The provision of professional, independent consulting services to assist Eskom in compiling applications for renewed postponement of the Minimum Emission Standards:

Component 4: Health impact focused cost benefit analyses

Review of 2018 Final Report in the context of updated ambient concentrations of PM dispersion modelling results

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1 INTRODUCTION

Purpose

This report presents an expert assessment of the impact of fugitive emission sources on the outcomes of the Health CBA Model developed by Prime Africa (2018) as reported on in the document entitled "**Component 4: Health impact focused cost benefit analyses**" (hereinafter referred to as the "2018 Study").

Scope of Work

The Scope of Work for this revision is as follows:

- *Prime Africa will receive from uMoya-Nilu, the revised dispersion modelling results, with an appropriate statistical comparison (by uMoya-Nilu) to the original dispersion modelling results, indicating variance in two datasets*
- *Prime Africa will perform an appropriate sensitivity analysis using the variance resulting from the various sets of dispersion modelling results in comparison to other sources of variances in the CBA analysis;*
- *Compile a report, Project Memorandum, that provides an Economic Opinion on the extent to which the revised dispersion modelling results is likely to affect the numerical outputs of the Cost Benefit Analysis modelling;*
- *Work excludes any revisions to CBA model / results captured in Report and any revisions to the Report.*

Basis for assessment: Fugitive emission data

The revision is based on updated dispersion modelling results received from uMoya-NILU as contained in the report entitled "**Dispersion modelling report for Eskom's coal-fired power stations on the Highveld as input to the addendum for the cumulative assessment**" (Zunckel and Raghunandan, 2020) and associated data files.

The dispersion modelling updated involved adding the effects of fugitive emissions from coal stock yards and ash disposal facilities, measured as PM, to the other sources of PM generated by coal-fired power stations.

Methodology

A sensitivity analysis was performed to assess the impact of the additional health effects associated with fugitive emissions from coal stock yards and ash disposal facilities. The sensitivity analysis required by the Scope of Work, was performed using both average annual effect analysis, as well as a model audit approach. The average effect analysis tested the sensitivity of the complex Health CBA model outcomes to changes in the average annual PM emissions. Average analysis in a complex model has the risk of missing specific hot spot problematic areas. For that reason, the model audit process traced a set of data points, selected from the highest PM values, lowest PM values and a randomly selected set of midpoint PM values, and evaluated these w.r.t. possible changes in model outcomes.

Assessment of Health CBA outcomes was based on the following definitions:

Likelihood rating	Assessed probability of occurrence	Description
Almost certain	> 90%	Extremely or very likely, or virtually certain
Likely	> 66%	Will probably occur
Possible	> 50%	Might occur; more likely than not
Unlikely	< 50%	May occur
Very unlikely	< 10%	Could occur
Extremely unlikely	< 5%	May occur only in exceptional circumstances

Report structure

The methodology to the 2018 Study, fully described in that report, is set out in the "Overview of Methodology" **Section 2** below for convenience. This section demonstrates the various inputs required in the overall model, and the assumptions made in this Revision of the 2018 Study (refer to Table 1). It is to be noted that the revised dispersion modelling released in 2020 is the only data input that is assumed to have changed for this Revision of the work.

For convenience of comparison, the Scenario analysis results of the 2018 Study are set out in **Section 4.**

The discussion and analysis of the effects of introducing the fugitive emissions effects on the Health CBA model are provided in **section 3** below.

2 OVERVIEW OF CBA METHODOLOGY

In 2018, Prime Africa executed a study to estimate the incremental health benefits associated with abatement technology options that achieves compliance with the new Minimum Emission Standards (MES) of the Department of Environmental Affairs (DEA).

The 2018 study developed an integrated Health CBA Model. The Health CBA Model followed the General Principles of the World Health Organisation (WHO, 2016) for performing air pollution health risk assessment (AP-HRA). The detailed methodology and assumptions proceeded through 8 steps, as briefly summarised in the schematic and proceeding text below:

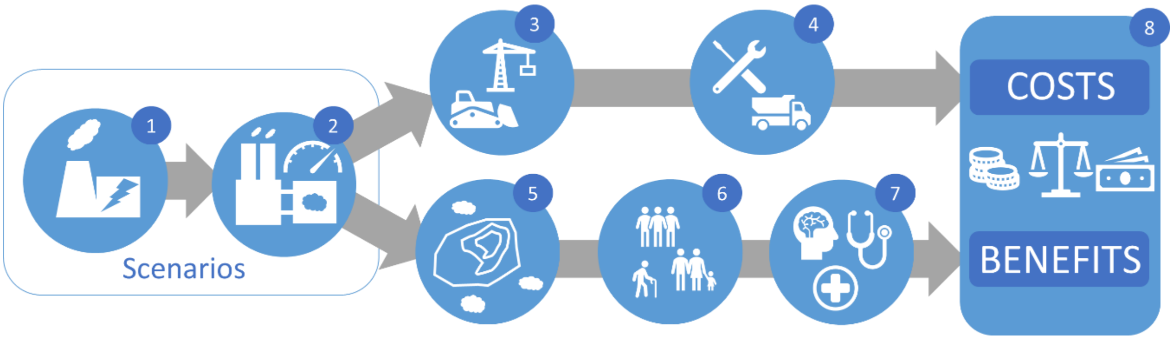

Table 1. Components of the health cost model and the assumptions made in this Revision.

