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YSSP Report
Young Scientists Summer Program

Optimising the Management of Ambient Particulate Matter Pollution in Gauteng, South Africa

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Approved by

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Program: Energy, Climate and Environment Program

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Abstract

According to the World Health Organisation, air pollution is now regarded as the world's single biggest environmental threat to human health. Amongst the principal air pollutants, particulate matter pollution has been identified as the dominant contributor to the global health burden of outdoor air pollution. While population densification and urbanisation are seen as key drivers for particulate matter pollution, by far the largest contribution to future urbanisation and densification is expected to occur in Africa. This renders the continent especially susceptible to rapidly increasing particulate matter pollution.

High particulate matter pollution levels are already observed in South Africa, specifically in the Gauteng Province, which makes it an excellent case study for other South African and African urban areas, experiencing similar challenges. While air quality management in the region has been supported by Air Quality Management Plans (AQMP) both at city and provincial level, none of these plans have been based upon an integrated assessment and optimization of costs and benefits towards the goal of complying with the NAAQS or to minimize negative impacts on human health.

This project aims to supply such an actionable evidence base for the Gauteng Province which will optimise the South African air quality management framework through control measures which address both health as well as economic concerns.

Acknowledgments

First and foremost, thank you to IIASA for the YSSP and finding ways to make this exciting program possible during such challenging times. Special thanks also to the South African National Research Foundation for their flexibility and willingness to provide full funding and support for this project. Finally, thank you to each of the collaborating partners for their unique input and assistance, namely the IIASA Pollution Management Group, Northwest University and the Council for Scientific and Industrial Research.

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Introduction

This YSSP project forms part of a larger collaboration under the auspices of the World Bank's Pollution Management and Environmental Health Program (PMEH) between the South African Council for Scientific and Industrial Research (CSIR) the International Institute for Applied Systems Analysis (IIASA) and the North-West University (NWU). The project aims to supply such an actionable evidence base for air quality management through solid data and robust analytical underpinnings in Johannesburg, Ekurhuleni, and Tshwane (JET; i.e. three metros). The phases of the collaboration which are most relevant to this YSSP project includes Gauteng Province emissions inventory development, ambient air quality modelling and harmonization of the outputs with the GAINS (Greenhouse Gas-Air Pollution Interactions and Synergies) model. Subsequently various preliminary emissions scenarios were developed by means of the GAINS model. The main focus of this YSSP project was those phases of the collaboration which are related to the GAINS model.

This report gives a brief background of the study area and describes the technical approach and methodology as well as some of the preliminary scenarios developed in GAINS. The final scenarios (and their cost-optimization) are still under development.

Background

Available air quality monitoring data within Gauteng Province show that ambient air pollutant concentrations often exceed South Africa's National Ambient Air Quality Standards (NAAQS), especially for particulate matter (PM) and ozone (CSIR, 2016). Particulate matter pollution is especially an issue within low-income townships, where it is largely driven by community-based emissions associated with residential fuel combustion for cooking and heating, waste burning, and wind-blown dust (Hersey et al., 2015).

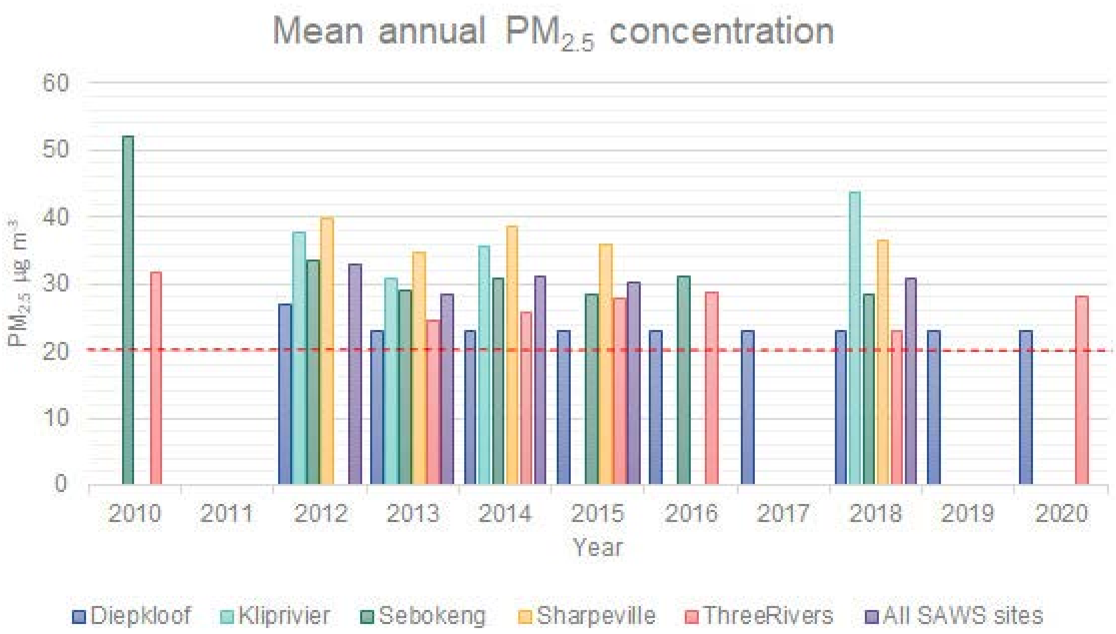

Figure 1: Annual average $PM_{2.5}$ concentrations for South African Weather Service measurement sites located within the Gauteng Province. The red dotted line is the annual average PM2.5 NAAQS value that went into effect 1/1/2016.

Within the Gauteng Province there is a spatially and temporally heterogeneous mix of pollutants, with varying concentrations, which makes effective air quality management a difficult task; thus, any cost-effective interventions to improve air quality in the province needs to consider and address a wide range of emission sources, across many different economic sectors and throughout a large region. While air quality management in the region has been supported by Air Quality Management Plans (AQMP) both at city and provincial level, none of these plans have been based upon an integrated assessment and optimization of costs and benefits towards the goal of complying with the NAAQS or to minimize negative impacts on human health. Without this evidence base, it is difficult for decision-makers to select and implement the most effective interventions to improve air quality.

This project aims to supply such an actionable evidence base for the Gauteng Province.

Approach and Methodology

The project aims to improve, through solid data and robust analytical underpinnings, the evidence base on air quality and air quality management in Gauteng to provide recommendations on the most effective control strategies to mitigate air pollution. Objectives and aspects of this project, which include,

- Internally consistent and comprehensive emissions inventory, including stratification by socio-economic status
- Air quality modelling,
- Incorporation of updated information into the GAINS model
- Development of cost-effectiveness analysis in support of air quality management in the Greater Johannesburg Area, with explicit consideration of impacts and benefits of these interventions as a function of socio-economic status and population sensitivity,

Key tools used

The main tools that were applied to address the complexities and heterogeneities in the study, were the air quality model CAMx and the integrated assessment model GAINS.

i) Air Quality Model: WRF-CAMx

The key tool for assessing air quality hotspots in the region and improving the local Source-Receptor Transfer Functions for the integrated assessment model was the Chemical Transport Model (CTM) Comprehensive Air Quality Model with Extensions (CAMx version 6.50) developed by Ramboll-ENVIRON (see www.camx.com). CAMx is able to simulate ambient air quality due to both primary and secondary air pollutants at varying spatial and temporal scales. This is critical in Gauteng, due to the heterogeneity described above as well as the high levels of secondary pollutants (i.e. PM2.5 and ozone).

ii) Integrated assessment model: GAINS

The key tool used for the integrated assessment was the GAINS (Greenhouse Gas-Air Pollution Interactions and Synergies) model which was developed by the International Institute for Applied Systems Analysis (IIASA) as a scientific tool to support policy makers in the exploration of cost-effective air quality management strategies that simultaneously reduce (i) human health impacts from the exposure to harmful outdoor and indoor air pollution (ii) reduce emissions of greenhouse gases, and (iii) contribute to balanced economic development and progress on the UN Sustainable Development Goals (Amann et al. 2011).

The GAINS model enables users to identify cost-effective portfolios of specific emission control measures that meet user-specified targets on air quality indicators, health impacts and/or greenhouse gas emissions at least costs. GAINS identifies the balance of measures and associated distribution of emission control costs across all economic sectors and societal groups in the various administrative regions distinguished in the GAINS implementation.

Most importantly, GAINS addresses the full set of emission sources that contribute to poor air quality in a given region. Beyond sources which are in the focus of public attention (e.g., large industrial sources and vehicle emissions), GAINS can highlight the importance of other sources that are particularly relevant in developing countries, such as management of municipal waste, solid fuel use in households, the burning of agricultural waste, small manufacturing, construction work, road dust, manure management, fertilizer application and fireworks (Amann et al. 2017).

