Health impacts and social costs of Eskom's proposed non-compliance with South Africa's air emission standards

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The state-owned utility Eskom is applying for wide-ranging postponements from the South African law setting minimum emission standards for power plants. The purpose of the applications is to enable the company to follow a euphemistically named "Emission Reduction Plan" that would entail dramatically higher air pollution emissions than compliance with the Minimum Emission Standards (MES) for decades. This non-compliance would render these provisions of the law close to meaningless, as they concern the majority of South Africa's thermal power stations.

Air pollution emissions from thermal power plants contribute to ambient particulate matter, which is the most important environmental health risk globally, as well as to emissions of mercury, a potent neurotoxin that harms the mental development of children. Regardless of this, Eskom has refused to assess the health impacts of its proposed postponements, the majority of which are effectively exemptions.

This paper applies available modeling tools implementable in GIS software to provide an estimate of the health damages and economic costs that would be avoided by requiring Eskom to comply fully with the national air emission standards.

Data and methodology

The assessment of the health and economic impacts follows the impact pathway approach: estimate excess emissions resulting from Eskom's planned non-compliance with the MES; model the increases in population exposure to PM2.5 and mercury that would result from these emissions; assess the health impacts of these increases; and value the health impacts in monetary terms.

Emissions

Data on power plant locations and current average emissions are available from the Eskom study plan. The exception is the Medupi power plant, for which only the expected stack emission concentrations were available. The plant's projected annual CO2 emissions were taken from the CARMA database, and were used to calculate annual flue gas volume for the estimation of the annual emissions. This paper focuses on the continuously operating coal-fired power plants which are responsible for the vast majority of annual emissions.

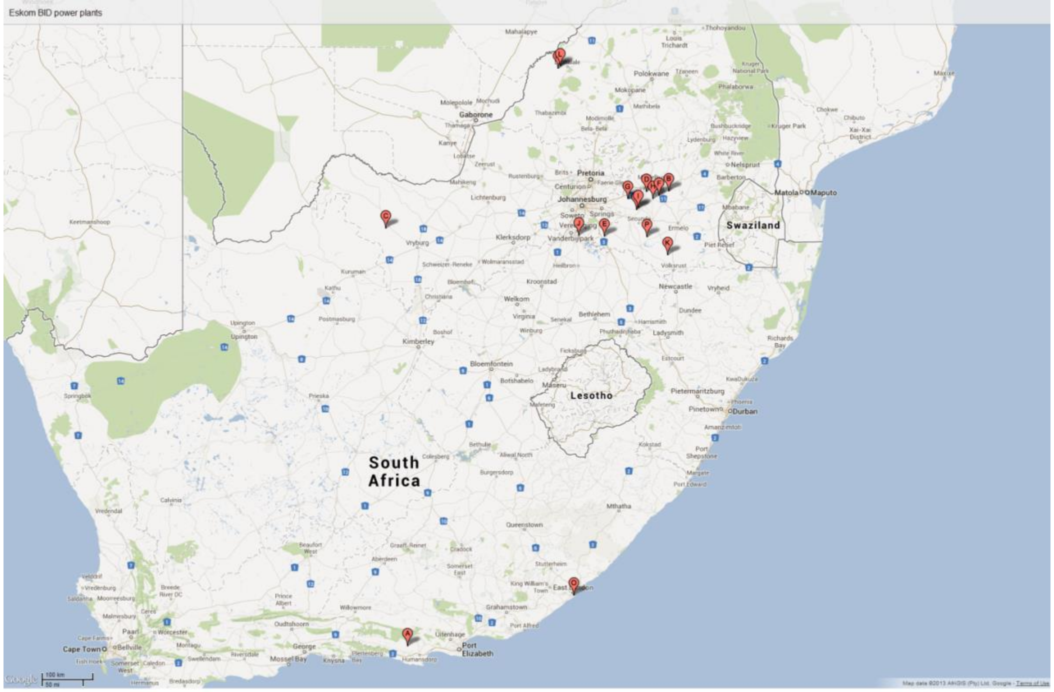

Figure 1. Locations of the power plants covered by Eskom's request for postponements.

Table 1. Current emissions (except projected emissions for Medupi), from Eskom study plan. Values highlighted in blue are taken from the December 2013 Atmospheric Impact Reports, as different values were reported.