Step	2018 Study	This Revision
1	Plant lifetimes were described for 13 coal-fired power plants and included commissioning and decommissioning dates (provided by Eskom).	For this Revision, decommissioning dates remained as assumed in 2018 Study. The 2018 Study assumed early decommissioning would start in 2019. A change to this schedule would affect the results by either increasing or decreasing the benefit depending on the nature of the change. Note this is not assessed in this Revision.
2	Abatement technologies required for each scenario were defined, by type and likely implementation schedule	For this Revision, abatement technologies and implementation dates remained as per 2018 Study. The 2018 Study assumed some abatement installation actions would start in 2019. A change to this schedule would affect the results by either increasing or decreasing the benefit depending on the nature of the change. Note this is not assessed in this Revision.
3	Capital expenditure required for abatement in each scenario was attributed per plant and per year using Eskom's internal estimates.	For this Revision, Capital expenditure required for abatement in each scenario remained as per 2018 Study.
4	Operational expenditure required for abatement in each scenario was attributed per plant and per year using Eskom's internal estimates.	For this Revision, Operational expenditure required for abatement in each scenario remained as per 2018 Study.
5	Dispersion modelling results were obtained from uMoya-NILU (Zunckel and Raghunandan, 2018). This data was segregated spatially, by ward and municipal boundaries to align with population data. Two sets of dispersion modelling data were obtained. The first set modelled predicted ambient concentrations of PM, NO_2 and SO_2 around individual power stations. The second set	For this Revision, revised dispersion modelling results were obtained from uMoya-NILU (Zunckel and Raghunandan, 2020). The modelling was limited to a revised set of PM dispersion models that modelled additional PM emissions as a result of fugitive emissions from ash disposal facilities and coal stockyards, which are in addition to the primary and secondary effects emissions

Step	2018 Study	This Revision
	modelled cumulative predicted ambient concentrations of PM, NO_2 and SO_2 from all power stations on the Highveld. The dispersion modelling results were unique because in addition to primary PM, the modelling predicted secondary PM effects, resulting from NO_2 and SO_2 reactions in the atmosphere.	modelled in the 2018 study.
6	Population exposure was estimated at a spatial resolution of municipality and municipal wards. At each municipality or ward, the number of people exposed to different concentration ranges were determined per scenario per year, based on Stats SA population estimates and United Nations population growth forecasts.	For this Revision, Population exposure in each scenario remained as per 2018 Study.
7	Health impacts were determined by using the AP-HRA methodology. Epidemiological evidence, in the form of Exposure-response functions (ERFs) and baseline incidence rates were provided by the SA Medical Research Council (SAMRC) (Wright and Oosthuizen, 2018). The ERFs were limited to mortality incidence. The Cost of Illness (COI) methodology used was the value of statistical life (VSL). This method estimates the willingness to pay (WTP) of an individual for reducing their health risk. The VSL should not be interpreted as the intrinsic value of a life.	For this Revision, ERFs and VSL used in each scenario remained as per 2018 Study.
8	The CBA compares the overall scenario benefits and costs. The outputs of the AP-HRA, the health cost savings of each scenario, was used as the benefit. The capital and operational cost estimates were used as the costs in the CBA. The analysis timeline spans 2015 – 2045. This timeframe allows for 5-year interval analysis, aligning to the 2020 MES. It also captures mitigation activities implemented since 2016. The base year was 2018, due to dispersion modelling timeframe. The CBA was performed in an Excel spreadsheet, which consolidated all data sources, which contains all calculations, and was macro-enabled to run the large spatial exposure estimates for each scenario for the review period. Finally, an assessment of uncertainty of the results was done.	For this Revision, the CBA model was not run for the updated PM dispersion modelling data, however a sensitivity analysis was performed as set out in the methodology section above.

3 ASSESSMENT OF FUGITIVE EMISSION EFFECTS IN HEALTH CBA MODEL

1. Impact of additional fugitive emissions to Health CBA results

Introducing into the Health CBA model the additional effect of fugitive emissions from coal stock yards and ash disposal facilities, is expected to increase the annual average ambient PM concentration. This in turn is expected to increase the health risk to exposed populations to PM. This section assesses the likelihood of a significant change in Health CBA outcome.

uMoya-NILU analysed the additional effect of fugitive emissions on ambient conditions.