Thereby, GAINS model analyses provide powerful information to decision makers for prioritization of action, and useful input into negotiations between different stakeholders. The GAINS model has been successfully implemented and employed for practical policy analyses in numerous regions across the world. Over the past 25 years, the GAINS model serves as the backbone scientific tool for international negotiations on clear air strategies in Europe under the Convention on Long-range Transboundary Air Pollution. Since 1995, the European Union employs GAINS for internal analyses and negotiations with Member States and stakeholders on all major new air pollution legislation. National model versions that enable more detailed cost-effectiveness analyses for individual countries have been implemented for France, Ireland, Italy, Netherlands, Russia and Sweden. Finally, under the PMEH program, GAINS is currently being implemented for the Jing-Jin-Ji region in China, in order to enable a systematic analysis of cost-effective priority measures in the 28 prefectures of the Beijing, Hebei and Tianjin region. GAINS was also previously implemented in South Africa, namely in the Vaal Triangle Airshed Priority Area (VTAPA) (DEFF, 2019; Muyemeki et al., 2018; CRG, 2019).

The cost-effectiveness analysis in this project focuses on reducing PM pollution. Source-receptor transfer coefficients were developed which describe the impact of emissions of primary PM and gaseous precursors of secondary PM on ambient PM2.5 concentrations within the project geographical domain. In addition, the impact of PM and the scope and costs of its mitigation were quantified. While particulate matter is the focus, the implications of management options and scenarios on emissions of greenhouse gases, short-lived climate pollutants (SLCPs) and other pollutants were evaluated in GAINS for the agreed upon scenarios, and the impact of the final agreed upon policy scenario was simulated in CAMx. Control strategies were applied across JET, but impacts were assessed at a higher spatial resolution.

Scenario development

The GAINS model assesses emissions in five-year intervals (in this case for the ten-year period between 2020 and 2030). While 2019 was selected as the base year for the current project (largely due to the anomalous circumstances associated with the world-wide COVID-19 pandemic in 2020), this 2019 base year is labelled as “2020” for purposes of uniformity in the GAINS modelling outputs. This base year is aligned with the emissions from the emission inventory which was developed by the CSIR for air quality modelling.

Five scenarios were modelled, namely a baseline scenario with current levels of enforcement (CLE-CE), a baseline scenario with proper enforcement (CLE_PE), a residential sensitivity case for the CLE_PE, a No Further Control scenario and a maximum feasible reduction scenario (MFR). These are described below:

Baseline scenario with current enforcement (CLE-CE)

The baseline emissions for 2019 were developed from local information as far as possible. Future trends in energy usage, as reflected by the International Energy Agency (IEA) Stated Policies Scenario for South Africa, were then used to estimate the emissions for 2025 and 2030 (i.e. the relative changes in energy usage in the national projections were applied to the 2019 baseline for Gauteng). In the cases where other provincial drivers indicated a likely deviation from the national Stated Policy Scenario trends, these were adjusted to reflect such deviation. Furthermore, the team also conducted an independent policy review to ensure that all relevant local information was considered when developing the baseline scenario. A list of legislation, standards and policies considered is included at the end of this document. A summary of assumptions and drivers per sector in developing the baseline future trends in energy use and emissions in the Gauteng domain in GAINS are described per sector below.

Power and heating plants

As there are currently no available plans to expand the existing coal fired power generation capacity, recommission any currently decommissioned stations, or to build additional power stations in the Gauteng Province, coal usage for the power sector in Gauteng remains constant up to 2030, with a move towards renewable energy, mainly solar photovoltaic installations. Current mitigation controls for the existing coal fired power station (i.e. Kelvin) include electrostatic precipitator technology for the abatement of particulate matter pollution while SO_2 and NOx will remain largely unabated.

Domestic combustion

The GAINS definition of “domestic combustion” is consistent with the IEA definition which includes residential combustion as well as combustion related sources in the commercial and agricultural sectors.

Domestic burning: Household use of fuels for cooking, heating and lighting

The number of households using a specific fuel type as their main source of energy (for heating or cooking) has been taken from the 2016 Community Survey (StatsSA, 2017). Household consumption of solid fuels (i.e., coal, wood) is based on previous studies done within the region. Wood consumption is derived from Kaoma (2015) and Scheepers (2013). They cover townships in Limpopo and North-West provinces, and cover formal and informal housing, bought, and collected wood and electrified and non-electrified households. The average of reported consumption is ~ 3 tons/household/year, with an average upper bound of 8590 kg/household/year and an average lower bound of 2977 kg/household/year. Coal consumption per household is taken from Nkosi (2018). The study used survey data from KwaDela, a township in Mpumalanga, between Ermelo and Bethal. Coal consumption ranged between 4.9 kg to 9.1 kg per household on a winter day and the daily summer usage is in the range of 3.3 kg and 6.9 kg per household. Taking the average of either a winter or summer day and scaling up for a year, total coal consumption is 2121 kg/household/year. That is, 5.1 kg/household/day for summer months (October to April) and 6.8 kg/household/day for winter months (May to September).

In order to assess future changes in emissions, the IEA’s Stated Policy Scenario (IEA, 2020) trends were applied for the residential combustion sector. These indicate that residential solid fuel burning decreases between 2020 and 2030. This is in line with a national programme aimed at electrification (Integrated National Electrification Programme) and differential pricing strategies for poorer households. In terms of abatement controls for stoves, it is further assumed that from the total number of cooking and heating stoves 5% burn with improved efficiencies while the remainder of these stoves are unabated.

Commercial and Agriculture

Fuel use for the commercial and agriculture sectors were obtained from the latest available national Department of Energy (DoE) Commodity Flow and Energy Balance (DoE, 2018). These values were then downscaled to the provincial level by means of provincial GDP figures indicating what the relative contribution was to the national GDP for these sectors in 2019 in Gauteng (StatsSA, 2020).

Industrial combustion and processes

For industrial activities it is assumed that the Gauteng Province will follow national IEA trends where applicable. For the non-metallic minerals industry (including ceramics and glass) this implies a slight transition from coal combustion to gas. For the iron and steel industry coal consumption is expected to stay fairly constant, with a slight increase in electricity use.

IEA trends which are aligned with national economic growth estimates were also applied to estimate growth trends of future industrial processes. In this scenario, the level of implementation of control measures remains the same over time assuming current level of compliance, (i.e., no improvement and therefore by 2030 some do not comply with the Minimum Emissions Standards (Department of Water and Environmental Affairs, 2019)).

On-road vehicles

Future vehicle fleet numbers, kilometers traveled and fuel use projections in Gauteng are based on IEA figures, while current penetration of control technologies (shares of vehicles with various EURO standards) for on-road vehicles are based on a scrapping curve developed by Merven et al. (2012). Since there is no legislation requiring vehicles to comply with any particular standard, however, import of second hand vehicles has been prohibited since 2020, the evolution in the future is driven by replacement rates of current fleet with newly purchased vehicles. Considering current age and EURO stage structure and applying scrapping curve, we derive that all road vehicles will be EURO6 compliant by 2040.

Non-road vehicles and machinery

Non-road vehicles and machinery, which are applicable to the Gauteng Province, includes construction, aircraft, rail and agricultural vehicles and machinery with combustion engines. Fuel use for these categories were derived from the national energy balance supplied by the Department of Energy which was then downscaled with GDP figures for each of the relevant economic sectors in the Gauteng Province. Future projections are based on the relevant IEA trends.

Agriculture

Emissions classified under the agriculture sector include those originating from livestock and mineral fertilizer production and application. These activities are especially relevant for ammonia emissions. Livestock numbers were obtained from the Community Survey, 2016, Agricultural households. For fertilizer application, there is larger uncertainty, and current national GAINS figures for South Africa (developed based on the UN FAO agricultural outlook) were downscaled by means of GDP for the agriculture sector in the Gauteng Province.

Municipal Solid Waste

Municipal Solid Waste (MSW) projections are based on two socio-economic drivers, namely, GDP and population with MSW generation as an activity data. Information on population projections at provincial level is gathered from Le Roux et al. (2019). GDP data is adopted from national GDP growth estimates. Information on MSW generation in kg per capita is collected from Rodseth et al. (2020). Application rates of the different MSW control strategies built on CSIR (2011), Komen et al. (2016) and the South Africa State of Waste Report (2018). Fractions of open burnt waste are derived from Rabaji (2019).

Uncontrolled biomass burning

The assumption for biomass burning (i.e., veld fires and open burning of agricultural waste) is that this practice will continue and that current emission levels will remain constant up to 2030.