Emission source				Emissions, t/a			Currently achievable emission limits, mg/Nm3 @10%O2		
Power station	Stack	Lat	Lon	NOx	SO2	PM10	NOx	SO2	PM10
Arnot	Stack 1	-25.94	29.79	25692	38637	1495	1200	2500	50
Arnot	Stack 2	-25.94	29.79	25691	38637	1495	1200	2500	50
Camden	Stack 1	-26.62	24.09	10345	21325	1041	1700	4000	75
Camden	Stack 2	-26.62	24.09	10345	21325	1041	1700	4000	75
Camden	Stack 3	-26.62	24.09	10345	21325	1041	1700	4000	75
Camden	Stack 4	-26.62	24.09	10345	21325	1041	1700	4000	75
Duvha U1-3	Stack 1	-25.96	29.34	39638	68618	4548	1100	2600	200
Duvha U4-6	Stack 2	-25.96	29.34	39638	68618	4548	1100	2600	350
Grootvlei	Stack 1	-26.77	28.50	12376	23929	4084	1200	3800	350
Grootvlei	Stack 2	-26.77	28.50	12376	23929	4084	1200	3800	340
Hendrina	Stack 1	-26.03	29.60	24089	56871	1273	1300	3800	50
Hendrina	Stack 2	-26.03	29.60	24089	56871	1273	1300	3800	50
Kendal	Stack 1	-26.09	28.97	45772	109019	5144	750	2800	100
Kendal	Stack 2	-26.09	28.97	45772	109019	5144	750	2800	100
Kriel	Stack 1	-26.25	29.18	50272	56167	7610	1600	2800	350
Kriel	Stack 2	-26.25	29.18	50272	56167	7610	1600	2800	350
Komati	Stack 1	-26.09	29.47	11150	11462	1253	1400	3200	100
Komati	Stack 2	-26.09	29.47	11150	11462	1253	1400	3200	100
Lethabo	Stack 1	-26.74	27.98	54026	98105	6725	1100	3100	150
Lethabo	Stack 2	-26.74	27.98	54026	98105	6725	1100	3100	150
Majuba	Stack 1	-27.10	29.77	68904	87582	1245	1500	3200	50
Majuba	Stack 2	-27.10	29.77	68904	87582	1245	1500	3200	50
Matimba	Stack 1	-23.67	27.61	33796	154631	2452	750	3700	100
Matimba	Stack 2	-23.67	27.61	33796	154631	2452	750	3700	100
Matla	Stack 1	-26.28	29.14	56520	89082	6773	1400	2900	200
Matla	Stack 2	-26.28	29.14	56520	89082	6773	1400	2900	200
Medupi	Stack 1	-23.70	27.56	30691	224308	2046	750	4000	50
Medupi	Stack 2	-23.70	27.56	30691	224308	2046	750	4000	50
Tutuka	Stack 1	-26.78	29.35	52332	89216	7494	1200	3400	350
Tutuka	Stack 2	-26.78	29.35	52332	89216	7494	1200	3400	350

Table 2. Projected non-compliance with MES in Eskom's "Emission Reduction Plan". Table entries indicate dates on which Eskom plans to comply; "end-of-life" indicates that the units will not comply at all; blank entries indicate compliance from the onset.

Pollutant	**PM**		**NOx**		**SO2**	
Standard	**2015**	**2020**	**2015**	**2020**	**2015**	**2020**
Power plant						
Acacia				End-of-life		
Ankerlig - all units						
Arnot			End-of-life	End-of-life		End-of-life
Camden		End-of-life	End-of-life	End-of-life	End-of-life	End-of-life
Duvha U1-3				End-of-life		End-of-life
Duvha U4-6	Apr 2024	Apr 2024		End-of-life		End-of-life
Gourikwa - all units						
Grootvlei	End 2017	End-of-life	End-of-life	End-of-life	End-of-life	End-of-life
Hendrina			End-of-life	End-of-life	End-of-life	End-of-life
Kendal		End-of-life				End-of-life
Komati		End-of-life	End-of-life	End-of-life		End-of-life
Kriel	Apr 2025	Apr 2025	Apr 2025	Apr 2025		End-of-life
Kusile						
Lethabo		End-of-life		End-of-life		End-of-life
Majuba			Apr 2025	Apr 2025		End-of-life
Matimba		End-of-life			End-of-life	End-of-life
Matla	Apr 2025	Apr 2025	Apr 2025	Apr 2025		End-of-life
Medupi					End 2026	End 2026
Port Rex				End-of-life		
Tutuka	Apr 2024	Apr 2024	Apr 2025	Apr 2025		End-of-life

For some power plants, Eskom has proposed emission limits that are different from both currently achieved values and the new emission standards[1]. These values are taken into account. Eskom is also requesting unlimited PM10 emissions for 10-20% of the time for Arnot, Camden, Hendrina, Kendal, Komati and Matimba. This provision could increase average annual emissions by up to 2-fold. The effect on the attainment of ambient air quality standards is even more dramatic. However, the provision for unlimited emissions is not taken into account in estimating annual emissions to keep the estimates conservative.

In the applications Eskom states: "Actual average emissions need to be 30-40% lower than the emission limit to ensure that the emission limit is consistently achieved." This is assumed to apply to both the current emission limits and the new emission standards. The annual emissions resulting from full compliance with the emission standards were calculated by scaling the current annual emissions, reported by Eskom, down by the ratio of the emission standard to the current emission limit that the plant is able to comply with. The excess emissions are the difference between the current emissions and the emissions under full compliance. So for example, if a power plant is currently emitting 1,000 tonnes

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[1] Grootvlei PM10 75 mg/Nm3 from 2020 and Komati SO2 and NOx 3200 and 1400 mg/Nm3 respectively.

of PM10 per year, and can comply with an emission limit value of 100 mg/Nm3, compliance with an emission standard of 50 mg/Nm3 would result in annual emissions of 500 tonnes of PM10.

To calculate the cumulative excess emissions over time, information on the projected retirement dates of the power plants is needed. The information provided by Eskom in the applications is vague, so the dates given in South Africa's 2012 Integrated Energy Planning Report are used instead. Taking averages of the ranges given by Eskom would result in longer projected plant lives and hence higher cumulative emissions than assumed here.