Reading of the uMoya-NILU 2020 report shows very limited effects of these additional emissions, as displayed on isopleth maps, with exceedances in a few relatively limited areas in close proximity to the emission sources, and with apparently very limited population exposure.

The Health CBA model by nature is, however, highly sensitive to any changes in emissions. A sensitivity analysis was performed to assess impact of the additional emission effects (see section 1). The sensitivity analysis was performed using both average effect analysis, combined with a data and model audit approach.

Data from uMoya-NILU shows an increase in the average annual PM concentration across 24,300 grid points within the selected modelling domain. The average increase, weighted spatially to Ward level, is 0.07 μg/m^3 (an increase from an average of 0.29 μg/m^3 to 0.36 μg/m^3). This small increase is regarded as insignificant, as the CALPUFF modelling software used in the analysis is regarded to be accurate only to one decimal (personal communication: Mark Zunckel). Moreover, the exposed population in the Wards covering the highest 20 average PM concentration grid points is a mere 0.4% of the total modelling domain, and thus the health outcome effect will be small.

However, within the modelling domain, there is expected to be specific zones (Wards), in closer proximity to the sources of fugitive emissions, which may be significantly affected. For this reason a data/model audit approach was followed to trace selected grid point data changes and assess their likely effect in the Health CBA model. A sample of data points representing the highest 20 average PM concentration grid points, lowest 20 grid points and a random selection of midlevel grid points were selected, traced through the Heath CBA model, and assessed for likely effects on the Health CBA model outputs.

In the data set representing the highest 20 average PM concentration grid points, average annual exposure could increase by as much as 0.7 – 2.1 μg/m^3 as a result of the fugitive emission effect. In the data set representing the lowest 20 average PM concentration grid points, no significant effects were evident. In the data set representing the midlevel average PM concentration grid points, average annual exposure could increase by between 0.0 – 0.3 μg/m^3.

High level sensitivity analysis was subsequently done by applying the above variances to the CBA model. A variance of 0.1 μg/m^3 was used to perform the sensitivity analysis. This is the smallest value at which CALPUFF data outputs are regarded as significant.

The following conclusions can be made:

- The additional effect of fugitive emissions is **extremely unlikely** to have a significant effect on the Health CBA outputs.
- Health effects resulting from fugitive emissions are highly localised and is **likely** to have a significant effect on the model output at a localised level. Note however that the exposed population in the Wards covering the highest 20 average PM concentration grid points is a mere 0.4% of the total modelling domain, and thus the health outcome effect will be small.

2. Discussion on interpreting data sensitivity

It is noted from the revised dispersion modelling results (Zunckel and Raghunandan, 2020), for the Scenarios modelled by uMoya-NILU, that the maximum predicted ambient concentrations for PM_{10} are below the NAAQS for the respective averaging periods at all the sensitive receptor points.

Exceedance occur for PM_{10} only for the predicted 99th percentile of the 24-hour PM_{10} concentration. The areas where these PM_{10} limit values are exceeded is predicted over a relatively small area between Matla and Kriel Power Stations, and close to Lethabo, Kendal, Majuba Arnot and Hendrina Power Stations. The highest concentrations close to each power station result from the low-level fugitive particulate emissions.

Similarly, exceedance occur for $PM_{2.5}$ in the predicted annual average PM2.5 concentration and for the predicted 99th percentile of the 24-hour $PM_{2.5}$ concentration only over relatively small areas. As above, these areas are between Matla and Kriel Power Stations, and close to Lethabo, Kendal, Majuba Arnot and Hendrina Power Stations.

These spatially limited exceedances need to be considered in the context of the variation in health outcome incidences between the various ERFs provided by SAMRC, that in some cases exceed 80%.

Given the above, it is therefore **extremely unlikely** that the fugitive emissions would impact significantly on the Health CBA results.

3. Fugitive emission effect on Health CBA Scenarios

In this section the Health CBA model is tested for sensitivity analysis biased to the higher impact localised effects, i.e. an adjustment of 0.1 $\mu g/m^3$. This assumes an increase of 0.1 $\mu g/m^3$ across the total exposed population, as well mitigation of fugitive emissions through appropriate dust suppression measures. Within the Health CBA model, an increase 0.1 $\mu g/m^3$ of would imply higher risk of mortality, or health costs, and further that the benefits of mitigation actions in each scenario become marginally larger. As a result, the CBA ratios decrease across all scenarios.

It is significant that the Scenarios tested as part of this sensitivity analysis were not found not change in order of preference (refer to Table 2).

Furthermore, the addition of fugitive emissions to the analysis does strengthen the CBA ratio of Scenario 4 relative to the other scenarios. This is because earlier closure of power plants would reduce the fugitive emission effect relative to the other Scenarios. Scenario 4 therefore become even more preferred.

