materials Handling (quantity-based)	0.60	0.28	0.04
		Wind Erosion (surface area-based)	45.11	22.55	9.02
	Ash Dump	Materials Handling (quantity-based)	0.12	0.06	0.01
		Wind Erosion (surface area-based)	3 134.27	1 567.13	626.85
		Sub-total	**3 180.10**	**1 590.03**	**635.93**
All Power Stations		**TOTAL**	**12 877.82**	**6 438.71**	**2 574.60**

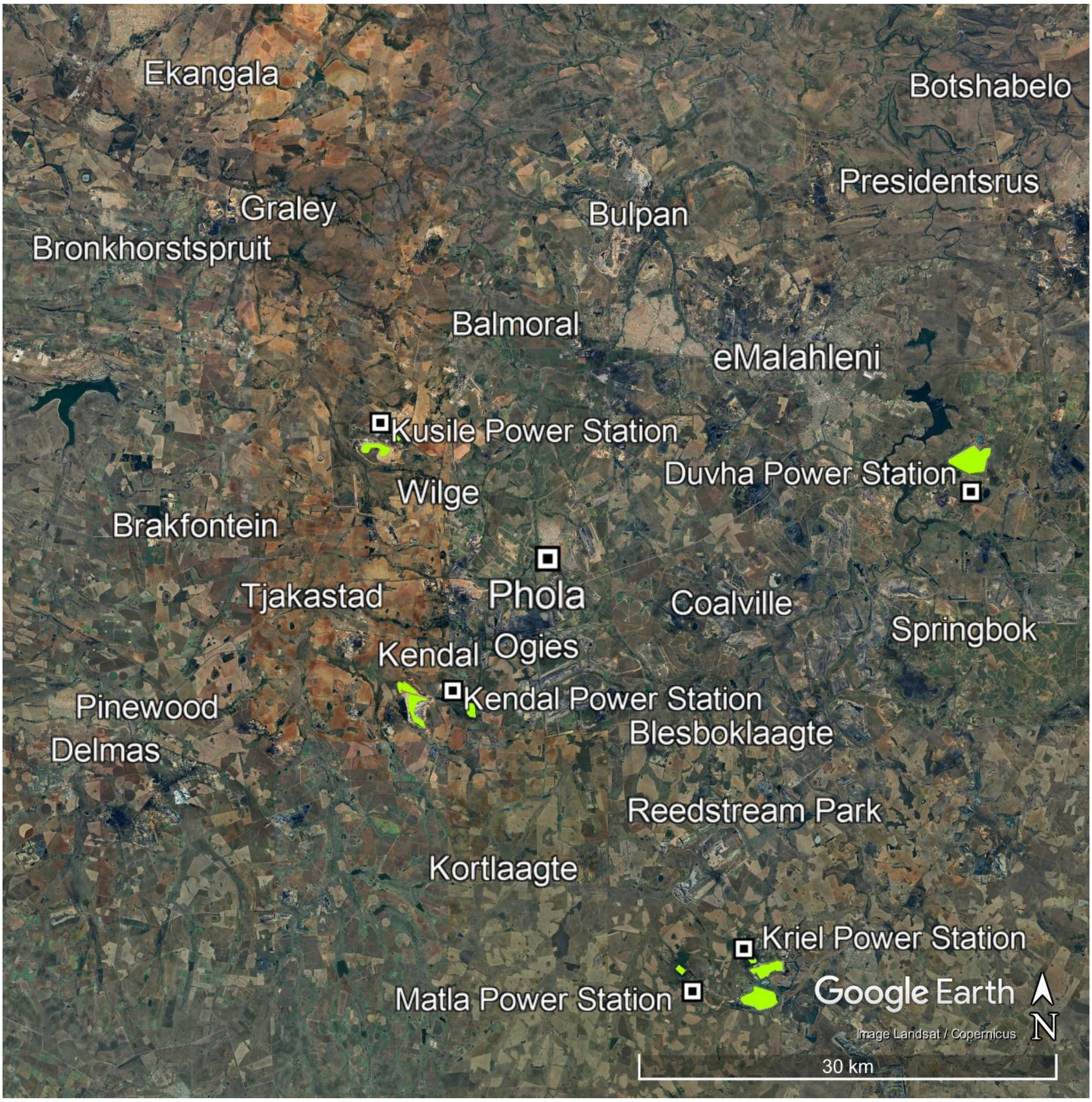

Figure 3-1: Location of the Eskom Power Stations, Coal Yards and Ash Dumps relative to Phola

3.2 Residential Fuel Burning

3.2.1 Introduction

There is growing evidence of a decreased reliance on fossil fuel combustion for energy use in the residential environment in South Africa. This is primarily due to increased access to electricity. According to Statistics South Africa (via the official Census and annual general household surveys), the percentage of households, as of 2019, with access to electricity is 85%. While this does not necessarily mean the total disuse of fossil fuel combustion in those homes (particularly for heating), it does offer an indication of potentially decreased residential fuel combustion. This could potentially be offset by population growth, particularly in areas predominantly reliant on indoor fuel combustion.

The proximity of the emission source to people is one of the key issues concerning household fuel combustion. This issue is exacerbated by inadequate combustion devices and poor indoor ventilation. Important pollutants include PM, CO, SO_2, NO_X and various VOCs. Importantly, not all fuels emit equal quantities of certain pollutants, with the amount of each pollutant emitted depending on the type of fuel burnt. As an example, SO_2 is relevant for coal combustion, while PM is less of a concern for LPG. Considering these pollutant complexities, it is important to understand the type of fossil fuel being burned, for which purpose and in which area to ensure the development of appropriate air pollution interventions.

The spatial variability and different pollutant contributions (both primarily driven by variability in fuel use by type) need to be captured in detail to estimate a gridded representation of emissions from residential fuel burning. Approaches to derive an emission inventory for residential fuel use generally rely on activity data from the 2011 and 2022 census community data. The data was sourced from the Statistics South Africa Superweb2 data catalogue's 2011 Census community profile (https://superweb.statssa.gov.za/webapi/jsf/dataCatalogueExplorer.xhtml).

The 2011 dataset contained detailed population statistics and number of households per municipal level, as well as population and number of households per ward level. Due to the lack of population statistics and number of households per ward level for the 2022 data set, population and number of households per ward level for the 2022 period was calculated by upscaling the 2011 household and population data. This was done by taking the 2011 municipal data and 2011 town data to calculate the ratio of town against municipality. This ratio would then be applied to the 2022 municipal data to calculate the town's household and population numbers.

The 2022 household and population numbers were utilised in a bottom-up approach to develop area-specific emission inventories for the study.

3.2.2 METHODOLOGY

The emission inventory development process for the Residential Fuel Burning emission inventory employed both a top-down and bottom-up approach. A top-down approach for gas, paraffin, and coal was used for the residential fuel use emissions in this study; and the spatial aspect was refined using a dwelling inventory. Naturally, the top-down approaches have inherent uncertainties since it relies on a national fuel consumption estimate, which is subject to uncertainty in assumptions on the aggregated national level. On the other hand, while wood burning is a well-known fuel used for residential purposes i.e., cooking, heating and lighting, the data from the South African Census i.e., Stats SA 2016 Community Survey does not have questions around wood as the type of fuel used in residential areas. As such, it is difficult to obtain the spatial variability for wood burning captured in detail to estimate a finer resolution representation of emissions from residential fuel burning.

BOTTOM-UP

A useful feature of the Stats SA 2016 Community Survey is that is provides information on the number of households in each Local Municipality using a specific fossil fuel for residential fuel burning activities. The provincial fossil fuel consumption is aggregated by the number of households using residential fuel burning to obtain a household fossil fuel consumption figure. This value is then used to estimate the fossil fuel consumption per household at the Local Municipality level which is then cascaded down to the three wards in Phola.

While this method is scientifically sound, it does present some challenges with an underestimation of fossil fuel use, which may not necessarily align with ground-truth surveys. In order to overcome this, literature values are used as a substitute where the national total for residential bituminous coal combustion is noted to significantly underestimate residential coal combustion at the household level e.g., 46.44 kg/ household level in Mpumalanga where domestic coal use is thought to be significantly greater. Consequently, literature values are used as a substitute with the value of 2.4 tonne of coal assumed to be burned per annum at the household level also informed by the Highveld Priority Area Health Study (HPAHS) (CSIR, 2017). Additionally, while residential wood combustion is a component of residential fuel burning, this data is not detailed in the DMRE National Commodity Flows Commerce and Public Services (2018). In order to overcome this, literature values are used as a substitute with the value of 3 tonnes of wood being assumed to be burned at the household level as informed by the HPAHS published by the CSIR and SAMRC (2019).

TOP-DOWN

The bottom-up approach detailed above has effectively provided the estimated fossil fuel combustion at the household level which must then be applied to the number of households at a more local level which, in this case, is at the ward level. The Stats SA 2016 Community Survey details the number of households at the Local Municipality level with associated intercensal growth rates which estimates population growth between two census campaigns as a percentage. This percentage is applied to Ward Level populations data obtained from Stats SA (2011) as to estimate ward populations in 2022 where household level fossil fuel literature values are applied to 2022 ward level population estimates. Fuel specific emission factors are then applied to the total volume of fuel burned for the various wards in question. The selected emissions factors are detailed below

3.2.3 EMISSION FACTORS

An emission factor (EF) is a quantity of a pollutant emitted relative to an activity metric, such as the quantity of fuel or material burned. It is a representative value that attempts to relate the quantity of a pollutant released to the atmosphere, with an activity associated with the release of that pollutant. For instance, an EF for the release of SO_2 from combustion of coal would be expressed in grams (g) SO_2 emitted per kilogram (kg) of coal combusted. EFs are usually expressed as the weight of pollutant divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant. EFs are generally used in calculating the rate at which a pollutant is being released from a source (emission rate), which can be used to simulate the concentration of the pollutant at a receptor. The general equation (1) for emissions estimation is:

$$E_i = F_B \times EF_i \qquad \text{Equation 1}$$

Where:

- E_i: The emission of pollutant i
- F_B: The amount of fuel burned
- EF_i: Emission factor of the fuel burned

A comparison of emission factors was done, considering those from the FRIDGE study (Scorgie et al., 2004), the USEPA AP-42 dataset, the GAINS United States and Australia model (Amann et al., 2011), Ballard-Tremeer (1997), Britton (1998), Scorgie (2012) and Makonese et al. (2015). Many of the South African studies focused on coal. A hybrid selection from these studies is considered in this household fuel combustion emissions methodology and are presented in Table 3-3.

Table 3-3: Emission factors used for residential fuel combustion

Pollutant	LPG		Paraffin		Coal		Wood	
	Emission Factor (g/kg)	Source	Emission Factor (g/kg)	Source	Emission Factor (g/kg)	Source	Emission Factor (g/kg)	Source
SO_2	0.01	FRIDGE	0.851	FRIDGE	11.6	Scorgie, 2012	0.123	Ballard-Tremeer, 1997
NO_X	1.4	FRIDGE	1.5	FRIDGE	3.95	Makonese et al., 2015	1.224	AP-42
PM_{10} [(a)]	0	NA	0	NA	0	Makonese et al., 2015	1.035	AP-42
$PM_{2.5}$	0.068	AP-42	0.359	AP-42	16.146	Makonese et al., 2015	13.745	AP-42

Note: (a) PM_{10} represents only the coarse fraction (i.e., PM with a diameter 2.5 µm to 10 µm)

For alignment with the recently published HPA Second-Generation AQMP Baseline Report (DFFE, 2024), Table 3-4 is a summary of the EFs utilised in this study.

Table 3-4: Emission factors used for residential coal combustion

Fuel	$PM_{2.5}$	PM_{10}	SO_2	NO_2 as (NO_X)
Coal (g/kg)	12.01	12.91	9.91	4.55

3.2.4 Emission Inventory

Emission estimates were calculated by multiplying the total fuel use by emission factors in Table 3-4. Table 3-5 summarises the pollution contribution of each residential fuel burning fuel type to the total residential fuel burning emission estimated for the Phola modelling domain. Table 3-5 indicates that the highest emissions in terms of residential fuel burning are PM_{10} and $PM_{2.5}$, followed by SO_2 and NO_X. In this study, emissions from residential fuel burning are calculated at the Sub Place level.

Table 3-5: Pollution contribution summary for residential coal burning estimated for the Phola emission inventory (tonne/annum)

Fuel Type	SO_2	NO_X	PM_{10}	$PM_{2.5}$
Coal	5 622.18	2 581.32	7 324.15	6 813.56

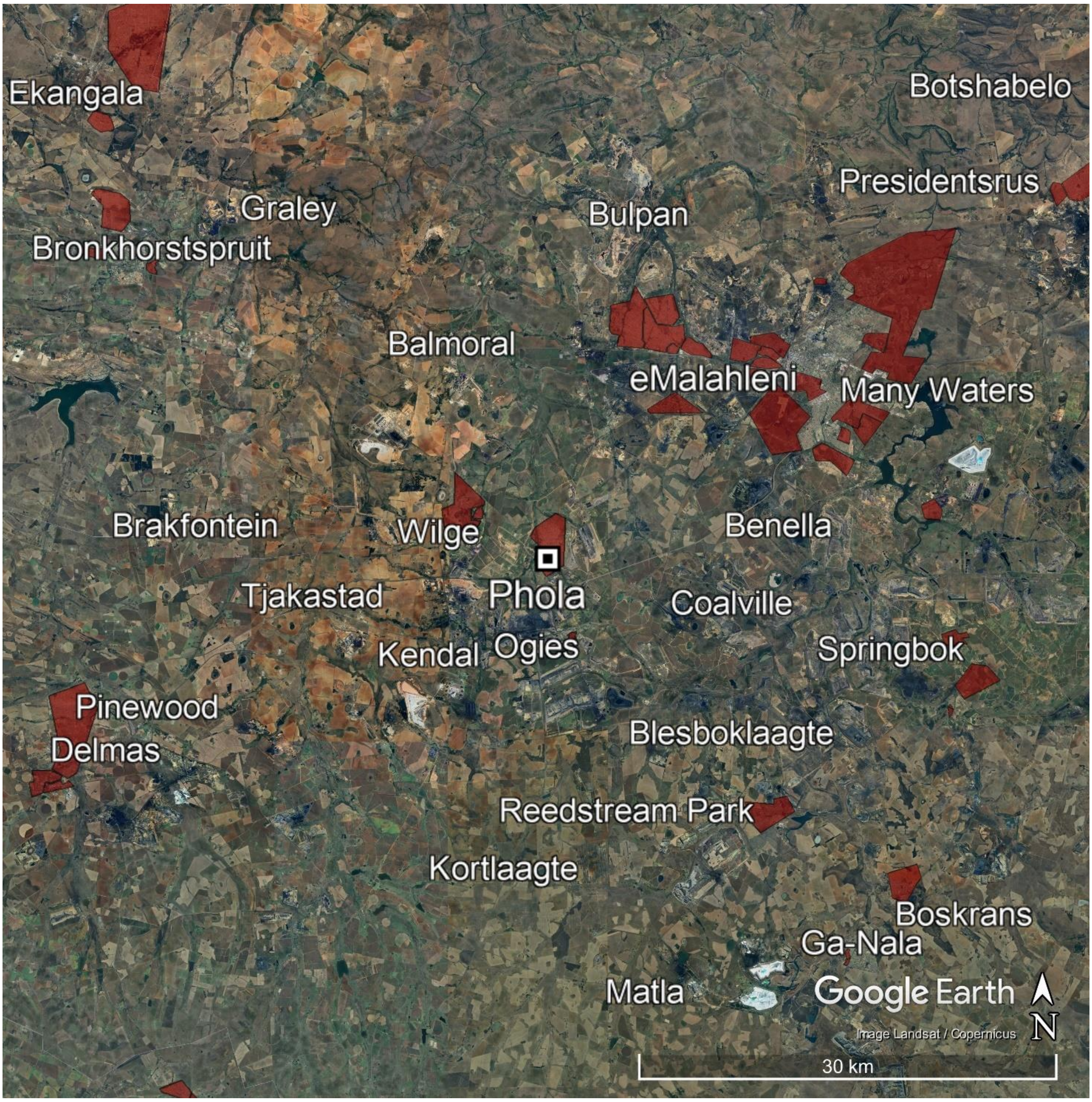

Figure 3-2: Location of residential areas within the Phola modelling domain for which Residential Fuel Burning emissions were applied

3.3 Residential Waste Burning

3.3.1 Introduction

In South Africa, open burning of waste typically occurs in low-income settlements where municipal collection of waste is infrequent, and waste generation is high due to the high population density in these areas. In the absence of municipal waste collection, residents are forced to find alternative means of disposal other than through formal landfills. Disposal can be done either through open burning or burial of waste. Open burning of waste has a negative impact on ambient air quality.

Open burning of residential waste can impact air quality through the emission of a range of pollutants. In this emission inventory, an international database was used to estimate the emissions from waste burning in the Phola modelling domain by following a top-down approach. The approach for the development of the inventory is described below.

3.3.2 Methodology

In this study, the approach used to estimate domestic waste burning emissions is based on Wiedinmyer et al. (2014), which follow IPCC methods (IPCC, 2006). Based on Equation 1, the emission of pollutant i (Ei) are estimated as the product of the emission factor of the waste (EFi) and the amount of waste burned (WB). The generalized equation to estimate waste burned is shown in Equation 2.

$$E_i = W_B \times EF_i \qquad \text{Equation 1}$$

Where:

- E_i: The emission of pollutant i
- W_B: The amount of waste burned
- EF_i: Emission factor of the waste

$$W_B = P \times P_{frac} \times MSW_P \times B_{frac} \qquad \text{Equation 2}$$

Where:

- W_B: The amount of waste burned
- P: Population
- P_{frac}: The fraction of the population accounts whose waste is not collected i.e., assumed to burn their waste
- MSW_p: The mass of annual per capita waste production
- B_{frac}: The fraction that is available to be burned that is actually burned

In this study, waste burning emissions are based on local data relating to waste accumulated per person and per composition i.e., waste generated per person per capita. Waste information was taken from Jeffares & Green (Pty) Ltd. (2016), in which waste composition and the amount for 2015 were calculated and assessed for six municipalities in South Africa. According to Equation 2, population is another variable required to estimate the amount of waste burned. Local municipality data (population data) were used to calculate a waste per person per year estimate. The population data was calculated utilising the same approach as described for residential fuel burning.

According to the 2018 Sasol Waste Collection Interventions (WCI) Study (Mamadi and Co., 2018), waste generated per capita was estimated at 0.612 tonne/person/annum. This rate (waste generated per capita) is assumed to be representative of the Phola study area. Equation 2 takes into account that some of the waste is not combustible. For example, glass and metals will not readily burn, thus a burn fraction is required. The IPCC recommended fraction of 0.6 is used i.e., 60% of the waste generated by people that do not have waste removal services is burned.

Additionally, an area surveillance assessment was conducted on the residential areas in the modelling domain, and a scaling factor was introduced to the 0.612 tonne/person/annum of waste being generated at the population per annum if the residential areas are more affluent. Another assumption was introduced to the 60% of the waste generated by people who do not receive removal services is burned that the composition of the waste is a 50:50 split between paper and plastic.

