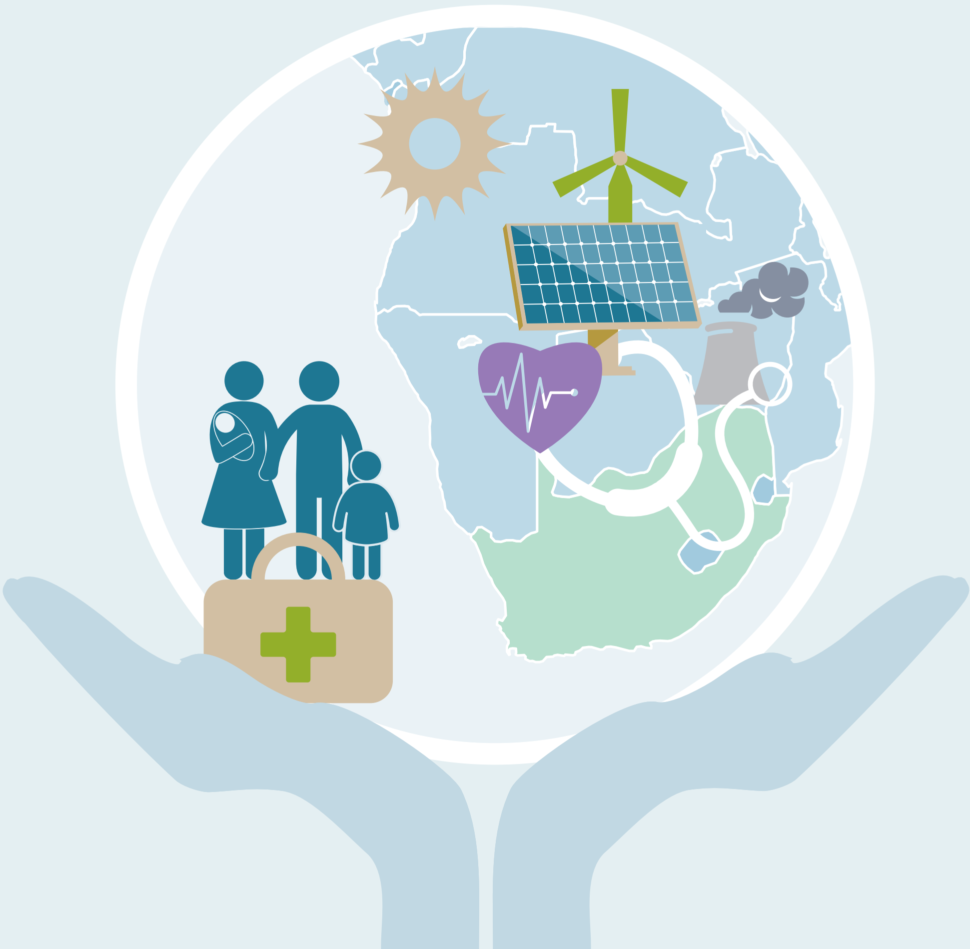
COBENEFITS STUDY

October 2019

Improving health and reducing costs through renewable energy in South Africa

Assessing the co-benefits of decarbonising the power sector

Executive report



This COBENEFITS study has been realised in the context of the project "Mobilising the Co-Benefits of Climate Change Mitigation through Capacity Building among Public Policy Institutions" (COBENEFITS). This print version has been shortened and does not include annexes. The full version of this report is available on www.cobenefits.info.

This study is part of a 2019 series of four studies assessing the co-benefits of decarbonising the power sector in South Africa, edited by IASS and CSIR. All reports are available on www.cobenefits.info.

- Improving health and reducing costs through renewable energy in South Africa
- Consumer savings through solar PV self-consumption in South Africa
- Economic prosperity for marginalised communities through renewable energy in South Africa
- Future skills and job creation through renewable energy in South Africa

COBENEFITS is part of the International Climate Initiative (IKI). The Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (BMU) supports this initiative on the basis of a decision adopted by the German Bundestag. The project is coordinated by the Institute for Advanced Sustainability Studies (IASS, Lead) in partnership with the Renewables Academy (RENAC), Independent Institute for Environmental Issues (UfU), IET – International Energy Transition GmbH and the Council for Scientific and Industrial Research (CSIR).

Revised edition October 2019. First published March 2019.

Editors: Ayodeji Okunlola, David Jacobs, Ntombifuthi Ntuli, Ruan Fourie, Laura Nagel and Sebastian Helgenberger – IASS Potsdam, CSIR and IET

Technical implementation: Nuveshen Naidoo, Jackie Crafford, Mark Zunckel and Joseph Mulders – Prime Africa Consultants

Supported by:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
based on a decision of the German Bundestag

INTERNATIONAL CLIMATE INITIATIVE (IKI)

COBENEFITS of the new energy world of renewables for the people in South Africa

South Africa is in the midst of an energy transition, with important social and economic implications, depending on the pathways that are chosen. Economic prosperity, business and employment opportunities as well as health impacts, issues related to the water–energy–food nexus and global warming impacts: through its energy pathway, South Africa will define the basis for its future development. Political decisions on South Africa's energy future link the missions and mandates of many government departments beyond energy, such as environment, industry development, science and technological innovation.

Importantly, the whole debate boils down to a single question: **How can renewables improve the lives of the people in South Africa?** Substantiated by scientific rigor and key technical data, the study at hand contributes to answering this question. It also provides guidance to government departments and agencies on further shaping an enabling environment to maximize the social and economic co-benefits of the new energy world of renewables for the people of South Africa.

Under their shared responsibility, the CSIR Energy Centre (as the COBENEFITS South Africa Focal Point) and IASS Potsdam invited the Department of Environmental Affairs (DEA) and Department of Energy (DoE), together with the Independent Power Producers (IPP) Office, the Department of Trade and Industry (DTI), Department of Science and Technology (DST) and the South African National Energy Development Institute (SANEDI) to constitute to the COBENEFITS Council South Africa in May 2017 and to guide the COBENEFITS Assessment studies along with the COBENEFITS Training programme and political roundtables.

We particularly highlight and acknowledge the strong dedication and strategic guidance of the COBENEFITS Council members: Olga Chauke (DEA); Nomawethu Qase (DoE); Gerhard Fourie (DTI); and Lolette Kritzinger-van Niekerk, Frisky Domingues, Thulisile Dlamini and Lazarus Mahlangu (IPP Office). Their contributions during the COBENEFITS Council sessions guided the project team to frame the topics of the COBENEFITS Assessment for South Africa and to ensure their direct connection to the current political deliberations and policy frameworks of their respective departments. We are also indebted to our highly valued research and knowledge partners, for their unwavering commitment and dedicated work on the technical implementation of this study. The COBENEFITS study at hand has been facilitated through financial support from the International Climate Initiative of Germany.

South Africa, among 185 parties to date, has ratified the Paris Agreement, to combat climate change and provide current and future generations with opportunities to flourish. Under the guidance of the National Planning Commission, municipalities, entrepreneurs, citizens and policymakers are debating pathways to achieve a just transition to a low-carbon, climate-resilient economy and society in South Africa. With this study, we seek to contribute to these important deliberations by offering a scientific basis for harnessing the social and economic co-benefits of building a low-carbon, renewable energy system while facilitating a just transition, thereby **making the Paris Agreement a success for the planet and the people of South Africa**.

We wish the reader inspiration for the important debate on a just and sustainable energy future for South Africa!

Ntombifuthi Ntuli
COBENEFITS Focal Point
South Africa
CSIR Energy Centre

Sebastian Helgenberger
COBENEFITS
Project Director
IASS Potsdam

Executive Summary

COBENEFITS

Improving health and reducing costs through renewable energy in South Africa
Assessing the co-benefits of decarbonising the power sector

Air pollution, primarily from coal-fired power plants, is one of the main impacts that the energy sector has on the environment and human health. These pollutants have many negative impacts, of which those of greatest concern include heart disease, lung cancer, stroke and chronic obstructive pulmonary disease (WHO, 2016). The consequences of such diseases include increased levels of morbidity, which further result in elevated health costs and losses of productivity.

This study quantifies the impacts of South Africa's power sector on human health, and how a shift to a less carbon-intensive power sector can help to reduce negative impacts and contribute to reducing costs in South Africa's health system.

- **Key policy message 1:** Estimated health costs of coal power generation in 2018 range from R11 billion (lower estimate) up to R30 billion (upper estimate) and will continue to rise until 2022. This equates to a health cost externality of Rand 5–15 cents per kWh of energy generated from coal. As many as 2080 premature deaths annually can be attributed to air pollution from power plants in South Africa. These externalities should not be disregarded by policymakers in their integrated resource planning.
- **Key policy message 2:** South Africa can significantly cut health costs by increasing the share of renewable energy. With its decision to scale up renewables by moving from IRP 2016 to IRP 2018, South Africa by the year 2050 can cut health costs associated with the power sector by 25%, and considerably reduce negative health impacts and related costs for people and businesses.
- **Key policy message 3:** Health impacts and related costs can be reduced even further by following (or going beyond) the DEA's Rapid Decarbonisation pathway. By the year 2050, this scenario could cut an additional 20% of health costs associated with the power sector, amounting to as much as R100 billion in absolute savings.

KEY FIGURES:

- Up to 44 million people are exposed to air pollution from coal power plants in South Africa.
- Health costs related to coal emissions will peak in 2022, at up to R45 billion in that year alone.
- As many as 2080 premature deaths annually were predicted due to air pollution from power plants in South Africa.
- Health cost externalities of Eskom's power plants range from Rand 5 to 15 cents per kWh.

COBENEFITS South Africa (2019): Improving health and reducing costs through renewable energy in South Africa. Assessing the co-benefits of decarbonising the power sector

available on www.cobenefits.info

KEY FINDINGS:

- **Health costs of coal power generation will continue to rise until 2022**, ranging from R13 billion (lower estimate) to 45 billion (upper estimate) in 2022 alone, a trend shown by all energy generation scenarios. In 2018, Eskom generated about 215 TWh of electricity, at an estimated health cost of R11–30 billion. Accordingly, the health cost externalities of Eskom's power plants are within the range Rand 5–15 cents per kWh.
- **Health effects are most severe in the Highveld Priority Area, where most of South Africa's coal-fired power plants are located.** The proximity of settlements to a power plant is a major factor in total health costs, and therefore considering the locations of plants when formulating decommissioning strategies could drastically reduce human exposure to pollution.
- **Health costs can be reduced significantly by increasing the share of renewables.** By scaling up renewables in IRP 2018 in comparison to IRP 2016, South Africa by the year 2050 will cut health costs from the power sector by 25%. In absolute terms, up to R12.7 billion (upper estimate) and at least R3.8 billion (lower estimate) will be unburdened from health costs by the year 2035. For the year 2050, the estimated health cost savings are between R168 billion and R48 billion respectively.
- **By following the DEA's Rapid Decarbonisation pathway an additional 10% of health costs** (compared with IRP 2018) **associated with the power sector can be cut by the year 2035. By the year 2050, these additional cost savings would amount to almost 20%.** In monetary terms, this represents **additional savings** (compared with IRP 2018) of **at least R14 billion** (lower estimate) and up to R50 billion (upper estimate) by the year 2030, and between R28 billion and R101 billion by the year 2050. Given that this pathway included coal power generation beyond 2050, health costs could be further reduced in a scenario that phases out coal power before 2050.
- **Decommissioning of Eskom's oldest and dirtiest coal-fired power plants in the 2020s** will contribute to bringing down health costs in the nearer future to around R5–18 billion by 2030 (compared to peak costs ranging from R13 to 45 billion in 2022).
- **Health impacts on workforce productivity: The study findings show that** (independent of the choice of dispersion model) **around 27% of health costs are associated with restricted activity days.** Most studies do not model mercury – however, mercury damage accounted for up to 5% of health costs in the present study. This means that health impact assessments are highly sensitive to the estimated cost of mercury damage and to the value of a statistical life (VSL) employed.