Table 2. Comparison of CBA outputs based on a sensitivity analysis of a 0.1 µg/m^3 increase in PM across the modelling domain, on the Health CBA model

2018 Study Results	FC (S1)		ERP (S2)		ERP+FGD (S3)		ERP+ED (S4)	
Million Rands	lower	upper	lower	upper	lower	upper	lower	upper
NPV of Costs	(43,369)	(65,053)	(16,923)	(25,385)	(21,205)	(31,808)	(16,923)	(25,385)
NPV of Benefits	2,403	21,625	1,962	17,661	2,252	20,264	3,374	30,367
NPV of Benefits minus Costs	(40,966)	(43,428)	(14,961)	(7,724)	(18,954)	(11,544)	(13,549)	4,982
Cost: Benefit Ratio (range)	18.0	3.0	8.6	1.4	9.4	1.6	5.0	0.8
Cost: Benefit Ratio (central)	4.5		2.2		2.4		1.3	

0.1 µg/m3 increase in PM	FC (S1)		ERP (S2)		ERP+FGD (S3)		ERP+ED (S4)	
Million Rands	lower	upper	lower	upper	lower	upper	lower	upper
NPV of Costs	(43,369)	(65,053)	(16,923)	(25,385)	(21,205)	(31,808)	(16,923)	(25,385)
NPV of Benefits	2,538	22,842	2,073	18,655	2,378	21,405	3,564	32,076
NPV of Benefits minus Costs	(40,831)	(42,211)	(14,851)	(6,730)	(18,827)	(10,403)	(13,359)	6,691
Cost: Benefit Ratio (range)	17.1	2.8	8.2	1.4	8.9	1.5	4.7	0.8
Cost: Benefit Ratio (central)	4.3		2.0		2.2		1.2	

4. Uncertainty of the estimated health effects

In addition to the discussion of uncertainties mentioned in the 2018 Study, the following uncertainties need to be highlighted as part of this review:

- For this Revision, earlier plant decommissioning dates remained as assumed in 2018 Study. The 2018 Study assumed early decommissioning would start in 2019. A change to this schedule would affect results of Scenario 4 by decreasing benefits. Note this is not assessed in this Revision.
- It is to be noted that in the 2018 Study, four ERFs were selected for evaluation in the AP-HRA, of which PM was an indicator for cerebrovascular mortality and diabetes mellitus mortality only:
    - Respiratory mortality using SO_2 as an indicator pollutant, and thus this effect was not assessed in the sensitivity analysis performed
    - Cardiovascular mortality using NO_2 as an indicator pollutant, and thus this effect was not assessed in the sensitivity analysis performed
    - Cerebrovascular mortality using $PM_{2.5}$ as an indicator pollutant (Hazard ratio 1.11, this effect was assessed as part of the sensitivity analysis
    - Diabetes mellitus mortality using $PM_{2.5}$ as an indicator pollutant (Hazard ratio 1.13) , this effect was assessed as part of the sensitivity analysis.
- Thus, the relative effect of a change mortality as a result of a change in PM only, would be an underestimate. However, given the assessments discussed above, it is

our opinion that the additional effect of fugitive emissions is extremely unlikely to have a significant effect on the Health CBA outputs.

- The costs of implementation of abatement technologies would put additional pressure on Eskom CAPEX and debt requirements. Overnight prices were used in the model, and thus additional debt effects were not estimated. This is an important economic externality that would put significant upward pressure on electricity prices. These would result in additional economic costs, and these were not assessed.
- W.r.t. Scenario 4, earlier decommissioning of power stations would likely require replacement base-load capacity with alternate energy that may be more expensive. These would result in additional economic costs, and these were not assessed.

4 REFERENCES

Prime Africa (2020): Naidoo, N.; Crafford, J.; Mulders, J.; Mathebula, V. (2018): Component 4: Health impact focused cost benefit analyses (as additional information to Eskom's MES application), Deliverable 2, 26 November 2018.

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ACRONYMS AND ABBREVIATIONS

AP-HRA	Air Pollution Health Risk Assessment
CBA	Cost-Benefit Analysis
COI	Cost of Illness
COPD	Chronic Obstructive Pulmonary Disease
DEA	Department of Environmental Affairs
ERF	Exposure Response Function
ESP	Electrostatic Precipitators
FGD	Flue Gas Desulphurisation and Fabric Filter Plants (FFP).
HPA	Highveld Priority Area
ICD	International Classification of Diseases
IRP	Integrated Resource Plan
kW	Kilowatt
LNB	Low NOX Burners
MES	Minimum Emissions Standards
NAAQS	National Ambient Air Quality Standard
NO_2	Nitrogen Oxide
NPV	Net Present Value
PM	Particulate Matter
RR	Relative Risk
SAMRC	South African Medical Research Council
SO_2	Sulphur Dioxide
TB	Tuberculosis
VSL	Value of Statistical Life
WHO	World Health Organisation
WACC	Weighted Average Cost of Capital
WTP	Willingness to Pay