Table 3. Projected plant retirements (2012 Integrated Energy Planning Report)

Plant	Retirement
Arnot	2023
Camden	2025
Duvha U1-3	2032
Duvha U4-6	2032
Grootvlei	2029
Hendrina	2022
Kendal	2040
Komati	2024
Kriel	2028
Kusile	2053
Lethabo	2037
Majuba	2051
Matimba	2039
Matla	2031
Medupi	2052
Port Rex	2025
Tutuka	2037

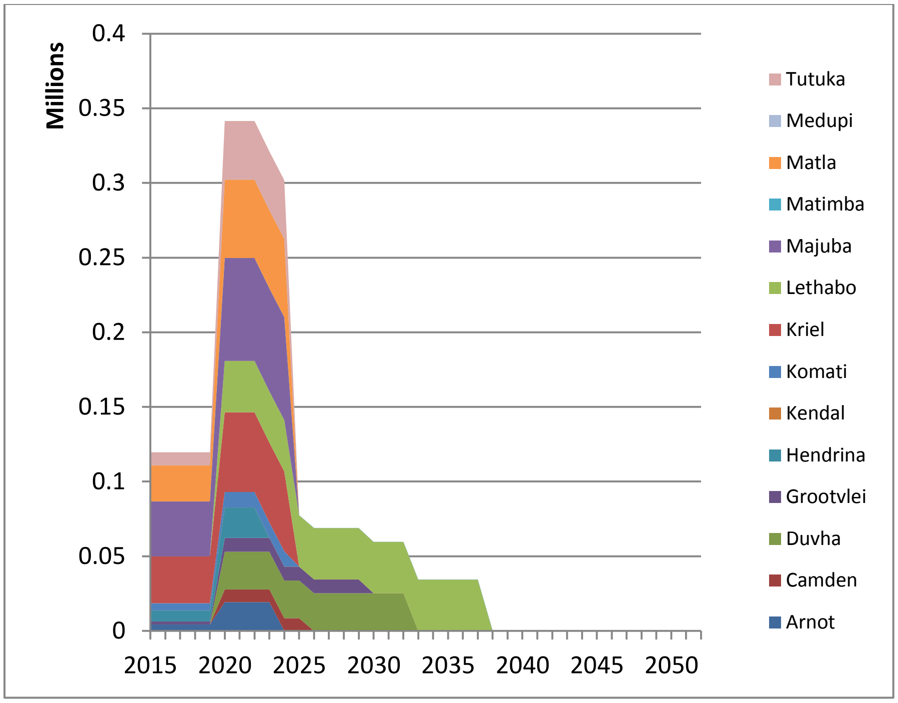

Figure 2. Estimated emissions of NOx in excess of the MES (Mt).

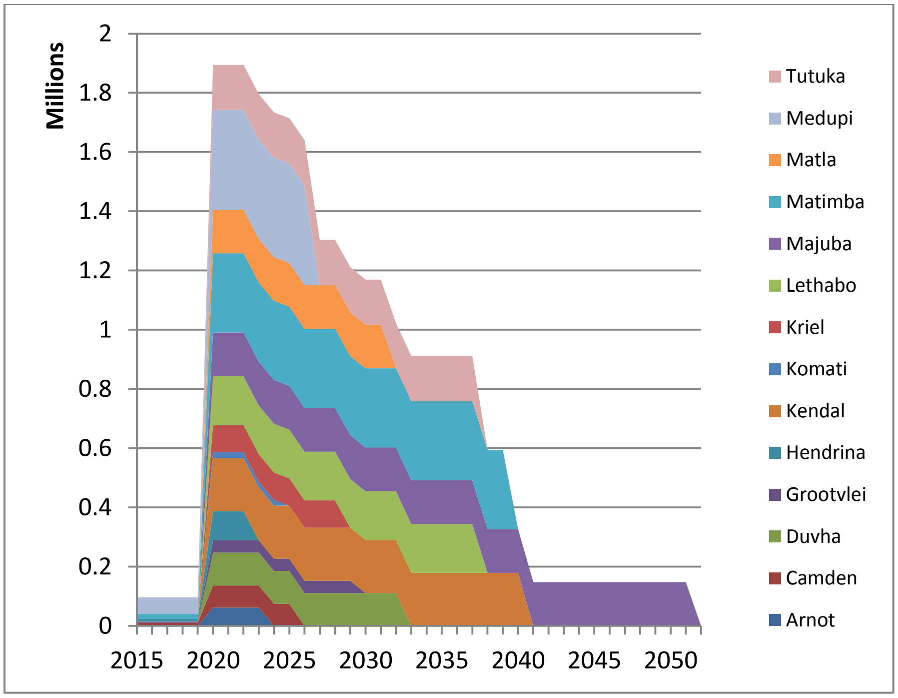

Figure 3. Estimated emissions of SO2 in excess of the MES (Mt).