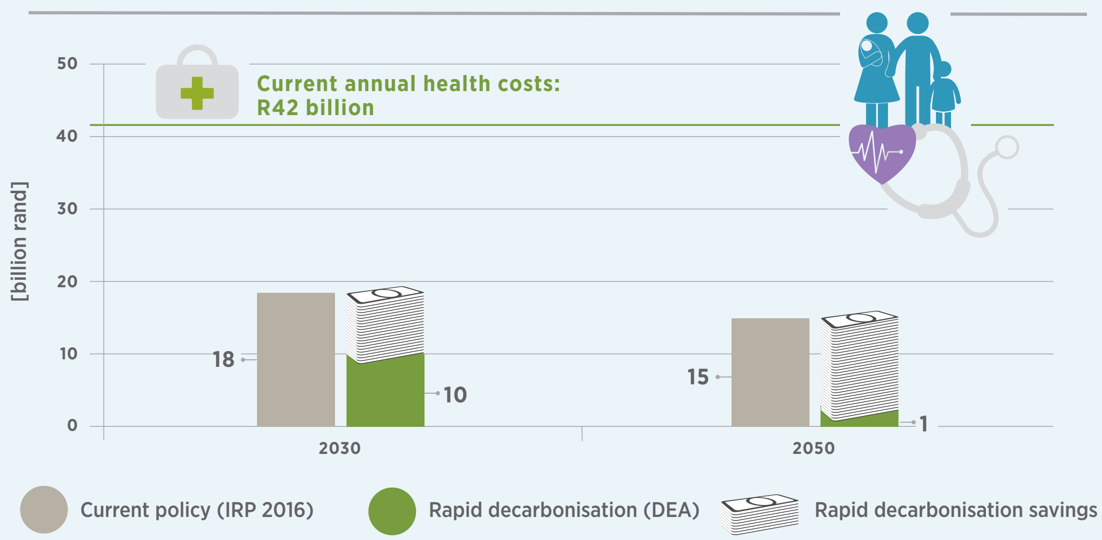
5-step/5-scenario approach for evaluating health co-benefits

The approach taken comprises five broad steps (cf. figure below): (1) Evaluate air pollution emissions for a range of energy-generation scenarios; (2) Model the dispersion of air pollutants in the atmosphere; (3) Calculate the proportion of the population exposed to different concentrations of air pollutants; (4) Estimate the change in disease incidence associated with pollution exposure; (5) Attribute monetary costs to different diseases, thereby calculating the total financial cost of health impacts in each scenario.

Four different scenarios for the future development of the electricity sector in South Africa were analysed: the Integrated Resource Plan 2016 (IRP 2016), which is used as the baseline case; the Integrated Resource Plan 2018 (IRP 2018); Council for Scientific and Industrial Research Least cost planning scenario (CSIR_LC); and the Department of Environmental Affairs Rapid Decarbonisation scenario (DEA_RD).

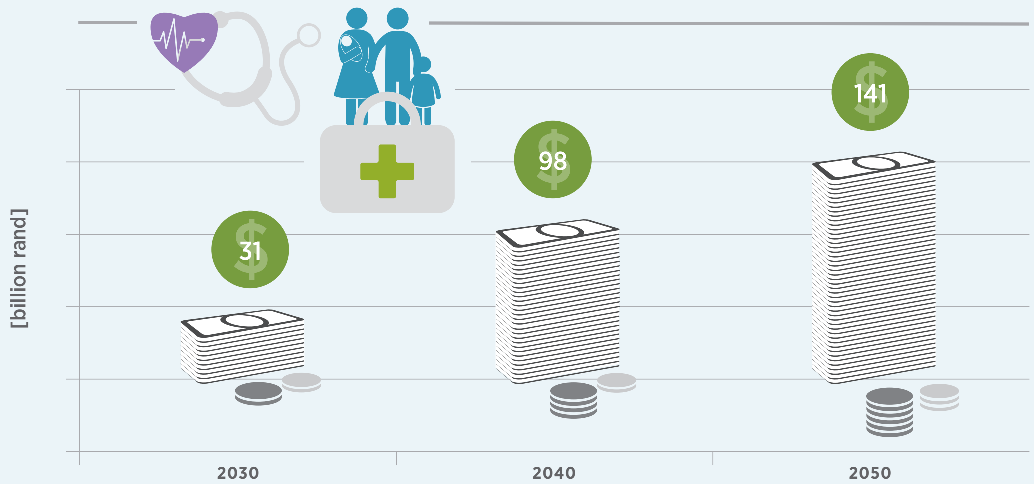
Given the challenges in modelling the dispersion of pollutants over the South African territory, this study took a comparative approach based on two recent models, representing the possible lower and upper estimates of atmospheric pollutant concentrations in South Africa, thereby providing the big picture of possible effects.

By 2050, South Africa can almost completely eliminate its health costs from the power sector by following an ambitious decarbonisation pathway



Health costs from the power sector

South Africa can save as much as R141 billion in health costs by 2050 by following a rapid decarbonisation pathway



Accumulated savings in the health sector by moving from current policy (IRP 2016) to rapid decarbonisation (DEA)

Contents

List of Tables

List of Figures

1. Reducing air pollution from the power sector has many benefits

Air pollution in South Africa is caused by myriads of industrial processes, vehicle emissions, biomass and waste burning, domestic fuel burning, mines and mine dumps. Due to the strong dependence on coal as a fuel source for power generation, the power sector has become a major contributor to air pollution in the country; with emissions from the coal power plants having severe negative impacts on the health status and wellbeing of the citizens. Amongst others, cardiovascular and respiratory diseases occur more frequently and with high mortality and morbidity rates, thus significantly impacting the country's health sector costs.

By reducing the harmful emissions generated from the power sector and moving towards higher shares of renewable energy sources in the country's energy mix, national health care costs can be reduced. A proactive deployment of renewables driven by a need to improve the air-quality standard in provinces around the power plants while in turn delivering on the broad economic and health co-benefits[1] and savings are in line with South Africa's "just transition" approach. Accounting for the positive externalities of a decarbonised power sector in South Africa is therefore integral in delivering on the objectives of South Africa's Nationally Determined Contributions (NDCs) and Paris commitments.

1.1 What is in the air we breathe?

Air pollution, primarily from coal-powered power plants, is one of the main impacts that the energy sector has on the environment and human health. These pollutants have many negative impacts, of which those of most concern include heart disease, lung cancer, stroke and chronic obstructive pulmonary disease (WHO, 2016). The consequences of such diseases include premature death and increased levels of morbidity, which further result in elevated health costs and losses of economic productivity. Accurately estimating morbidity and mortality, and attributing these to a specific pollutant, is contentious in the South African context, due to a lack of local epidemiological data, and the combined effects of factors such as indoor pollutants.

The various impacts of air quality are most relevant to coal-fired power stations, particularly when these all occur within the three priority areas identified by the Department of Environmental Affairs (DEA) under the National Environmental Management Act (NEMA: AQA, 2004), where ambient air quality standards are not being met and specific interventions are required to manage air quality.

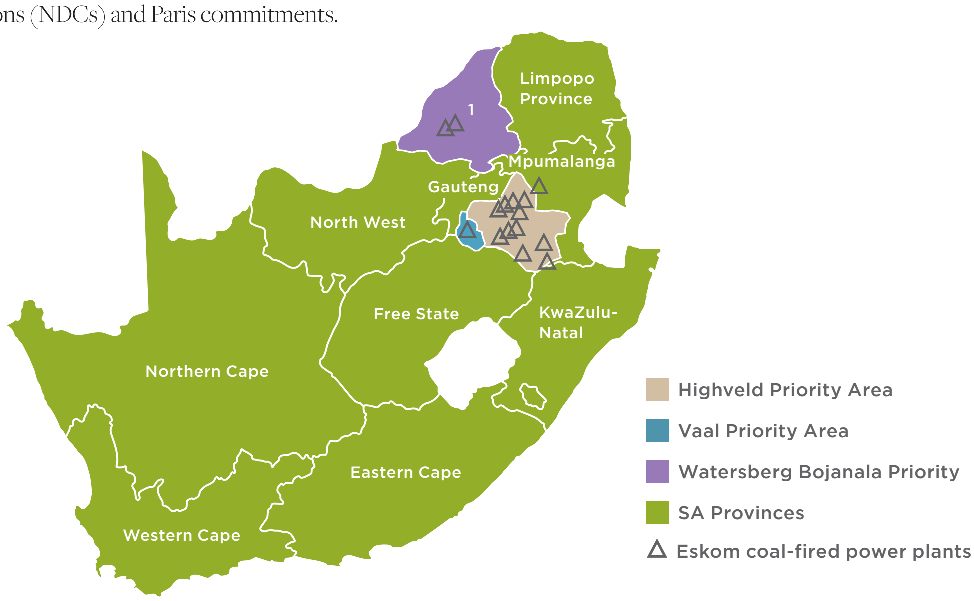


Figure 1: Auction results for large-scale solar PV projects worldwide

Source: Senatla & Mushwana, 2017, based on information from IRENA

[5] The term "co-benefits" refers to simultaneously meeting several interests or objectives resulting from a political intervention, private sector investment or a mix thereof (Helgenberger et. al, 2019). It is thus essential that the co-benefits of climate change mitigation are mobilized strategically to accelerate the low-carbon energy transition (Helgenberger et al. 2017)

Emissions of air pollutants from the concentration of heavy industry (including power generation), domestic fuel burning, mining and biomass burning contribute to poor air quality across South Africa. Air quality in the Highveld, which contains most of South Africa's coal-fired power stations, often fails to meet National Ambient Air Quality Standards (NAAQS) (DEA, 2009 and 2012). As a result, the Minister of Environmental Affairs declared the Highveld Priority Area (HPA) in November 2007 under the terms of Chapter 18 of the National Environment Management: Air Quality Act, 2004 (Act No. 39 of 2004) (NEMA: AQA).

In 2008 the DEA established a network of five ambient monitoring stations within the HPA, located at Ermelo, Hendrina, Middelburg, Secunda and Witbank. An overview of the state of air quality (per pollutant) in the HPA follows. There are some gaps in the data record from periods when monitoring stations were non-operational.