APPENDIX 1: RESULTS AND DISCUSSION: 2018 STUDY

4.1 Scenarios

The scenarios evaluated in this study (against a baseline) included:

1. Full compliance with new plant standards (FC) (S1)
2. Eskom Emission Reduction Plan (ERP) (S2)
3. ERP + FGD at Kendal (S3)
4. ERP + Early decommissioning (ED) of Komati, Hendrina and Grootvlei (S4)

4.1.1 Scenario 1: Full compliance with new plant standards (FC)

Scenario 1 (FC) assumes that all 13 plants investigated will be in full compliance with new plant standards. FC sees the retrofitting of power plants with LNB (6 plants), FFP (6 plants) and FGD (7 plants), in addition to those already installed. LNB installations begin in 2016 at Camden, and end in 2031 at Lethabo. FFP installations begin in 2017 at Duvha, and end in 2026 at Matla and Tutuka. FGD installations begin in 2019 at Kriel and end in 2038 at Lethabo.

Full compliance with all new plant standards for all stations

S1

	Plant Comissioning Period		Decomissioning Period		Abatement Technologies Installed (1-				Abatement Technology Comissioning Period							
Plant	COD Start	COD End	S1DS	S1DE	ESP	LNB	FFP	FGD	ESP-S	ESP-E	LNB-S	LNB-E	FFP-S	FFP-E	FGD-S	FGD-E
Arnot	1971	1975	2021	2029												
Camden	2005	2008	2020	2023		1					2016	2020				
Duvha	1980	1984	2030	2034			1	1					2017	2022	2024	2029
Grootvlei	2008	2011	2025	2028												
Hendrina	1970	1976	2020	2026												
Kendal	1988	1992	2038	2043			1	1					2019	2025	2028	2033
Komati	2009	2013	2024	2028												
Kriel	1976	1979	2026	2029		1	1	1			2019	2025	2019	2025	2019	2025
Lethabo	1985	1990	2035	2040		1	1	1			2026	2031	2019	2025	2032	2038
Majuba	1996	2001	2046	2050		1		1			2020	2026			2030	2036
Matla	1979	1983	2029	2033		1	1	1			2021	2027	2020	2026	2023	2029
Tutuka	1985	1990	2035	2040		1	1	1			2021	2026	2021	2026	2031	2037
Kusile	2017	2022	2051	2051												

Figure 1 (in original report) Scenario 1 (FC) power plant commissioning and decommissioning periods, and abatement technology installation schedules. An S-suffix denotes the start of an activity, and the E-suffix denotes the end of the activity. Abatement technologies are assumed to run from the end of their commissioning date to the decommissioning date of the power plant.

4.1.2 Scenario 2: Emission reduction plan (ERP)

Scenario 2 (ERP) assumes that Eskom will continue with its planned emission reduction plan up to the decommissioning of each power plant. ERP sees the retrofitting of power plants with LNB (4 plants), FFP (1 plant), ESP (4 plants) and FGD at none of the 13 plants modelled, in addition to those abatement technologies already installed. ESP refurbishment installations begin in 2019 at Kendal, Kriel and Lethabo, and end in 2026 at Matla. LNB installations begin in 2016 at Camden, and end in 2027 at Matla. FFP installations begin in 2017 at Duvha, and end in 2026 at Matla and Tutuka. FFP is only installed at Tutuka, beginning in 2021 and ending in 2026.

Planned emission reduction plan up to 50 year life for each station (with only FGD at Medupi)

S2

	Plant Comissioning Period		Decomissioning Period		Abatement Technologies Installed (1-				Abatement Technology Comissioning Period							
Plant	COD Start	COD End	S2DS	S2DE	ESP	LNB	FFP	FGD	ESP-S	ESP-E	LNB-S	LNB-E	FFP-S	FFP-E	FGD-S	FGD-E
Arnot	1971	1975	2021	2029												
Camden	2005	2008	2020	2023		1					2016	2020				
Duvha	1980	1984	2030	2034												
Grootvlei	2008	2011	2025	2028												
Hendrina	1970	1976	2020	2026												
Kendal	1988	1992	2038	2043	1				2019	2025						
Komati	2009	2013	2024	2028												
Kriel	1976	1979	2026	2029	1				2019	2025						
Lethabo	1985	1990	2035	2040	1				2019	2025						
Majuba	1996	2001	2046	2050		1					2020	2026				
Matla	1979	1983	2029	2033	1	1			2020	2026	2021	2027				
Tutuka	1985	1990	2035	2040		1	1				2021	2026	2021	2026		
Kusile	2017	2022	2051	2051												

Figure 2 (in original report) Scenario 2 (ERP) power plant commissioning and decommissioning periods, and abatement technology installation schedules. An S-suffix denotes the start of an activity, and the E-suffix denotes the end of the activity. Abatement technologies are assumed to run from the end of their commissioning date to the decommissioning date of the power plant.