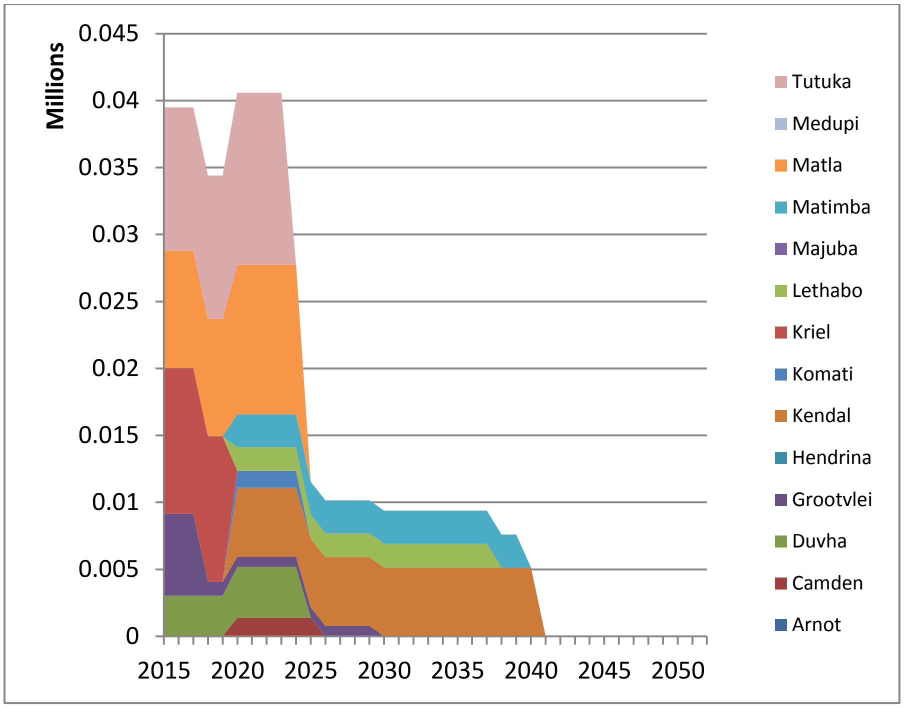

Figure 4. Estimated emissions of PM10 in excess of the MES (Mt). The "odd" shape of the graph results from Grootvlei's PM10 emissions being brought into compliance with the 2015 MES in 2018.

PM2.5 emissions are estimated from PM10 using a ratio of 4/9, as per US EPA AP-42 and European Environment Agency.

Calculating excess emissions of mercury resulting from Eskom's planned non-compliance

The new South African emission control requirements would have significant ancillary mercury control benefits, and hence the failure by Eskom to install the required emission controls would lead to higher mercury emissions than in the case of full compliance.

Current mercury emissions and removal rates (share of mercury contained in the burned coal that is not emitted through the stack) of Eskom fleet were estimated by Scott (2011). The same methodology was used to estimate emissions for Medupi.

Table 4. Current mercury emissions.

	Hg emissions in 2009/10, kg[1]	**Current removal rate**
Arnot	578	50%
Camden	728.5	50%
Duvha	1883.7	30%
Grootvlei	347.2	30%
Hendrina	724.5	50%
Kendal	5504.4	10%
Komati	107.1	50%

Kriel	2218.5	10%
Lethabo	5896.8	10%
Majuba	1599	50%
Matimba	5913	10%
Matla	2901.6	19%
Medupi	2250	50%
Tutuka	2766.6	10%

[1] Medupi emissions projected

Table 5. Mercury removal rates assumed for different air pollution control technologies.

ESP	30%
Fabric filter	50%
Fabric filter + FGD	70%

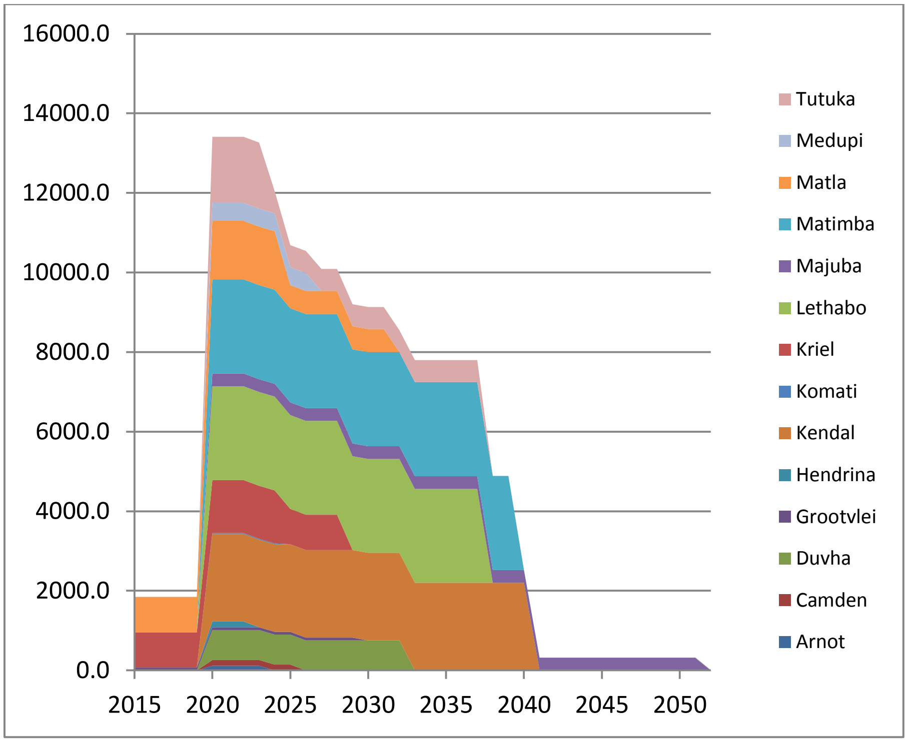

Figure 5. Estimated emissions of mercury in excess of the emission rates associated with compliance with the MES (kg).

Table 6. Estimated total cumulative excess emissions.

NOx (Mt)	2.9
SO2 (Mt)	27.9
PM10 (Mt)	0.56
Mercury (t)	207

Implementing the single-source PM2.5 regression models

The preferred method to study source contributions to ambient PM2.5 levels is to use atmospheric chemical-transport models (CTMs). However, the preparation of atmospheric data and execution of these models is time-consuming and computationally expensive, and was not possible within the timeframe of the public consultation on Eskom's applications for exemptions. It is possible to emulate the full modeling results by using regression models derived from a large number of single-source CTM model runs. This paper implements two such models - Baker & Foley (2011) model based on CAMx modeling of stack emissions of large U.S. air pollution emission sources, and developed by U.S. Environmental Protection Agency staff, and Zhou et al (2006) model based on CALPUFF modeling of power plants in China. Together, these two modeling exercises cover a large range of conditions. The input data and data sources for the models are presented below.