In this study, emissions from waste burning are calculated at Sub Place level. With respect to the modelling, the Sub Place level emissions were applied only over areas which corresponded specifically to residential areas (Figure 3-3).

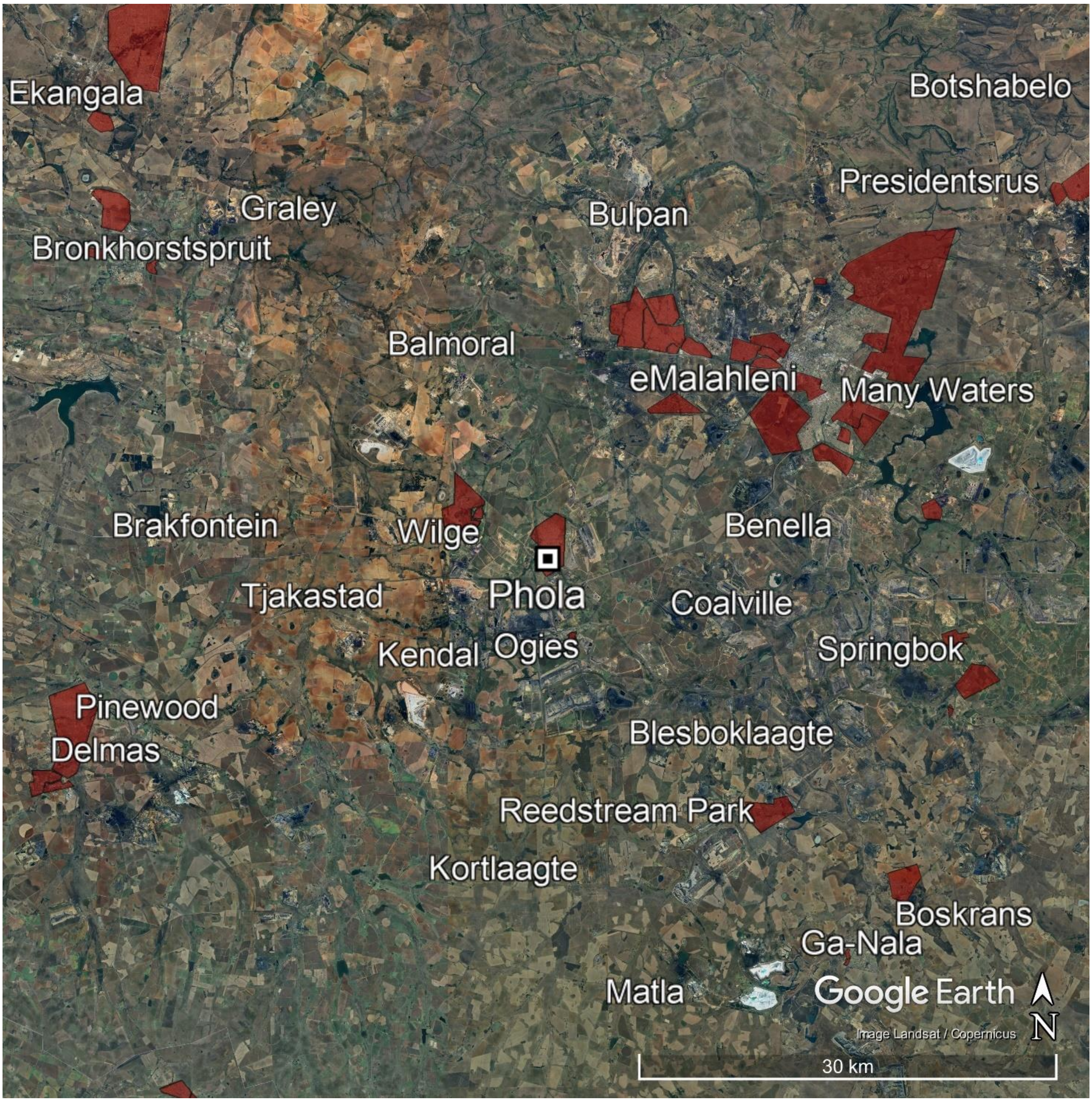

Figure 3-3: Location of residential areas within the Phola modelling domain for which Waste Burning emissions were applied

3.3.3 Emission factors

The most recent compilation of waste emission factors for a South African context are presented in the Sasol South Africa Emission Factors for Criteria Pollutants from Solid Waste Material Combustion Report (Mamadi & Co., 2018). In this report, several categories of materials are identified that are commonly found in waste burned in South African townships. A weight distribution for the composition of waste materials collected by the Sasol WCI program is presented in Figure 3-4. The major waste components identified in this program were paper, leather/rubber, textile, plastic bottles and bags, ceramic, metal, and glass. Emission factors used for estimating SO_2, NO_X, PM_{10} and $PM_{2.5}$ due to waste burning emissions is presented in Table 3-6.

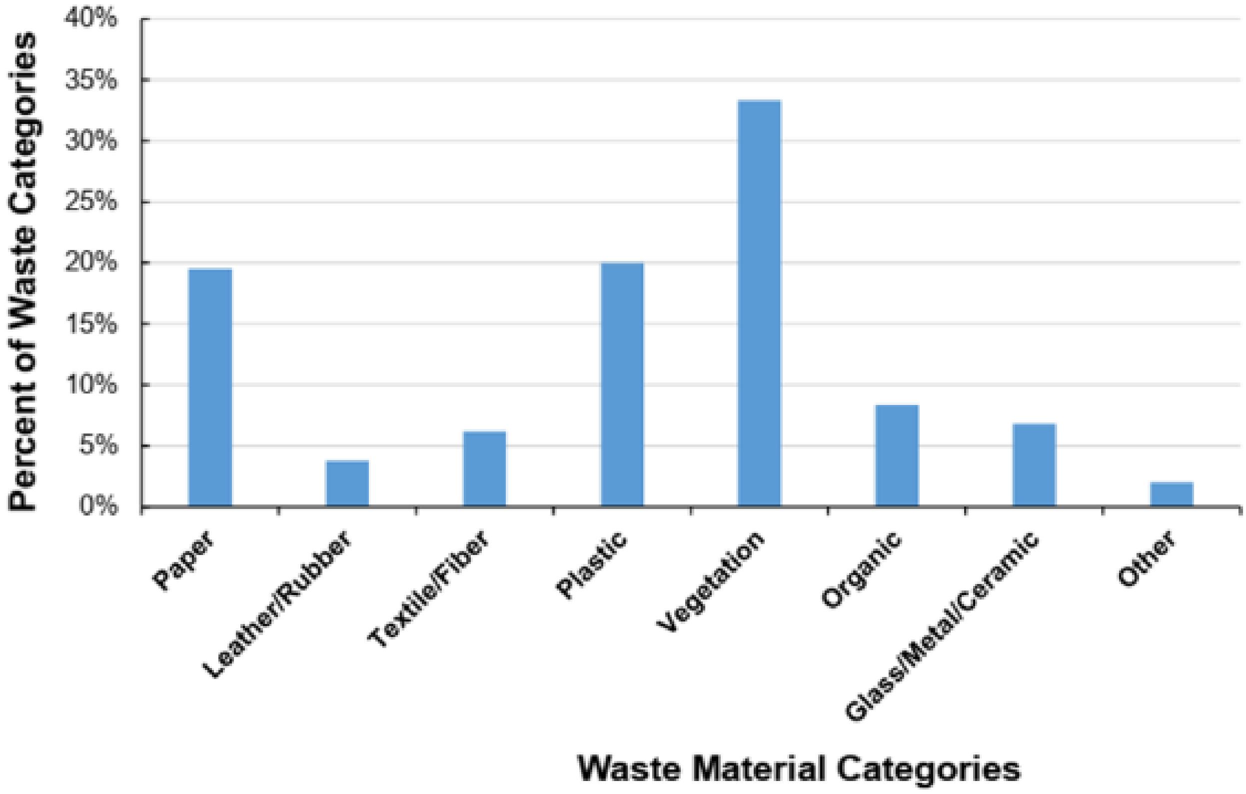

Figure 3-4: Weight fraction of municipal solid waste categories collected by Sasol (data provided by Mr Warren Carter, Sasol Technology)

Table 3-6: Waste burning emission factors

Emission Factors (g/kg fuel)				
	SO_2	NO_X	PM_{10}	$PM_{2.5}$
Paper	0.33	1.66	15.16	15.21
Plastic	0.36	10.61	722.47	651.0

3.3.4 Emission Inventory

Equation 2 is applied to the residential waste generated per capita and the emission factors detailed in Table 3-6 are applied thereafter, thereby determining grams per species emitted per kilogram of waste burned. Emissions of SO_2, NO_X, PM_{10} and $PM_{2.5}$ for the Phola study area due to waste burning is presented in Table 3-7. Compared to SO_2 and NO_X, it is evident that PM_{10} and $PM_{2.5}$ have the highest emission loading in the area.

Table 3-7: Emission inventory for waste burning emissions estimated for the Phola area

Pollutant	SO_2	NO_X	PM_{10}	$PM_{2.5}$
Emission Rate (tonnes/annum)	38.73	196.50	1 911.99	1 904.43

3.4 Biomass Burning

3.4.1 Introduction

Biomass burning refers to the large scale burning of vegetation, which includes savanna, forests and grasslands, domestic fuels and agricultural wastes (Andreae, 1991; Crutzen and Andreae, 1990). Open fires, such as wildfires, prescribed burns, agricultural fires, and land-clearing fires, are sources of atmospheric pollutants. Fire activity contributes to local, regional, and global emissions of greenhouse gases including carbon dioxide (CO_2) and methane (CH_4), reactive gases such as non-methane organic gases (NMOGs) and nitrogen oxides (NO_X) that form ozone, dioxins and other air toxics, and particulate matter (PM).

Fire emissions and their transport change the atmospheric composition, which cause impacts at many scales, with implications for air quality, regional and global climate, visibility and human health outcomes. Many factors contribute to the spatial and temporal patterns and severity of fires and their emissions, including agricultural, forest, and waste management practices, land use change, climatic factors such as temperature, rainfall, and drought conditions, and ecosystem diversity and health.

Accurate estimates of fire emissions are required to understand chemistry and climate, to assess ambient pollutant concentrations and population exposure, and to evaluate the effectiveness of emissions control programs for air quality planning and management.

In southern Africa, biomass burning occurs predominantly during the dry season corresponding to the period from May to October (Cahoon et al., 1996; Scholes et al., 1996a, 1996b; Scholes and Andreae, 2000; Swap et al., 1996). The majority of fires on the Highveld are thought to be anthropogenic in nature and include veld fires, burning of grazing land and crop-residue (DEFF, 2010). The biomes of South Africa (Figure 3-5) which are categorised as high to extreme risk include the following: fynbos, savanna and grassland. Mpumalanga is predominantly a grassland biome, thus an area at high to extreme risk of veld fires.

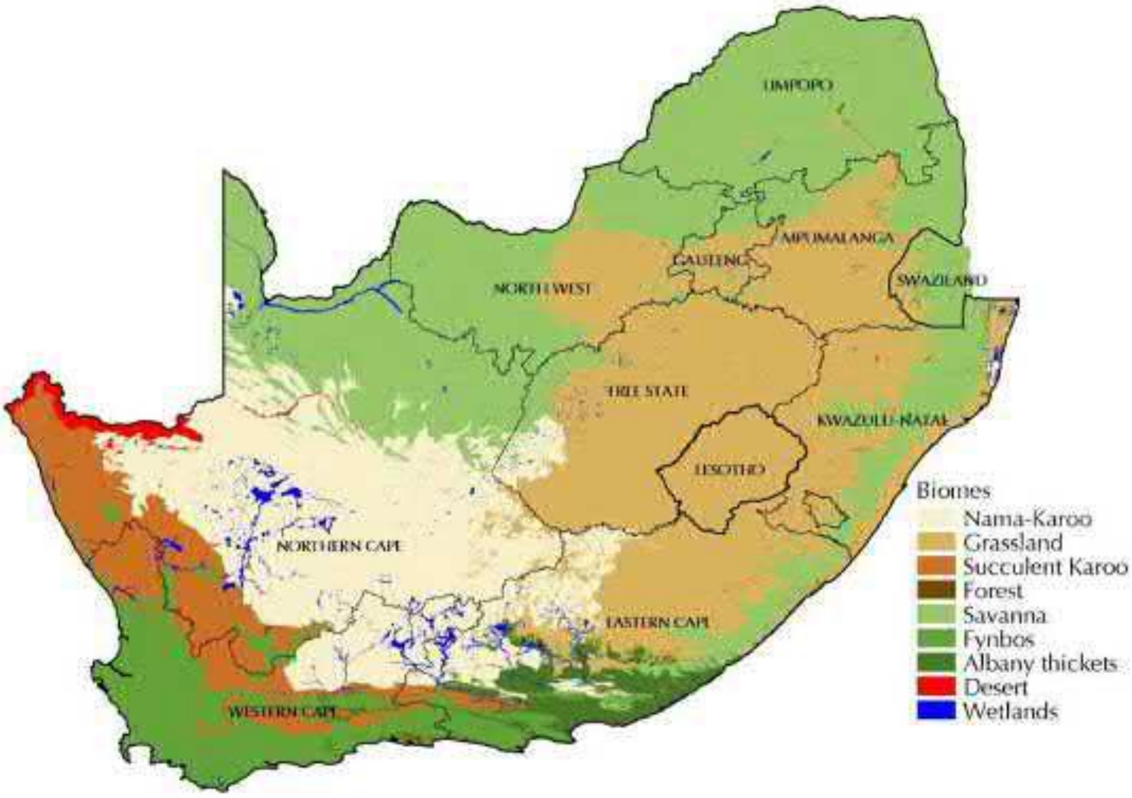

Figure 3-5: South African Biomes (SANBI, 2004)

3.4.2 Methodology

The Fire Inventory from NCAR version 2.5: an updated global fire emissions model for climate and chemistry applications

The FINN (Fire INventory from the National Center for Atmospheric Research (NCAR)) inventory (Wiedinmyer et al., 2011) was developed more than a decade ago to provide daily global estimates of pollutant emissions from open fires with a high spatial and temporal resolution for use in air quality, atmospheric composition, and climate modelling applications. The National Center for Atmospheric Research (NCAR) has served as the central repository for FINN global emissions files spanning from 2002–2020. FINN emission estimates have been applied in regions of the world that experience high fire activity to evaluate the influences on air quality and public health to assess emissions trends, to examine the effects of changing climate and development patterns on wildfire emissions and in comparisons with surface, aircraft, and satellite-based observations. Real-time emissions estimates from FINN version 1 (FINNv1) are currently used in the NCAR Whole Atmosphere Community Climate Model (WACCM) chemistry and aerosol forecasts.

The Fire INventory from NCAR version 2.5 (FINNv2.5) is an updated global fire emissions model that provides publicly available emissions of trace gases and aerosols for various applications, including use in global and regional atmospheric chemistry modelling. FINNv2.5 is an updated version of the FINN version 1 framework, with many updates to better represent burned area, vegetation burned, and chemicals emitted.

Some of the major updates include:

- The use of active fire detections from the Visible Infrared Imaging Radiometer Suite (VIIRS) at 375 m spatial resolution, which allows smaller fires to be included in the emissions processing.
- The calculation of burned area has been updated to improve aggregate fire detections, which better accounts for larger fires and enables using multiple satellite products simultaneously for emissions estimates.
- Fuel characterization and emissions factors have also been updated in FINNv2.5.

The FINNv1 model is based on a bottom-up approach to estimate the emissions described by Wiedinmyer et al. (2011). In FINNv1, global observations from the Moderate Resolution Imaging Spectroradiometer (MODIS) sensors on board the National Aeronautics and Space Administration's (NASA) Terra and Aqua satellites are used to detect fire activity, beginning with the MODIS Rapid Response (MRR) system or the MODIS Adaptive Processing System (MODAPS) Collection 5 (Davies et al., 2009).

Fuel characterization in FINNv1 is based on the Collection 5 MODIS Land Cover Type (LCT) product for 2005 (Friedl et al., 2010), with land cover classifications defined by the International Geosphere–Biosphere Programme (IGBP) and the Collection 3 MODIS Vegetation Continuous Fields (VCF) product for 2001 (Carroll et al., 2011). Fuel loadings are assigned from Hoelzemann (2004) or Akagi et al. (2011). Estimates of fuel burned use the approach of Ito and Penner (2004). Emissions factors by land cover classification for trace gases and particulate air pollutants in FINNv1 are based on the published literature (Akagi et al., 2011; Andreae and Merlet, 2001; Andreae and Rosenfeld, 2008; McMeeking, 2008).

FINN version 2.5 (FINNv2.5) has extensive updates to the input data and processing used for the detection of fire activity, characterization of annual land use and/or land cover and vegetation density, determination of area burned, and the application of fuel loadings by global region compared to the FINNv1 configuration. FINNv2.5 also includes revisions to emissions factors based on the current literature.

METHODS USED FOR THE DEVELOPMENT OF FINNV2.5

FINNv2.5 was released in 2022. A global emissions database for the period 2002 to 2021 has been created for public use, for incorporation in emission inventories, chemical modelling and climate modelling applications. FINNv2.5 uses the same FINNv1 bottom-up methodology (Wiedinmyer et al., 2011) as defined by the following overall equation:

$E_i = A(x,t) \times B(x) \times FB \times EF_i$

where the emissions (*E*; mass of pollutant *i*) is the product of the area burned at location *x* and time *t* [$A(x,t)$], the biomass at location *x* [$B(x)$], the fraction of biomass that is burned (FB), and an emissions factor (EF_i; mass of pollutant *i* per biomass burned).

The FINNv2.5 model framework has the following three components:

- Burned area and land cover determination
- Fuel consumption and emissions calculation
- Speciation of the non-methane organic gases.

FIRE LOCATION AND TIMING

FINNv2.5 first determines the burned area from daily satellite detections of active fires. FINNv2.5 uses MODIS detections at a 1 km^2 resolution (as in FINNv1) and adds an option to use active fire detections at 375 m resolution from the Visible Infrared Imaging Radiometer Suite (VIIRS), which is on board the Suomi National Polar-orbiting Partnership (Suomi-NPP) satellite, in isolation or together with MODIS active fire data. The use of VIIRS 375 m detections is regarded as a major advancement from the use of MODIS-only fire detections, as this product is able to capture small fires better.

The MODIS Collection 6 (MCD14DL) and VIIRS active fire products are obtained from NASA's Fire Information for Resource Management System (FIRMS) data portal. The MODIS product provides the location, overpass time (Coordinated Universal Time, UTC), and confidence of daily fire detections. Data confidence in the MODIS product is specified by a numerical scale of 0 % to 100 %. Detections with a confidence specification that is less than 20 % are eliminated from calculations in FINNv2.5, as implemented in earlier versions of FINN.

With its improved spatial resolution of 375 m, the VIIRS product provides a more sensitive detection of the fires of relatively small areas, fully global coverage, improved mapping of large fire perimeters, and improved nighttime performance relative to MODIS fire detections (Schroeder et al., 2014). Detection confidence is provided by the VIIRS product and is specified by three categories, i.e. low, nominal, and high. In the FINNv2.5 preprocessor, detections with a confidence specification identified as low are eliminated from the analysis. Only data attributed to thermal anomalies from vegetation fires are included in the analysis. Thermal anomalies associated with active volcanos or static land sources are eliminated from the analysis.