Sulphur dioxide (SO_2)

Industrial processes and power generation are the main sources of atmospheric SO_2, through the combustion or refining of fuels containing sulphur. The highest concentrations occur in Witbank, where the NAAQS was exceeded in 2010 and 2011, and annual average concentration is 90% of the NAAQS in most other years. Noteworthy is the decreasing trend in SO_2 concentrations over the 9-year monitoring period at Hendrina, Middelburg and Ermelo (Figure 2).

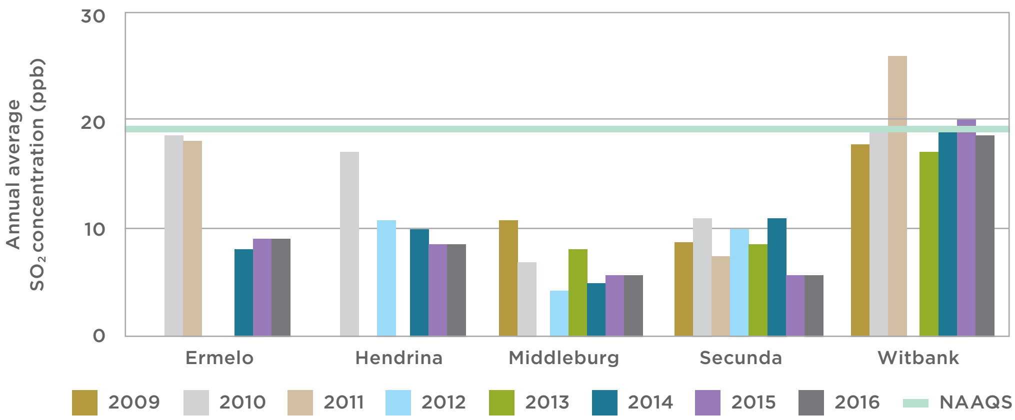


Figure 2: Annual average SO_2 concentrations at DEA monitoring stations in the HPA (ppb: parts per billion)

Source: own

Nitrogen dioxide (NO_2)

Industrial processes and power generation are the main sources of NO_2 in the atmosphere, through the combustion or refining of fossil fuels, with some contribution from motor vehicle emissions, residential fuel burning and biomass burning. In the HPA, annual average ambient NO_2 concentrations are relatively low compared to the NAAQS, except at Secunda in 2009 and Witbank in 2016 where exceedances occurred. Noteworthy is the increasing trend in annual average NO2 concentrations at all the monitoring stations since 2014, except at Ermelo (Figure 3).

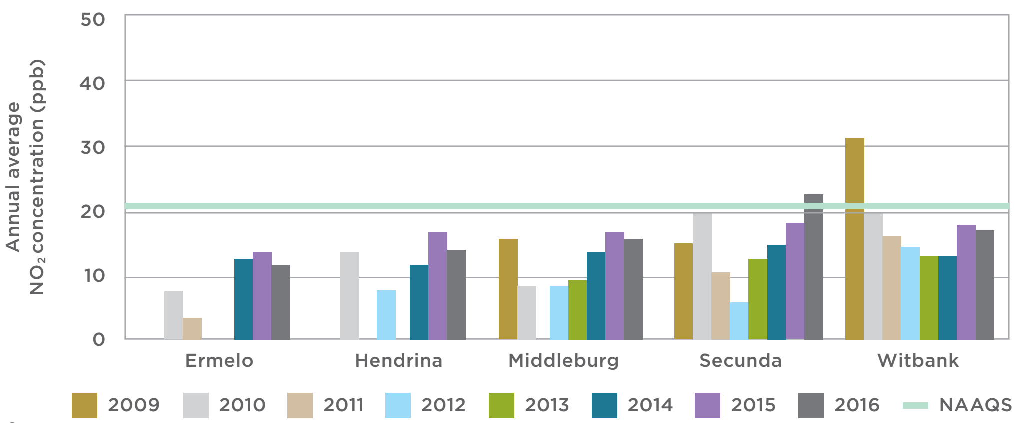


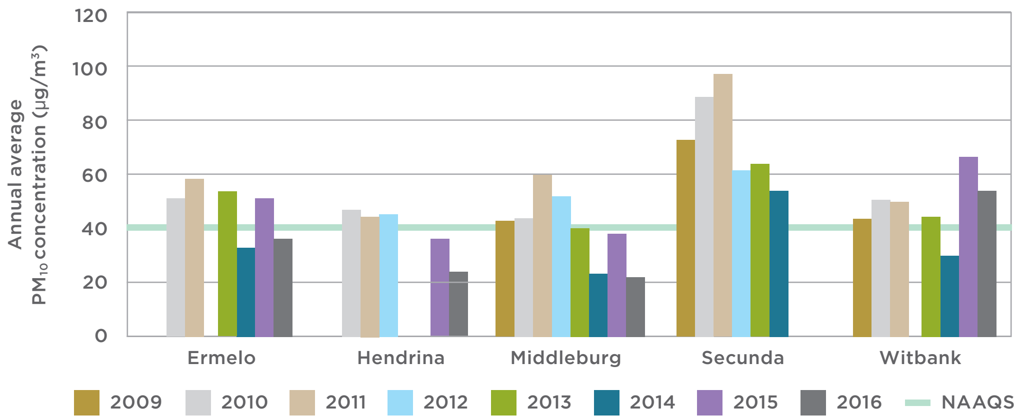
Figure 3: Annual average NO_2 concentrations at HPA monitoring stations (ppb: parts per billion)

Source: own

Particulate matter (PM_{10} and $PM_{2.5}$)

There are numerous sources of particulate matter in the HPA, including industry, mining, biomass burning and agricultural, as well as natural sources such as wind entrainment. Collectively, they contribute to high annual average PM10 concentrations at most of the DEA monitoring stations. Monitoring records show consistent exceedances of the NAAQS (Figure 4).

The annual average $PM_{2.5}$ concentrations are also high at the HPA monitoring stations relative to the NAAQS (25 µg/m³ prior to 2016, 20 µg/m³ thereafter), except at the Hendrina and Secunda stations. The data series also shows consistent exceedances of the NAAQS.



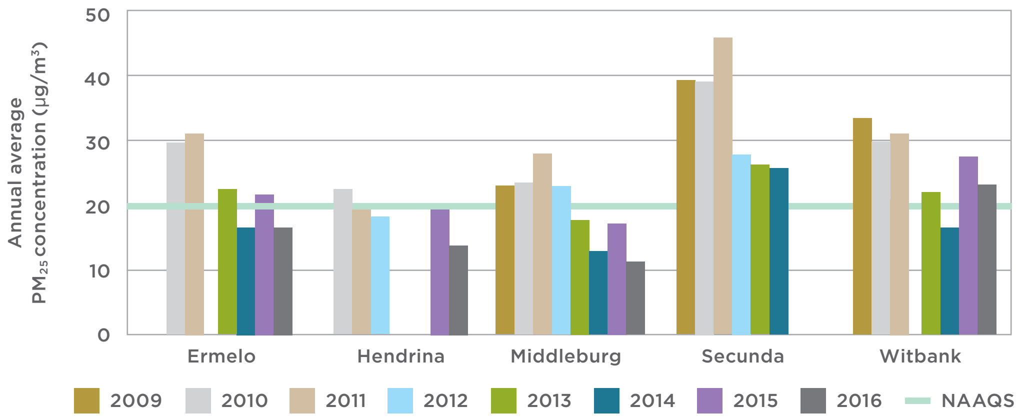


Figure 4: Annual average PM10 (top) and PM2.5 (bottom) concentrations for the HPA (µg/m³)

Source: own

1.2 Existing knowledge and gaps

Many studies have estimated the health impacts of either fossil fuel power plants, air pollution in general or specific sources of pollutants in South Africa. They estimated morbidity and mortality, and in some instances attributed monetary costs to these health impacts. Studies of this type can employ either bottom-up (deterministic) or top-down (stochastic) approaches to modelling pollution exposure, with the latter usually preferable in data-poor environments or large spatial domains (Dios et al., 2012). Previous studies also varied in geographic scale, ranging from selected areas to the national scale. Some of the most recent and relevant include:

The World Health Organization (2009) estimated that, during 2009, approximately 1100 deaths in South Africa could be attributed to poor outdoor air quality.

- Scale: National (All air pollution)
- Resolution: Coarse
- Health outcomes: Mortality
- Modelling approach: Top-down

The Institute for Health Metrics and Evaluation listed air pollution as the 9th largest risk factor for death and disability combined in 2016 in South Africa (IHME, 2016).

- Scale: National (All air pollution)
- Resolution: Medium
- Health outcomes: Morbidity and mortality
- Modelling approach: Bottom-up

A study commissioned by Greenpeace in 2014 estimated that air pollution emissions from Eskom's coal-fired power plants could cause as many as 2200 premature deaths per year (Myllyvirta, 2014). The study also estimated the impacts of mercury pollution.

- Scale: National (Air pollution from coal-fired power plants)
- Resolution: Medium
- Health outcomes: Morbidity and mortality
- Modelling approach: Bottom-up

A 2017 study commissioned by Groundwork estimated that the health impacts of air pollution from coal-fired power plants cost South Africa $2.4 billion annually (Holland, 2017). The study used many of the results of the previously discussed Greenpeace study.

- Scale: National (Air pollution from coal-fired power plants)
- Resolution: Medium
- Health outcomes: Morbidity and mortality
- Modelling approach: Bottom-up

Van Horen (1996) evaluated the health costs associated with Eskom's power stations as part of understanding the true costs of electricity generation. The valuation of morbidity outcomes was found to be small in terms of costs per kWh generated.

- Scale: National (Air pollution from coal-fired power plants)
- Resolution: Medium
- Health outcomes: Morbidity and mortality
- Modelling approach: Bottom-up

The Fund for Research into Industrial Development Growth and Equity, in 2004, assessed the economic impact of air pollution in selected areas of South Africa. The study found that power generation was responsible for 51% of the 8700 respiratory cases in Mpumalanga (FRIDGE, 2004).

- Scale: Selected areas (All air pollution and air pollution from power plants)
- Resolution: Medium
- Health outcomes: Morbidity and mortality
- Modelling approach: Bottom-up

A review by Spalding-Fecher and Matibe (2003) aimed to calculate the external costs of electric power generation in South Africa, and estimated the health costs to be R1.1 billion per year.

- Scale: National (Air pollution from power plants)
- Resolution: Coarse
- Health outcomes: Morbidity and mortality
- Modelling approach: Top-down

Summary:

- Except for studies on a small geographical scale, most studies use very coarse pollution dispersion models. There is the opportunity to leverage existing information on power plant emissions in order to obtain not just more accurate dispersion models, but finer resolution on population exposure.
- All the studies listed made use of internationally developed exposure–response functions. There are many factors that will cause South Africans to have different responses to air pollution, including tobacco usage, HIV prevalence and socio-economic circumstances; consequently, there is a lack of local exposure–response functions.
- There are sufficient data and useful methodologies to enable detailed bottom-up (deterministic) models for the present study.
- Mortality health outcomes make up the bulk of health costs (>80%) in most studies. This means that health impact assessments are highly sensitive to the value of a statistical life (VSL) used.