Baseline scenario with proper enforcement (CLE-PE)

In this scenario, emission limit values are achieved through development goals like increased electrification rates and the recycling of plastic by 2030. There are no new policies to eliminate open burning of waste, agricultural burning, high emitters (vehicles), or road dust. However, we assume that all power plants and industrial facilities are in compliance with existing legislation for both old and new plants by 2030 (i.e., minimum emission standards; Department of Water and Environmental Affairs, 2019).

Specifically, for the municipal waste management this scenario is based on the National Waste Management Strategy of South Africa and integrates the following targets: by 2025, 95% of households should receive collection services, 50% of households should separate waste and 50% of organic waste should be diverted from landfills within 5 years. Assumptions on recycling rates integrate the following stated targets: 70% of paper, 60% of plastic, 90% of glass, and 90% of metal.

Baseline: Sensitivity case

Due to uncertainties over available statistical data for household cooking an additional baseline sensitivity assessment was performed which assumes a larger proportion of solid fuel use in the Gauteng Province than the figures reflected in the CLE-PE scenario.

There has been a decline in electrification rates over the last ten years in the Gauteng Province (General household Survey 2019). The decline in electrification in combination with electricity price increases make the declining IEA and national policy trend questionable. It is likely that the 2019 Community Household Survey underestimates the percentage of households cooking with solid fuel. In the light of these uncertainties and because households use multiple fuels (not captured in Census or IEA data), this scenario assumes a larger proportion of solid fuel use in the Province than is reflected in the CLE-PE scenario and follows the IEA's Stated Policy Scenario trends until 2030. The CLE-PE scenario assumes that 90% of households use electricity, for cooking, heating and lighting. However, the General Household Survey for 2019 indicates that the electrification rate for 2019 in the Gauteng region is 76.6%. In this sensitivity case scenario, an electrification rate of 75% is assumed in urban and 50% in rural areas (see Figure 23 for actual fuel use data).

No further control scenario (NFC)

The No Further Control (NFC) scenario applies the baseline scenario activity data, while keeping the level of control technology unchanged from 2005 levels. It turns back the clock to 2005 in terms of policies, i.e., freezing the development of and further introduction of more ambitious environmental policies. One could see this scenario as a counterfactual case showing the impact/achievements of air quality legislation since 2005 and implications for the future if very few air quality mitigation actions would have been taken. It shows the success of policies since 2005, including the expansion of the National Environmental Management: Air Quality Act 39 of 2004 (NEMAQA) through policies including, but not limited to, minimum emission limit values and NAAQS.

Maximum feasible reduction scenario (MFR)

The Maximum Technically Feasible Reduction (MFR) scenario applies the best emissions abatement technologies across all sectors including feasibility assumptions to 2030, with no consideration of cost/investment constraints. The technical feasibility is estimated taking into account current stock and average lifetime of production and abatement technologies. The short time horizon (2030) limit potential to introduce some of the low emission technologies to a large extent and an analysis of longer term, i.e., towards 2050, would be desirable to understand how introducing very ambitious policies now would allow to reduce emissions in the longer term. While this scenario is in most regards not practically achievable it indicates the theoretical emission reduction potential of applying various abatement technologies and serves as a maximum achievable threshold towards which other more feasible scenarios may aspire.

Scenario assessment

Baseline scenario with current enforcement (CLE-CE)

The baseline scenario with current levels of enforcement sees increases in emissions for Gauteng Province between 2020 and 2030, for all pollutants (Figure 2 - Figure 4). Key growing sectors are industry and municipal solid waste management, while emissions from residential combustion and cars are declining highlighting the impact of existing policies that include reduction of reliance on solid fuels for cooking and heating as well as increased penetration of new and cleaner cars. Power plants do not play any significant role in Gauteng total emissions since most of the coal capacity is outside the region.

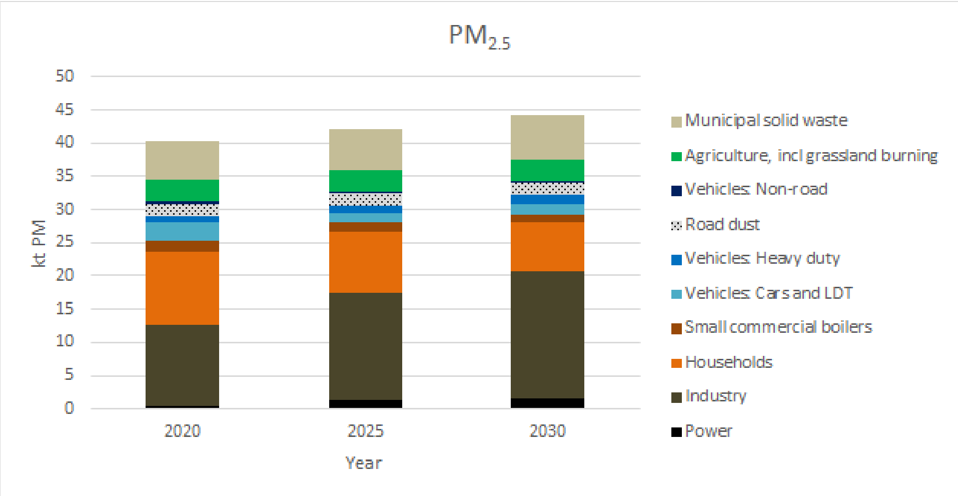

Figure 2: Baseline (CLE-CE) 2020-2030 $PM_{2.5}$ emissions per sector

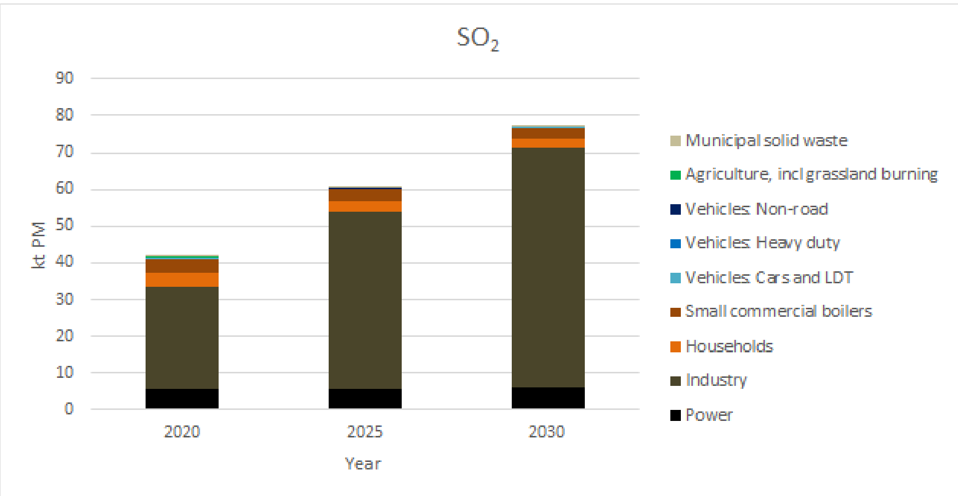

Figure 3: Baseline (CLE-CE) 2020-2030 SO_2 emissions per sector

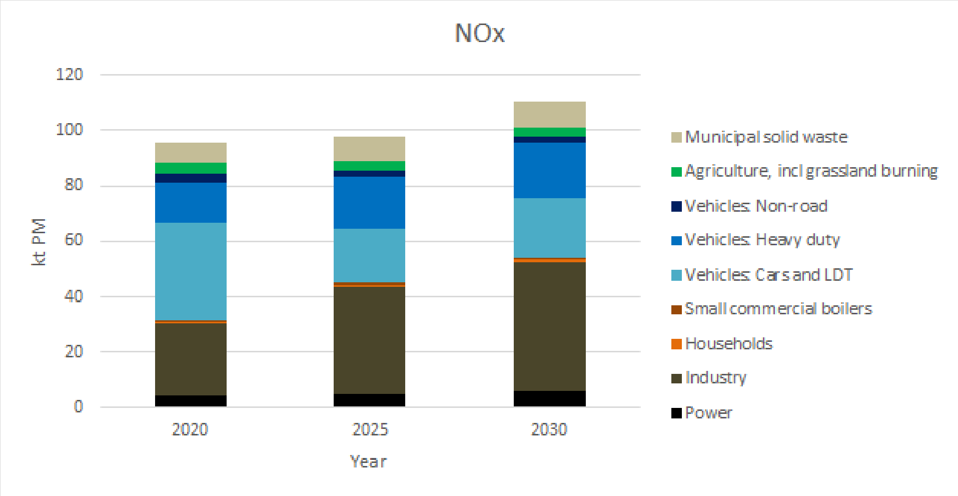

Figure 4: Baseline (CLE-CE) 2020-2030 NOx emissions per sector

Baseline scenario with proper enforcement (CLE-PE)

The baseline scenario with proper (i.e., increased) levels of enforcement highlights the impact that increased enforcement of current legislation could have on air quality levels. There is a decrease in $PM_{2.5}$ emissions in this scenario (Figure 5), while there was an increase in the baseline with current levels of enforcement (Figure 2). Also, there is less of an increase in SO_2 (Figure 6) and NOx (Figure 7) emissions in this scenario compared to the baseline with current levels of enforcement (Figure 3 and Figure 4).