The processing of the two simultaneous fire products in FINNv2.5 does not lead to double-counting of the fires; the FINNv2.5 method determines the spatial union of all adjacent detections for a given day as the daily burned area of a fire. The identity of the sensor is not relevant for the determination of the burned area, as long as the pixel size for each detection is correctly represented (i.e., 0.14 km^2 for VIIRS and 1 km^2 for MODIS).

BURNED AREA

FINNv1 estimates burned area for each fire pixel identified individually, and the nominal pixel size for the MODIS fire detections of 1 km^2 is assumed per detection. Spatially overlapping detections are eliminated from further analysis. It was recognized that for large fires in forested regions, an array of multiple discrete detections is typically reported, and an estimate of a contiguous area that represents the total area burned by a fire is needed.

In FINNv2, a new approach is adopted where the burned area estimate is improved to better represent the area associated with each fire. In the new approach used in FINNv2.5, each reported active fire detection is assigned a square area of 0.14 km^2 from VIIRS or 1 km^2 from MODIS, based on the nominal horizontal resolution of the data. Detections determined to be in proximity with one another are aggregated by two different approaches, depending on the land cover type and forest cover. Initially, it is assumed that multiple detections by adjacent pixels in a satellite sensor array are part of a larger fire, and these detections are merged. The scan and track sizes of the satellite pixel are provided by the fire detection product and define the actual resolution of the fire detection. The scan and track sizes for each fire detection are used for identifying groups of records that represent adjoining or overlapping detections. A rectangle with easterly and northerly sizes equal to 110 % of the scan and track sizes is established for each detection, with the objective of identifying adjacent neighbouring detections but not for direct application to the burned area estimation. Fire detections are identified as being from one larger fire when any of the satellite detection rectangles overlap. To minimize an overestimation of the burned area, a convex hull is generated between corresponding pairs of detection rectangles that directly intersect. The union of pairwise convex hulls from a cluster forms an extended fire polygon that represents the tentative estimated burned area for a single fire event or group of nearby fires for the day. This approach effectively fills any gap between instrument resolution squares (Wiedinmyer and Emmons, 2023).

For each of the extended polygons, the MOD44B v006 MODIS/Terra VCF annual product is overlaid, and the average tree cover fraction is determined. For forested areas with tree cover ≥50 %, as determined by the VCF product, the merged polygons are accepted as the final burned area estimate. Otherwise, the merging is not used, and instead, an alternative, more conservative, approach is applied to determine the burned area for the region. This alternative approach is used to prevent overestimation of emissions in regions with many small fires, as in the savanna fires in sub-Saharan Africa. The alternative polygon aggregation is achieved by aggregating nearby detections only when the instrument pixels themselves are intersecting and therefore not with the extended detection footprints. The result is an aggregation algorithm that is repeated with a smaller set of detections to determine the alternative conservative set of polygons (denoted as the conservative fire polygon). The final burned area polygons is ultimately a composite of polygons based on these two different aggregation approaches (Wiedinmyer and Emmons, 2023).

Subsequently, the final burned area polygons are subdivided using a Voronoi tessellation algorithm in order to develop emissions estimates by land cover classification. Each of the undivided final burned area polygons are assigned a unique fire ID to enable users to group emission estimates from a presumed single fire event (Wiedinmyer and Emmons, 2023).

FUEL LOADING AND VEGETATION INPUTS

The NASA MODIS VCF product provides estimates of the percentage of bare surface, herbaceous, and forested cover at a horizontal resolution of 250 m. For each fire area, the subdivided polygons are overlaid on the vegetation cover data from the MOD44B v006 MODIS/Terra VCF annual product. The VCF data for the prior year are chosen, so that the VCF before any land cover changes due to fire are used in the emissions estimation process. The VCF raster is clipped to the geometry of the fire polygon, and the averages of the VCF tree, herbaceous, and bare cover are calculated for each fire polygon (Wiedinmyer and Emmons, 2023).

FINNv2.5 uses the Terra and Aqua combined MODIS LCT MCD12Q1 Version 6 data product with the International Geosphere–Biosphere Programme (IGBP) classification scheme as its default land cover information. Use of the LCT and VCF products in FINNv2.5 is an improvement on FINNv1. FINNv1 used one static map of LCT and VCF (from 2002) for any year processed. FINNv2.5 employs year-specific MODIS LCT and VCF maps that change annually. Furthermore, the specific vegetation assignments for each subdivided polygon enable different vegetation types and coverage to be represented across larger fires. These input data and processes enable better representation of the vegetation that is burned. All fire polygons are assigned to 1 of 13 global regions (Wiedinmyer et al., 2011) used to assign fuel loadings. This completes the first component of the FINNv2.5 modelling framework and results in a file of daily burned areas and associated land cover information (Wiedinmyer and Emmons, 2023).

EMISSION CALCULATION

The next step of the model framework is the emissions calculation. In this step, the daily burned area and associated vegetation information (described above) are assigned associated fuel loadings. Using the same process described by Wiedinmyer et al. (2011), where the biomass burned is assigned based on land cover type and global region (B), the fraction of the biomass that is burned (FB) is assigned as a function of tree and herbaceous cover, emissions factors (EFs) are determined based on land cover, and daily pollutant emissions estimates are calculated following Eq. (1). Overall, the emissions calculation process follows this framework, as described by Wiedinmyer et al. (2011).

Similar to earlier FINN versions (Wiedinmyer et al., 2011), the 16 IGBP land cover classifications of the LCT product are mapped to consolidated vegetation types, depending on the land cover class and latitude that distinguish tropical, temperate, and boreal forests (Table 3-8). The consolidated vegetation types used in FINNv2.5 are grassland and savanna, woody savanna or shrubs, tropical forest, temperate forest, boreal forest, temperate evergreen forest, and crops.

The fuel loading, or the potential maximum amount of biomass available to be burned ($B(x)$ in Eq. 1), is assigned by generic vegetation type and global region (Table 3-9). Selected values were updated for FINNv2.5 from earlier versions of FINN, based on van Leeuwen et al. (2014). The fuel loading for crops was updated to 902 g m^{-2}, based on an average from the literature (Akagi et al., 2011; van Leeuwen et al., 2014; Pouliot et al., 2017). Emissions factors are then assigned based on the generic vegetation type (Table 3-10).

Table 3-8: LCT IGBP and generic vegetation type descriptions

IGBP LCT description	LCT value	Generic vegetation type	Generic vegetation value
Evergreen needleleaf forests	1	If latitude >50, then boreal forest; otherwise, temperate evergreen forest	5,6
Evergreen broadleaf forests	2	If latitude >-23.5 and	3, 4
Deciduous needleleaf forests	3	If latitude >50, then boreal forest; otherwise, temperate forest	5,4
Deciduous broadleaf forests	4	Temperate forest	4
Mixed forests	5	If latitude >5, then boreal forest; if latitude >-23.5 and	5, 3, 4
Closed shrublands	6	Woody savanna or shrubs	2
Open shrublands	7	Woody savanna or shrubs	2
Woody savannas	8	Woody savanna or shrubs	2
Savannas	9	Grassland and savanna	1
Grasslands	10	Grassland and savanna	1
Permanent wetlands	11	Grassland and savanna	1
Croplands	12	Croplands	9
Urban and built-up lands	13	If tree cover 40 and 60, then assign based on latitude	**
Cropland/natural vegetation mosaics	14	Grassland and savanna	1
Permanent snow and ice	15	Remove	
Barren	16	Grassland and savanna	1
Waterbodies	17	Remove	
Unclassified	255	Remove	

** if latitude > 50, then Boreal Forest; if latitude > -30 and < 30, then Tropical Forest; Else, Temperate Forest

Table 3-9: Fuel loadings (g/m^2) assigned by generic land cover type and global region as described by Wiedinmyer et al. (2011), unless noted otherwise (values in bold indicate those updated for FINNv2.5, based on van Leeuwen et al. (2014)

Global region	Tropical forest	Temperate forest	Boreal forest	Woody savanna/ shrublands	Savanna and grasslands[e]
North America	28 076[a]	**10 661**[c]	**17 875**[c]	4762	976
Central America	**26 500**[c]	11 000		2224	418
South America	**26 755**[c]	7400		3077	**624**[c]
Northern Africa	25 366	3497		2501	**382**[c]
Southern Africa	25 295	6100		2483	**411**[c]
Western Europe	28 076[a]	7120	6228	4523	1321
Eastern Europe	28 076[a]	11 386	8146	7752	1612
North central Asia	6181[b]	20 807	**14 925**[c]	11 009	2170
Near East	6181[b]	10 316		2946	655
East Asia	**14 941**[c]	7865		4292	722
Southern Asia	**26 546**[c]	14 629		5028	1445
Oceania	16 376	**13 535**[c]		**2483**[d]	**552**[c]

[a] Tropical forest class added for North America and Europe (in LCT). [b] All of Asia is assigned equal tropical forest values. [c] Taken from van Leeuwen et al. (2014). [d] Taken as the same for African woody savanna from van Leeuwen et al. (2014). [e] Croplands are assigned the same fuel loading as grasslands.

Table 3-10: Emissions factors (g/kg) for FINNv2.5

Chemical species	Generic vegetation index and type						
	1	2	3	4	5	6	9
	Savanna grasslands[a]	Woody savanna/ shrubs	Tropical forest	Temperate forest[b]	Boreal[c]	Temperate evergreen forest[b]	Crops[d]
Carbon dioxide (CO_2)	1686	1681	1643	1510	1565	1623	1444
Carbon monoxide (CO)	63	67	93	122	111	112	91
Methane (CH_4)	2	3	5.1	5.61	6	3.4	5.82
Non-methane organic gases (NMOGs)[e]	28.2	24.8	51.9	56	48.5	49.3	51.4
Hydrogen (H_2)	1.7	0.97	3.4	2.03	2.3	2	2.59
Nitrogen oxides (NO_X as NO)	3.9	3.65	2.6	1.04	0.95	1.96	2.43
Sulfur dioxide (SO_2)	0.9	0.68	0.4	1.1	1	1.1	0.4
Particulate matter with diameters less than 2.5 µm ($PM_{2.5}$)	7.17	7.1	9.9	15	18.4	17.9	6.43
Total particulate matter (TPM)	8.3	15.4	18.5	18	18.4	18	13
Total particulate carbon (TPC)	3	7.1	5.2	9.7	8.3	9.7	4
Particulate organic carbon (OC)	2.6	3.7	4.7	7.6	7.8	7.6	2.66
Particulate black carbon (BC)	0.37	1.31	0.52	0.56	0.2	0.56	0.51
Ammonia (NH_3)	0.56	1.2	1.3	2.47	1.8	1.17	2.12
Nitrogen oxide (NO)	2.16	0.77	0.9	0.95	0.83	0.95	1.18
Nitrogen dioxide (NO_2)	3.22	2.58	3.6	2.34	0.63	2.34	2.99
Non-methane hydrocarbons (NMHCs)	3.4	3.4	1.7	5.7	5.7	5.7	7
Particulate matter with diameters less than 10 µm (PM_{10})	7.2	11.4	18.5	16.97	18.4	18.4	7.02

[a] Emissions factors for tropical forests, savannah/grasslands, and woody savannah/shrubs are updated to the average values from Akagi et al. (2011; updated in February 2015). [b] Emissions factors for temperate forest and temperate evergreen forests are the average values from Akagi et al. (2011; updated February 2015), and the results are from Liu et al. (2017), Paton-Walsh et al. (2014), and Urbanski (2014). For temperate evergreen forest, only the results from evergreen forests are included. [c] Boreal forest emissions factors are the average of Akagi et al. (2011), with the emissions factors from boreal forest taken from Urbanski (2014). [d] Crop emissions factors are updated with the average values from Akagi et al. (2011) and results from Fang et al. (2017), Liu et al. (2016), Santiago-De La Rosa et al. (2018), and Stockwell et al. (2015; Table S3). [e] NMOG emissions factors now include identified and unidentified compounds.

3.4.3 Emission Inventory

The FINNv2.5 model was run in two ways to produce emissions for evaluation and assessment, namely (1) for comparison with the previous version of FINN (FINNv1.5) using MODIS-only fire detections and calculated starting in 2002 (FINNv2.5(MODIS)) and (2) by using both MODIS and VIIRS fire detections and calculated starting in 2012 (FINNv2.5(MODIS + VIIRS) (Wiedinmyer and Emmons, 2023).

For all emitted species, FINNv2.5(MODIS + VIIRS) global emissions are higher than, and approximately double, those predicted by FINNv1.5. This is the case, even when only MODIS fire detections are considered. The increase in emissions from previous versions is primarily due to the new processing of the area burned. In previous versions, the fire area was determined from a satellite detection pixel only; the updated version here also includes the composite of many detections into larger areas of fire activity. The inclusion of VIIRS into the FINNv2.5(MODIS + VIIRS) inventory globally adds approximately 25 % above the FINNv2.5(MODIS) processing for all emitted species. Further, emissions of NMOGs and the individual species that make up NMOGs (e.g., CH_2O and C_2H_6) are increased significantly due to the use of updated emissions factors from recent field campaigns. Previous studies have shown low biases in FINN regional and species-specific estimates. The updated version is expected to correct some of these prior biases (Wiedinmyer and Emmons, 2023).

FINNv2.5(MODIS + VIIRS) emissions estimates are overall at the higher end of the range of annual global total emissions compared to other commonly used emission inventories, likely due to a combination of the aggregated burned areas and the fact that FINNv2.5(MODIS + VIIRS) includes fire information from VIIRS, which captures more small fires. Globally, fire emissions peak in August–September, with the largest emissions in Southern Hemisphere Africa and Southern Hemisphere South America (Wiedinmyer and Emmons, 2023).

The biomass emissions used in the study has been extracted using the extents of the modelling domain. The FINNv2.5 biomass burning emissions are calculated over a period spanning from 2002–2021. Biomass burning emissions are not available for 2022. An average of the 2020 and 2021 period have therefore been averaged to provide an annual average emission rate for biomass burning emissions. The annual average biomass burning emissions for the modelling domain is presented in Table 3-11. The location of biomass burning fires for the 2020 and 2021 period is presented in Figure 3-6.

Table 3-11: Estimated biomass burning emissions

Pollutant	SO_2	NO_X	PM_{10}	$PM_{2.5}$	TPM
Emission Rate (tonnes/annum)	247.63	54.09	2 550.06	2 451.40	3 666.53

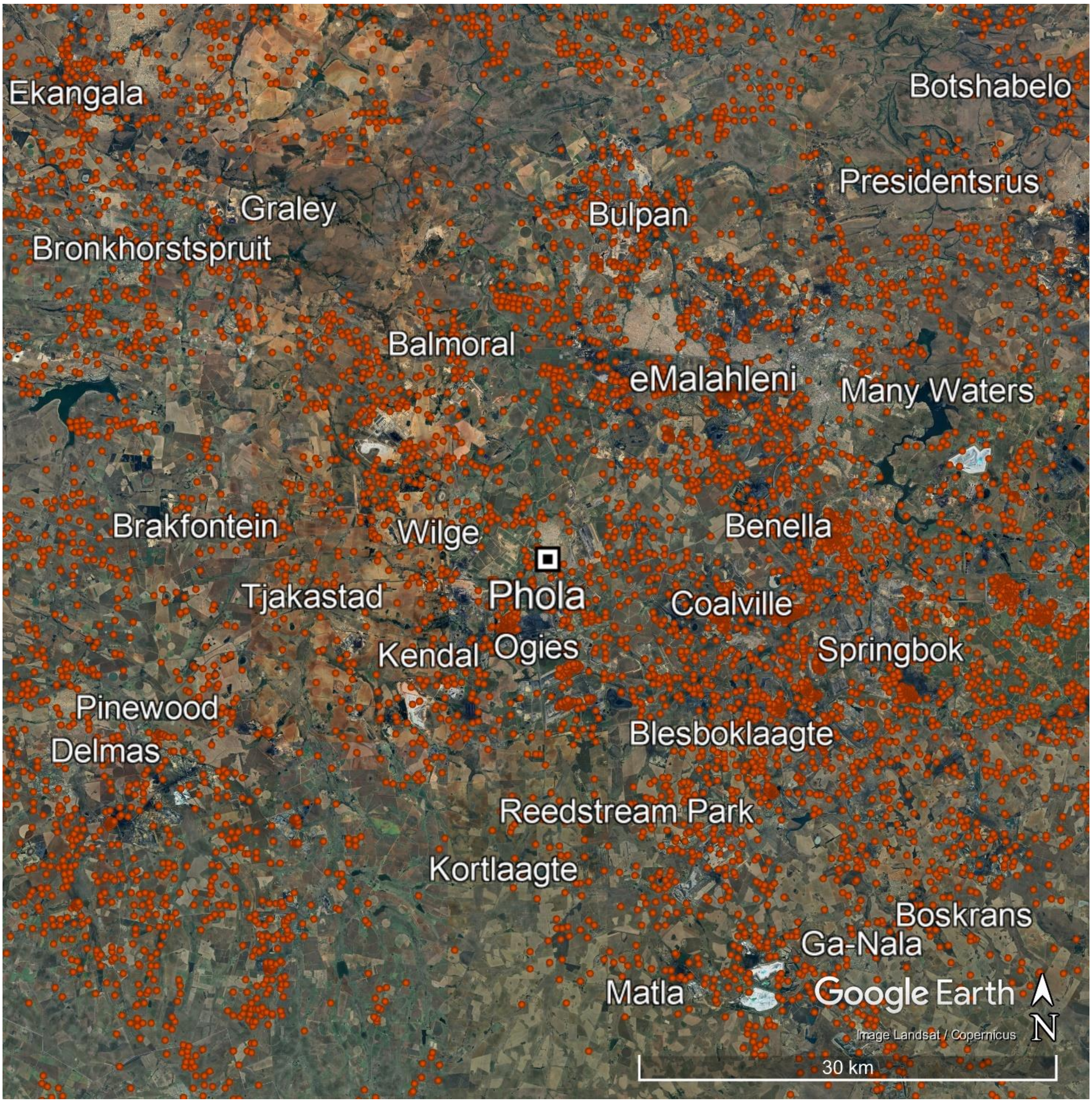

Figure 3-6: Location of biomass burning fires (indicated by orange dots)

3.5 Vehicles – Paved Roads

3.5.1 Introduction

A paved road is defined as any road that has a semi-permanent surface placed on it (for example, asphalt or concrete). In this section, emissions are calculated for exhaust emissions, brake, tyre and road wear for vehicles travelling on paved roads.