Study limitations

- Air quality data and information: The lower estimate used in this study relied on domain-constrained predicted ambient concentrations related to only 13 of Eskom's coal-fired power plants, and thereby underestimates total health impacts.

- Local exposure–response functions: No local exposure–response functions are available for South Africa. The international functions used in this study do not take into account local factors such as economic status, access to health care, HIV prevalence and tobacco consumption, which could lead to an overestimation of health costs since these factors increase baseline disease incidence. In order to develop local functions, certain preconditions need to be met, including adequate monitoring, reporting and verification of disease incidence, and greatly improved monitoring and modelling of ambient air quality.

- Availability of health data: While mortality data are published by Statistics South Africa, there is limited information available on morbidity. The study therefore used international baseline estimates for morbidity. Improved reporting by both the private and public health sectors is required to improve health cost estimates.

- Scenario descriptions: Scenarios are based on various policy documents that describe power generation by technological capacity. The lack of detail, specifically on the positioning of new builds, means that assumptions must be made regarding population exposure. The study assumes that new coal power stations will be built close to coal resources in Limpopo and Mpumalanga, and that natural gas- and diesel-powered stations will be built close to ports in the Western Cape, Eastern Cape and KwaZulu-Natal.

- Health effects: Mortality health effects made up the majority of the health costs (67–71%) and are typically >80% in most studies that do not model mercury. This means that health impact assessments are highly sensitive to the value of a statistical life (VSL) used in modelling.

- Exposed population: The Integrated Health Cost Model assumed evenly distributed population growth (in line with the United Nations Population Fund's middle estimate) at the ward and municipal levels from now until 2050 (i.e., all wards and municipalities grow at the same rate). While population growth is unlikely to be homogenous, in the absence of finer-scale population growth estimates, this is a necessary assumption. Furthermore, because the model evaluates average pollution concentrations at the ward level, it may slightly underestimate exposure of populations that are very close to the power station.

2. Methodology

To achieve the study's aim of quantifying the health impacts of improved air quality resulting from a less carbon-intensive power sector, a detailed Integrated Health Cost Model was developed. The Microsoft Excel-based model integrates scenario permutations, dispersion patterns, exposure–response functions, population data and health cost estimations into a user-friendly tool to estimate the health costs of each scenario over a specific period. The approach can be simplified into five broad steps:

Figure 5: Broad methodological steps involved in the Integrated Health Cost Model

Source: own

1. Scenario emissions: Evaluate air pollution emissions expected for each scenario;
2. Dispersion modelling: Model the dispersion of air pollutants in the atmosphere;
3. Exposure modelling: Estimate the population numbers exposed to different concentrations of air pollutants;
4. Health effects: Estimate the effects on disease incidence associated with changes in pollution exposure;
5. Health costs: Attribute monetary costs to diseases and provide total health impacts in each scenario.

2.1 Reference policy and scenarios

Four scenarios were analysed for the future development of the power sector in South Africa. From these four, three government-level scenarios from the Department of Energy (DOE) and the Department of Environmental Affairs (DEA) South Africa represent the composition of South Africa's energy mix over medium- and long-term planning horizons, and form the basis in this study for assessing health costs associated with the power sector. The power supply mix and new capacity additions from the Integrated Resource Plan 2016 (IRP 2016)[2] scenario developed by the DOE are chosen as the baseline, representing the policy-planning status quo in the power sector. The Integrated Resource Plan Policy Adjusted scenario 2018 (IRP 2018)[3], also developed by the DOE, is an updated version of the IRP 2016 document, which shows the new medium- and long-term electricity sector planning document under consideration by the South African Government. It shows the increased share of renewable energy sources in the energy mix, and also provides insight into the planned timeline for decommissioning existing coal power plants by the years 2030 (for the short term) and 2050 (for the medium and long term). The third government reference policy and scenario assessed is the DEA Rapid Decarbonisation scenario[4] (DEA_RD), which presents an alternative approach for rapidly

[2] The IRP refers to the coordinated schedule for generation expansion and demand-side intervention programmes, taking into consideration multiple criteria to meet electricity demand. The IRP 2016 presents insights on the preferred generation technology required to meet expected demand growth post-2030. The planning period further extends beyond 2030 up to 2050. The scenario's calculations are based on broadly different factors, such as technology cost calculations, energy policy direction and emission targets. The base case scenario (BC) is used for the analysis.

[3] The draft IRP 2018 was published for consultation in August 2018. It considered demand-growth scenarios that tested the impacts of projected load demand (at a moderate rate) on the energy mix up to 2030. Details of the scenario can be found here: http://www.energy.gov.za/IRP/irp-update-draft-report2018/IRP-Update-2018-Draft-for-Comments.pdf

[4] The DEA_RD scenario presents an alternative mitigation pathway via emission reduction in the power sector as well as the technological requirements for power generation. The scenario has a baseline set from 2015 and projected until 2050. The data for this scenario were provided directly by the Department of Environmental Affairs (as a member of the COBENEFITS COUNCIL) to be analysed in this study.

reducing the greenhouse gas and harmful emissions generated from the power sector. The scenario increases the share of renewable energy in the power sector to more than 70% by the year 2050. It also has a planning horizon up to the years 2030 for the short term and 2050 for the long term. The last scenario analysed is the Council for Scientific and Industrial Research Least Cost planning scenario[5] (CSIR_LC). This scenario was developed as the least-cost alternative to power sector planning, as a formal and independent review of the IRP 2016. The scenario places no annual techno-economic limitations on expanding the shares of renewable energy sources over the planning horizon until 2050.

2.2 Dispersion modelling

The dispersion of air pollutants from sources (power plants) to receptors (ground level) are modelled using dispersion models. Dispersion models take into consideration the quantities and concentrations of pollutants emitted from sources, and model how they are dispersed throughout the modelling domain based on factors such as topography, meteorological conditions and properties of pollutants. The outputs of these models are predictions of ambient pollutant concentrations.

The following indicator pollutants were used:

- Particulate matter ($PM_{2.5}$) is a complex mixture of extremely small particles and liquid droplets emitted from the combustion process, and includes uncombusted fuel components.
- Oxides of nitrogen (NO_X), expressed as nitrogen dioxide (NO_2), are produced from the reaction of atmospheric nitrogen and oxygen at high temperature during combustion.
- Sulphur dioxide (SO_2) is produced during combustion, depending on the sulphur content of the fuel.
- Mercury (Hg) is produced during combustion, depending on the mercury content of the fuel. It is primarily a threat to health when absorbed as methylmercury through the food chain. Total mercury emissions were presumed to scale with coal capacity.

Comparative approach representing the possible lower and upper estimates of atmospheric pollutant concentrations

Given the challenges in modelling the dispersion of pollutants over the South African territory this study took a comparative approach based on two recent models, representing the possible lower and upper estimates of atmospheric pollutant concentrations in South Africa, thereby providing the big picture of possible effects.

The two models, the predicted pollutant concentrations show some similar trends over time, but differ in the magnitude of their predictions. Consequently, the two models are used here to represent the possible lower (Naledzi, 2018) and upper (Myllyvirta, forthcoming) ranges of atmospheric pollutant concentrations in South Africa:

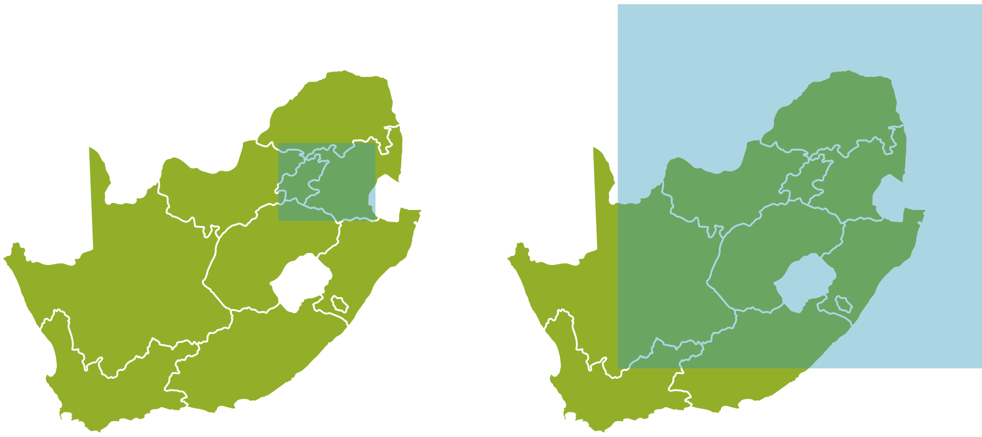
Naledzi (2018), commissioned by Eskom:

- Models the dispersion of pollutants from 13 coal-fired plants (excluding Medupi and Matimba),
- The modelling results covered a domain of 97 200 km^2 (360 km by 270 km), including 41 municipalities.
- The maximum mean annual concentrations observed per municipality (attributed to power stations) in 2018 were 2.1 $\mu g/m^3$ (NO_2), 2.9 $\mu g/m^3$ ($PM_{2.5}$) and 9.0 $\mu g/m^3$ (SO_2).
- The dispersion of air pollutants was modelled based on the requirements of the DEA (DEA, 2014). The study employed CALPUFF, a multi-layer, multi-species, non-steady-state puff dispersion model that simulates the effects of temporally- and spatially-varying meteorological conditions on pollution transport, transformation and removal. Stack, emission, topographical and meteorological parameters were obtained from publicly available sources.

[5] The CSIR least-cost scenario was developed as an independent review of the IRP 2016 (Wright et al., 2017). The scenario places no annual technical limitations on the penetration of solar and wind technologies over the planning horizon until 2050. It shows lower emissions in the energy mix, and consumes less water than the Draft IRP 2016. Renewable energy costs are set to be compatible with the global learning curve on energy technologies. Furthermore, the scenario presents solar PV and wind energy as the largest contributors to the energy supply mix in South Africa by 2050. 2050. The data for this scenario were provided directly by the Department of Environmental Affairs (as a member of the COBENEFITS COUNCIL) to be analysed in this study.

Myllyvirta (forthcoming), produced by Greenpeace:

- Models the dispersion of pollutants from 15 coal-fired and 2 open cycle gas turbine (OCGT) at Acacia and Port Rex.
- The model covered a domain of 2 250 000 km² (1500 km by 1500 km), comprising 208 municipalities.
- The maximum mean annual concentrations (attributed to power stations) observed per municipality in 2018 were 6.0 μg/m3 (NO_2), 8.3 μg/m3 ($PM_{2.5}$) and 9.6 μg/m³ (SO_2).
- Stack, emission, topographical and meteo-rological parameters were obtained from publicly available sources.



(Naledzi, 2018), commissioned by Eskom

(Myllyvirta, forthcoming), produced by Greenpeace

Figure 6: Spatial domains used in the models

Source: Naledzi, 2018 commissioned by Eskom (Myllyvirta, forthcoming), produced by Greenpeace

2.3 Exposure modelling

Estimating actual exposure to pollutants is crucial to understanding their health impacts. In general, populations closer to pollution sources are exposed to higher concentrations of pollution, and the cumulative health impact is higher when the population concentration is high as more people are exposed. However, exposure to pollution is also dependent on how the pollution is dispersed in the atmosphere, for example a population close to a power plant may have low exposure if prevailing wind patterns move pollution away from the population. Thus, exposure to air pollution is determined primarily by three factors: the locations of pollution sources (Figure 7), the dispersion of pollutants (Figure 8), and population density (Figure 9).