4.1.3 Scenario 3: ERP + Flue gas desulphurization (ERP+FGD)

Scenario 3 (ERP+FGD) assumes that Eskom will continue with its planned emission reduction plan up to the decommissioning of each power plant, as well as installs FGD at Kendal. ERP+FGD sees the retrofitting of power plants with LNB (4 plants), FFP (1 plant), ESP (4 plants) and FGD (1 plant), in addition to those abatement technologies already installed. ESP refurbishment installations begin in 2019 at Kendal, Kriel and Lethabo, and end in 2026 at Matla. LNB installations begin in 2016 at Camden, and end in 2027 at Matla. FFP installations begin in 2017 at Duvha, and end in 2026 at Matla and Tutuka. FFP is only installed at Tutuka, beginning in 2021 and ending in 2026. FGD is only installed at Kendal with installation beginning in 2028 and ending in 2033.

Planned emission reduction plan, as above, and FGD at Kendal and Matimba
S3

	Plant Comissioning Period		Decomissioning Period		Abatement Technologies Installed (1-				Abatement Technology Comissioning Period							
Plant	COD Start	COD End	S3DS	S3DE	ESP	LNB	FFP	FGD	ESP-S	ESP-E	LNB-S	LNB-E	FFP-S	FFP-E	FGD-S	FGD-E
Arnot	1971	1975	2021	2029												
Camden	2005	2008	2020	2023		1					2016	2020				
Duvha	1980	1984	2030	2034												
Grootvlei	2008	2011	2025	2028												
Hendrina	1970	1976	2020	2026												
Kendal	1988	1992	2038	2043	1			1	2019	2025					2028	2033
Komati	2009	2013	2024	2028												
Kriel	1976	1979	2026	2029	1				2019	2025						
Lethabo	1985	1990	2035	2040	1				2019	2025						
Majuba	1996	2001	2046	2050		1					2020	2026				
Matla	1979	1983	2029	2033	1	1			2020	2026	2021	2027				
Tutuka	1985	1990	2035	2040		1	1				2021	2026	2021	2026		
Kusile	2017	2022	2051	2051												

Figure 3 (in original report) Scenario 3 (ERP+FGD) power plant commissioning and decommissioning periods, and abatement technology installation schedules. An S-suffix denotes the start of an activity, and the E-suffix denotes the end of the activity. Abatement technologies are assumed to run from the end of their commissioning date to the decommissioning date of the power plant.

4.1.4 Scenario 4: ERP + Early decommissioning (ERP+ED)

Scenario 4 (ERP+ED) assumes that Eskom will continue with its planned emission reduction plan up to the decommissioning of each power plant, as well initiates early decommissioning at Grootvlei, Hendrina and Komati. ERP+ED sees the retrofitting of power plants with LNB (4 plants), FFP (1 plant), ESP (4 plants), in addition to those abatement technologies already installed. ESP installations begin in 2019 at Kendal, Kriel and Lethabo, and end in 2026 at Matla. LNB installations begin in 2016 at Camden, and end in 2027 at Matla. FFP installations begin in 2017 at Duvha, and end in 2026 at Matla and Tutuka. FFP is only installed at Tutuka, beginning in 2021 and ending in 2026.

Planned emission reduction plan and without Komati/ Hendrina/ Grootvlei from 2018/2019

S4

	Plant Comissioning Period		Decomissioning Period		Abatement Technologies Installed (1-				Abatement Technology Comissioning Period							
Plant	COD Start	COD End	S4DS	S4DE	ESP	LNB	FFP	FGD	ESP-S	ESP-E	LNB-S	LNB-E	FFP-S	FFP-E	FGD-S	FGD-E
Arnot	1971	1975	2021	2029												
Camden	2005	2008	2020	2023		1					2016	2020				
Duvha	1980	1984	2030	2034												
Grootvlei	2008	2011	2019	2019												
Hendrina	1970	1976	2019	2019												
Kendal	1988	1992	2038	2043	1				2019	2025						
Komati	2009	2013	2019	2019												
Kriel	1976	1979	2026	2029	1				2019	2025						
Lethabo	1985	1990	2035	2040	1				2019	2025						
Majuba	1996	2001	2046	2050		1					2020	2026				
Matla	1979	1983	2029	2033	1	1			2020	2026	2021	2027				
Tutuka	1985	1990	2035	2040		1	1				2021	2026	2021	2026		
Kusile	2017	2022	2051	2051												

Figure 4 (in original report) Scenario 4 (ERP+ED) power plant commissioning and decommissioning periods, and abatement technology installation schedules. An S-suffix denotes the start of an activity, and the E-suffix denotes the end of the activity. Abatement technologies are assumed to run from the end of their commissioning date to the decommissioning date of the power plant.