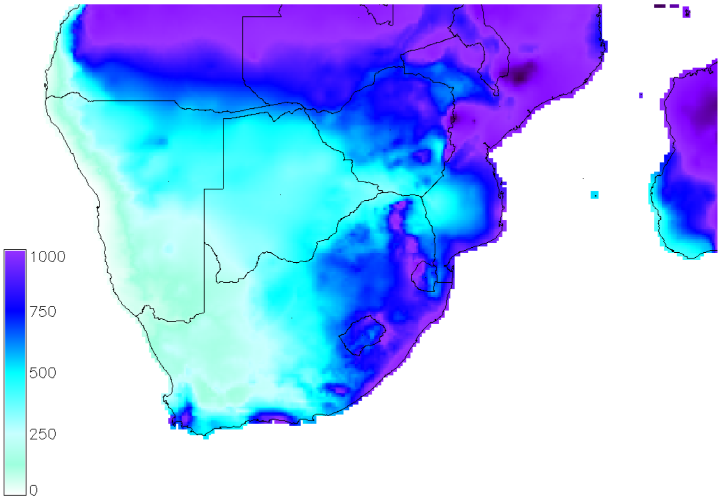

Figure 6. Rainfall, mm/yr (Hijmans et al 2005).

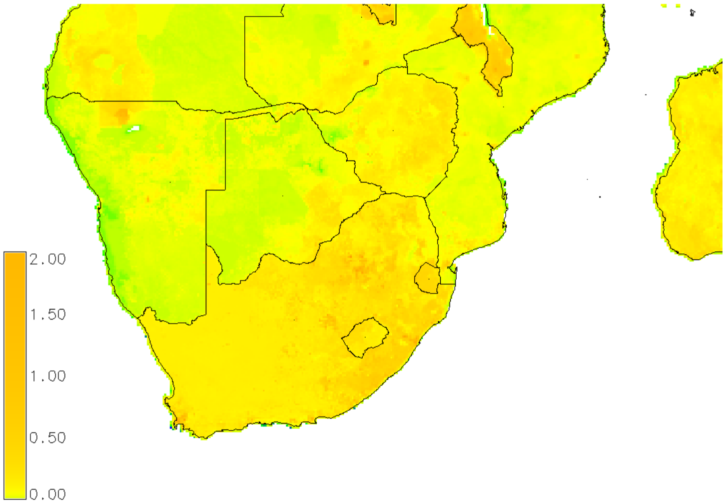

Figure 7. Ammonia emissions t/km2/year (EDGAR v4.2).

Assessing exposure and health impacts

Once the contributions to ground-level PM2.5 concentrations from the power plant emissions are estimated, resulting population exposure is assessed using high-resolution population data. Health impacts associated with the population exposure are estimated using the PM2.5 risk functions for lung cancer, ischemic heart disease, stroke, chronic obstructive pulmonary disease in adults, based on the American Cancer Society study that followed half a million U.S. adults for 20 years (Krewski et al 2009), and that was used for the Global Burden of Disease 2010 study. For children, increased mortality from acute lower respiratory infections in children is evaluated, based on the extensive literature survey by Mehta et al 2011). Application of these risk functions requires data on the cause-specific baseline death rates for South Africa, which is taken from the Global Burden of Disease 2010 study. Using the all-age death rates accounts for population age and sex structure, health status and quality of medical care in South Africa, among other factors.

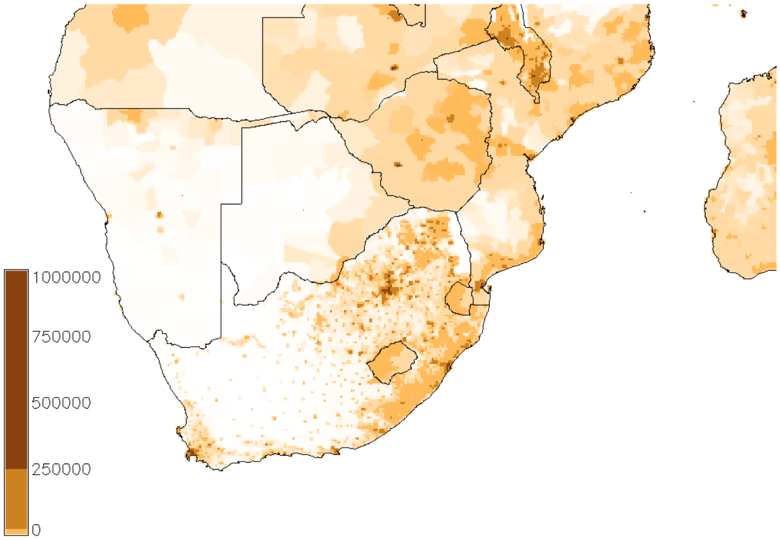

Figure 8. Population counts at 0.1x0.1 degree resolution (GPWv3 projections for 2010).

Table 7. Cause-specific death rates per 100,000 population, 2010, all ages (Global Burden of Disease 2010).

Cause of death	Age	Mean	95% CI low	95% CI high
Lung cancer	All ages	9.08	7.57	12.27
IHD	All ages	34.63	30.58	43.32
COPD	All ages	11.83	10.49	13.84
Stroke	All ages	48.58	58.63	42.28
Lower respiratory infection	Under 5 years[2]	12.15	16.85	8.62

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[2] Deaths in children under 5 years per 100,000 people in the whole population (all ages).