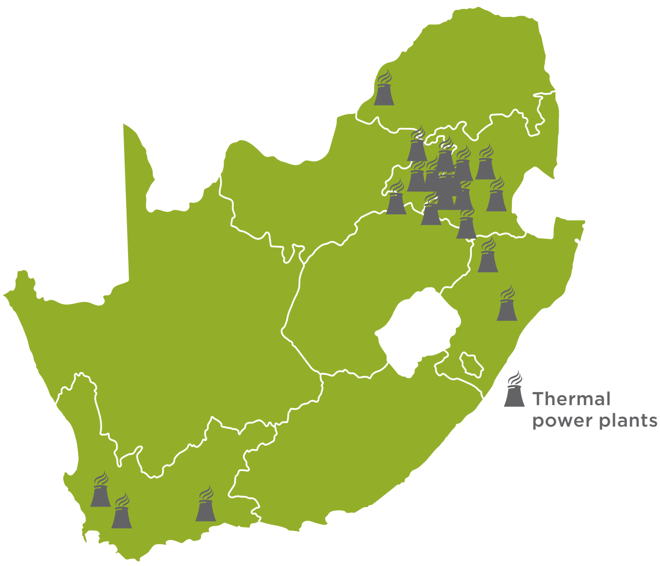


Figure 7: Location of thermal power plants (coal, diesel, and natural gas) in South Africa

Source: own

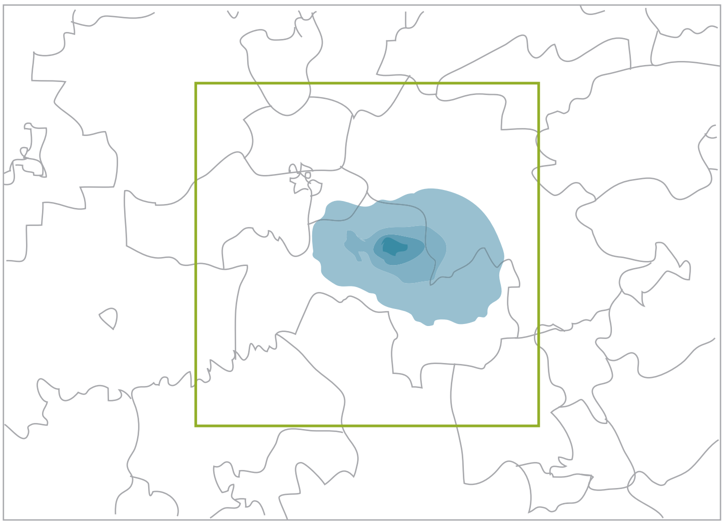


Figure 8: Pollution dispersion model demonstrating ground-level exposure to NO_x from Camden coal-fired power station

Source: own

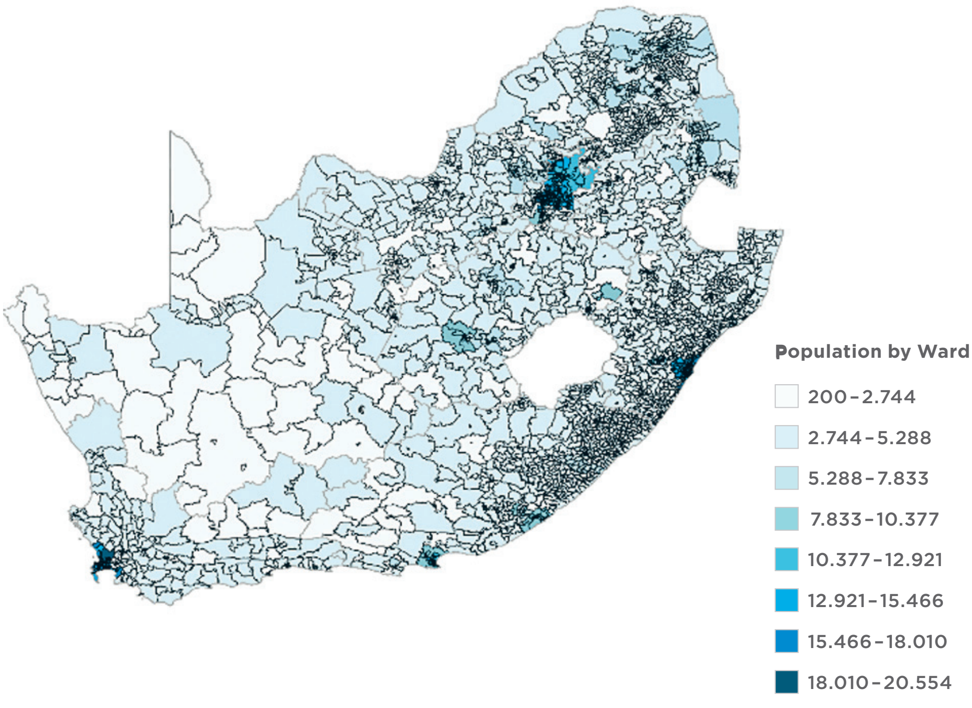


Figure 9: Population distribution in South Africa

Source: own, adapted from Stats SA, 2012

Combing these three data sources by means of a geographical information system (and suitable scaling) enables estimation of the population exposed to different concentrations of pollutants.

The population exposure to each pollutant per year for each scenario was modelled by combining the outputs from the preceding methodological steps (figure 10). The Integrated Health Cost Model overlays dispersion models (figure 8; figure 9) onto power plant locations (figure 7) to produce a pseudo-ambient air quality data set (attributable to power station emissions). These annual average concentrations per pollutant are averaged over suitable administrative boundaries (wards) and then overlaid onto the population data (figure 9) at the same spatial scale. Simultaneously, temporal effects are considered, such as population growth (adapted from United Nations, 2017), and fleet capacity changes are modelled for each scenario (section 2.1).

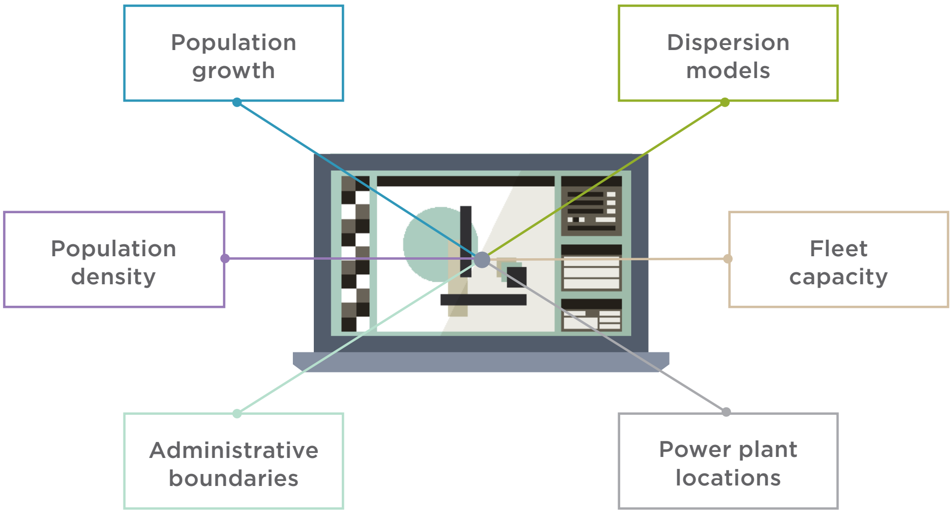


Figure 10: Exposure modelling components of the Integrated Health Cost Model

Source: own

Mercury is produced during the combustion process, depending on the mercury content of the fuel, although it is primarily a threat to health when absorbed as methylmercury through the food chain. As such, mercury-related impacts were calculated as a borderless cost, with just the quantity emitted being material. Garnham and Langerman (2016) estimated that Eskom coal power stations released 16.8–22.6 tons of mercury in 2015. Using the average value (19.7 tons), for Eskom's 38,234 MW coal capacity that year (Eskom, 2017), an emission factor of 0.51 kg/MW of coal capacity was calculated. This emission factor was extrapolated to the entire study period for each scenario, based on modelled coal capacity per year.

2.4 Measuring health effects and health costs

The fundamental goal of a health cost study is to evaluate the economic burden that illness imposes on society as a whole (Jo, 2014). A study by Rice et al. (1985) was instrumental in standardising the methodology for estimating COI, and continues to be used internationally with periodic updates (Rice, 1996; 2000). COI studies traditionally stratify costs into three categories: direct, indirect, and intangible. However, intangible costs have seldom been quantified in COI studies, due to measurement difficulties and related controversies (Jo, 2014).

Direct costs arise from the use of health care services in the prevention, diagnosis and treatment of diseases. For example, acute (short-term) and chronic (long-term) human exposure to air pollution can result in a range of health effects (FRIDGE, 2004). Such effects impose direct costs on the health care system, such as hospitalisation for respiratory or cardiovascular diseases, and exacerbation of respiratory diseases such as asthma. In order to provide a monetary estimate of the annual costs associated with air pollution, estimated health endpoint incidences are applied to costs obtained from the South African Health Review (Gray and Vawda, 2017) commissioned by the Health Systems Trust.

Indirect costs are caused by loss of economic productivity resulting from issues such as absenteeism, temporary or permanent disability and premature mortality.

Health outcomes indicate the results of various policy interventions (e.g., in the fields of health, environment, etc.), represented as changes in patients' health over time. Monitoring health outcomes over time can indicate the environmental and health impacts of policy objectives such as reducing the concentrations of atmospheric pollutants. To be of use in assessing the health impacts of air pollution, the chosen health outcomes should provide suitable evidence demonstrating a causal link with air pollutants, such as exposure–response functions that quantify the relationship and data on average costs of treatment.

Exposure–response functions were used to estimate the increased disease incidence attributable to the annual average pollution concentration to which the population per ward was exposed. The specific health effects evaluated were: cerebrovascular, cardiovascular, respiratory and diabetes mellitus mortality; respiratory or cardiac hospital admissions; restricted activity days; and mercury damage (table 1). The exposure–response functions demonstrate a relative increase in disease incidence (from the baseline incidence) per 10 μg/m³ increase in mean annual average exposure per pollutant (figure 11).

Health costs were then attributed to each incidence of disease. A contentious method of estimating health costs is the value of a statistical life, an economic value that is used to quantify the benefit of avoiding a fatality, estimates of which are generally within the range R4–40 million (our medium estimate assumes R12 million). Hospital admission costs range from R11 000 to R24 000 and the monetary value of a restricted activity day (reduced productivity) was assumed to be R633. Mercury health costs were based on a study by Myllyvirta (2014). Their estimated cost of $1500 per kg of Hg was adjusted to current US dollar prices and then converted to the rand-equivalent (using a conversion factor of 14 rand per dollar), giving a damage cost of R25 000 per kilogram of mercury emitted. The total cost associated with mercury per year in each scenario used the average emissions per MW of energy generated from coal, multiplied by the coal capacity.