Emissions from vehicles arise during the different cycles of driving from start-up, during driving, evaporation from the engine and fuel line, and during re-fueling (DEFF, 2010). Particulate matter is also emitted from brake, tyre and road wear (DEFF, 2013). Other pollutants associated with vehicle emissions include SO_2, NO_2, carbon monoxide, benzene and lead. In this study, only SO_2, NO_X, and particulates (PM_{10} and $PM_{2.5}$) will be considered. The emission rates are co-dependent on various factors relating to vehicle parc (vehicle class, model, speed and maintenance); fuel specifications and environmental factors (Samaras *et al*., 1999). Considering the complexity of vehicle emission inventory development, this study has opted to use the COPERT vehicle emission estimation model which is regarded as the EU standard vehicle emissions calculator and has been used in other regulatory strategic documents such as the Second-Generation Vaal Triangle Airshed Priority Area (VTAPA) Air Quality Management Plan (DEFF, 2020). COPERT stands for COmputer Programme to calculate Emissions from Road Transport. It uses vehicle population, mileage, speed and other data such as ambient temperature and calculates emissions and energy consumption for a specific country or region. As an initial input basis of the emission estimates, a detailed road network of the region in question is required for which the associated vehicle population, mileage, speed and other data are estimated. The road network within the Great Phola Airshed is presented in Figure 3-7.

The network shown in Figure 3-7 is sourced from the World Bank data CatLog for South African roads delineated by the Word Bank (https://datacatalog.worldbank.org/dataset/south-africa-roads) and based on the South African national roads network.

The dataset classifies roads into three basic classes i.e., Primary, Secondary and Tertiary with road traffic apportioned according to these classifications with "Primary" carrying high volumes of traffic and "Tertiary" carrying less traffic. Thus, two factors play a role in emission intensity when considering these three types of roads. Primary roads may carry more vehicle volume and lead to higher emissions, together with congestion (therefore lowering speed and travel time) can also increase emissions. In general, factors that impact vehicle emissions estimates are:

- Fuel type
- Fuel specifications
- Engine technology

- Engine capacity
- Vehicle speed
- Vehicle age
- Engine/exhaust temperature
- Number of kilometres travelled.

Other, more detailed factors requiring information that is generally not available (particularly on such a large scale) are gearing, driving style, tyre friction and road grading, and are generally not available in a South African context.

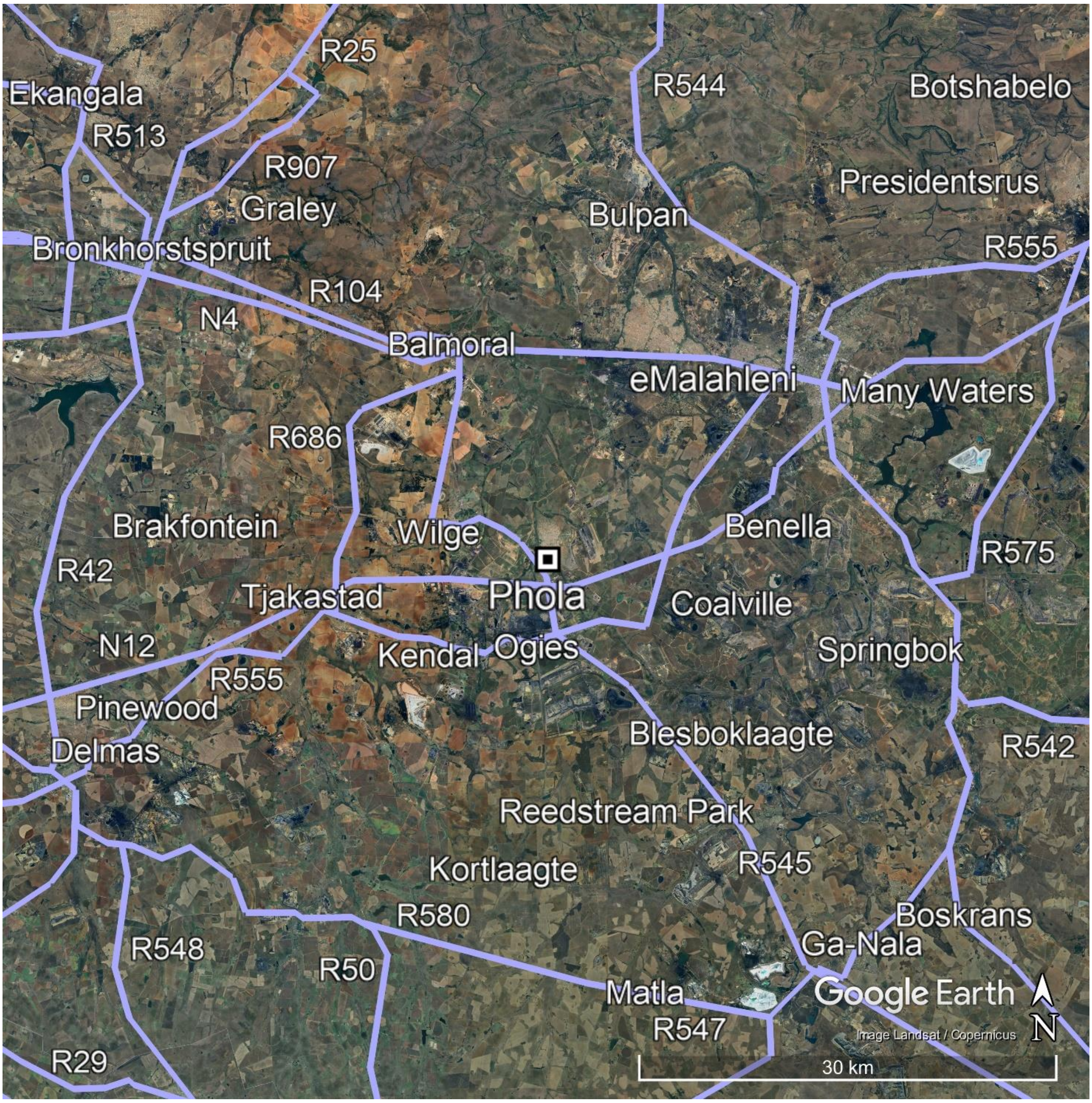

Figure 3-7: Road Network within the Greater Phola Airshed modelling domain

The basis of deriving vehicle emissions is an estimate of Vehicle Kilometres Travelled (VKT). This data represents an activity to which emission factors are applied. The emission factors are dependent on all other factors noted above and are accounted for in the COPERT model. Thus, any approach to generate a vehicle emission inventory includes an estimation of VKT and use of appropriate emission factors generated via COPERT. The level of detail included in each factor varies depending on available information which is required at the grid cell level for the most accurate estimation results. This is not necessarily possible for all the above-listed factors because many (for example, fuel type) are not tracked at a fine scale.

Thus, assumptions are made using spatial surrogates to generate a finer resolution emission inventory that is spatially representative. There are instances when very detailed information is available (such as traffic count data); however, these are then often spatially limited. Assumptions are then used to extrapolate this data to the larger spatial scale – this is termed a bottom-up approach – more detail on this approach is provided in section below. When larger scale, but more generalised data exists e.g., Provincial or District Municipality Level Fuel Sales, assumptions are made to create a finer scale variation based on surrogates – this is termed a top-down approach. Both these approaches are viable when estimating vehicle emissions but largely depend on the data available.

3.5.2 METHODOLOGY

As detailed above, estimation of the on-road vehicle emission inventory in this study has employed both a top-down and bottom-up approach. This is possible due to road count data being available from various sources which is also inherently contained in the road network data set i.e. Primary, Secondary and Tertiary classified roads. For both the top-down and bottom-up methodologies, the common underlying spatial units are the World Bank data CatLog for South African roads road links (Figure 3-7). Vehicle classes for which emissions are estimated are presented in Table 3-12.

Table 3-12: Vehicle classes for which emissions are estimated

<table>
<tr><th>eNaTIS Classification</th><th>ADDT Light</th></tr>
<tr><td rowspan="4">Motor Cars and Station Wagons</td><td>Car Diesel</td></tr>
<tr><td>Car Petrol</td></tr>
<tr><td>SUV Diesel</td></tr>
<tr><td>SUV Petrol</td></tr>
<tr><td>Motorcycles, Quads and Tricycles</td><td>MotoBike Petrol</td></tr>
<tr><td rowspan="2">LDV'S, Panel Vans etc</td><td>LCV Diesel</td></tr>
<tr><td>LCV Petrol</td></tr>
<tr><th>eNaTIS Classification</th><th>ADDT Heavy</th></tr>
<tr><td rowspan="4">Trucks</td><td>HCV1 Petrol</td></tr>
<tr><td>HCV1 Diesel</td></tr>
<tr><td>HCV2 Diesel</td></tr>
<tr><td>HCV3 Diesel</td></tr>
</table>

eNaTIS Classification	AADT Very Heavy
Trucks	HCV4 Diesel
	HCV5 Diesel
	HCV6 Diesel
	HCV7 Diesel
	HCV8 Diesel
eNaTIS Classification	**ADDT Bus**
Buses, bus trains, minibuses	Bus
Taxi	Minibus Taxis

It is important to note that various vehicles may be travelling on a particular piece of road at any given moment which requires a comprehensive vehicle typology or parc to be developed for which emissions will be estimated. Considering this, emissions for the classes listed in Table 3-12 are estimated which follow the electronic National Traffic Information System (eNaTIS) broad classifications as reported in the provincial statistics. This is then used to calibrate the COPERT model. A top-down approach uses fuel sales to estimate VKT and allocates this to roads by their type; however, the bottom-up approach serves as a starting point of the emission inventory.

BOTTOM-UP

Road count data is used to estimate VKT for each count station by applying the count to the immediate road link and this data is contained within the World Bank data CatLog for South African roads delineated by the Word Bank. The extents are limited in this way because there is no other methodology to describe traffic flow in other links around the station, except using a full-scale network flow model. These links are then removed from the full road network together with estimated fuel consumption for that link by converting VKT to fuel-use using fuel efficiency data that is also generated by the COPERT model. This ensures there is no double counting of both VKT and spatial features. All VKT are converted into fuel consumption using the efficiency data extracted from the COPERT model (see “Emission Factors” section below). This fuel consumption is subtracted from the provincial fuel sales, together with the road links associated with counts, going into the top-down methodology. The SANRAL count data is also useful in that average vehicle speeds are given. Using this information, it was possible to assign typical speeds for different World Bank data CatLog Road types. These speeds are necessary for selecting appropriate emission factors further in the process. Figure 3-8 shows the average speeds for light, heavy and overall classes for each World Bank data CatLog Road class. After all bottom-up estimations are done, the remaining road network is used for the top-down approach.

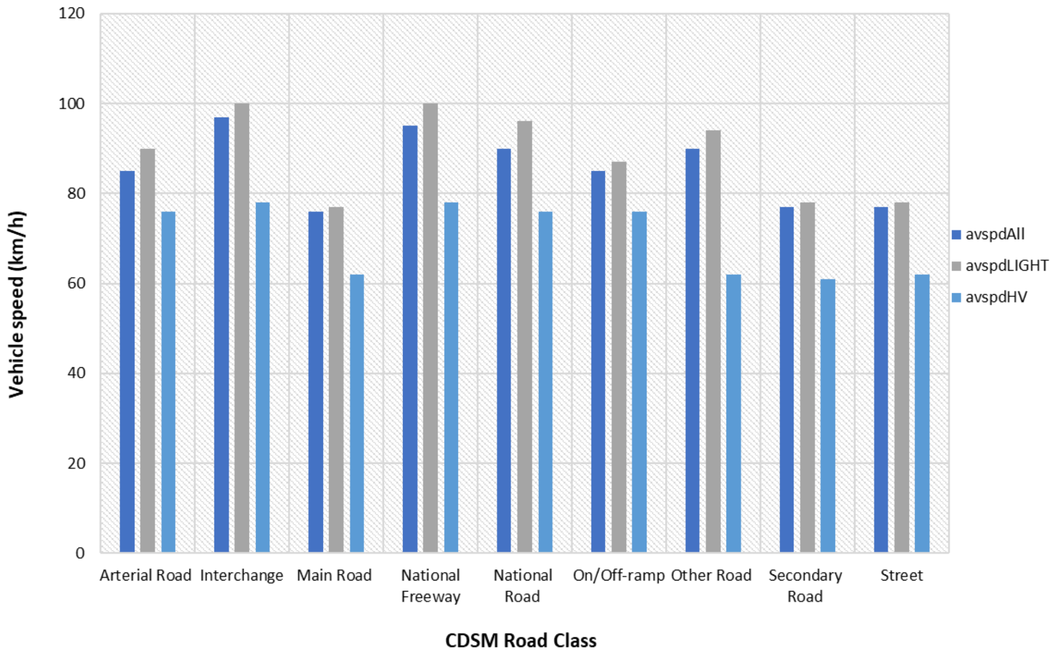

Figure 3-8: Average vehicle speeds for all light and heavy-duty vehicles for each CDSM road class (derived from SANRAL count data)

TOP-DOWN

The top-down approach uses provincial fuel sales and fuel efficiency data (from COPERT; see "emission factors" section) to estimate VKT. A key assumption is that fuel sales equate to fuel consumption. This is the case for total national volume; however, the possibility of fuel sales being consumed elsewhere is likely when looking at regional fuel sales. Therefore, Magisterial District sales are used rather than provincial sales (also available from the Department of Energy (DoE)) to minimize this effect. DoE obtained fuel sale data is classified into "Travel Analysis Zone" (TAZ) which comprises of various towns to which fuel/VKT is associated to specific road links.

Once fuel sales are allocated to TAZ, it is necessary to disaggregate further down to road level. This is accomplished by using data from the South African Road Classification and Access Manual (SARCAM) (SANRAL, 2012). Tables B and C of the manual provide typical average annual daily traffic (AADT) for different road classes. These typical road AADTs were used to proportionally distribute fuel to different World Bank data CatLog for South African roads classes. The result of this process is unique road classes, to which typical AADT from the SARCAM can be assigned. Fuel within each TAZ is then distributed by the typical AADT proportion amongst classes.

The final level of disaggregation is achieved by then allocating fuel proportionally within classes based on link length. The result is a fuel consumption estimate on each of the remaining (after removals from the bottom-up processing) World Bank data CatLog for South African roads. This fuel consumption is converted to VKT using the COPERT-derived fuel efficiency data.

3.5.3 Emission Factors

In this study, “hot running” (thermally stabilized engine and exhaust treatment) emission factors were derived from the COPERT 5 (version 5.0.1145) model. The model is developed by EMISIA SA and supported by the European Environment Agency (EEA). The methodological approach (and thus formulae) for COPERT 5 is identical to the Tier 3 methodology laid out in the EMEP/EEA air pollutant emission inventory guidebook 2013 (European Environment Agency, 2013) for “Exhaust emissions from road transport” (Part B, Section 1.A.3.b.i-iv).

The COPERT approach was chosen since all other locally derived emissions factors (e.g., Stone, 2000; Wong, 1999; Wong and Dutkiewicz, 1998) provided an emission factor at a generalized single speed; while what is required for this emission inventory is a speed-based estimate since emission factors are sensitive to vehicle speed that are effectively linked to the World Bank data CatLog for South African roads and vehicle speeds. Additionally, locally derived emission factors represent a much older vehicle fleet; typically, pre-EURO2. Emission factors were modelled for EURO 1-6 stage vehicles from the classes specified in Table 3-13. An approximate manufacture year for each EURO stage is also listed in Table 3-13.

Table 3-13: Vehicle EURO stage and corresponding manufacture years

EURO Stage	Vehicle Model Year
EURO 1	1992 – 1995
EURO 2	1996 – 1999
EURO 3	2000 – 2004
EURO 4	2005 – 2009
EURO 5	2010 – 2014
EURO 6	2015 – current

Emission factors for SO_2, NO_X, and particulates were estimated in COPERT for speeds from 20 to 120 km/hr (in 20 km/hr increments). COPERT also estimated fuel consumption (i.e., efficiency in l/km) for each speed. Note that in practice the closest speed emission factor is matched to the specific speeds for vehicles travelling on that road. The full emission factor/fuel consumption dataset thus comprised 4 536 factors (6 EURO classes by 6 speeds by 18 vehicle classes by 7 pollutants).

Since there is no indication of vehicle age or technology within the activity data used (both counts for the bottom-up and fuel sales for the top-down) it is necessary to aggregate the emission factors by EURO stage. To simply take an average would not be accurate since that would assume all vehicle ages exist at an equal proportion in the vehicle parc. This is not true as newer vehicles enter the parc, older ones leave, resulting in a shift towards newer vehicles.

The spread of vehicle age in a parc can be determined through scrapping curves. A weighted average of emission factors between EURO stages can then be obtained to derive a single emission factor per vehicle class and pollutant (still at the different speeds). The scrapping curve used in this study is based on Merven et al., (2012) eNaTIS calibrated (year 2010). Weibull cumulative distribution functions show probability of vehicle survival as a function of age. These functions are then applied to the time periods relevant to this study. The scrapping curves used for each class is presented in Figure 3-9 (after Merven et al., 2012). These curves were used for deriving an age proportion weighted average emission factor for each speed and pollutant per vehicle class. The diesel NO_X emission factors derived from COPERT is presented in Figure 3-10 illustrates the importance of vehicle speed.

The emission factors were then applied to the VKT per vehicle class and road type to derive an annual emission estimate per road link for all pollutants of concern. For verification, the VKT and fuel consumption estimates derived from the COPERT model are adjusted to ensure a +/- 10% agreement with petrol and diesel fuel sales determined for each TAZ, ensuring accurate estimation of emissions in each area.