Table 8. Relative risk factors for cause-specific mortality, per 10µg/m3 increase in annual average ambient PM2.5 (as used for Global Burden of Disease 2010 by Lim et al 2012; original source American Cancer Society study, Krewski et al 2009; except LRI: Mehta et al 2011).

Cause of death	RR	95% CI low	95% CI high
Lung cancer	1.14	1.06	1.23
IHD	1.26	1.16	1.38
COPD	1.05	0.95	1.17
Stroke	1.12	1.01	1.24
Lower respiratory infection (children under 5)	1.12	1.03	1.3

Neurotoxic effects of mercury emissions on children are evaluated using the globally applicable damage functions derived by Spadaro & Rabl (2008).

Evaluating the economic cost of the health impacts

The economic valuation of human health impacts is a tool to estimate what would be an acceptable cost for avoiding those impacts. The approach used in this paper measures people's own willingness to pay to avoid a risk of death. The premise is that since health risks from air pollution affect a large number of South Africans fairly uniformly, the government's willingness to direct resources to reducing health impacts from air pollution should be the same as the willingness of the people it governs. Eskom appears to accept this principle in its applications, writing: "*Although emission retrofits increase the cost of electricity … the cost is justified if based on health benefits.*"

Unfortunately, willingness-to-pay studies applicable to air pollution have not been carried out for South Africa. The approach followed here is recommended by OECD (2012) and based on a recent and comprehensive survey of willingness-to-pay studies. The difference in income levels between OECD countries and South Africa is taken into account, as well as the observed difference in willingness-to-pay to avoid mortality risks for children and adults. The causes of death covered in the health impact assessment result in average loss of 20-25 life years for each death for adults and over 80 years for small children (Global Burden of Disease 2010), so willingness-to-pay studies covering healthy adults and children are applicable.

The estimated annual costs over time are adjusted and discounted to the present by applying a discount rate of 5% and assuming a GNI per capita growth rate of 4.7% (2002-2012 average, based on World Bank statistics), and an income elasticity of 0.8 over time, implying 3.8% annual increase in willingness to pay.

For mercury, globally applicable damage cost values have been derived by Spadaro & Rabl (2008). The authors used a discount rate of 3%, which yields lower estimates than the combination of 5% discount rate and 3.8% increase in value of statistical life used in this paper. No adjustment was performed.

Table 9. Deriving the value of statistical life (VSL) for South Africa using the approach recommended by the OECD.

	Central	Low	High	Unit	Reference
VSL, OECD 2005	3	*1.5*	*4.5*	mln USD(2005)	OECD 2012
Income elasticity of VSL	0.8	*0.9*	*0.4*	mln USD(2005)	OECD 2012
Children VSL compared to adults	2	*1.5*	*2*		OECD 2012
OECD GNI per capita 2005	35,115			USD(2005)	World Bank statistics
U.S. GDP deflator 2005-2012	1.18				U.S. Bureau of Labor Statistics
South Africa GNI 2012	11,190			USD(2012), PPP	World Bank statistics
USD-ZAR exchange rate 2012	8.548				Oanda.com
VSL, South Africa, 2012, adults	**12.1**	**5.4**	**28.7**	**mln ZAR(2012)**	
VSL, South Africa, 2012, children	**24.2**	**8.1**	**57.5**	**mln ZAR(2012)**	

Table 10. Mercury emission damage costs (Spadaro & Rabl 2008).

Mercury damage costs	**central**	**low**	**high**
USD-2005 /kg	3,400	288	5,099
ZAR-2012/kg	41,484	3,515	62,212

Results

This section presents the results of the evaluation: first the estimated impacts from the current emission rates from Eskom power plants, and then the projected excess emissions and impacts caused by Eskom's proposed non-compliance with the Minimum Emission Standards.

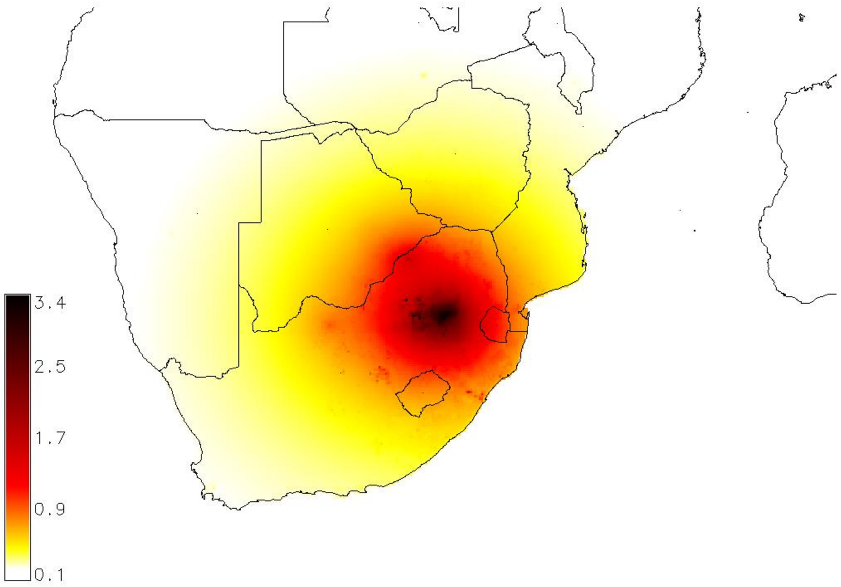


Figure 9. Predicted annual average PM2.5 contributions by Eskom plants covered by Eskom's postponement applications (Baker & Foley 2011 model), µg/m^3.

The Baker&Foley regression model is not validated beyond 1000km from each source, so estimated population exposure beyond this distance is excluded from the totals.