Table 1: Health effects, related indicator pollutants, baseline incidence, exposure–response functions and health care costs used in the health impact model

Source: own

Code	Indicator Pollutant	Health Effect (Disease)	Baseline Incidence (% or no.)	Relative Risk (Ratio)	Cost per Case (Rand)
HO_01	PM	Diabetes mellitus mortality	0.045 %	1.13	12 000 000
HO_02	PM	Cerebrovascular mortality	0.041 %	1.11	12 000 000
HO_03	SO_2	Respiratory mortality	0.076 %	1.0106	12 000 000
HO_04	NO_2	Cardiovascular mortality	0.174 %	1.0206	12 000 000
HO_05	PM	Respiratory hospital admissions	0.620 %	1.013	11 513
HO_06	PM	Cardiac hospital admissions	0.860 %	1.013	23 869
HO_07	PM	Restricted activity days	19	1.09	633

Each health effect was attributed to an individual indicator pollutant. While health effects can be attributed to many different indicator pollutants, using all indicators would result in double accounting of health impacts as these pollutants are associated with each other.

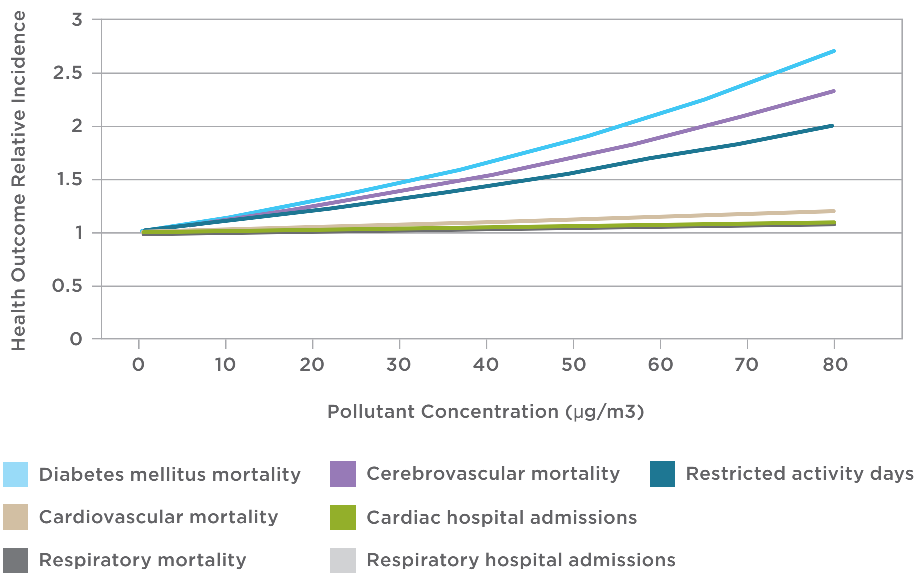


Figure 11: Exposure–response functions demonstrating relationships between pollutant exposure and disease incidence

Source: own

3. The status quo: high health-related costs from the power sector

Health costs associated with coal power generation will continue to rise until 2022, ranging from R13 billion (lower estimate) to 45 billion (upper estimate) in 2022 alone, a trend shown by all energy generation scenarios (see figure 12 and figure 13). In 2018, Eskom generated about 215 TWh of electricity, at an estimated health cost of R11–30 billion. Accordingly, the health cost externalities of Eskom's power plants are within the range Rand 5–15 cents per kWh. This high cost is due to South Africa's overwhelming dependence on coal-fired power plants for power generation. The study shows that, independent of the applied dispersion models (shown in figure 13), around 27% of health costs are due to restricted activity days. Most studies do not model mercury – however, mercury damage accounted for up to 5% of health costs in the present study. This means that health impact assessments are highly sensitive to the estimated cost of mercury damage and to the value of a statistical life (VSL) employed. From 2021, the estimated health cost trajectories change across the four scenarios. This is attributed to certain exogenous factors, such as the gradual decommissioning of coal power plants across the country, the share of renewable sources in the energy mix (and the pace at which they are added), the introduction of peaking power plants (gas power plants), and declining dependence on coal as a major fuel source for power generation.

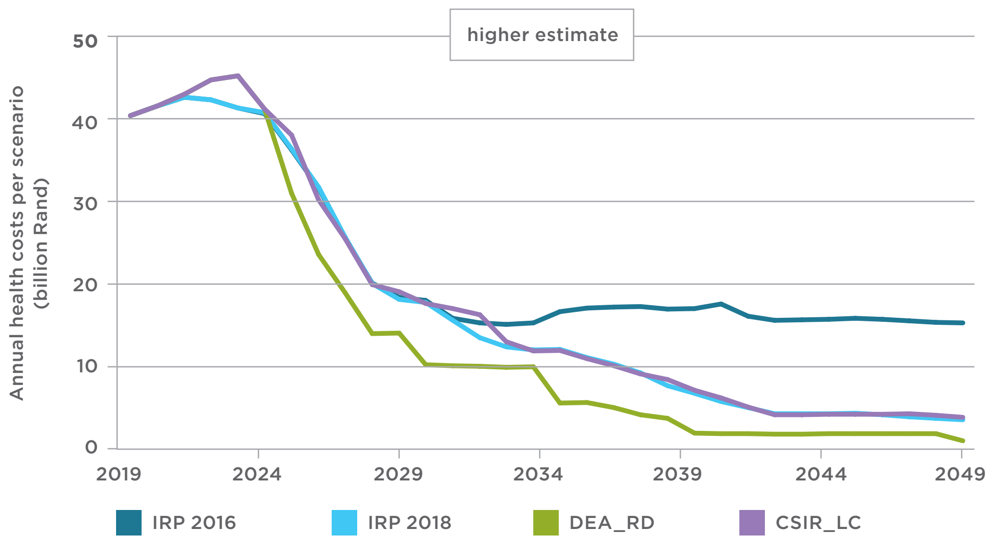


Figure 12: Health costs from the power sector across all scenarios between years 2019 and 2050 (higher estimate case)

Source: own

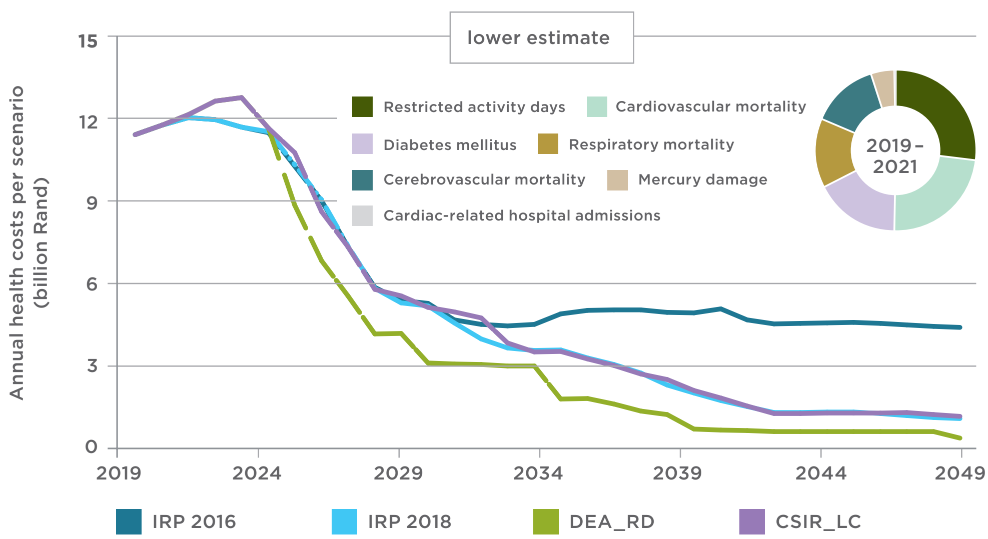


Figure 13: Health costs associated with the power sector across all scenarios between years 2019 and 2050, with the shares of "disease" burden from the year 2019 to 2021 (lower estimate case)

Source: own

3.1 IRP 2018, defining the pathway to a power sector with reduced negative health externalities

The IRP 2018 scenario, which closely mirrors the CSIR least cost scenario in its trajectory from the year 2021 until 2050, shows a steady decline in health costs associated with the power sector. This decline is a result of the increased share of renewable energy sources in the energy mix, including a combined solar PV and wind installed capacity of 12 GW between 2025 and 2030. By scaling up renewables in IRP 2018 in comparison to IRP 2016, South Africa by the year 2050 will have cut health costs from the power sector by 25% (see figure 14 and 15). In absolute terms, health costs will be reduced by as much as R12.7 billion (upper estimate) and at least R3.8 billion (lower estimate) by the year 2035. For the year 2050, the health cost savings amount to R168 billion and R48 billion respectively. Decommissioning of Eskom's oldest and dirtiest coal-fired power plants in the 2020s will contribute to bringing down health costs in the nearer future to around R5–18 billion by 2030 (compared to peak costs ranging from R13 to 45 billion in 2022). Health costs in the IRP 2016 scenario do not decline further post-2030, as shown in figure 14. This non-decline can be attributed to the continued dependence on coal as a fuel for power generation (despite the introduction of nuclear in the energy mix) in this scenario, as well as the stagnated increase in the share of renewables in the energy mix (despite the system's capacity to accommodate a higher share of renewables, justified by the revised IRP 2018 scenario).

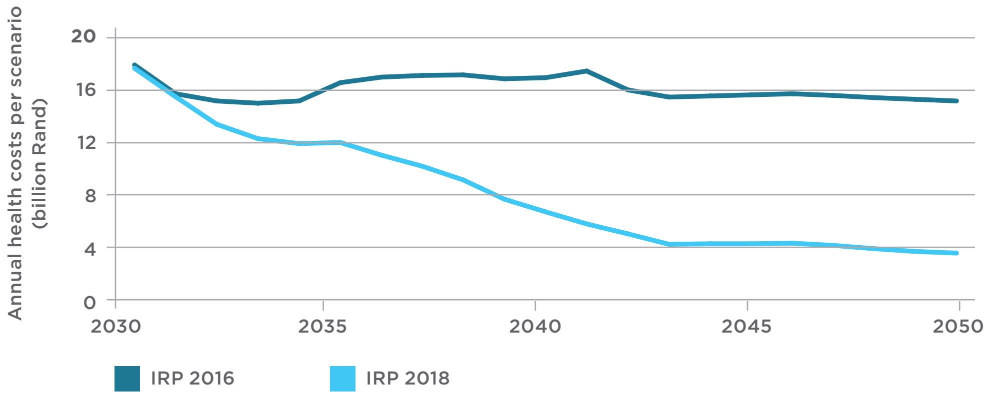


Figure 14: Annual health cost trend (deviation) between IRP 2018 and IRP 2016 between years 2030 and 2050 (higher estimate case)