4.2 Summary: 2018 Study

Approximately 20.3 million people are exposed to air pollution from the 13 power plants modelled, that fall within the modelling domain. The mean additional annual average exposure to air pollution of the population within this domain, resulting from coal-fired power station emissions, was estimated by averaging dispersion modelling results over municipal boundaries. Approximately 17.7 million people were exposed to more than an additional 1µg.m^3 (mean annual average) of $PM_{2.5}$. Similarly, 15.3 and 19.0 million people, respectively, were exposed to more than an additional 1µg.m^3 of NO_2 and SO_2.

The health effects of this increased exposure were determined using an AP-HRA, that applied ERFs to the baseline incidence rates, and determined that air pollution from the 13 power plants do have a large health impact. There was extreme variability with the total health costs estimates, which varied by as much as 80%. Furthermore, the total health cost is extremely sensitive to the VSL used, and a conservative value of R48 million was used.

Health benefits associated with each scenario were calculated against the baseline that assumed no new abatement technologies would be installed, and all plants would continue to emit air pollution at their current rates until decommissioning. The scenario with the highest health benefits was ERP+ED (S4), highlighting the immediate results achievable if early decommissioning of power plants can be achieved. The ERP+ED (S4) is estimated to result in health benefits with a NPV that varied between R 3.4 billion and R 30.1 billion. The FC (S1) had the next highest health benefits with a NPV that varied between R 2.5 billion and R 22.1 billion. The ERP+FGD (S3) had marginally higher health benefits than ERP (S2) due to the additional FGD at Kendal. Figure 27 demonstrates the averaged flow of benefits for the four scenarios.

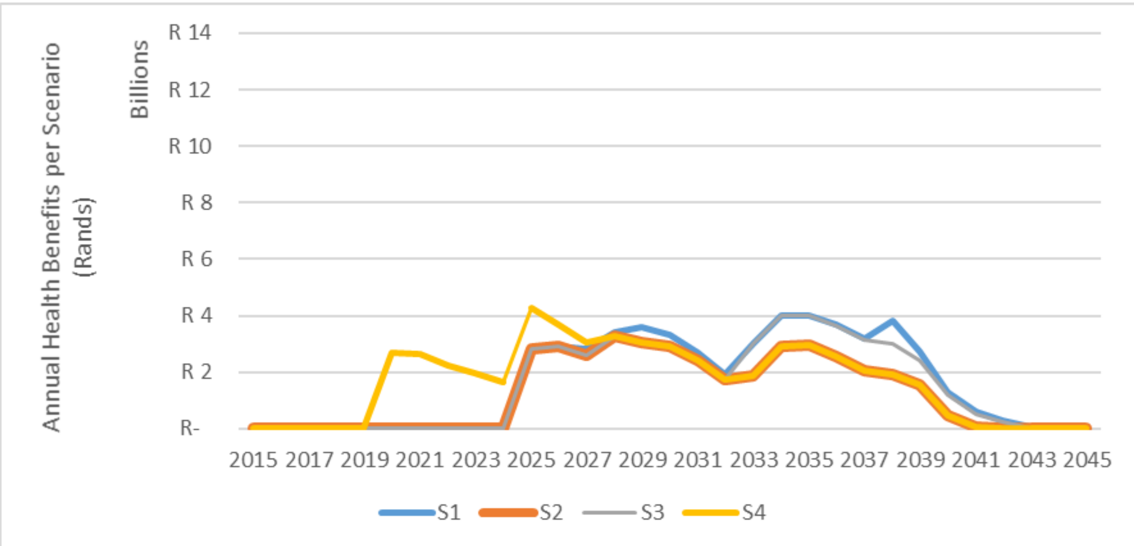

Figure 5 Annual health benefits per scenario

Scenario costs were calculated using Eskom's estimates of abatement technology capital and operational spending requirements. As expected, the FC (S1) had the highest costs due to having the most abatement technologies installed, with the NPV between -R43.4 billion to -R65.1 billion. The ERP (S2) and ERP+ED (S4) had the same costs as they both had the same abatement technology additions with a NPV between -R16.9 billion to -R25.3 billion. The ERP+FGD (S3) had a higher cost with a NPV of -R21.2billion to -R31.8 billion due to the additional FGD at Kendal. Figure 28 demonstrates the averaged flow of costs for the four scenarios.