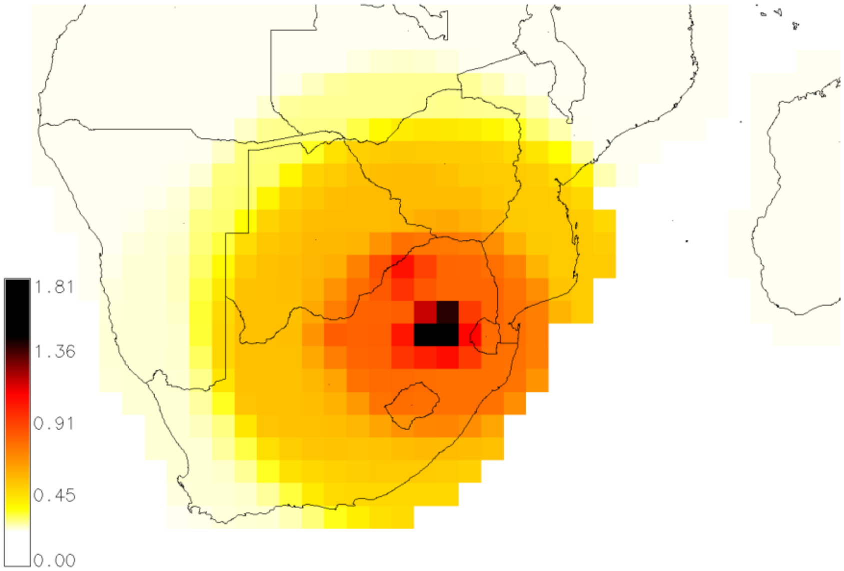
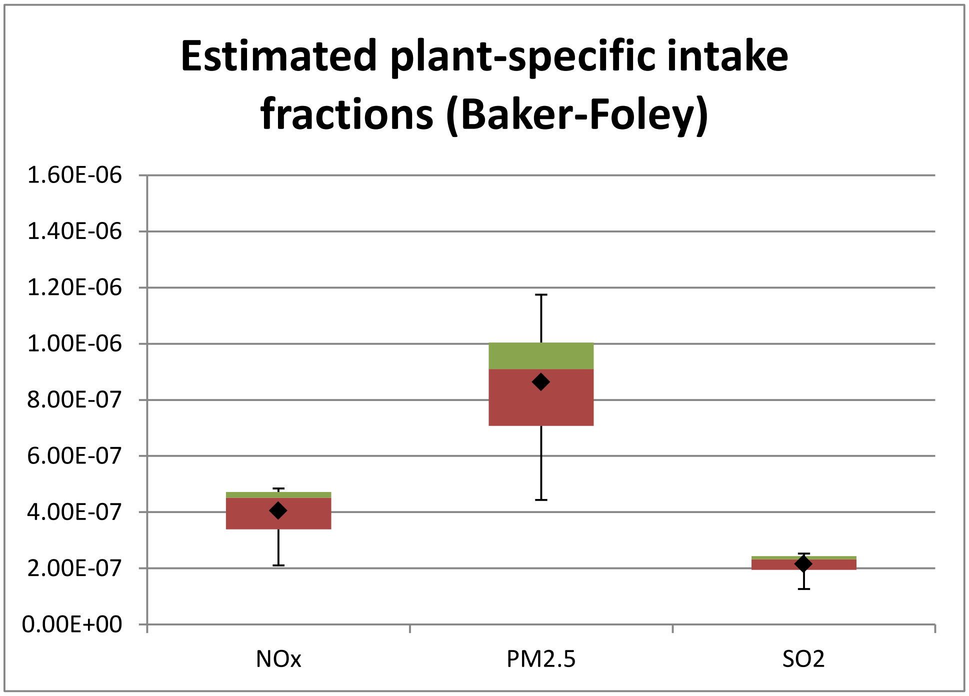
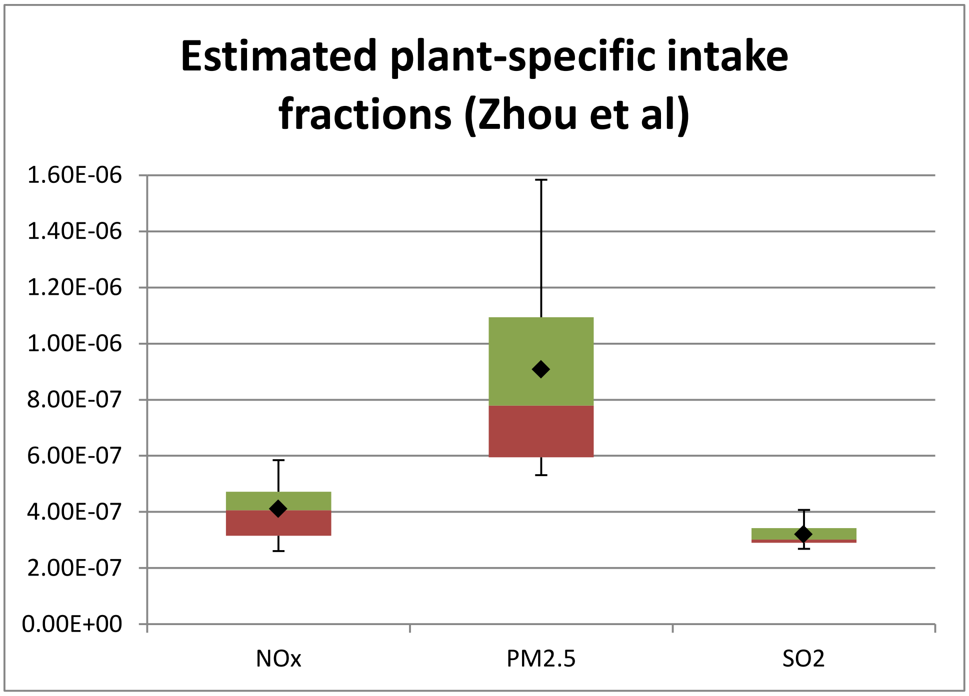


Figure 10. Predicted annual average PM2.5 contributions by Eskom's postponement applications (Zhou et al model), µg/m3.