Key factors determining slightly different trends are slower growth of emissions in industry, decline of emissions from municipal solid waste management, and stronger decline of emissions from cars and light duty vehicles. All of these show the importance of compliance enforcement. Additionally, benefits of assuring enforcement across the country would benefit Gauteng as coal power plants and industrial emissions would decline strongly in the neighboring regions of the province (not shown).

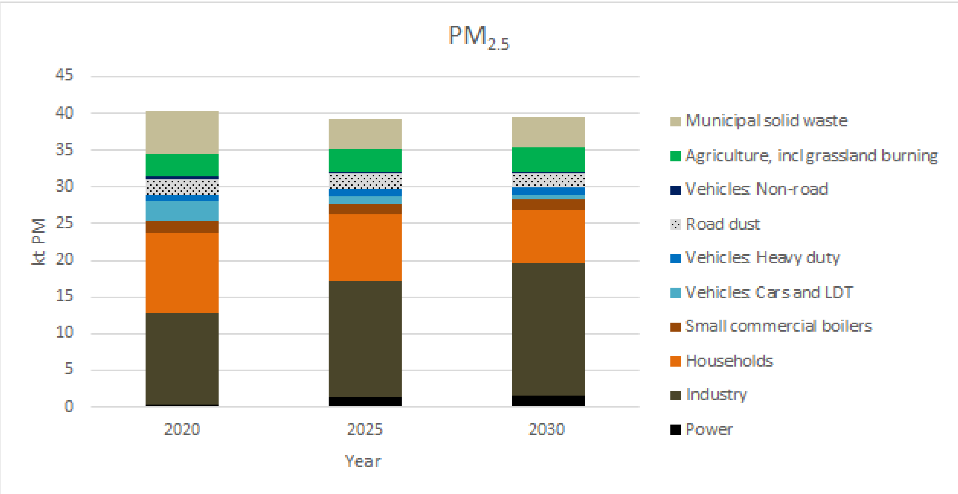

Figure 5: Baseline (CLE-PE) 2020-2030 PM2.5 emissions per sector

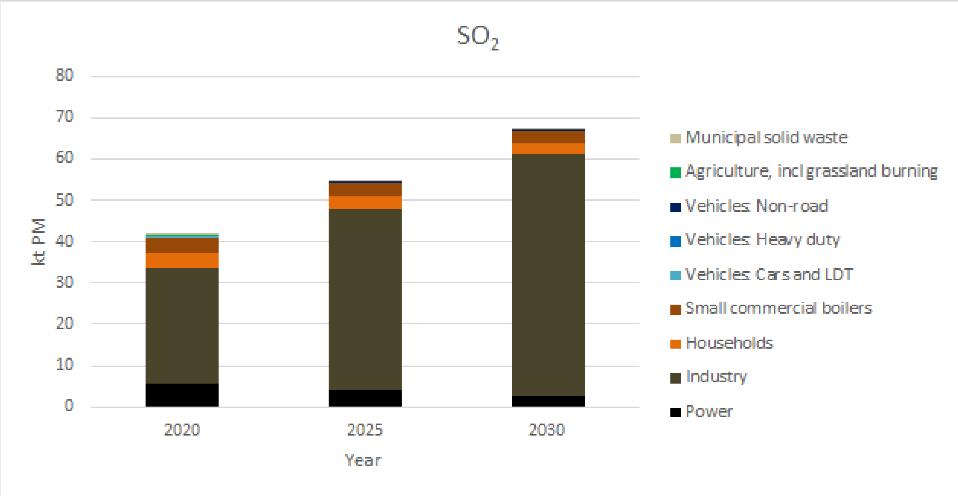

Figure 6: Baseline (CLE-PE) 2020-2030 SO_2 emissions per sector

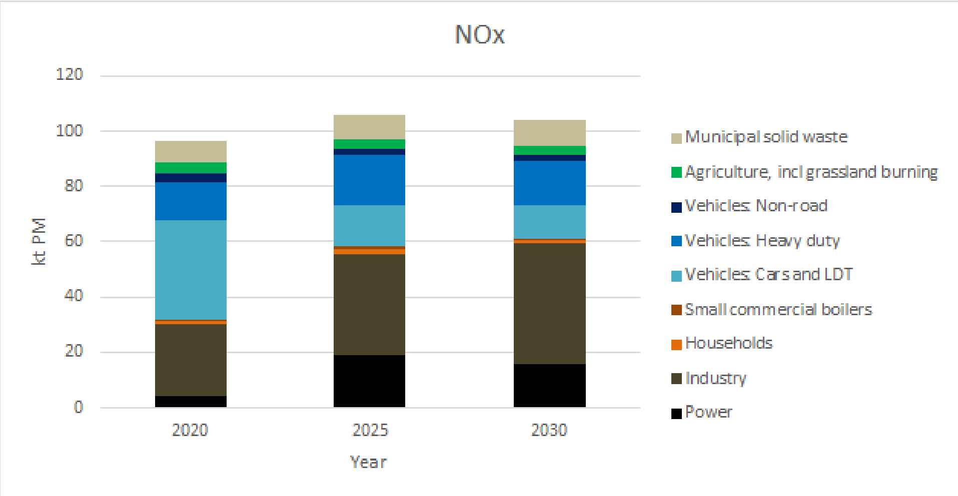

Figure 7: Baseline (CLE-PE) 2020-2030 NOx emissions per sector

Residential sensitivity case for the CLE-PE scenario

Figure 8 displays the change in $PM_{2.5}$ emissions with the sensitivity test for domestic burning. As noted above, the inputs (fuel use, emission factors) used to estimate emissions often have large uncertainties and this figure highlights how sensitive emissions are to changes in input parameters, specifically assumptions about fuel use.

The sensitivity case shown in Figure 8 attempts to account for multiple household fuel use. The baseline estimate makes use of Statistics South Africa Census and Community Survey data, in which households were asked about their primary energy source; however, it is generally known through experience during specific community surveys that households may use a variety of fuels for different purposes (DoE, 2012). Importantly, some households that have access to electricity would still use solid fuel stoves for cooking and heating, e.g., because electricity remains comparatively expensive (some of the fuel wood costs nothing – but time to collect it). This is not captured within the national Census or Community Surveys and impacts the coal and wood fuel consumption estimated for the baseline emissions inventory. Through expert consultation it was decided to scale coal and wood consumption by a factor of 1.8 to account for multiple fuel use, and this is represented by the Residential sector sensitivity case scenario.

It is acknowledged that uncertainty remains whether this is indeed the case within the Gauteng region.

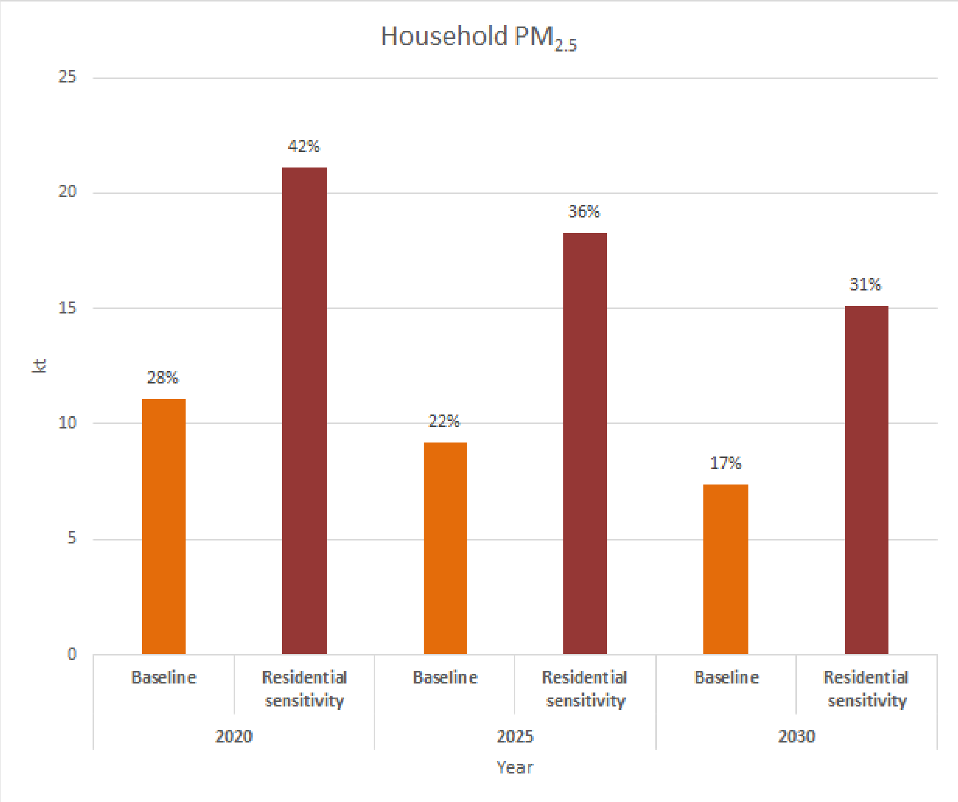

Figure 8: Sensitivity case: Higher wood and coal consumption for household cooking and heating, i.e., lower use of electricity; % refer to the share in total estimated anthropogenic $PM_{2.5}$ emissions.