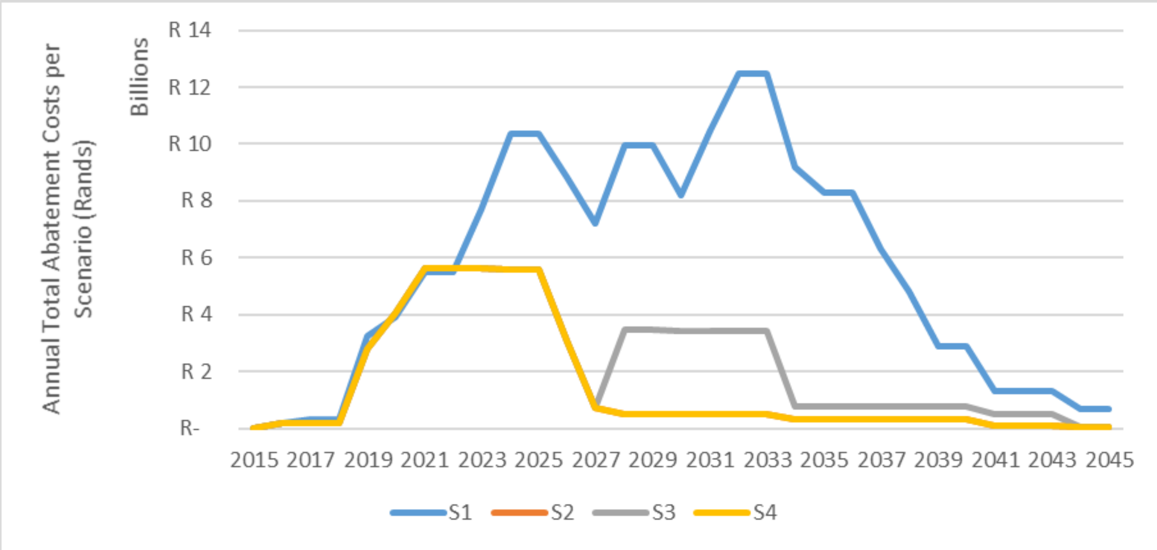

Figure 6 Total abatement costs (CAPEX and OPEX) associated with each scenario's abatement retrofits

Scenarios were compared in a cost-benefit analysis. The cost-benefit analysis apportioned costs (capital and operation expenditure on abatement technologies) and benefits (health benefits) to the years in which they would be realised. Because costs and benefits are accrued in different years according to the intervention schedules, the net present values of costs and benefits, using Eskom's weighted average cost of capital (WACC) rate of 8.4% as the discount rate allows an objective comparison of scenarios. Dividing the NPV of costs by the NPV of benefits provides a cost:benefit ratio, which when greater than 1 indicates that the costs outweigh the benefits, and when less than 1 indicate that the benefits outweigh the costs.

The CBA ratios need to be interpreted with care. They are meant only to provide a perspective on and inform the decision-making process underlying the scenarios. They are not meant to be interpreted as a definitive answer to making abatement decisions. Decisions involving human health has to be informed by non-economic criteria as well. In addition, uncertainty inherent in the analysis, the cost benefit ratio should thus not be viewed as absolute, but rather as a relative value from which to compare scenarios.

Table 3 Costs and benefits NPV estimates (lower and upper ranges) for each scenario, and cost:benefit ratios

	FC (S1)		ERP (S2)		ERP+FGD (S3)		ERP+ED (S4)	
Million Rands	*lower*	*upper*	*lower*	*upper*	*lower*	*upper*	*lower*	*upper*
NPV of Costs	-43 369	-65 053	-16 923	-25 385	-21 205	-31 808	-16 923	-25 385
NPV of Benefits	2 403	21 625	1 962	17 661	2 252	20 264	3 374	30 367
NPV of Benefits minus Costs	-40 966	-43 428	-14 961	-7 724	-18 954	-11 544	-13 549	4 982
Cost: Benefit Ratio (*range*)	18.0	3.0	8.6	1.4	9.4	1.6	5.0	0.8
Cost: Benefit Ratio (*central*)	4.5		2.2		2.4		1.3	

In spite of the uncertainties that are inherent in the current assessment process, the assessment provides valuable insights into the effects of air pollution and abatement. The larger investigation has made significant progress on improving the accuracy of dispersion modelling, through modelling secondary PM emissions and through performing cumulative emissions analysis. This work has increased our understanding of the exposed population. It is recommended that the analysis performed here be continuously improved to address prioritised sources of uncertainty. Improving the accuracy of the ERFs needs priority attention as AP-HRA applications continue to be improved.

In spite of the level of uncertainty associated with ERFs, epidemiological evidence is sufficient to confirm the hypothesis that abatement technologies would have positive impacts on human health.

More significantly, early decommissioning of the coal-fired power stations assessed in ERP+ED (S4), would have a significantly larger beneficial effect on health costs than abatement technologies alone. This plays a large role in positioning Scenario 4 as the most beneficial scenario, both in terms of largest health cost benefits, lowest cost of abatement, as well as relative cost:benefit ratio. While the FC (S1) would eventually have the most absolute benefits (see Figure 27), the uncertainty of the effectiveness of actual emission reduction (assumed to meet MES) as well as the long implementation timeframe mean that NPV of benefits values are reduced.

It is also noted that the abatement technologies are expensive and would place a significant financial burden on Eskom.