Figures 11a-b. Distribution of the emission intake fractions estimated for the power plants by the two regression models. For NOx and SO2, the intake fractions refer to kilograms of secondary PM2.5 inhaled per kilogram of pollutant emitted. The estimated intake fractions are significantly lower than in European and Chinese studies, reflecting lower population density.

Table 11. Estimated health impacts: current annual premature deaths attributable to PM2.5 and precursor emissions from power plants covered by the BID.

	Baker-Foley			Zhou et al		
	central	low	high	central	low	high
Lung cancer	157	56	348	191	68	425
IHD	1,110	603	2,029	1,355	736	2,477
COPD	73	-65	290	89	-79	354
Stroke	719	72	1,251	877	88	1,527
Lower respiratory infection	180	62	319	219	76	389
Total	2,238	729	4,237	2,731	890	5,171

Based on the two models, it is estimated that 2,200 to 2,700 premature deaths are caused each year by the air pollution emissions from Eskom's coal-fired power plants, including 200 deaths of young children.

The two regression models are in good agreement, given that they are based on entirely different geographical regions and atmospheric models. The Zhou et al model yields approximately 20% higher estimates, so conservatively, the Baker-Foley model is used as the central estimate.

Table 12. Estimated cumulative premature deaths caused by PM2.5 exposure as a result of the excess air pollution emissions allowed by ESKOM's planned non-compliance with the MES (Baker-Foley model).

	central	low	High
Lung cancer	1,419	507	3,152
IHD	10,054	5,463	18,383
COPD	660	-586	2,627
Stroke	6,509	655	11,331
Lower respiratory infections (children under 5)	1,628	565	2,888
Total	20,271	6,604	38,381

The excess emission of 210 tonnes of mercury, and resulting exposure of children and pregnant women to toxic mercury, would be associated with the loss of an estimated 280,000 IQ points (confidence interval of 24,000-420,000), as per Spadaro & Rabl (2008). Similarly, the current emissions are associated with the loss of 45,000 IQ points each year.

Table 13. Estimated annual external costs to the society currently caused by air pollution emissions from Eskom's coal-fired power plants, bln ZAR.

	central	Low	high
PM2.5 (Baker-Foley)	30	4	134
Mercury (no threshold)	1.4	0.12	2.2
Total	31	4	136

Table 14. Estimated cumulative external costs to the society caused by Eskom's non-compliance with the MES, bln ZAR.

	central	Low	high
PM2.5 (Baker-Foley)	224	31	1,001
Mercury (no threshold)	7.2	0.61	10.8
Total	231	32	1,011

Summary

Air pollution emissions from Eskom's coal-fired power plants are currently causing an estimated 2,200 premature deaths per year, due to exposure to fine particulate matter (PM2.5). This includes approximately 200 deaths of young children. The economic cost to the society is estimated at 30 billion rand per year, including premature deaths from PM2.5 exposure and costs from the neurotoxic effects of mercury on children.

The non-compliance of Eskom's coal-fired power plants with the Minimum Emission Standards implied by the company's so-called "Emission Reduction Plan" would allow Eskom to emit an estimated 28,000,000 tonnes of excess SO2, 2,900,000 tonnes of NOx, 560,000 tonnes of PM10 and 210 tonnes of toxic mercury over the remaining life of the power plants. The excess SO2 emissions, for example, are equal to Eskom's entire emissions for 15 years at current rates.

The excess emissions are projected to cause approximately 20,000 premature deaths, over the remaining life of the power plants. This includes approximately 1,600 deaths of young children. These deaths will be avoided if Eskom's applications are rejected and full compliance with the MES is required. The neurotoxic effects of the excess emissions of mercury would result in a projected loss of 280,000 IQ points.

The economic cost associated with the premature deaths, and the neurotoxic effects of mercury exposure, is estimated at 230 billion rand, with a confidence interval of 32 to 1,010 billion rand. This cost is based on the estimated willingness of the affected people, given their income levels, to pay to avoid the increased risk of death. As individual people do not have the choice of spending money to significantly reduce toxic power plant emissions, government action to mandate polluters to invest in emission reductions is justified.

Valuing the life of people with lower incomes at a lower level is a contentious concept, and using the value of life based on studies in OECD countries for cost-benefit analysis, without adjusting for lower income in South Africa, would result in a several times higher estimate. Furthermore, the cost evaluation is conservative in that it does not account for health impacts other than deaths.

The aim of this study, carried out using a simplified approach to air pollution exposure assessment, is not to be the final word on the health impacts of Eskom's power plants. The uncertainties associated with the estimates are quite large, as is typical of health impact assessment studies. However, even given the uncertainties, the results clearly demonstrate that the potential health impacts and economic burden associated with Eskom's proposed non-compliance with the MES are very large. In the same vein, they demonstrate the acute need for recognition and assessment of the health impacts of the MES "rolling postponements" as a part of the decision-making process – an assessment that Eskom has so far refused to carry out.

In Exeter, UK, February 10 2014

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