No further control scenario (2005)

This scenario imagines a different reality, where there were no further air quality management policies enacted and implemented post 2005. In this scenario, the emissions in 2020 (i.e., current day) are very different. This can be used as a counterfactual scenario to understand the impact of air quality management since 2005. The emissions of $PM_{2.5}$ (Figure 9), SO_2 (Figure 10) and NOx (Figure 11) are higher than in other scenarios, with large increases in SO_2 being seen between 2020 and 2030 (Figure 10).

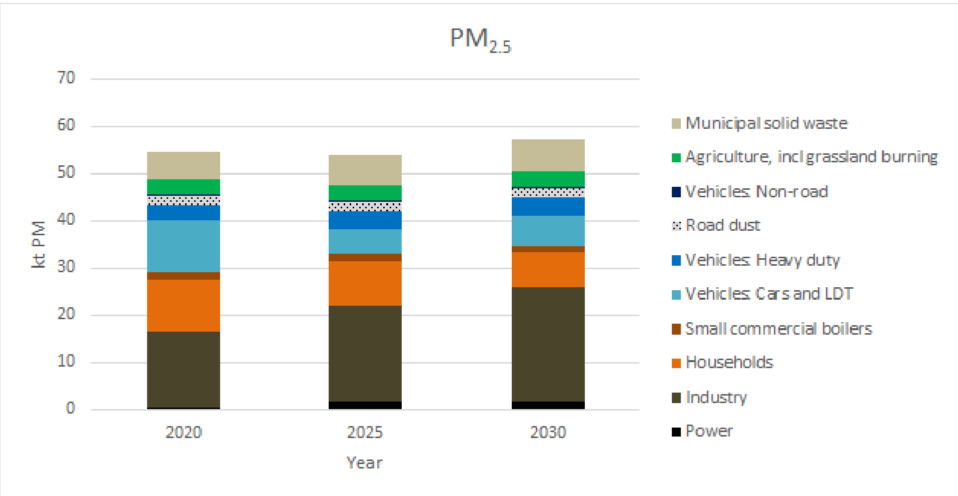

Figure 9: No further control (from 2005) scenario 2020-2030 PM2.5 emissions per sector

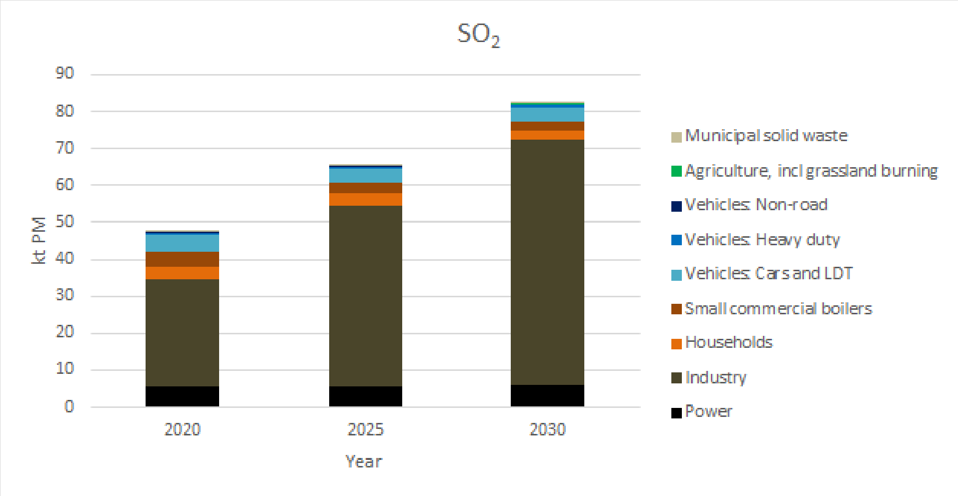

Figure 10: No further control (from 2005) scenario 2020-2030 SO2 emissions per sector

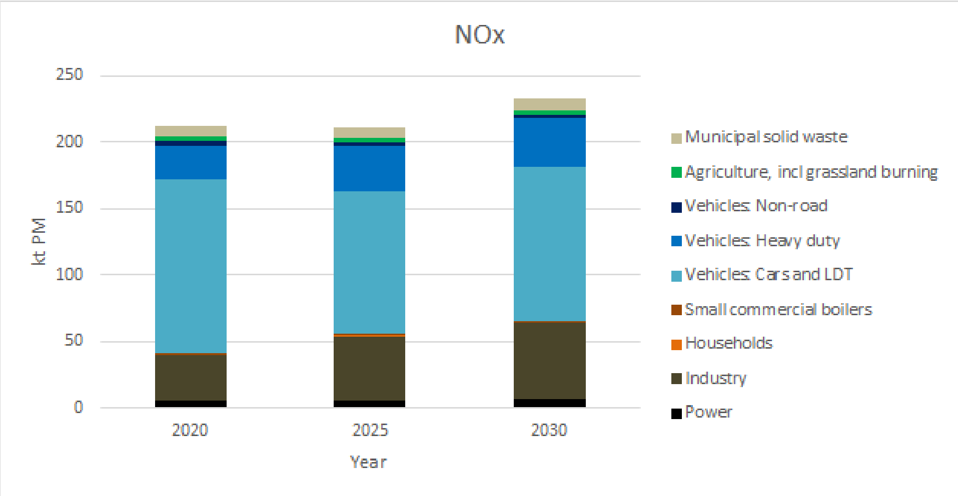

Figure 11: No further control (from 2005) scenario 2020-2030 NOx emissions per sector

Maximum feasible reduction scenario (MFR)

The MFR scenario highlights the estimated technical emission reduction potential and serves as a maximum achievable threshold towards which other more feasible scenarios may aspire. It must be kept in mind that costs are not considered in this analysis, i.e., it assumes that resources to quickly install low emission technologies where feasible are readily available.