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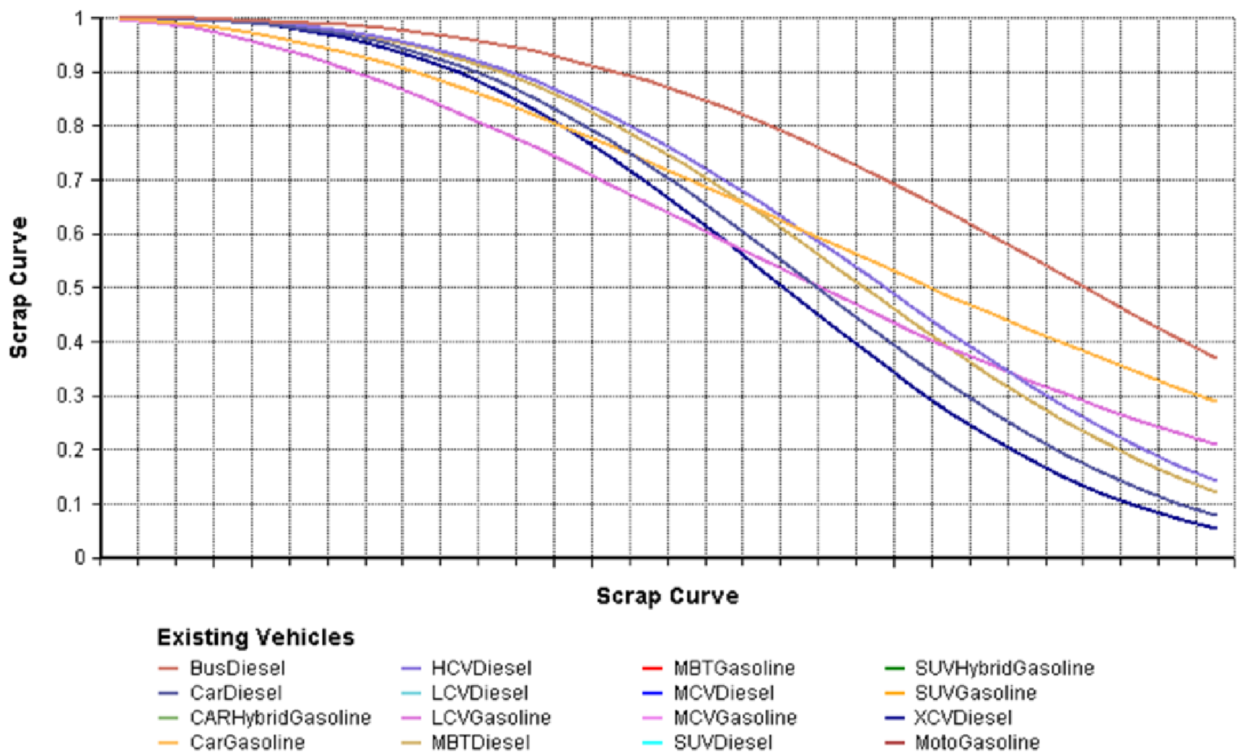


Figure 3-9: Base year scrapping curves for the vehicle technology types in the vehicle parc model (After Merven et al., 2012)

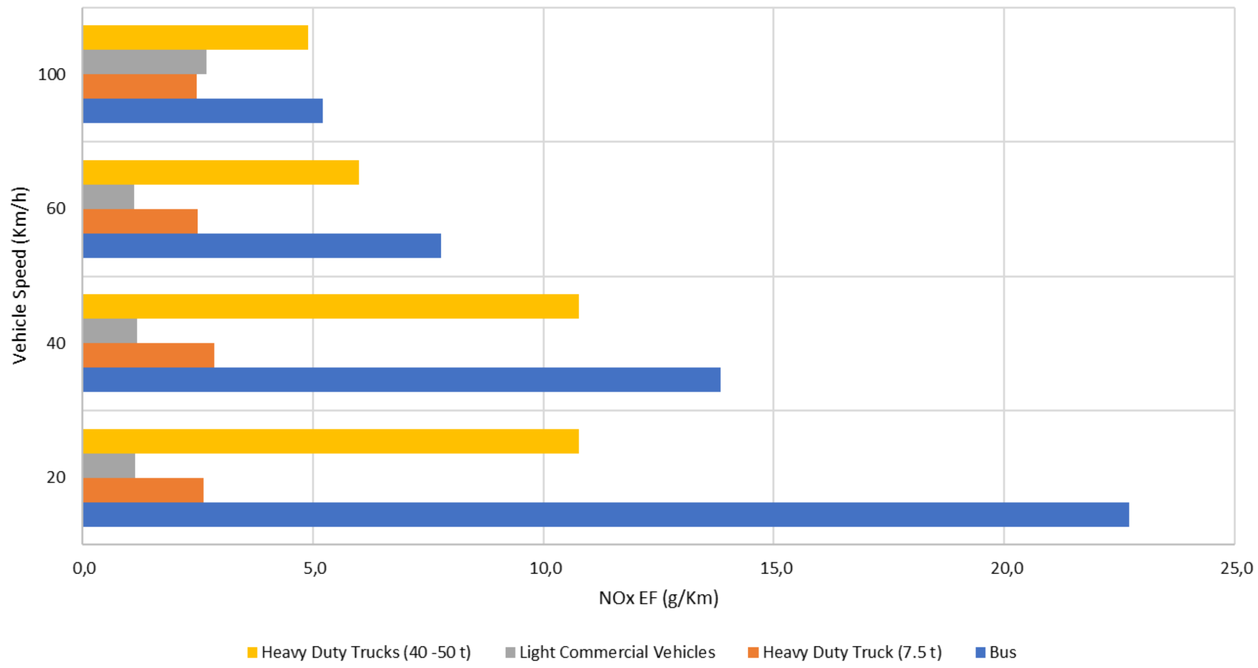


Figure 3-10: NO_X emission factors for diesel classes

3.5.4 Emission Inventory

Expectedly, higher on-road vehicle emissions are observed in areas with greater fuel sales. Having the greatest volume of daily traffic and fuel sales subsequently results in the greatest emission from on-road vehicles in the region. Table 3-14 presents the total tonnage of estimated annual tonnage of estimated on-road vehicle emissions within the Phola modelling domain.

Table 3-14: Estimated on-road vehicle emissions (tonnes/annum) within the Phola modelling domain

Pollutant	SO_2	NO_X	PM_{10}	$PM_{2.5}$
Emission rate (tonnes/annum)	133.57	8 991.08	183.00	183.00

3.6 Vehicles – Unpaved Roads

3.6.1 Introduction

An unpaved road is a road which has a surface that does not meet the definition of a paved road. The road surface may be dirt, rock, gravel, or other non-solidified material and may have a dust palliative applied (*dust palliatives* are substances applied to roads or ground surfaces to reduce airborne dust and its health impacts). Unpaved roads often contribute a significant amount of atmospheric dust formed due to re-suspension of road material by vehicles and observed as a dust cloud behind the driving vehicle. If a dust suppressant is applied to an unpaved road, this segment of road is still considered to be an unpaved road surface.

Most of the roads in South Africa are classified as gravel roads. A gravel road is a type of unpaved road surfaced with gravel that has been brought to the site from a quarry or stream bed. In many cases, replacement of gravel on these roads may not always be available or feasible. In 2016, SANRAL estimated between 74-79% of South African roads are gravel (https://www.arrivealive.co.za/The-South-African-National-Roads-Agency-LTD). Most of these roads are found within rural areas but a large percentage of these gravel roads are also found in urban areas. According to the roads infrastructure statistics, presented by the Mpumalanga Provincial Department (Mpumalanga Province, 2023), 60% of the Mpumalanga Road network is considered gravel, and these gravel roads are in very poor condition. It is expected that a large portion of the unpaved road network in Mpumalanga is found in outer lying urban areas and within townships.

The climatology of a particular place is controlled primarily by its latitude, which determines the amount of solar radiation that is received, its distance from the sea and the height above sea level. Secondary influences on climate are the general circulation of the atmosphere, the nature of the underlying surface and topography. South Africa lies in the sub-tropical high-pressure belt, which causes the general circulation over the sub-continent to be generally anticyclonic above 700 hPa for most of the year. The Mpumalanga Highveld lies in temperate latitudes between 25º 25’ S and 27º 31’ S and varies between 1500 and 1900 m above sea level. As a result, the Highveld experiences a temperate climate with dry winters according to the Köppen Climate Classification system. Winters are mild and dry, but cold at night when frost may occur. Rain occurs in summer, and temperatures are warm. The rain is mostly a consequence of the development of low-pressure troughs over the central plateau in summer and the dry winters are due to the dominant subtropical high-pressure system. The temperate temperatures are the consequence of the relatively high altitude (DEA, 2011).

The average rainfall in the Highveld varies from about 900 mm in the higher lying areas in the east to about 650 mm in the west. Rainfall is almost exclusively in the form of showers and thundershowers and occurs mainly in the summer from October to March, with the maximum in January. Winters are typically dry, but some rain does occur (DEA, 2011). This combined with potentially intense traffic in the urban areas, unpaved roads may present a significant local source of PM (Naidoo, 2023).

When a vehicle travels on an unpaved road, the force of the wheels on the road surface causes pulverization of surface material. Particles are lifted and dropped from the rolling wheels, and the road surface is exposed to strong air currents in turbulent shear with the surface. The turbulent wake behind the vehicle continues to act on the road surface after the vehicle has passed. Emissions caused by vehicles can be minimized by paving, windbreaks, frequent water and/or environmentally friendly chemical applications, and using gravel as a means of dust suppression.

LOCATION OF UNPAVED ROADS

Google Earth satellite imagery was used to map out locations of unpaved roads, mainly focusing on densely populated townships within the modelling domain. Based on the satellite imagery, it is noted that there are a few main roads and access roads within townships that are paved. This accounts for a very small fraction of the total length of all roads within a township. From a modelling perspective, a modelling exercise to include all unpaved road segments would be an exceptionally time-consuming exercise and would require exceptionally long model run-times. It was therefore decided to include the unpaved roads as area sources. Area sources corresponding with unpaved roads, which has been used in the modelling is presented in Figure 3-11.

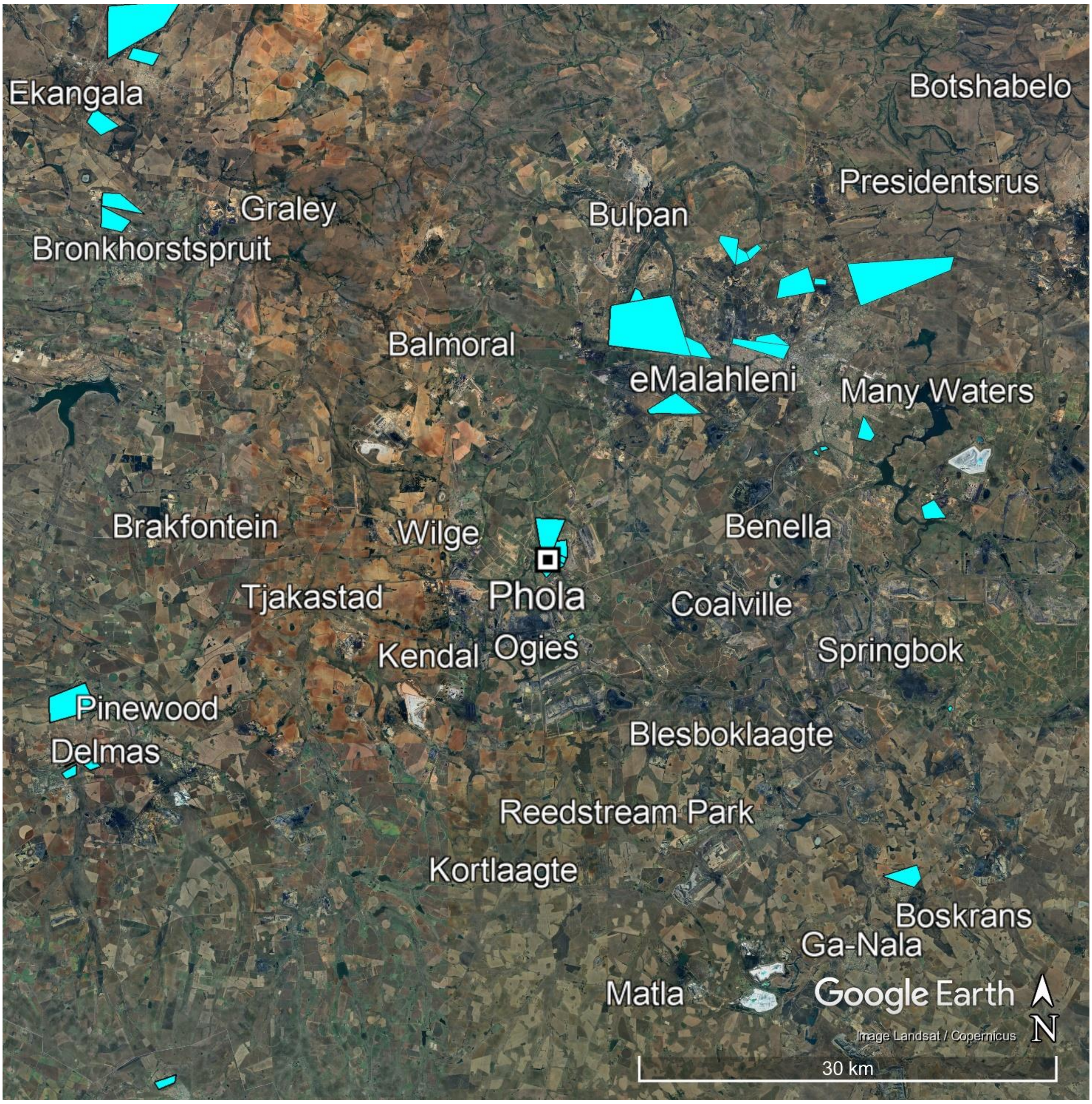


Figure 3-11: Location of areas corresponding with unpaved roads for the Greater Phola Airshed

ASSUMPTIONS

For development of the emission inventory, there was no available information for critical input data. A number of assumptions had to be made based on best judgement. To streamline the modelling process, the following profile was created based on a 1 square kilometre of a high-density township:

- Approximately 1000 homes are located within 1 square kilometre of a township, representing 1000 families.
- 50% of these homes have a car, but only half of them are used on a regular basis for travelling to work, dropping off children at school or for shopping. It is therefore assumed that 250 cars

travel on the unpaved roads on a daily basis. It is also assumed that each car travels on approximately 1 km of unpaved roads per day.

- Many children and family members depend on public transport for travelling to school or work or to shopping centres. It is assumed that 1 minibus taxi and 1 bus is in operation on a daily basis. It is also assumed that each minibus taxi travels and truck travels on approximately 20 km of unpaved roads per day.
- Goods (for example building material, furniture, food supplies to spaza shops) also need to be transported to and/or from the townships. It is therefore assumed that 1 truck is in operation within the area on a daily basis, travelling 10 km per day.

The total VKT is presented in Table 3-15.

Table 3-15: Total VKT

Trip length (VKT)	Trucks	Buses	Taxis	Cars
Round trip (km)	10	20	20	1
Number of trucks	1	1	1	250
Number of trips	1	1	2	1
Number of days	365	365	365	365
Total distance (km)	3650	7300	14600	91250

In this section, emissions are calculated for exhaust emissions for vehicles travelling on unpaved roads, and particulate emissions from unpaved road surfaces.

3.6.2 Methodology – Vehicle Exhaust Emissions from Unpaved Roads

The EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2022) provides a methodology, emission factors and relevant activity data to enable exhaust emissions to be calculated for the following categories of road vehicles:

- Passenger cars (NFR code 1.A.3.b.i)
- Light commercial vehicles (1) (< 3.5 t) (NFR code 1.A.3.b.ii)
- Heavy-duty vehicles (2) (> 3.5 t) and buses (NFR code 1.A.3.b.iii)
- Mopeds and motorcycles (3) (NFR code 1.A.3.b.iv)

It does not cover non-exhaust emissions such as fuel evaporation from vehicles (NFR code 1.A.3.b.v), tyre wear and brake wear (NFR code 1.A.3.b.vi), or road wear (NFR code 1.A.3.b.vii).

Emission Factors

The Tier 1 and Tier 2 emission factors have been calculated from detailed emission factors and activity data using the Tier 3 method.

The Tier 1 emission factors have been derived from the Tier 3 methodology using 1995 fleet data for the EU-15. The upper limits of the stated ranges in the emission factors correspond to a typical uncontrolled (pre-Euro) technology fleet, and the lower limit of the range corresponds to an average EU-15 fleet in 2005. The suitability of these emission factors for a particular country and year depends on the similarity between the national fleet and the assumptions used to derive the Tier 1 emission factors.

The Tier 2 emission factors have been calculated based on average driving and temperature conditions for the EU-15 in 2005. These emission factors assume average urban, rural and highway driving mileage shares and speeds for the EU-15. Again, the suitability of these emission factors depends on the similarity between the national driving conditions and the average of EU-15.

The Tier 3 emission factors have been derived from experimental (measured) data collected in a range of scientific programmes. The emission factors for old-technology passenger cars and light commercial vehicles were taken from earlier COPERT/CORINAIR activities (Eggleston et al., 1989), whilst the emissions from more recent vehicles are calculated on the basis of data from the Artemis project. (Boulter and Barlow, 2005; Boulter and McCrae, 2007).

Tier 2 emission factors are stated in units of grammes per vehicle-kilometre, and for each vehicle technology. These average European emission factors were determined using the Tier 3 methodology which follows in using typical values for driving speeds, ambient temperatures, highway-rural-urban mode mix, trip length, etc. A figure for fuel consumption (g/km), which is derived from carbon balance is also provided, so that fuel-based pollutants such as SO_2 can be calculated.

Vehicle exhaust emissions for unpaved roads were calculated using an estimate of Vehicle Kilometres Travelled (VKT) and Tier 2 exhaust emission factors provided in the EMEP/EEA air pollutant emission inventory guidebook (EMEP/EEA, 2022). Emissions were calculated for passenger cars, light commercial vehicles, heavy-duty vehicles and buses.

Emission factors are based on the “PRE-ECE” and “conventional” technology class. PRE_ECE refers to emission technology of the 1970s and the conventional class refers to a very limited fleet of such vehicles which is still in circulation and no particular emission standards are applicable.

EMISSION RATES ON 1 SQUARE KILOMETRE BASIS

The emission rates for vehicle exhaust emissions from unpaved roads on 1 square kilometre basis is presented in Table 3-16 together with the VKT, fuel consumption and emission factors.

Table 3-16: Emission rates for vehicle exhaust emissions from unpaved roads on a 1 square kilometre basis together with the VKT, fuel consumption and emission factors

	Fuel Consumption Data	Fuel Usage	Emission Factors				Emission Rates			
			Heavy Duty Vehicles - 16-32t				**Emission Rates (tonnes/annum)**			
VKT (km)	Fuel consumption (g/km) for Diesel (500 ppm Sulphur)	Total Fuel Used by All Trucks (kg)	NO_X (g/km)	SO_2 (kg/kg)	PM_{10} (g/km)	$PM_{2.5}$ (g/km)	NO_X	SO_2	PM_{10}	$PM_{2.5}$
3 650	251.00	916.15	10.70	0.00050	0.42	0.42	0.03906	0.00046	0.00153	0.00153
			Buses				**Emission Rates (tonnes/annum)**			
VKT (km)	Fuel consumption (g/km) for Diesel (500 ppm Sulphur)	Total Fuel Used by All buses (kg)	NO_X (g/km)	SO_2 (kg/kg)	PM_{10} (g/km)	$PM_{2.5}$ (g/km)	NO_X	SO_2	PM_{10}	$PM_{2.5}$
7 300	2 671.80	2 671.80	16.50	0.00050	0.91	0.91	0.12045	0.00134	0.00664	0.00664
			Taxis				**Emission Rates (tonnes/annum)**			
VKT (km)	Fuel consumption (g/km) for Petrol (10 ppm Sulphur)	Total Fuel Used by All taxis (kg)	NO_X (g/km)	SO_2 (kg/kg)	PM_{10} (g/km)	$PM_{2.5}$ (g/km)	NO_X	SO_2	PM_{10}	$PM_{2.5}$
14 600	1 241.00	1 241.00	3.09	0.00001	0.0023	0.0023	0.04511	0.00001	0.00003	0.00003
			Passenger Cars				**Emission Rates (tonnes/annum)**			
VKT (km)	Fuel consumption (g/km) for Petrol (10 ppm Sulphur)	Total Fuel Used by All cars (kg)	NO_X (g/km)	SO_2 (kg/kg)	PM_{10} (g/km)	$PM_{2.5}$ (g/km)	NO_X	SO_2	PM_{10}	$PM_{2.5}$
91 250	7 026.25	7 026.25	2.53	0.00001	0.0022	0.0022	0.30782	0.00009	0.00027	0.00027
							TOTAL Emission Rates (tonnes/annum)			
							NO_X	SO_2	PM_{10}	$PM_{2.5}$
							0.51244	0.00190	0.00846	0.00846

3.6.3 Methodology – Particulate Emissions from Unpaved Road Surfaces

The particulate emissions of concern from unpaved roads are total particulate matter (TPM) including PM_{10} and $PM_{2.5}$. The quantity of dust emissions from a given segment of unpaved road varies with the volume of traffic, the condition of the road, the number of vehicles passes, the vehicle characteristics (e.g. vehicle weight, speed and number of wheels), the properties of the road surface material being disturbed (e.g. silt content, moisture content), and the climatic conditions (e.g., frequency and amounts of precipitation). Dust emissions from unpaved roads have been found to vary directly with the silt content in the road surface material.