Source: own

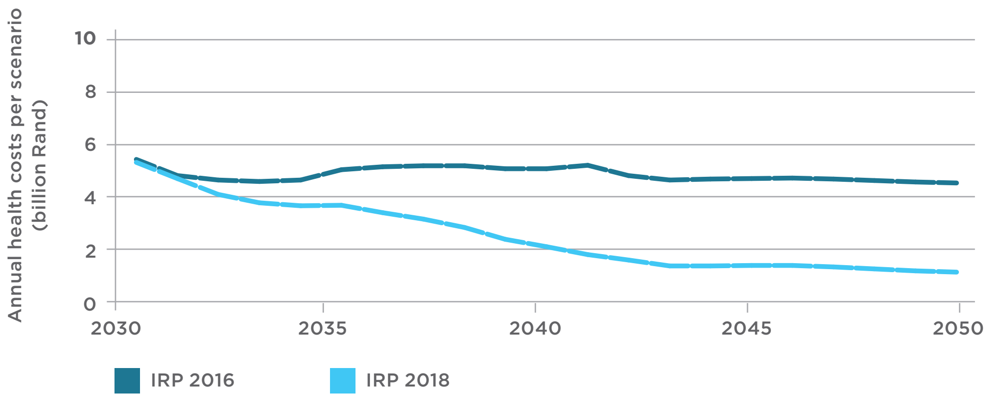


Figure 15:Annual health cost trend (deviation) between IRP 2018 and IRP 2016 between years 2030 and 2050 (lower estimate case)

Source: own

3.2 Surpassing IRP 2018's limitations through the DEA Rapid Decarbonisation scenario

Although IRP 2018 shows extensive health benefits by steadily decarbonising the power sector by shifting to renewable energy over the scenario horizon, the DEA Rapid Decarbonisation (DEA_RD) scenario provides evidence that "more" can still be done and even greater health benefits can be achieved. By following DEA's Rapid Decarbonisation pathway, the health costs associated with the power sector can be cut by an additional 10% as soon as the year 2035; by the year 2050, additional cost savings would amount to almost

20%. In monetary terms, additional savings of up to R50 billion (upper estimate) and at least R14 billion (lower estimate) can be achieved by the year 2030 in comparison to IRP 2018. For the year 2050 the health cost savings amount to R101 billion and R28 billion respectively. The rapid reduction in health costs from the power sector under the DEA_RD scenario in comparison to IRP 2018 (figure 16 vs figure 17) can be mainly attributed to the earlier and faster pace of introducing RE (especially wind and solar PV) as major sources in the power mix, as well as replacing (and offsetting) more coal power plants with installed RE sources (accounting for more than 70% of production share by 2050); although peaking plants are introduced by 2021 to ensure that the flexibility, reliability and adequacy requirements of the power system are maintained.

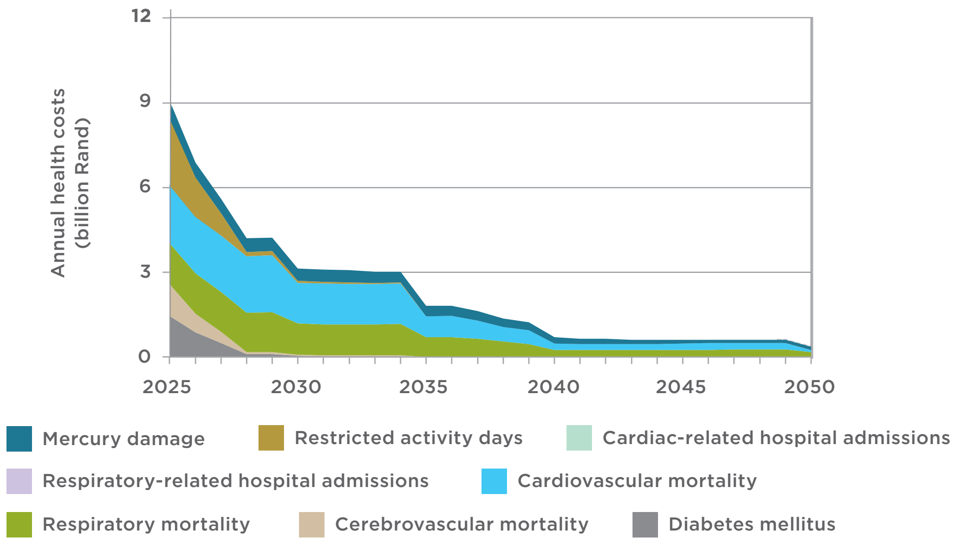


Figure 16: Lower estimate cost for each disease incidence (or ailment) from 2025 until 2050 for the DEA_RD scenario (further ambitious efforts could deliver net-zero health costs before 2045)

Source: own

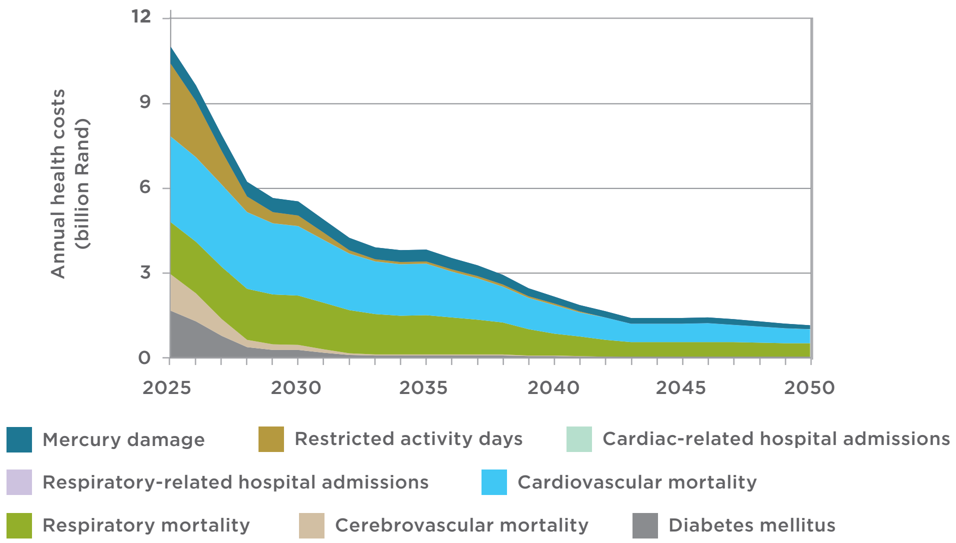


Figure 17: Lower estimate cost for each disease incident (or ailment) from 2025 until 2050 for the IRP 2018 (by 2050 the health costs from the power sector still exceed R1 billion)

Source: own

Given that the DEA_RD pathway also includes coal power generation beyond 2050, health costs could be further reduced through a scenario that phases out coal power before 2050. This could ultimately result in the power sector having net-zero health costs for metrics such as restricted activity days, cardio-related diseases and mercury damage, amongst others.

4. Creating an enabling environment to improve health and save costs

Impulses for furthering the debate

This COBENEFITS study has quantified the potential for South Africa to significantly improve the health of its people and reduce related costs by decarbonising the power sector. With its decision to progress its energy policy from IRP 2016 to IRP 2018, thereby accelerating the decarbonisation of its electricity supply, South Africa is set to cut health costs from the power sector by 25% by the year 2050. This study has also shown how, by following (or even going beyond) DEA's Rapid Decarbonisation pathway, during the same period an additional 20% can be cut from the health costs associated with the power sector, amounting to as much as R100 billion in absolute savings.

What can government agencies and political decision makers do to create a suitable enabling environment to maximise the health of the South African people and to unburden the health system?

How can other stakeholders harness the social and economic co-benefits of building a low-carbon, renewable energy system while facilitating a just energy transition?

Building on the study results and the surrounding discussions with political partners and knowledge partners, we propose to direct the debate in three areas where policy and regulations could be put in place or enforced in order to reduce air pollution from coal-fired power plants within the shift to a less carbon-intensive power sector:

- Integrate health externalities of coal into power sector planning
- Enforcement of Air Quality Act (emission standards) and potential retro-fitting of existing coal-powered plants
- Ensure better data availability for health cost assessments

Integrate health externalities of coal into power sector planning

This study has quantified the health costs related to coal-fired power generation in South Africa. Eskom's coal-fired power stations produced more than 202,106 GWh of energy in FY2017/18. At an estimated total health cost of R11–30 billion in 2018, this equates to a health cost externality of Rand 5–15 cents per kWh. These health cost externalities should be considered in power sector planning.

In addition, the locations of power plants need to be considered. Power plants that affect more densely populated areas create higher costs for society as a whole. Fortunately, in South Africa, the majority of the potential health impacts of power stations are reduced due to their distance from major population centres. However, health costs would increase with the growth of populations close to these fossil-fuelled power stations.

Finally, the emissions from individual power plants should be considered when planning the phase-out of these existing coal-fired plants. Older power plants usually have higher emissions than those that employ newer technologies. This way, the phase-out programme in line with the economic lifetime of existing power plants already implicitly takes emission intensity into account. However, there might be cases where individual power plants should be decommissioned earlier due to their specific emissions (or proximity to highly populated areas).

Enforcement of Air Quality Act (emission standards) and potential retro-fitting of existing coal power plants

Over the past decades, South Africa has elaborated a very sophisticated regulatory framework for air quality, starting with the Air Quality Act of 2004. As part of this framework, emission limits for the power sector were defined for the year 2015 and even stricter limits for the year 2020. However, Eskom and other industries have applied for postponement, since they were unable to comply with the existing regulation for the year 2015 and will likely be unable to comply with the even stricter limits proposed for 2020. Consequently, air quality in the Highveld, which contains most of South Africa's coal-fired power stations, often fails to meet National Ambient Air Quality Standards (NAAQS) (DEA, 2009 and 2012).

According to the latest DEA regulation:

- Existing coal power plants may apply for a one-off postponement of compliance with new plant standards. If granted, any such postponement cannot exceed 5 years and cannot extend beyond 31 March 2025.
- Existing coal plants that will be decommissioned before 2030 may apply for a one-off suspension of the timeframes for compliance with new plant standards, for a period not beyond 2030. In order to secure such a suspension, Eskom would need to table a clear decommissioning plan before 31 March 2019.

Technology can play a major role in reducing emissions from coal-fired power plants. For example, Eskom's current air quality improvement planning process is considering abatement technologies to reduce atmospheric pollutants, such as the use of low-NOX burners, flue gas desulphurisation and fabric filter bags. These abatement technologies, however, can add considerable costs to power generation, either directly due to capital and operational expenditure require-ments, or indirectly due to increased water consumption, carbon emissions and landfill require-ments. Therefore, any assessment of the viability of filtering technologies should consider the costs and potential negative side-effects (e.g., higher water consumption, increased carbon emissions).

As expected, scenarios with fewer fossil-fuelled power stations (and lower installed capacity) emit less air pollution; however, policies fail to take into consideration that absolute emissions is only one factor affecting health costs. The locations of power stations, and their proximity to densely populated areas, are also major factors for direct health care costs. Fortunately, in South Africa, the majority of the health impacts of power stations are reduced due to their distance from major population centres. Health costs would increase with the growth in populations close to these fossil-fuelled power stations.