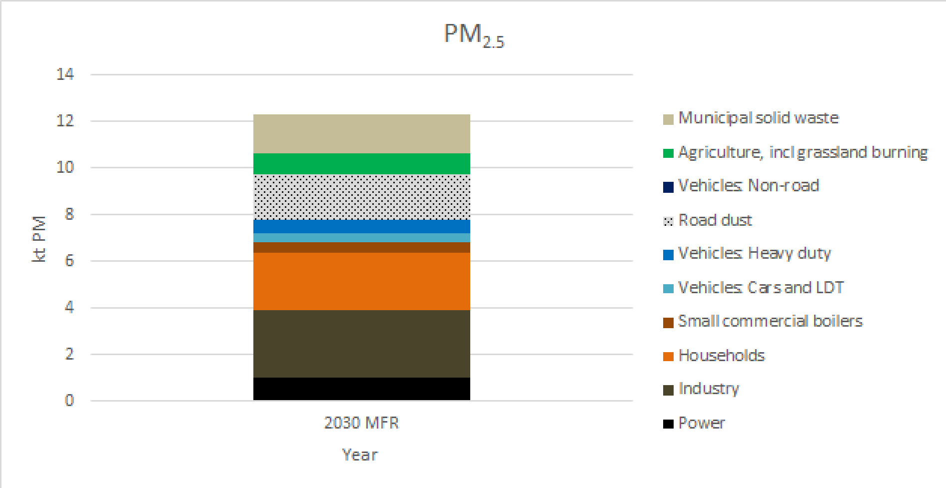

Figure 12: Ambitious maximum reduction scenario $PM_{2.5}$ emissions for 2030

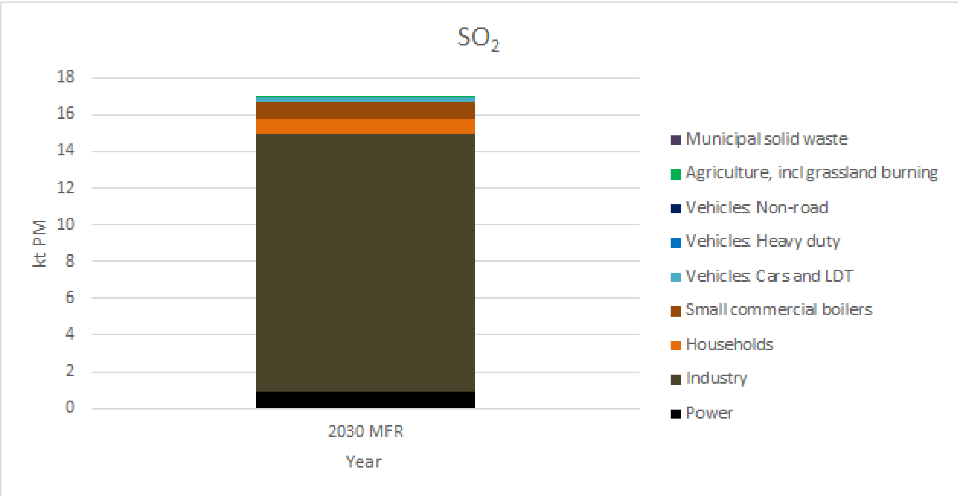

Figure 13: Ambitious maximum reduction scenario SO_2 emissions for 2030

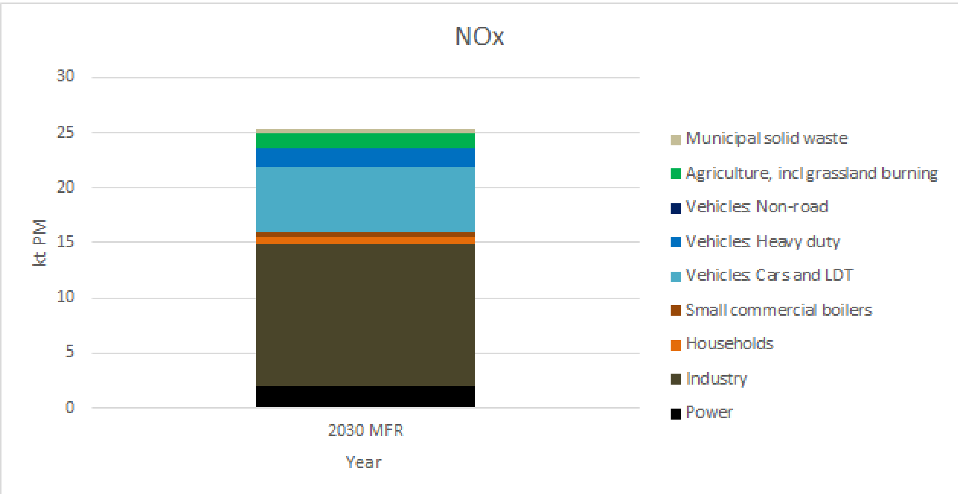

Figure 14: Ambitious maximum reduction scenario NOx emissions for 2030

Scenario comparison

The following figures show a comparison across the simulated scenarios. It should be kept in mind that in 2020 the CLE-CE and the CLE-PE scenarios are the same. The differences in enforcement only occur into the future. Both are shown here in 2020 for the sake of completeness.

A comparison of emissions of $PM_{2.5}$ for different scenarios for the years 2020 and 2030 is shown in Figure 15 below. In 2020, the effects of air quality management since the roll-out of the NEMAQA is evident. The emissions for both the CLE-CE and the CLE-PE scenarios are considerably lower than the scenario with No Further Controls (labelled NFC 2005). However, in 2030 the effects of the CLE-PE scenario become apparent as total emissions from this scenario in 2030 have decreased relative to 2020 while for the CLE-CE and the No Further Controls Scenario, emissions have increased, mainly from industry sectors. This highlights the merits of improving air quality management by ensuring effective enforcement of existing standards.

The year 2030 also introduces the MFR scenario. This scenario yields tremendous emission reductions when compared to the CLE-CE and the CLE-PE scenarios. The contribution from industry is considerably smaller in the MFR scenario, while road dust and household fuel burning still play an important, albeit smaller role. However, it must be kept in mind that in most regards the MFR scenario might be very difficult to be achieved in practice as it requires quick and strong legislative action introducing tight emission limit values requiring best reduction technologies and availability of sufficient resources. However, even in its current form, the MFR scenario indicates the technically feasible emission reduction potential of applying various abatement technologies and serves as a maximum achievable threshold towards which other more feasible scenarios may aspire.

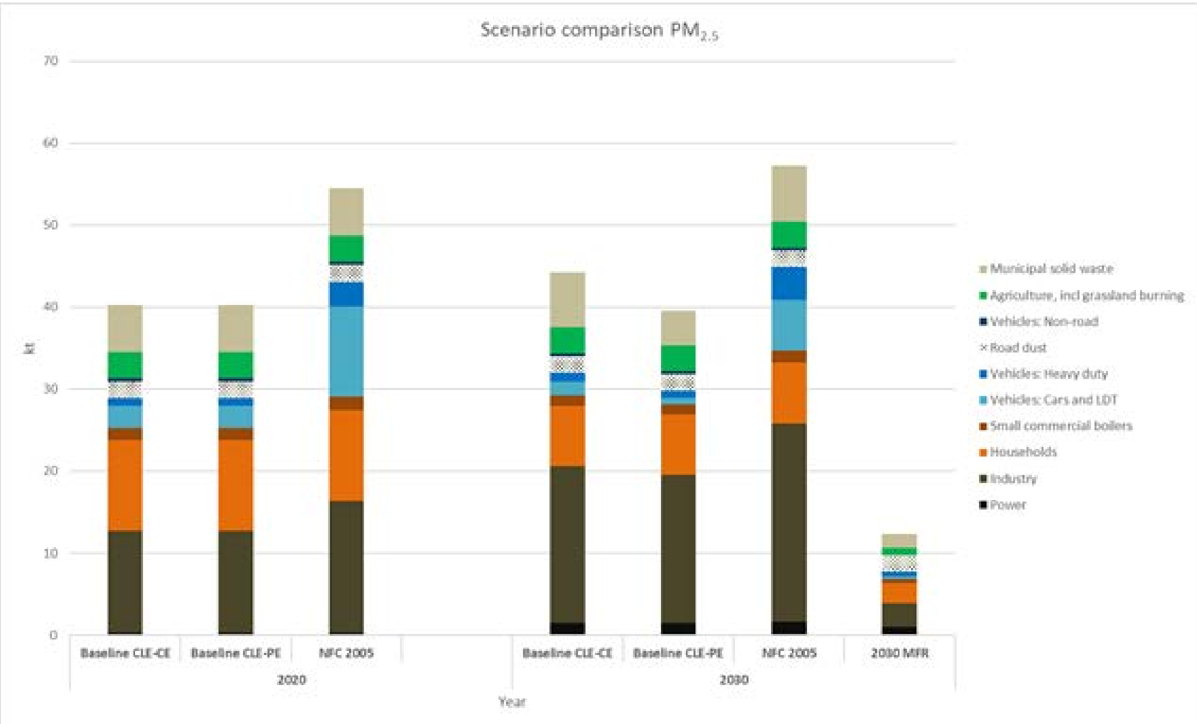

Figure 15: Scenario comparison 2020-2030 $PM_{2.5}$ emissions per sector

A comparison of emissions of SO_2 for different scenarios for the years 2020 and 2030 is shown in Figure 16 below. In both 2020 and 2030, across all scenarios, it is evident that industry is the largest contributor to SO_2 emissions. There are small differences between emissions in the CLE-CE, the CLE-PE and NFC scenarios for 2020 and emissions are slightly lower for the CLE-CE and the CLE-PE scenarios compared to NFC. In 2030, SO_2 emissions increase markedly for all three scenarios driven by industrial activities. Proper enforcement of SO_2 emissions abatement law and policy do not yield drastic reductions in SO_2, as was the case with $PM_{2.5}$ emissions above. This increase in SO_2 emissions in 2030 when compared to the MFR scenario appears even more dramatic. As expected, the application of the best available abatement controls in the MFR scenario yields much lower emissions than the CLE-CE and the CLE-PE scenarios.