In this study, the calculation methodology of unpaved roads emissions from resuspension of loose material on road surfaces due to vehicle travel is based on the USEPA Compilation of Air Pollutant Emission Factors, 5th Edition, Volume 1 (AP-42) Chapter 13 – Miscellaneous Sources, 13.2.2. The following generalised equation is used to determine the annual emissions of each size of PM from unpaved road surfaces (USEPA, 2006):

$$E_x = VKT*EF_x*ADJ*(1-CE/100) \quad (1)$$

Where:

- E_x: Emission of contaminant x (kg)
- VKT: Annual total vehicle kilometres travelled (km)
- EF_x: Emission factor of contaminant x (kg/VKT)
- ADJ: Adjustment factor for precipitation, snow cover and frozen days
- CE: Applied Dust Control Method's efficiency (%)

The following sections describe the process that was followed when using equation 1.

Total Vehicle Kilometres Travelled (VKT)

The VKT represents the kilometres travelled by all vehicles on the unpaved roads. This includes cars, minibus taxis, buses and heavy-duty trucks. The annual VKT should be obtained using the best available data. This can be odometer readings, the length of roads and the number of vehicles and vehicle classes travelling on the unpaved roads on a typical day. If no data is available, surveys should be conducted throughout the year on representative days of operation to estimate the total VKT.

No such data is available for this study. VKT has been calculated using assumptions outlined in the Introduction of this section and is presented in Table 3-15.

EMISSION FACTORS

The USEPA has developed an empirical equation (equation 2) for vehicles travelling on unpaved road surfaces (at industrial sites). The equation takes into account the silt content of the roadway and the mean weight of the vehicles travelling on the road. (For more information, refer to AP 42, Chapter 13: Miscellaneous Sources, Section 2.2, (USEPA, 2006)).

The emission factor in metric units (that is, kilograms/VKT) is calculated using the following equation:

EF = k*(s/12)^a*(W/2.72)^b (2)

Where:

- EF: Size-specific emission factor (kg/VKT)
- s: Surface material silt content (%)
- W: Mean vehicle weight, tonnes (metric)
- k, a, b: Numerical constants for calculation (refer to Table 3-17)

Table 3-17: Numerical constants used in the unpaved industrial road dust emission factor

Constant	$PM_{2.5}$	PM_{10}	TPM
k (kg/VKT)	0.042	0.423	1.381
a	0.9	0.9	0.7
b	0.45	0.45	0.45

The silt content (s) of an unpaved road may be obtained using the USEPA test method (Appendix C.1: Procedures for sampling surface/Bulk dust loading, AP-42, USEPA, 2003). Site-specific values for silt content was not available for unpaved roads in the study area. As recommended by AP42, an appropriate mean value from Table AP-42 13.2.2-1 (USEPA, 2006) (reproduced below in Table 3-18), should be used as a default value, in the absence of measured values. It is understood that the use of default values may affect the quality of estimated values. In this study, a silt value of 8.3 (Stone quarrying and processing – Haul road to/from pit) was chosen.

Table 3-18: Typical silt content values of surface material on industrial unpaved roads (USEPA, 2006)

Industry	Road use or surface material	Silt content (%)
Copper smelting	Plant road	17
Iron and steel production	Plant road	6
Sand and gravel processing	Plant road	4.8
Sand and gravel processing	Material storage area	7.1
Stone quarrying and processing	Plant road	10
Stone quarrying and processing	Haul road to/from pit	8.3
Taconite mining and processing	Service road	4.3
Taconite mining and processing	Haul road to/from pit	5.8
Western surface coal mining	Haul road to/from pit	8.4
Western surface coal mining	Plant road	5.1
Western surface coal mining	Scraper route	17
Western surface coal mining	Haul road (freshly graded)	24
Construction sites	Scraper routes	8.5
Lumber sawmills	Log yards	8.4
Municipal solid waste landfills	Disposal routes	6.4

Adjustment Factor (ADJ) for Precipitation, Snow Cover and Frozen Days (Natural Mitigation)

Road dust emissions are reduced due to the natural mitigation effects of precipitation (rain and snow falls), as well as on frozen or snow-covered roads. Equation 1 assumes that no dust emissions occur on days with precipitation exceeding 0.2 mm or on days when the road surface is covered with snow or is frozen without high traffic volume.

The ADJ value used in equation 1 is determined using the following equation:

ADJ = (Working Days - (p+snow))/Working Days (3)

Where:

- ADJ: Adjustment factor for precipitation, snow cover and frozen days
- Working Days: The number of operating days per year
- p: Estimated Annual Working Days with precipitation exceeding 0.2 mm
- snow: The estimated Annual Working Days when the roads were frozen or snow-covered and wet for winter

With respect to precipitation (and snow-covered days), the number of days with the specified precipitation parameters corresponds to 71 days according to long term climate statistics (SAWB, 1980).

Dust Control Methods (CE)

Several techniques are used to reduce road dust emissions caused by vehicular travel on unpaved road surfaces, such as the application of water or chemical dust suppressants (Buonicore and Davis, 1992; USEPA, 1987). Watering is the most common control technique used for unpaved road surfaces (AMEC, 2007). The control efficiency of watering depends on the application rate, the elapsed time between applications, traffic volume and meteorological conditions. Chemical stabilization is also used to reduce emissions of road dust from unpaved surfaces. Its control efficiency depends on the material used and the method of application. Table 3-19 lists available dust control methods and their respective efficiencies.

Table 3-19: Dust control methods and efficiencies (USEPA, 2006)

Dust control techniques	Control Efficiency (CE)
Watering twice a day	55%
Watering more than twice a day	70%
Chemical suppressants	80%

In this study, it is assumed that no dust reduction mechanisms are applied on unpaved roads. No control efficiencies have therefore been applied.

Emission Rates on 1 square kilometer basis

The emission rates for particulates from unpaved road surfaces on a 1 square kilometre basis is presented in Table 3-20 together with the VKT, emission factors, adjustment factor for natural mitigations, and the emission rate before and after mitigation.

Table 3-20: Emission rates for particulates from unpaved roads on a 1 square kilometre basis together with the VKT, emission factors, adjustment factor for natural mitigations, and the emission rate before and after mitigation

Vehicle Type	Pollutant	VKT (km)	EF Uncontrolled kg/VKT)	Total Release (tonnes)	Adjustment factor ADJ for natural mitigations	Annual adjusted emissions for natural mitigation (tonnes)
Trucks	TPM	3650	3.05	11.12	0.81	8.96
	PM_{10}		0.87	3.17	0.81	2.55
	$PM_{2.5}$		0.09	0.32	0.81	0.26
Buses	TPM	7300	2.39	17.44	0.81	14.05
	PM_{10}		0.68	4.97	0.81	4.00
	$PM_{2.5}$		0.07	0.50	0.81	0.40
Taxis	TPM	14600	1.12	16.42	0.81	13.23
	PM_{10}		0.32	4.68	0.81	3.77
	$PM_{2.5}$		0.03	0.47	0.81	0.38
Cars	TPM	91250	0.80	72.83	0.81	58.66
	PM_{10}		0.23	20.76	0.81	16.72
	$PM_{2.5}$		0.02	2.08	0.81	1.67

3.6.4 Emission Inventory

The Emission Inventory for the Vehicles – Unpaved Roads category is presented in Table 3-21 for all pollutants in the Phola modelling domain. It must be noted that the emissions presented is the total emissions made up of vehicle exhaust emissions and emissions from unpaved road surfaces.

Table 3-21: Emission Inventory for the Vehicles – Unpaved Roads Category

Pollutant	SO_2	NO_X	PM_{10}	$PM_{2.5}$	TPM
Emission Rate (tonnes/annum)	0.17	46.61	2 461.17	246.81	8 631.59

3.7 MINING

3.7.1 INTRODUCTION

Mines can be classified as either underground mines or open pit mines. Open pit and underground mining sometimes occur in combination. At underground mines, rock dumps, tailings dams, and load-out facilities are the main sources of dust emissions, whereas at open pit mines the same sources exist, with additional sources including blasting, loading, haulage, clearing, surface disturbance and exposure. Air quality issues relating to mining are mainly centred around particulate impacts, which include dust deposition, and health impacts associated with PM_{10} and $PM_{2.5}$ (Schwegler, 2012).

Mine tailings are made up of fine particles. When dry, these particles can be a significant source of dust problems. In Gauteng for example, tailings storage facilities which are no longer in operation have the potential to generate dust on windy days and can cause impacts over a wide area, especially during the dry season. Dust originating from coal and iron ore mining are a particular nuisance as they cause discolouration, and sometimes permanent damage. In the case of iron ore, these impacts usually occur near the site of operations, shipping zones, and in the vicinity of material handling (Schwegler, 2012).

Mines are not static as they have a continuously changing footprint in terms of haul road location and distance, the size and height of ore stockpiles, waste rock and tailings sites, and have varying production and mine development rates. The measurement and prediction of dust from mining sites is highly complex due to a wide range of potential emission sources and source types, many of which are diffuse and can be highly variable in nature. To add to the complexity, environmental factors such as rainfall, temperature, wind characteristics have a direct impact on the amount of dust generated by a mine. This is in contrast to point sources such as stacks, where process conditions dictate emission rates which can also be accurately monitored or modelled. In spite of this, methods used for dust dispersion modelling have progressed over the years to the point where dispersion modelling has now become an integral component of mine air quality planning (Schwegler, 2012).

Emission inventories generated for mines, particularly open-cast mines, are generally more complex than those for industries. A typical emissions inventory for a mine should include haul roads (geographical location and lengths of road segments, number of vehicles and vehicle types), area and geographical location of exposed surfaces, blasting data in terms of size and frequency of blasting, and material properties such as moisture and silt content of exposed surfaces and mined material. The emissions inventory should distinguish between total suspended particulates (TSP), PM_{10} and $PM_{2.5}$. Emissions estimates may also need to be modified to account for specific dust emission controls such as watering, re- vegetation, and chemical dust suppressants (Schwegler, 2012).

3.7.2 Location of Mining Areas

Google Earth satellite imagery was used to map out locations and extents of all mining areas within the modelling domain. These mining areas are assumed to include all potential emission sources such as open cast pits, haul roads, ore stockpiles, waste rock dumps and tailing facilities. Mining areas which appear to be dormant, rehabilitated or in the process of being rehabilitation were not considered as a source of mining emissions. Area sources corresponding with mining areas, which has been used in the modelling is presented in Figure 3-12.

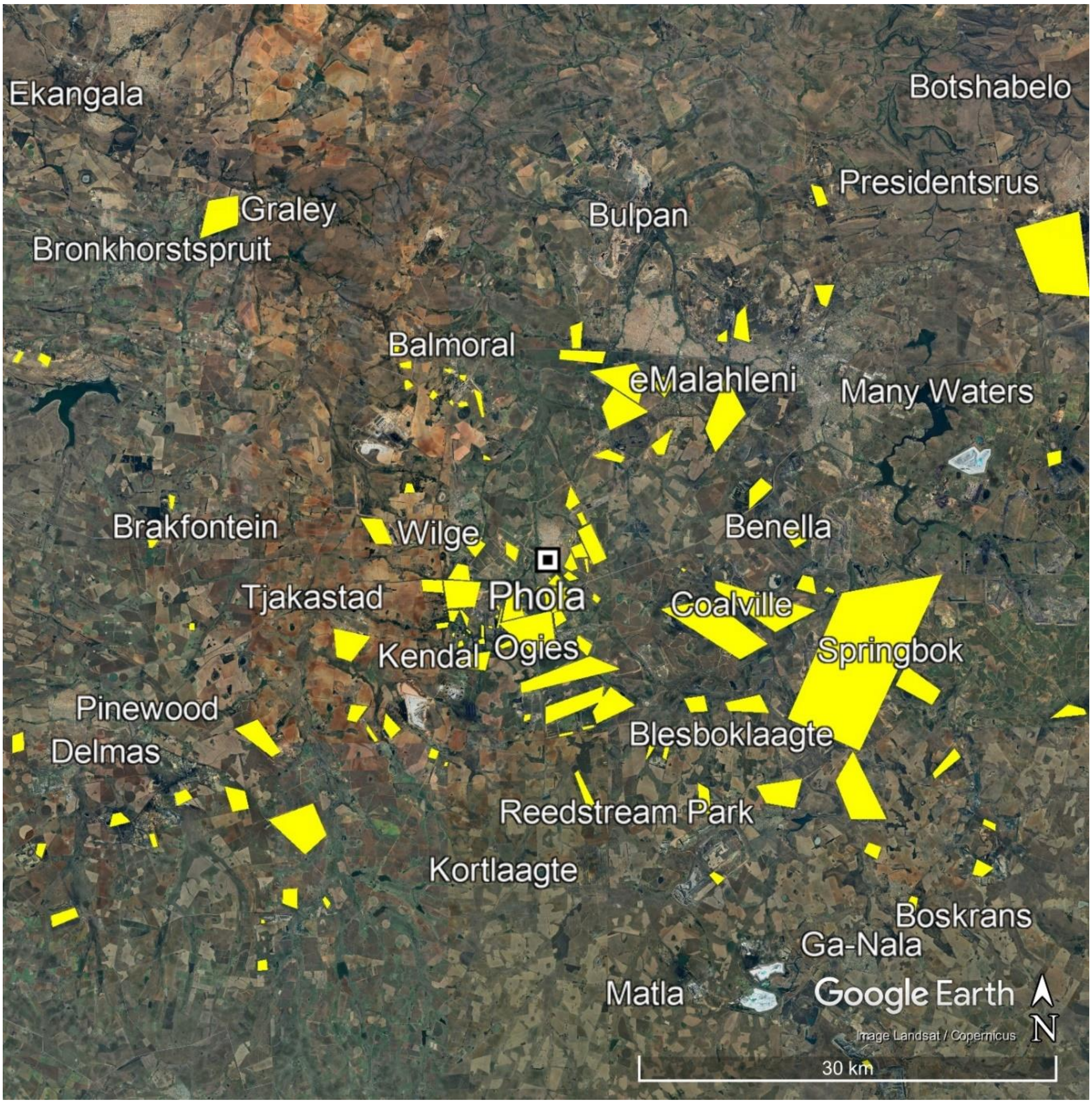


Figure 3-12: Location of areas corresponding with unpaved roads for the Greater Phola Airshed

3.7.3 Methodology for the Development of Emission Factors for the Mining Sector

The South African National Atmospheric Emission Inventory System (NAEIS) contains emissions information for mines. However, DEFF was not able to provide ARM with the NAEIS emissions data due to data policy privacy issues. An important point to consider is that at the 12th Air Quality Governance Lekgotla in 2017, it was reported that only a small percentage of the Mine and Quarry Sector reported to NAEIS (around 10%). Considering the contribution of the mining sector to the particulate matter, this omission means that the national inventory for PM source strength is grossly underestimated nationally (DEA, 2017). The completeness of this dataset as at 2024 has not been published and therefore remains uncertain.

Currently, there are no country-specific emission factors for the mining sector. The NAEIS emission factors for mining operations in South Africa is based on the US EPA, IPCC and other international databases. These emission factors are based on material throughput of a facility. Information on material throughput of mines captured in the NAEIS database was also not made available to ARM. Again, the completeness of this dataset as of 2024 has not been published and therefore remains uncertain.

Research suggests that open pit coal mines emit 0.726 kg of TPM and 0.180 kg of PM_{10} per Mg of coal produced. This study is based on a standardised emissions inventory methodology for open pit mining which was applied to seven of the eight open pit coal mine companies operating in the north part of Colombia for the years 2007, 2008 and 2009. The coal mines operational parameters were provided directly by each mining company (Huertasa et al., 2012). While it is noted that Columbian study is indeed based on sound scientific principles, the emission factors could not be used by ARM as it requires the throughput of mining facilities.

In order for ARM to derive representative emission factors for the mining sector in South Africa, it therefore needed to be based on the surface footprint of opencast mining areas and mining studies undertaken in South Africa. The surface footprint of mining areas over the study area was determined using Google Earth satellite imagery. As discussed in the previous section, these areas are assumed to include all potential emission sources such as open cast pits, haul roads, ore stockpiles, waste rock dumps and tailing facilities. In terms of the mining studies, ARM used information from detailed emission inventories developed for 3 recent opencast mining studies in the country. These studies were undertaken for the following mines:

- **Klipfontein Mine**
  - Draft Basic Assessment Report for the Expansion of the Klipfontein Opencast Operations (Inclusion of the Klipfontein Western Expansion).

- The Basic Assessment was carried out by Alta van Dyk Environmental Consultants (Alta van Dyk Environmental Consultants, 2024a) for Sibanye Rustenburg Platinum Mines (Pty) Ltd.
- The emission inventory for this study was compiled by uMoya-NILU Consulting (uMoya-NILU, 2024b).

- **N'Komati Anthracite Mine**
  - N'Komati Anthracite Mine - Integrated Environmental Authorisation for Open Cast Mining Areas and Expansion of the Madadeni Underground Area.
  - The Environmental Impact Assessment was carried out by Alta van Dyk Environmental Consultants (Alta van Dyk Environmental Consultants, 2024b) for N'Komati Anthracite (Pty) Ltd.
  - The emission inventory for this study was compiled by uMoya-NILU Consulting (uMoya-NILU, 2023).
- **Middellaagte Mine**
  - Draft Basic Assessment Report and Environmental Management Programme for the Proposed Expansion of the Middellaagte Opencast Pit Project, Environmental Authorisation and Waste Management Licence.
  - The Basic Assessment was carried out by Alta van Dyk Environmental Consultants (Alta van Dyk Environmental Consultants, 2024c) for the Limberg Mining Company (Pty) Ltd.
  - The emission inventory for this study was compiled by Airshed Planning Professionals (Airshed Planning Professionals, 2024).

In all three studies, emission factors used for the calculation of TPM, PM_{10} and $PM_{2.5}$ are the most recent factors published in the United States Environmental Protection Agency (US EPA), AP 42, Fifth Edition, Compilation of Air Pollutant Emission Factors, Volume 1: Stationary Point and Area Sources, Chapter 11: Mineral Products Industry (Section 11.9 Western Surface Coal Mining; Section 11.19.1 Sand and Gravel Processing; Section 11.19.2 Crushed Stone Processing and Pulverized Mineral Processing) (USEPA, 2009a) and Chapter 13: Miscellaneous Sources (Section 13.2.2 Unpaved Roads; Section 13.2.4 Aggregate Handling and Storage Piles; Section 13.2.5 Industrial Wind Erosion; Section 13.3 Explosive detonations) (USEPA, 2009b).