Power stations contribute a small fraction to the annual average ambient concentrations of atmospheric pollutants. Predicted additional ambient concentrations were low when averaged over a municipality, but as many as 43 million people are additionally exposed to more than 1 µg/m3 of each pollutant (a conservative threshold, as relative risks are quantified for 10 µg/m3 increments). These modelled values are low compared with monitored ambient air quality concentrations and national standards, suggesting that non-point sources of air pollution, such as domestic fuel burning, the transportation sector and natural sources of pollution, present greater risks to human health.

Eskom's coal-fired power stations produced more than 202,106 GWh of energy in FY2017/18. At an estimated total health cost of R11–30 billion in 2018, this equates to a health cost externality of Rand 5–15 cents per kWh.

Better access to information and further research needed:

- Public access to air quality information: Ambient air quality data sources are interspersed and difficult to access. There are online resources that share air quality information. Regulators should consider sharing real-time ambient air quality data, so that researchers have easier access and the public is better informed. Similarly, dispersion modelling results (shapefiles) should be shared when publishing atmospheric impact reports, to avoid the need for time-consuming and costly duplication of modelling efforts.
- More detailed information on policies: Policies such as the Integrated Resources Plan need to be supplemented by more detail on the underlying assumptions and externalities. With regard to air quality, policymakers need to consider the locations of power plants in terms of both their effects on ambient air quality as well as considering local population densities.
- Technology can play a major role in reducing emissions of pollutants from power plants. For example, Eskom's current air quality improvement planning process is considering abatement technologies to reduce atmospheric pollutants, such as the use of low-NOX burners, flue gas desulphurisation and fabric filter bags. These abatement technologies, however, can add considerable costs to power generation, either directly due to capital and operational expenditure require-ments, or indirectly due to increased water consumption, carbon emissions and landfill require-ments.
- While the peak health cost estimate of R13–45 billion is sufficient to drive policy positions on the carbon intensity of the energy sector, it should also be used in combination with other environmental (reduction of greenhouse gas emissions, water consumption, waste generation) and economic (job creation, enterprise development, industrialisation) co-benefits to influ-ence decision making.
- The R11–30 billion health cost estimate for 2018 is difficult to evaluate as a standalone figure; nevertheless, health cost savings as a result of reduced pollutant emissions represent a benefit and are a useful metric. This is especially true because the VSL used to attribute health costs is not a cost borne directly by the health care sector. In 2017, direct health care spending accounted for approximately 9% of South Africa's total GDP of R4.65 trillion. Cost–benefit analysis would provide further context on the estimates made in this study, allowing these benefits (health cost savings) to be weighed against the costs of mitigation options or other power generation options.

References

DEA, Department of Environmental Affairs (2009): National Ambient Air Quality Standards, Government Gazette, 32861, Vol. 1210, 24 December 2009

DEA, Department of Environmental Affairs (2012): National Ambient Air Quality Standard for Particulate Matter of Aerodynamic Diameter less than 2.5 micrometers, Notice 486, 29 June 2012, Government Gazette, 35463

DEA, Department of Environmental Affairs (2014): Code of Practice for Air Dispersion Modelling in Air Quality Management in South Africa, Government Notice R.533, Government Gazette, no. 37804, 11 July 2014

Dios, M.; Souto, J.A.; Casares, J.J.; Gallego, N.; Sáez, A.; Macho, M.L.; Cartelle, D.; Vellón, J.M. (2012): A mixed top-down and bottom-up methodology in spatial segregation of emissions based on GIS tools. 20th International Conference on Modelling, Monitoring and Management of Air Pollution, 16 – 18 May 2012, A Coruña, Spain

Eskom (2017): Integrated Report 31 March 2017. Eskom Holdings SOC Ltd. www.eskom.co.za/IR2017

FIRS, Forum of International Respiratory Societies (2017): The Global Impact of Respiratory Disease – Second Edition. Sheffield, European Respiratory Society. e-ISBN: 9781849840880

FRIDGE, Fund for Research into Industrial Development Growth and Equity (2004): Study to examine the potential socio-economic impact of measures to reduce air pollution from combustion.

Garnham, B.; Langerman, K.E. (2016): Belinda L.; Langerman, Kristy E. (2016): Mercury emissions from South Africa's coal-fired power stations. Clean Air Journal. 26(2): 14 – 20

Gray, A.; Vawda, Y. (2017): Health Policy and Legislation. In: Padarath, A., Barron, P., editors. South African Health Review 2017. Durban: Health Systems Trust; 2017.

Helgenberger, S., Gürtler, K., Borbonus, S., Okunlola, A., Jänicke, M. (2017): Mobilizing the co-benefits of climate change mitigation: Building New Alliances – Seizing Opportunities – Raising Climate Ambitions in the new energy world of renewables. – COBENEFITS Impulse (Policy Paper), November 2017. DOI: 10.2312/iass.2017.021

Helgenberger, S., Jänicke, M. (2017): Mobilizing the co-benefits of climate change mitigation: Connecting opportunities with interests in the new energy world of renewables. – IASS Working Paper, July 2017. DOI: 10.2312/iass.2017.015.

Helgenberger S., Jänicke M., Gürtler K. (2019): Co-benefits of Climate Change Mitigation. In: Leal Filho W., Azul A., Brandli L., Özuyar P., Wall T. (eds) Climate Action. Encyclopedia of the UN Sustainable Development Goals. Springer, Cham. DOI: 10.1007/978-3-319-71063-1

Holland, Mike (2017): Health impacts of coal fired power plants in South Africa. Centre for Environmental Rights. https://cer.org.za/wp-content/uploads/2017/04/Annexure-Health-impacts-of-coal-fired-generation-in-South-Africa-310317.pdf

Integrated Environmental Health Impact Assessment System. (2015): http://www.integrated-assessment.eu/eu/guidebook/exposure_response_functions_0.html (11.03.2019)

Institute for Health Metrics and Evaluation. (2016): Global Burden of Disease (GBD) Country Profiles: South Africa. http://www.healthdata.org/south-africa

Jo, Changik (2014): Cost-of-illness studies: concepts, scopes, and methods. Clin Mol Hepatol. 2014 Dec; 20(4): 327 – 337.

Myllyvirta, Lauri (2014): Health impacts and social costs of Eskom's proposed non-compliance with South Africa's air emission standards. Greenpeace. http://large.stanford.edu/courses/2017/ph240/mak1/docs/mulliverta.pdf

Myllyvirta, Lauri (forthcoming): Air quality and health impacts of ESKOM's planned non-compliance with South African Minimum Emission Standards. Greenpeace Global Air Pollution Unit.

Naledzi (2018): Summary Atmospheric Impact Report (AIR). In support of Eskom's application for postponement of the Minimum Emission Standards for its Coal-Fired Power Stations. (Draft for Public Review. Naledzi Environmental Consultants. November 2018.

NEMA (2004): AQA, National Environmental Management: Air Quality Act. 39/2004: Section 18

Rice, Dorothy P.; Hodgson, Thomas. A.; Kopstein, Andrea N. (1985): The Economic Cost of Illness: A Replication and Update. Health Care Financing Review, 6, 61 – 80

Rice, Dorothy P. (1996): Health Economics Series No 6. Washington: U. S. Government Printing Office; Estimating the Cost of Illness. PHS Pub. No. 947-6

Rice, Dorothy P. (2000): Cost of illness studies: what is good about them? Injury Prevention. 2000(6):177 – 179.

SAAQIS, South African Air Quality Information System: Department of Environmental Affairs. Available at http://www.saaqis.org.za/Priority%20Areas.aspx (11.03.2019)

Spalding-Fecher, R.; Matibe, D. K. (2003): Electricity and externalities in South Africa. Energy Policy 31 (8): 721 – 734

StatsSA. (2012): Census 2011 Statistical release – P0301.4 / Statistics South Africa. Pretoria: Statistics South Africa. https://www.statssa.gov.za/publications/P03014/P030142011.pdf

StatsSA. (2018): Mortality and causes of death in South Africa, 2016: Findings from death notification. Release PO309.3 http://www.statssa.gov.za/publications/P03093/P030932016.pdf

Van Horen, C. (1996): Counting the social costs: electricity and externalities in South Africa. University of Cape Town Press, 1996

WHO, World Health Organization (2009): Environmental Burden of Disease. South Africa. https://www.who.int/quantifying_ehimpacts/national/countryprofile/southafrica.pdfhttp://www.who.int/quantifying_ehimpacts/national/countryprofile/en/

WHO, World Health Organization (2016): International Statistical Classification of Diseases and Related Health Problems 10th Revision. http://apps.who.int/classifications/icd10/browse/2016/en

Glossary and abbreviations

COI	Cost-of-Illness
CSIR	Council for Scientific & Industrial Research
CSIR_LC	Council for Scientific & Industrial Research: Least Cost Scenario
DEA	Department of Environmental Affairs, South Africa
DEA_RD	the Department of Environmental Affairs Rapid Decarbonisation scenario
DoE	Department of Energy, South Africa
DTI	Department of Trade and Industry
FRIDGE	Fund for Research into Industrial Development Growth and Equity
GDP	Gross domestic product
GW	Gigawatt (1000 megawatts)
HPA	Highveld Priority Area
IASS	Institute for Advanced Sustainability Studies, Potsdam, Germany
IHME	Institute for Health Metrics and Evaluation
IPP	Independent Power Producers
IRP	Integrated Resource Plan
IRP 2010	Integrated Resource Plan 2010
IRP 2016	Integrated Resource Plan 2016: Base Case scenario
IRP 2018	Integrated Resource Plan 2018: Policy-Adjusted scenario
Hg	Mercury
MW	Megawatt (unit of power)
NAAQS	National Ambient Air Quality Standards
NEMA	National Environmental Management Act
NO_2	Nitrogen dioxide
PM_{10} and $PM_{2.5}$	Particulate matter
RE	Renewable energy
SAAQIS	South African Air Quality Information System
SO_2	Sulphur dioxide
VSL	Value of a statistical life

COBENEFITS

COBENEFITS
Connecting the social and economic opportunities of renewable energies to climate change mitigation strategies

COBENEFITS cooperates with national authorities and knowledge partners in countries across the globe such as Germany, India, South Africa, Vietnam, and Turkey to help them mobilise the co-benefits of early climate action in their countries. The project supports efforts to develop enhanced NDCs with the ambition to deliver on the Paris Agreement and the 2030 Agenda on Sustainable Development (SDGs) and to enable a just transition. COBENEFITS facilitates international mutual learning and capacity building among policymakers, knowledge partners, and multipliers through a range of connected measures: country-specific co-benefits assessments, online and face-to-face trainings, and policy dialogue sessions on enabling political environments and overcoming barriers to seize the co-benefits.

Contact

COBENEFITS focal point South Africa
Ruan Fourie, RFourie@csir.co.za

COBENEFITS project director
Sebastian Helgenberger, Institute for Advanced Sustainability Studies (IASS)
sebastian.helgenberger@iass-potsdam.de

DOI: 10.2312/iass.2019.008

www.cobenefits.info

@IKI_COBENEFITS

Supported by:
Federal Ministry for the Environment, Nature Conservation and Nuclear Safety
based on a decision of the German Bundestag

INTERNATIONAL CLIMATE INITIATIVE (IKI)