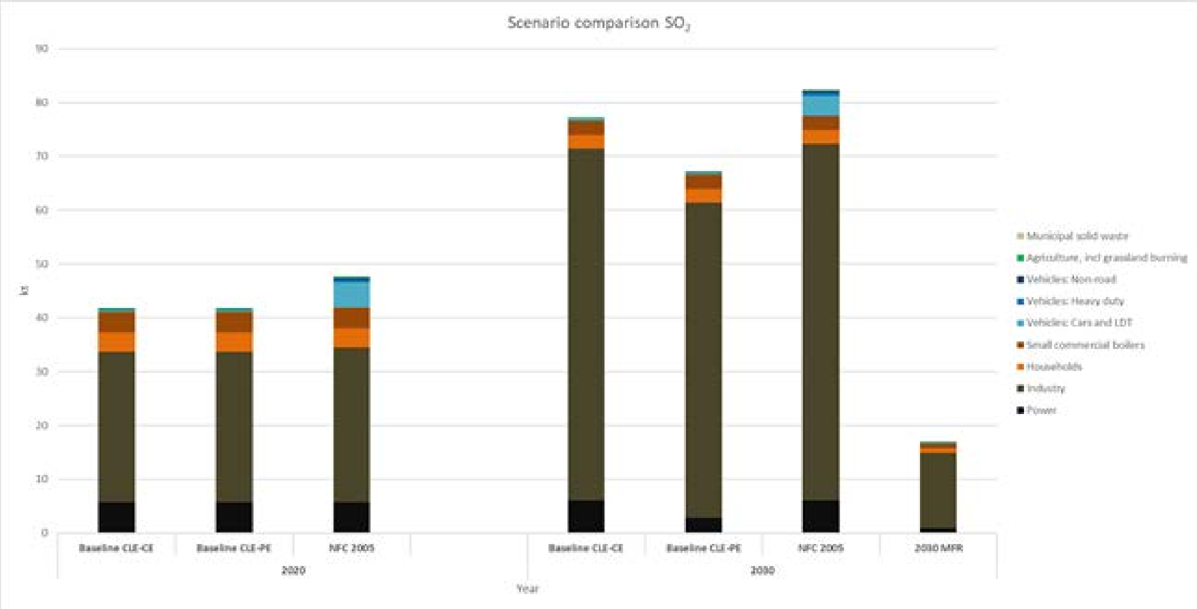

Figure16: Scenario comparison 2020-2030 SO2 emissions per sector.

The NOx emissions per scenario are shown in Figure 17 below. In 2020, similar to the other pollutants, the No Further Controls scenario has larger total emissions than the Baseline scenario. This difference is driven strongly by vehicle emissions from passenger cars and light duty trucks (light blue). This again highlights the impacts that air quality management since 2005 has had on emissions, as this counterfactual scenario has more than twice the emissions than the current baseline in 2020.

In 2030, the CLE-PE scenario does show lower total emissions than those of the CLE-CE scenario, which are mainly driven by larger decreases in the vehicular emissions.

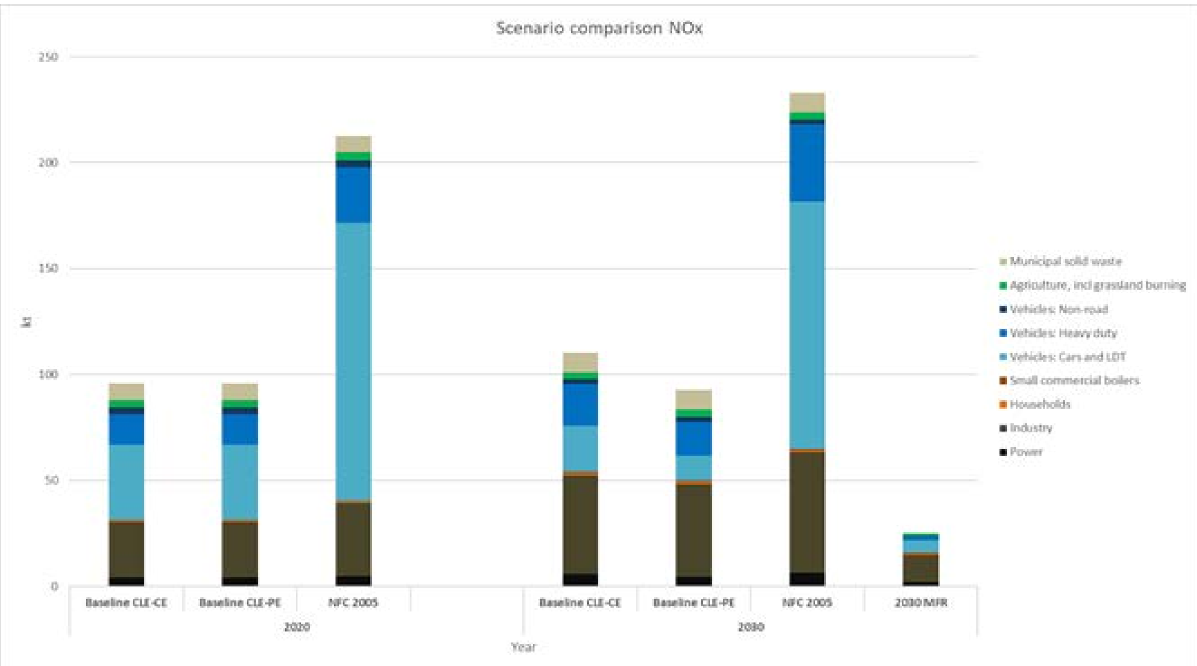

Figure 17: Scenario comparison 2020-2030 NOx emissions per sector.

Implications for air quality

This section discusses ambient $PM_{2.5}$ concentrations as modelled in GAINS for the base year, as well as the MFR scenarios for 2030. Ambient $PM_{2.5}$ concentrations are calculated for a given scenario and year on a 0.02° grid, using linear transfer coefficients based on perturbation simulations with the CAMx Chemistry Transport Model run at 0.02° x 0.02° resolution for the full meteorological year 2019. GAINS calculates $PM_{2.5}$ concentrations as the sum of contributions from natural sources such as wind-blown dust, primary $PM_{2.5}$ emissions as well as secondary $PM_{2.5}$ formation from SO_2, NOx, NH_3, and NMVOC emissions.

Ambient $PM_{2.5}$ concentrations in the base year are shown in Figure 18.

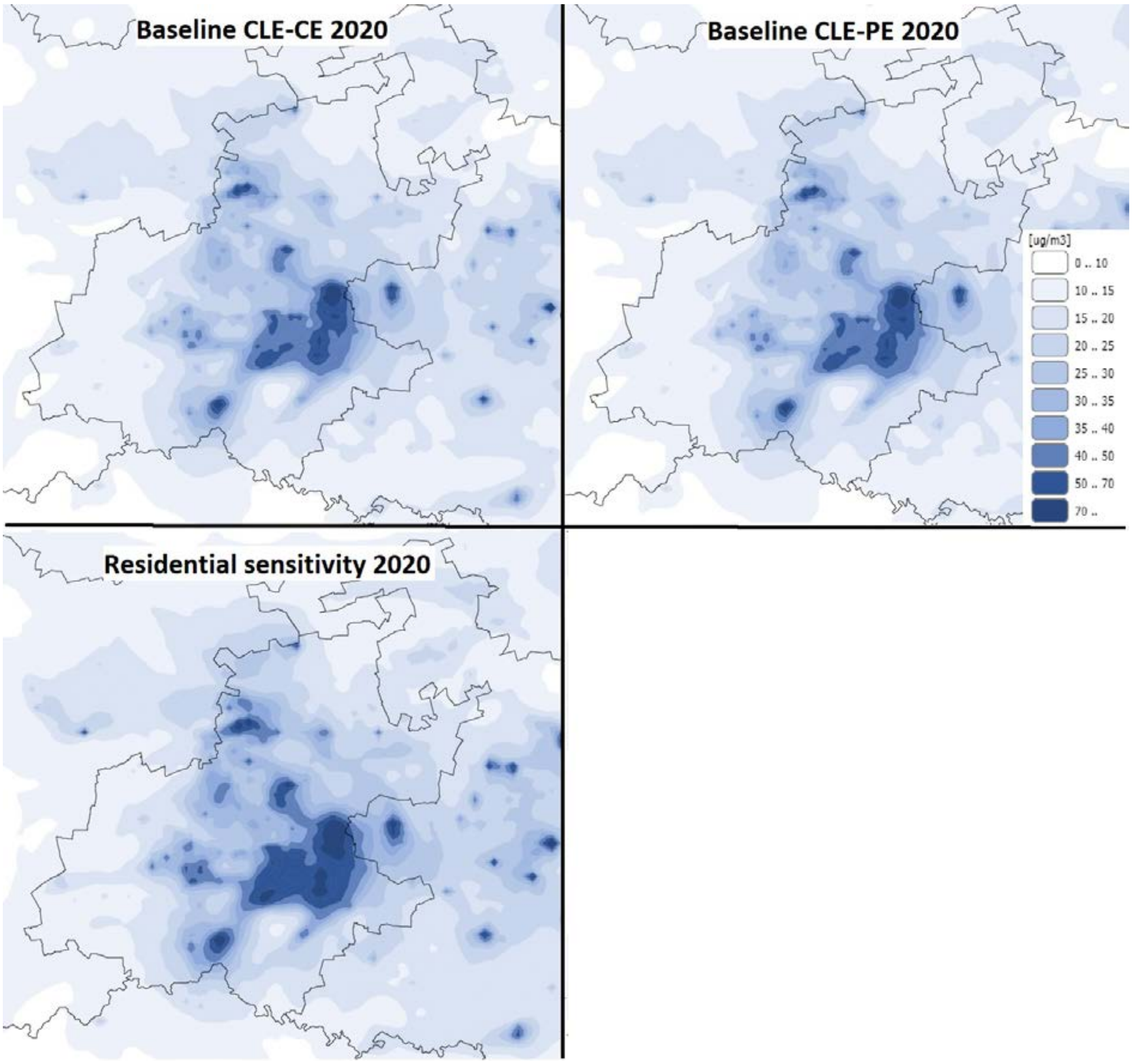

Figure 18: Ambient $PM_{2.5}$ concentrations modelled in GAINS for 2020, under the baseline (current as well as proper enforcement) and sensitivity scenarios

Ambient $PM_{2.5}$ concentrations in 2030 under the baseline and two sensitivity cases are shown in Figure 19.