In each study, a comprehensive emission inventory has been developed for the respective mines using a bottom-up approach, providing a reliable estimation of emissions. In other words, actual mine activity data for the assessments has been used with emission factors to estimate particulate emissions for specific mining activities and areas.

An overview of mining activities included in each of the emission inventories are as follows:

- Open Cast Mine Pit
  - Overburden Removal
  - Boring/Blast Hole Drilling
  - Blasting
  - Material Handling - Opencast ROM
  - Wind Erosion - Opencast ROM
- Process Plant – Crushing and Screening
  - Primary Crushing
  - Secondary Crushing
  - Screening
  - Fine Screening
  - Conveyor Transfer Point
- Process Plant ROM
  - Material Handling
  - Wind Erosion
- Topsoil Stockpiles
  - Material Handling
  - Wind Erosion
- Overburden Stockpiles
  - Material Handling
  - Wind Erosion
- Unpaved Plant Haul Roads

In all inventories, it is noted that the largest source of particulates is vehicle entrainment from the mine haul roads.

The total emission of TPM, PM_{10} and $PM_{2.5}$ estimated for each mine and the footprint of each mine (total mining area within mine boundary where mining activities are concentrated) is presented in Table 3-22. The total TPM, PM_{10} and $PM_{2.5}$ for all three mines was then divided by the total mine footprint to derive an emission factor for TPM, PM_{10} and $PM_{2.5}$ in tonnes/m^2/annum. Two emission factors were developed. The first emission factor assumes that 100% of the mining area is active and the second emission factor assumes that 40% of the area is active. It must be noted that in reality, mining activities do not take place all over a mine at once. Rather, mining activities are focused on particular areas within the mine boundary and moves sequentially as the mining plan dictates. In turn, this means that emissions do not occur across the entire mining area, but over focused areas. In light of the above considerations, the second emission factor was therefore used in this study.

Table 3-22: Total emission of TPM, PM_{10} and $PM_{2.5}$ estimated for the Klipfontein Mine, N'Komati Anthracite Mine and Middellaagte Mine; together with the footprint of each mine and resultant emission factor

	Emission Rate (tonnes/annum)			(m^2)
	TPM	**PM_{10}**	**$PM_{2.5}$**	**Mine Footprint**
Klipfontein Mine	373.04	106.92	13.47	1 600 000
N'Komati Anthracite Mine	616.88	180.09	40.36	4 200 000
Middellaagte Mine	985.90	322.40	108.60	950 000
Total	**1 975.82**	**609.41**	**162.43**	**6 750 000**
	Emission Factor (tonnes/m^2/annum)			
	TPM	**PM_{10}**	**$PM_{2.5}$**	
Emission factor (assuming 100% of area is active)	**0.000293**	**0.000090**	**0.000024**	
Emission factor (assuming 40% of area is active)	**0.000117**	**0.000036**	**0.000010**	

3.7.4 EMISSION INVENTORY

The Emission Inventory for the Mining emission source category is presented in Table 3-23 for all pollutants in the Phola modelling domain.

Table 3-23: Emission Inventory for the Vehicles – Unpaved Roads Category

Pollutant	PM_{10}	$PM_{2.5}$	TPM
Emission Rate (tonnes/annum)	10 068.07	2 683.46	32 642.47

3.8 SUMMARY OF PHOLA EMISSIONS INVENTORY

Table 3-24 and Table 3-26 are a summary of the emission inventories calculated for each emission source category in the previous sections. Table 3-24 is used to calculate the percent contribution of SO_2, NO_X, PM_{10}, $PM_{2.5}$ and dustfall for the Greater Phola Airshed as a function of the seven emission source categories and is presented in Table 3-25. Table 3-26 is used to calculate the percent contribution of SO_2, NOX, PM_{10}, $PM_{2.5}$ and dustfall for the Phola Airshed as a function of the seven emission source categories and is presented in Table 3-27.

Pie charts are used to illustrate the percent contribution for each pollutant. These are compared with the percent contribution for each pollutant for the Phola Airshed and greater Phola airshed in Figure 3-13 for SO_2, Figure 3-14 for NO_X, Figure 3-15 for PM_{10}, Figure 3-16 for $PM_{2.5}$ and Figure 3-17 for dustfall.

Table 3-24: Emission Inventory for SO_2, NO_X, PM_{10}, $PM_{2.5}$ and dustfall for the seven emission source categories in the Greater Phola Airshed

	Emission rate (tonnes/annum)				
Emission Source Category	**SO_2**	**NO_X**	**PM_{10}**	**$PM_{2.5}$**	**TPM**
Power Generation	1 184 740.46	862 755.33	209 216.17	92 539.93	12 877.82
Residential Fuel Burning	5 622.18	2 581.32	7 324.15	6 813.56	
Waste Burning	38.73	196.50	1 911.99	1 904.43	
Biomass Burning	247.63	54.09	2 550.06	2 451.40	3 666.53
Vehicles – Paved Roads	133.57	8 991.08	183.00	183.00	
Vehicles – Unpaved Roads	0.17	46.61	2 461.17	246.81	8 631.59
Mining			10 068.07	2 683.46	32 642.47
All Sources	1 190 782.75	874 624.93	233 714.61	106 822.59	57 818.41

Table 3-25: Emission source contribution (%) of SO_2, NO_X, PM_{10}, $PM_{2.5}$ and dustfall as a function of the seven emission source categories for the Greater Phola Airshed

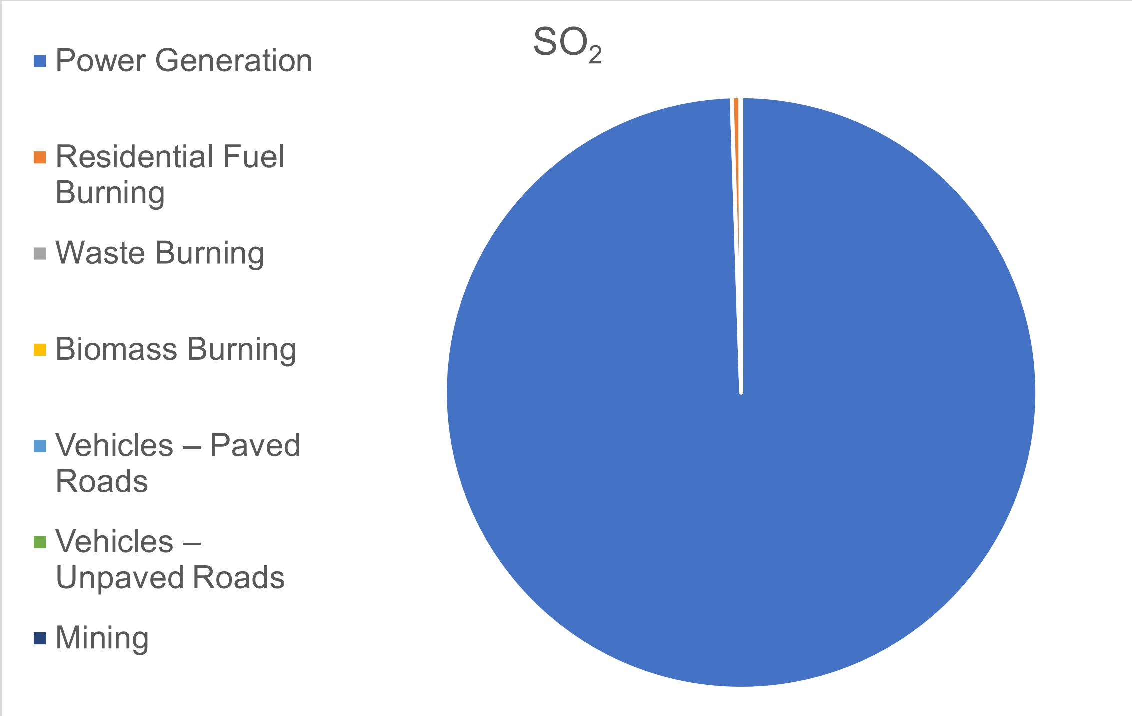
	Emission Source Contribution (%)				
Emission Source Category	**SO_2**	**NO_X**	**PM_{10}**	**$PM_{2.5}$**	**TPM**
Power Generation	99.49	98.64	89.52	86.63	22.27
Residential Fuel Burning	0.47	0.30	3.13	6.38	0.00
Waste Burning	0.00	0.02	0.82	1.78	0.00
Biomass Burning	0.02	0.01	1.09	2.29	6.34
Vehicles – Paved Roads	0.01	1.03	0.08	0.17	0.00
Vehicles – Unpaved Roads	0.00	0.01	1.05	0.23	14.93
Mining	0.00	0.00	4.31	2.51	56.46
All Sources	100.00	100.00	100.00	100.00	100.00

Table 3-26: Emission inventory for (tonne/annum) estimated for the Phola modelling domain

	Emission rate (tonnes/annum)				
Emission Source Category	**SO_2**	**NO_X**	**PM_{10}**	**$PM_{2.5}$**	**TPM**
Power Generation					
Residential Fuel Burning	291.04	133.63	379.15	352.72	
Waste Burning	2.12	10.76	104.74	104.32	
Biomass Burning	1.27	0.28	13.12	12.61	18.87
Vehicles – Paved Roads	3.71	252.64	5.17	5.17	
Vehicles – Unpaved Roads	0.01	3.45	182.16	18.27	638.85
Mining			448.49	119.54	1 454.09
All Sources	298.17	400.76	1 132.83	612.63	2 111.81

Table 3-27: Emission source contribution (%) of SO_2, NO_X, PM_{10}, $PM_{2.5}$ and dustfall as a function of the seven emission source categories for the Phola Airshed

	Emission Source Contribution (%)				
Emission Source Category	**SO_2**	**NO_X**	**PM_{10}**	**$PM_{2.5}$**	**TPM**
Power Generation	0.00	0.00	0.00	0.00	0.00
Residential Fuel Burning	97.61	33.34	33.47	57.57	0.00
Waste Burning	0.71	2.69	9.25	17.03	0.00
Biomass Burning	0.43	0.07	1.16	2.06	0.89
Vehicles – Paved Roads	1.24	63.04	0.46	0.84	0.00
Vehicles – Unpaved Roads	0.00	0.86	16.08	2.98	30.25
Mining	0.00	0.00	39.59	19.51	68.86
All Sources	100.00	100.00	100.00	100.00	100.00



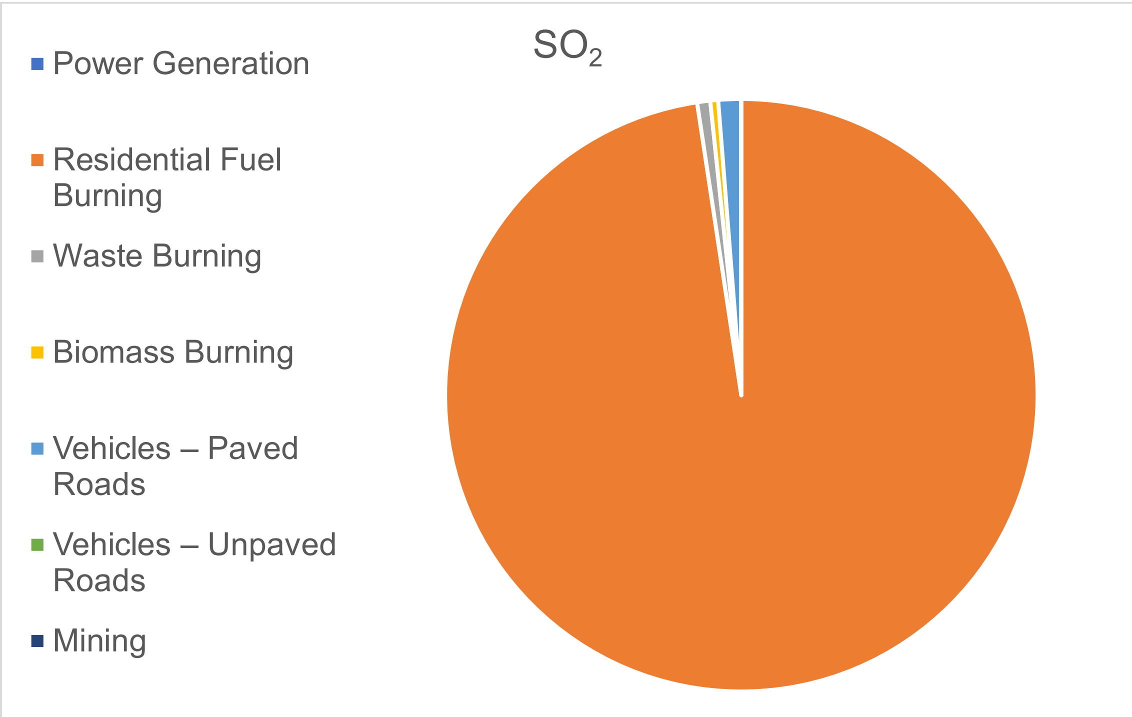
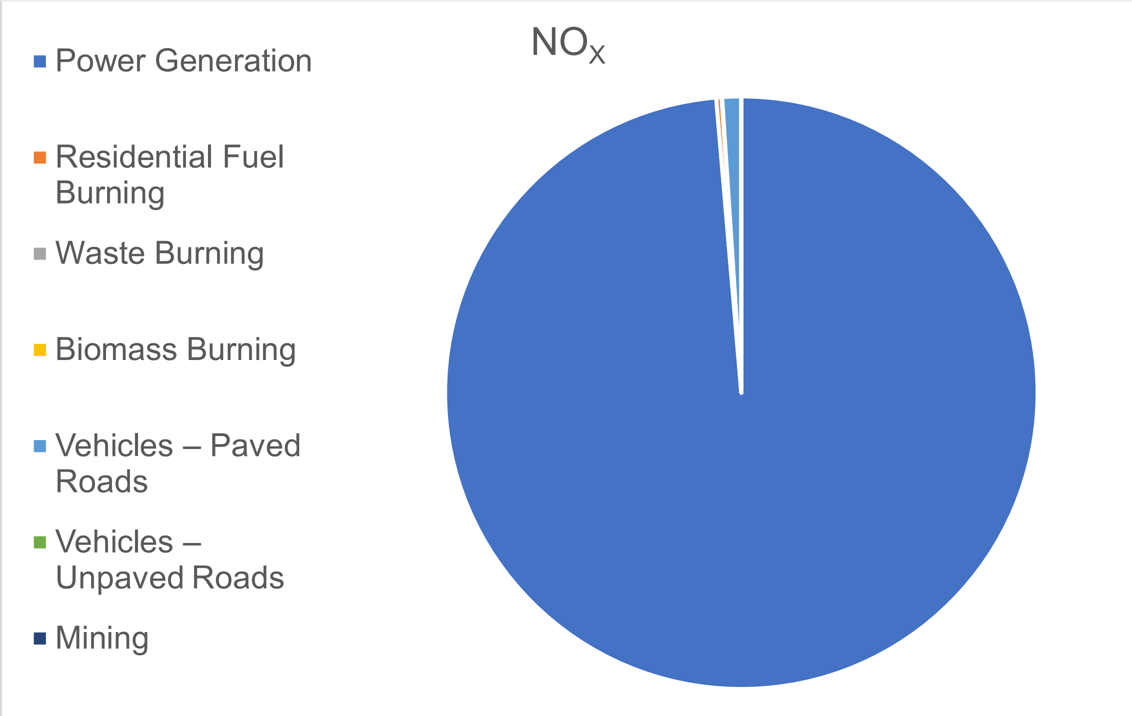


Figure 3-13: Emission source contribution (%) of SO_2 as a function of the seven emission source categories for the Greater Phola Airshed (top) and for the Phola Airshed (bottom)



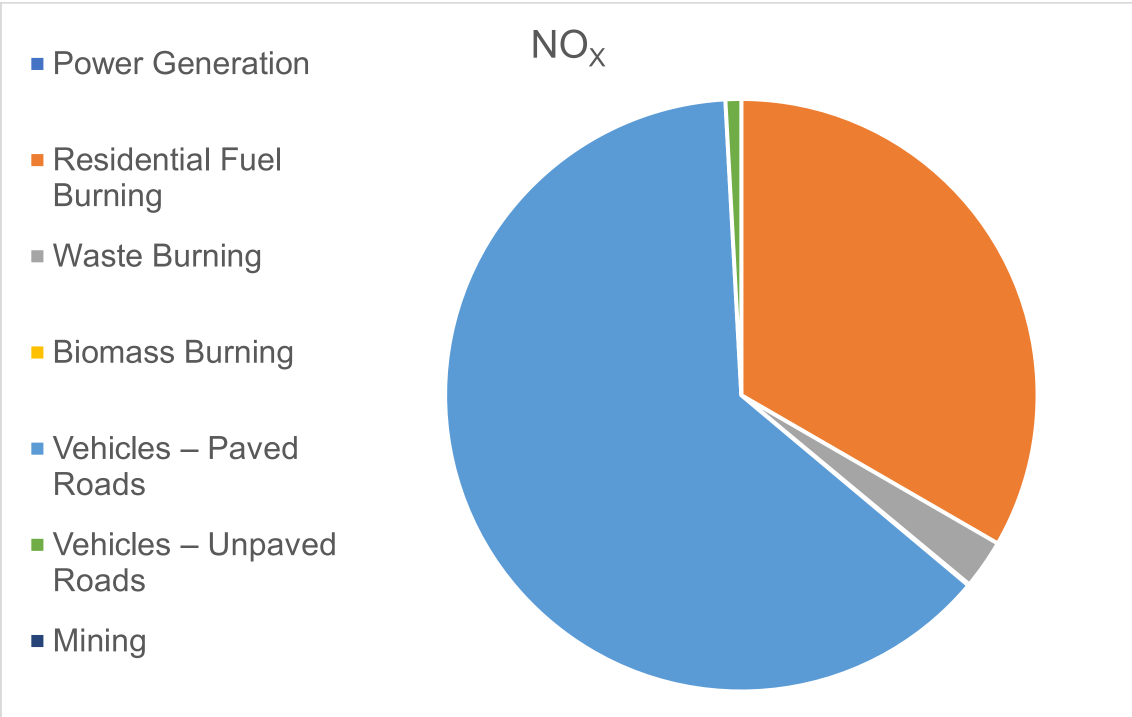
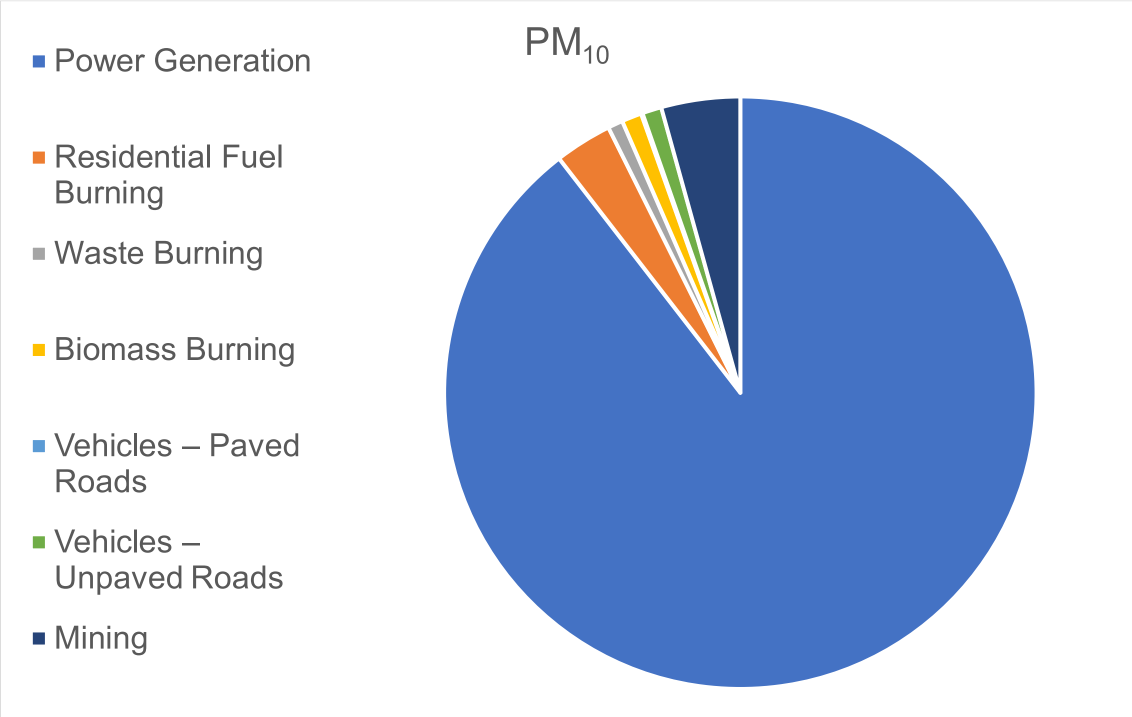