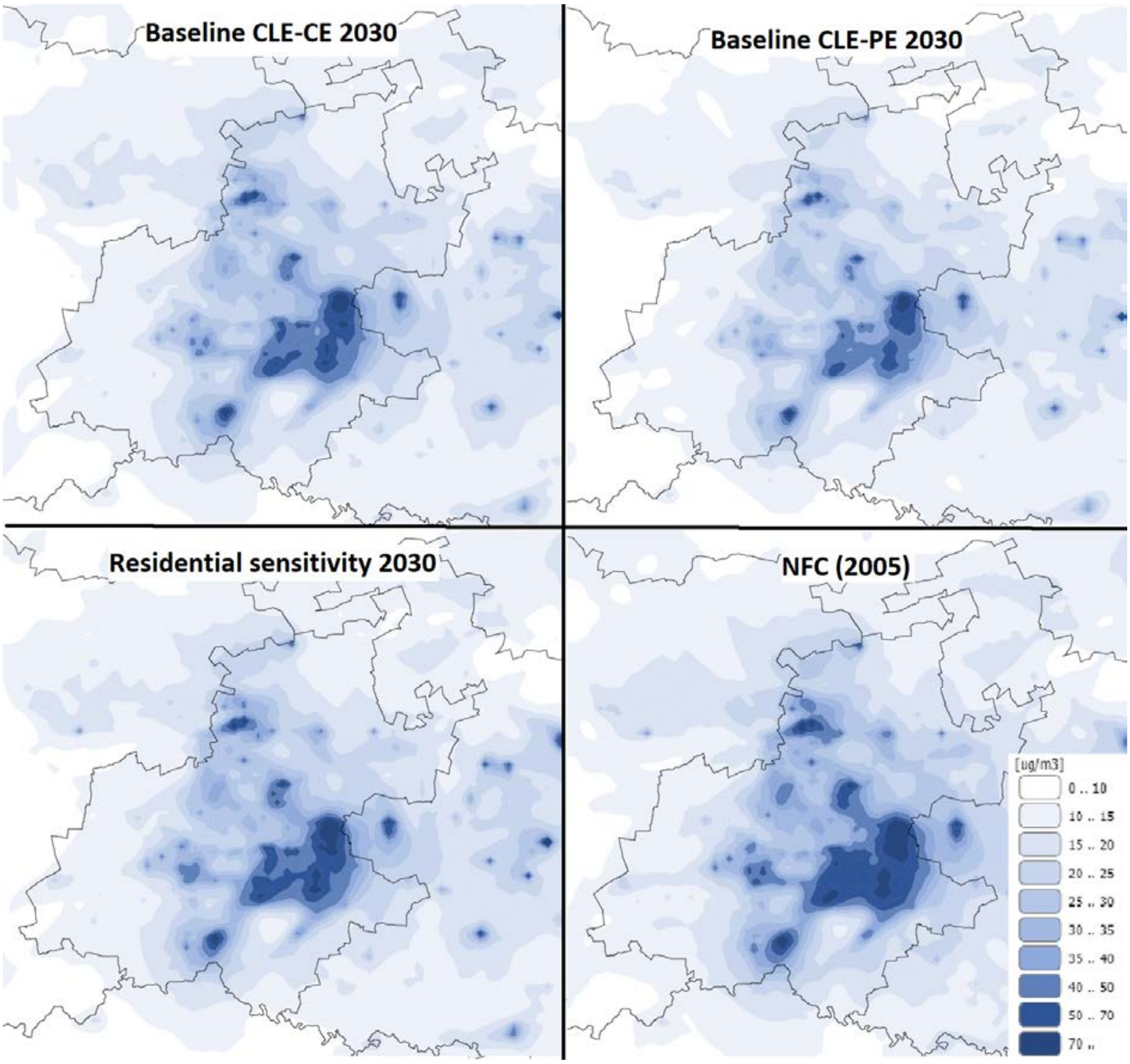

Figure 19: Ambient $PM_{2.5}$ concentrations in 2030 under the baseline (current enforcement as well as proper enforcement), Residential sensitivity and the counterfactual "No further control after 2005" scenarios.

Concentrations are expected to remain roughly stable in the Baseline CLE-CE scenario with a, while the CLE-PE scenario would bring clear reductions with less widespread annual mean $PM_{2.5}$ concentrations of between 40 µg/m^3 and 50 µg/m^3 as observed in the south east of the Gauteng Province. The NAAQS are expected to be achieved only in smaller areas in the south west and north east of the province. The pollution burden remains the highest in the south west, with individual grid cells reaching annual mean $PM_{2.5}$ concentrations above 70 µg/m^3. The Residential sensitivity case $PM_{2.5}$ concentrations are significantly higher especially in the densely populated south easterly areas of the Gauteng Province which leads to more widespread annual mean $PM_{2.5}$ concentrations above 50 µg/m^3. The NFC (2005) highlights the positive impact of air quality management measures since 2005 by showing that $PM_{2.5}$ concentrations above 50 µg/m^3 would be significantly more widespread were these measures not implemented.

As expected, strong improvements are observed under the MFR scenario. Concentrations for this scenario are shown in Figure 20.

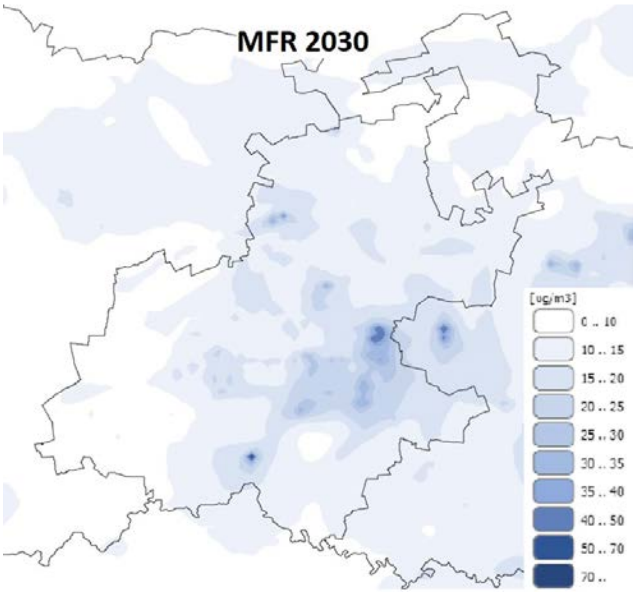

Figure 20: Modelled PM2.5 concentrations in the MFR scenario for 2030.

Conclusion

While the work for this collaborative project is still underway, work done during the YSSP has contributed significantly towards achieving the overarching aim of improving, through solid data and robust analytical underpinnings, the evidence base on air quality and air quality management in Gauteng. The preliminary scenarios give an indication of future emissions levels and impacts on $PM_{2.5}$ concentrations and health impacts under current legal enforcement and proper enforcement as well as exploring the effect of policy and law under the disposition of the National Environmental Management: Air Quality Act 39 of 2004 on current emissions levels, by means of a scenario which assumes no such legislative changes took place. Furthermore, the Residential sensitivity scenario explores the implications which a lack of credible data on domestic fuel-use patterns in the Gauteng Province hold for total $PM_{2.5}$ emission estimates and therefore impacts on human health. An additional optimisation scenario which is currently under development will indicate how the NAAQS $PM_{2.5}$ concentration target of 20 $\mu g/m^3$ can be achieved most effectively. This scenario will serve to indicate which sectors hold the most potential for intervention measures aimed at improving air quality across the Gauteng Province.

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