Figure 3-14: Emission source contribution (%) of NO_X as a function of the seven emission source categories for the Greater Phola Airshed (top) and for the Phola Airshed (bottom)



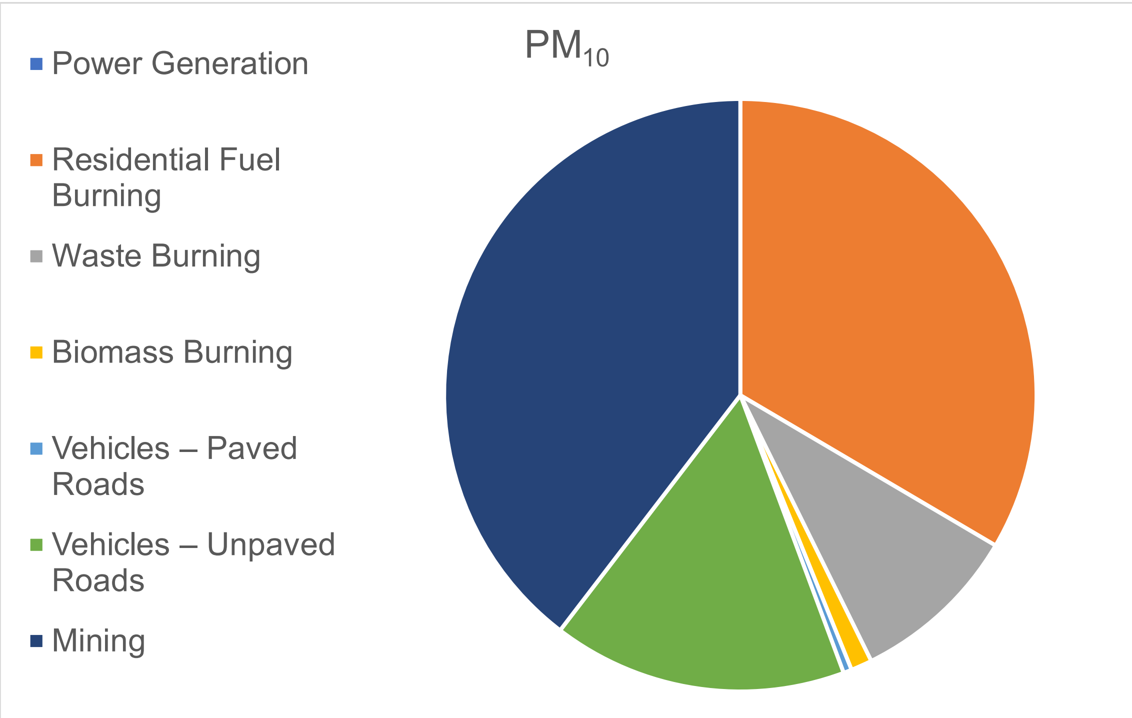
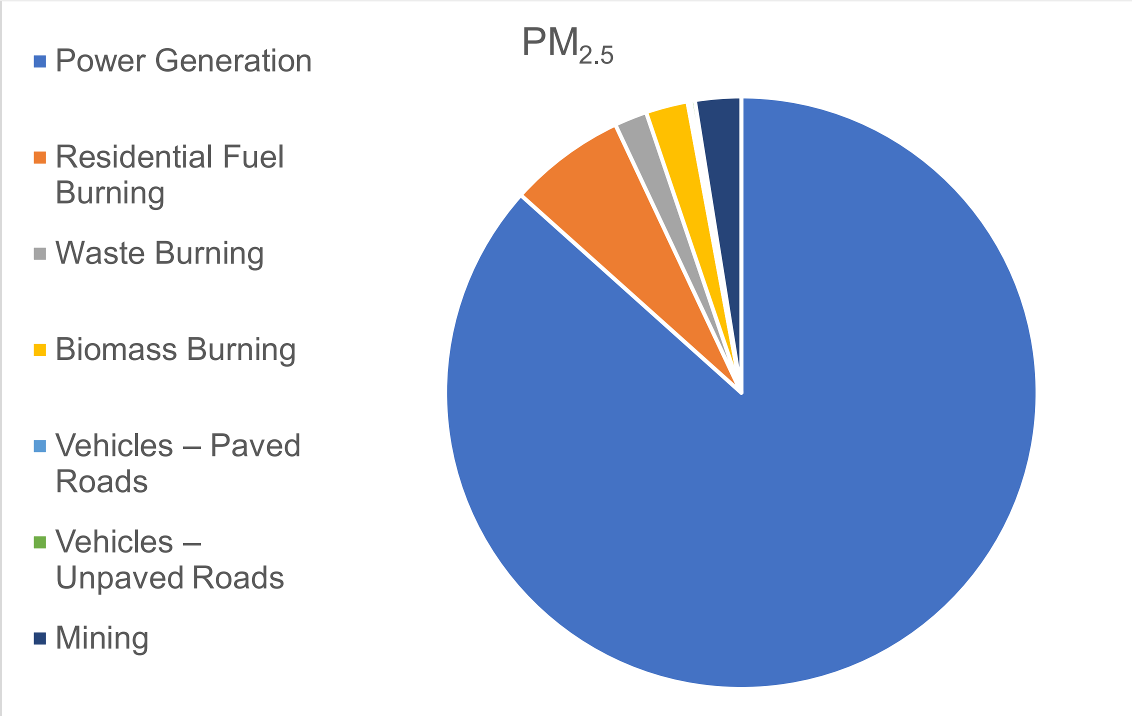


Figure 3-15: Emission source contribution (%) of PM_{10} as a function of the seven emission source categories for the Greater Phola Airshed (top) and for the Phola Airshed (bottom)



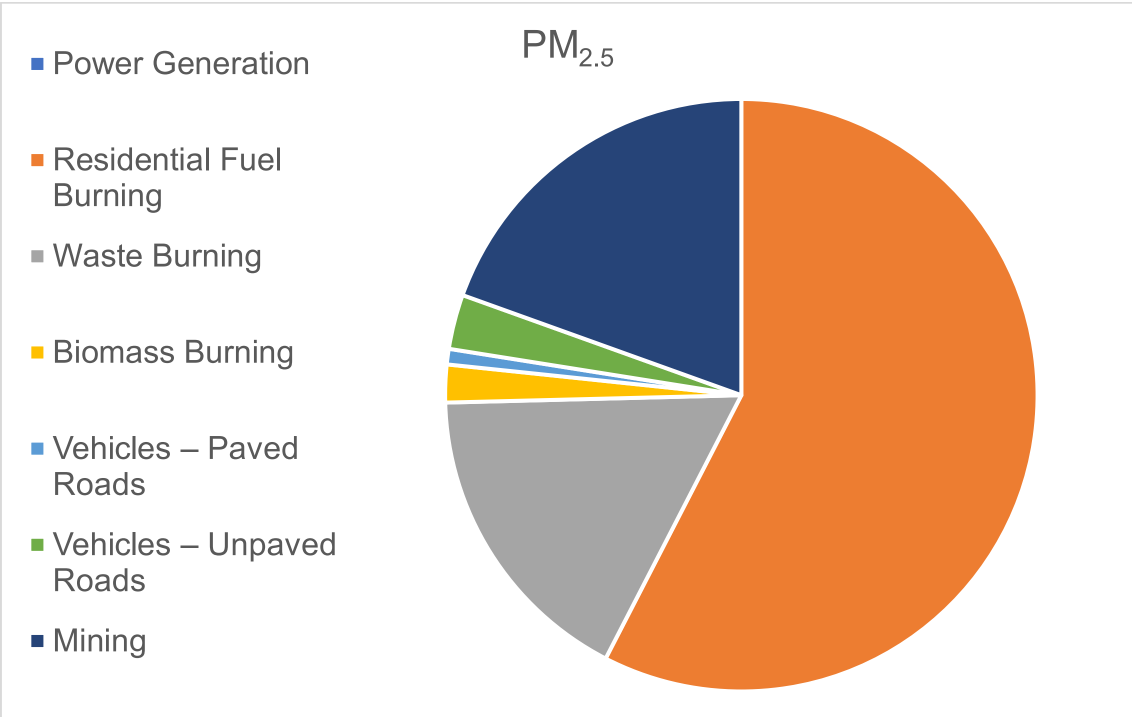
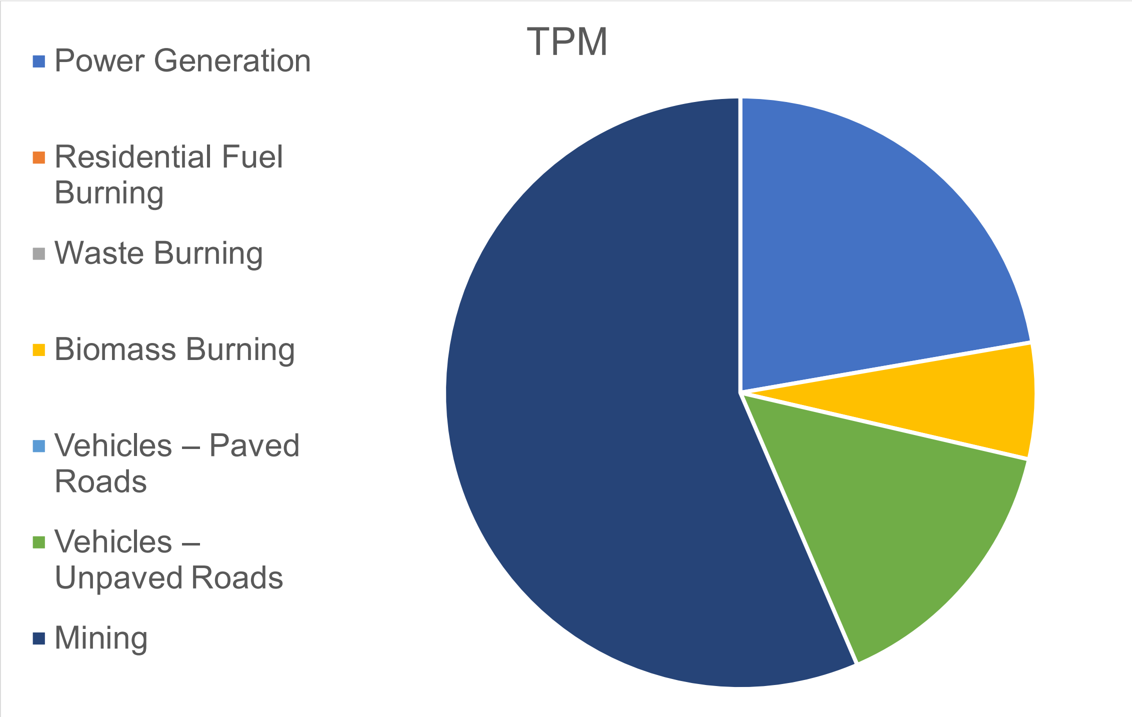


Figure 3-16: Emission source contribution (%) of $PM_{2.5}$ as a function of the seven emission source categories for the Greater Phola Airshed (top) and for the Phola Airshed (bottom)



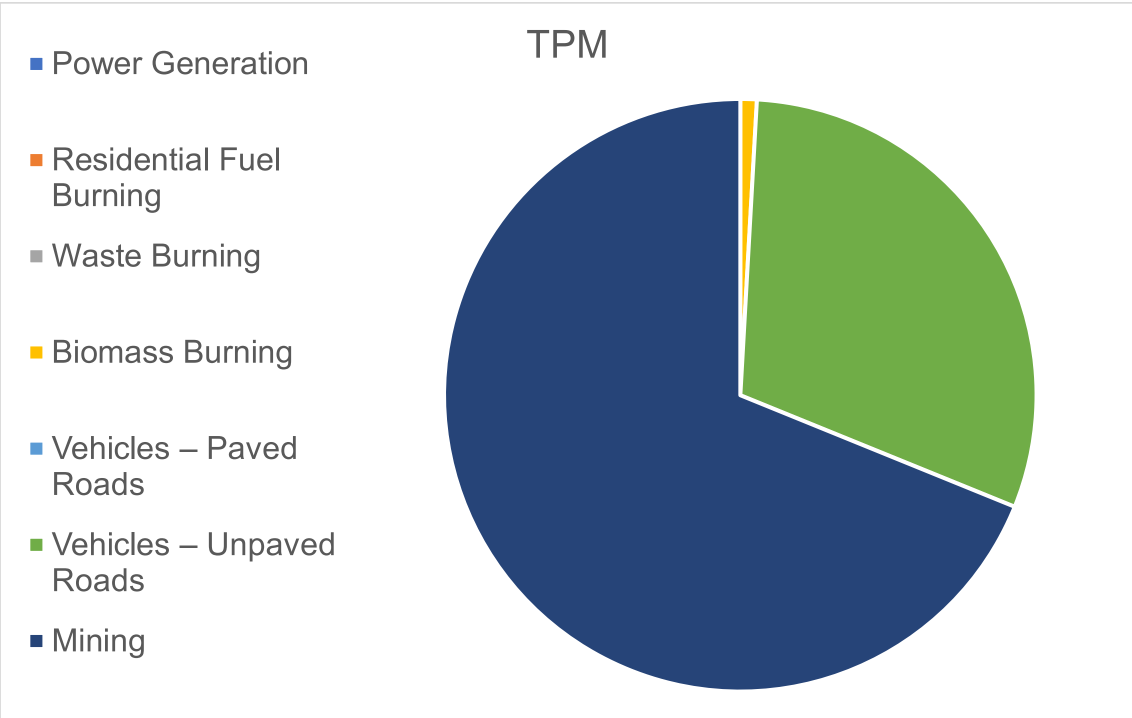


Figure 3-17: Emission source contribution (%) of dustfall as a function of the seven emission source categories for the Greater Phola Airshed (top) and for the Phola Airshed (bottom)

4. LIMITATIONS, POTENTIAL BIASES, UNCERTAINTIES & DATA GAPS

4.1 LIMITATIONS OF STUDY

For this baseline modelling assessment study, the following limitations must be noted:

i. Atmospheric Emission License (AEL) data serve as the principal information source for activity data in order to estimate emissions from industrial sources. Although ARM submitted a request to the Department of Environment, Forestry and Fisheries (DEFF) requesting the AEL data for industrial sources within the modelling domain, DEFF was unable to provide the data. DEFF responded stating that they will not be able to disclose the data due to data policy privacy issues. Thus, the cumulative impact of other industrial sources is not included in the model simulation which will result in an under-prediction of pollutant ambient concentrations for this emission source category.

ii. The South African National Atmospheric Emission Inventory System (NAEIS) contains emissions information for mines, controlled emitters and facilities identified in accordance with the local by-laws. DEFF was not able to provide ARM with the NAEIS emissions data due to data policy privacy issues. Thus, the cumulative impact of controlled emitters and facilities identified in accordance with the local by-laws have therefore been excluded from this study, which results in an under-prediction of the simulated pollutants. For the mining sector, ARM was able to develop its own emission factors (see Section 4) which is based on mine footprints.

iii. The data required to model "local unpaved roads" dust emissions are currently not available for Phola and other parts of the modelling domain. The information required to model these local roads include the location of unpaved roads, silt content of each road, number of vehicles, vehicle types, empty and full weight of cars, buses, heavy-duty vehicles and taxis using these roads. In order to develop an emission inventory for this emissions source category (Vehicles – Unpaved Roads), a number of assumptions had to be made based on best judgement. These are discussed under assumptions in Section 3.

iv. Residential fuel burning and waste burning was estimated based on energy use data at the Sub Place level for Phola using Stats SA Census data. There is currently no finer resolution residential fuel burning or waste burning data for Phola.

4.2 DATA GAPS

The exclusion of a source category can have a significant or insignificant impact on the results of a study depending on the magnitude and importance of the source category.

When compared with the VTAPA and HPA Study, the emission source categories common across all three studies include:

- Industrial Sources
- Residential Fuel Burning
- Waste Burning
- Biomass Burning
- Vehicle Emissions
- Mining Sources
- Wind Blown Dust from Exposed Topsoil Areas

When compared with the VTAPA Study and HPA Study, emissions source categories not included in the Phola Study are:

- Biogenic VOC's
- Agricultural Ammonia
- Spontaneous Combustion

v. As mentioned in Section 4.1, although ARM submitted a request to the DEFF requesting the AEL data for industrial sources and NAEIS data containing emissions information for mines, controlled emitters and facilities identified in accordance with the local by-laws within the modelling domain, DEFF was unable to provide the data due to data policy privacy issues. Thus, cumulative impact of other industrial sources, controlled emitters and facilities have therefore been excluded from this study, which results in an under-prediction of pollutant ambient concentrations. For the mining sector, ARM was able to develop its own emission factors (see Section 3) which is based on mine footprints.

Regardless of this, the emission source categories for the Phola Study are considered to be adequate, as all important sources have been included in the study. For industrial emissions, there are very few industrial sources in the modelling domain. Eskom power station stacks and fugitive emissions from the associated coal yard and ash dump for the Duvha Power Station, Kendal Power Station, Kriel Power Station, Kusile Power Station and Matla Power Station, which are included in the modelling, are some of the main industrial sources in the modelling domain.

Emissions from spontaneous combustion (burning and smouldering of coal dumps) are relatively small in comparison to the total emissions calculated for both the VTAPA and HPA studies; and impacts in the ambient environment is also considered to be localised. The inclusion of these source categories in the model will not have a significant impact on the results.

Biogenic VOC's and agricultural ammonia are not relevant to the Phola Study.

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