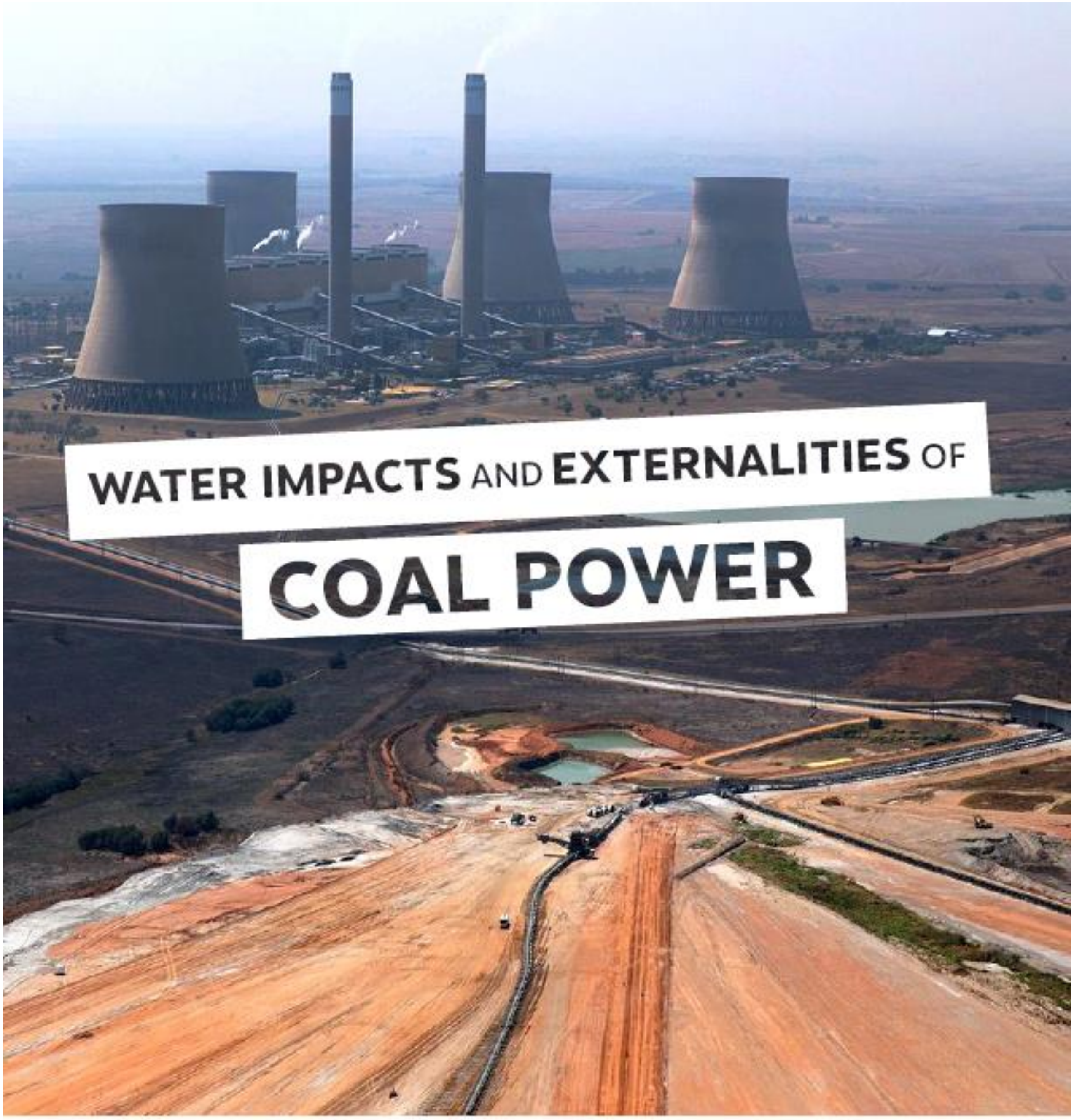
WATER IMPACTS AND EXTERNALITIES OF COAL POWER



LIFE AFTER COAL
IMPILO NGAPHANDLE KWAMALAHLE

Executive Summary

A negative environmental externality is a cost imposed on the environment and society due to the activities of a polluter; resulting in social, health, environmental degradation and other negative impacts. These costs are not paid for by the polluter. Rather, poor and marginal communities disproportionately carry the burden of these negative impacts. In the case of electricity supply, externalities occur when negative social and environmental impacts are not reflected in the costs of producing electricity or the price paid by electricity customers (National Research Council, 2009).

South Africa is still predominantly reliant on coal for electricity generation. Approximately 89% of South Africa's electricity is generated by coal-fired power stations. In the year to end-March 2015 Eskom bought 122 Mt of thermal coal. Coal-fired power - and the electricity sector in general - is a major source of externalities. Such externalities arise throughout the life cycle of coal, including the extraction (coal mining and transport), supply, and demand stages. The main categories of negative externalities in the electricity sector relate to health, ecosystem impacts, climate change, and water (Vivid Economics, 2014).

The Draft Integrated Resource Plan for Electricity (Draft IRP) (Department of Energy, 2016a) provides cost estimates for different electricity supply options or energy portfolios. However, it does not consider and evaluate a range of externalities in general and water-related externalities and impacts in particular. This results in a misrepresentation of the total costs of coal-fired power generation. There are several key considerations related to water impacts and externalities that are of critical importance for electricity planning. In this regard, the following key considerations are brought to the fore:

Coal power generation requires significant volumes of water: Coal mining and power generation consume 5% and 2% of South Africa's water respectively (DWA, 2013). Although water use for power generation may be relatively small at a national scale, it is far more significant on a regional level. For instance, power generation accounts for 37% of water use in the Upper Olifants (World Bank, 2017).

Water for power generation in South Africa is under-valued: In 2010 the electricity sector paid far less for water (approximately R3.40 per cubic meter) than the average household (approximately R8 per cubic meter) (StatsSA, 2010). Such under-valuing of water for power generation results in over-use and creates no incentive to prioritise water-efficient supply options (Vivid Economics, 2014). For instance, between 2006 and 2016 Eskom's water consumption per unit of energy has increased from 1.3 litres per kWh to 1.44 litres per kWh (Eskom, 2017). In contrast, valuing water would justify a rapid transition away from coal-based energy to water-efficient renewable energy. This would mean that water currently used for coal-power generation could be better allocated, to other more sustainable uses.

Mining and burning coal impacts on our scarce water resources: Our scarce water resources are impacted throughout the coal life-cycle including direct impacts on water quality during coal mining; impacts of air pollutants on water resources and coal ash contamination of groundwater. However, acid-mine drainage has the most severe impact, polluting our surface and groundwater with acid, salts and metals. This creates considerable negative impacts related to human health, livestock, crop production, and aquatic ecosystems (WWF-SA, 2011).

The capital and operational costs to treat mine water are considerable: A number of studies attempt to quantify water treatment costs associated with coal-fired power. Further, several examples of current water treatment projects, including eMalahleni Water Reclamation Project, illustrate the considerable costs and challenges associated with the long-term and sustainable treatment of acid-mine drainage (Bhagwan, 2012). These highlight that it is far more cost-effective to *preven*t water pollution.

Historical impacts of coal mining require treatment and associated costs for decades to come: South Africa has around 5 906 derelict and ownerless (D&O) mines captured on a database –there are likely significantly more. These create considerable health and safety risks and pollute water resources and agricultural land. It is estimated that the closure of D&0 mines, including long-term treatment of acid-mine drainage, would cost up to R60 billion (WWF-SA, 2011).

A decarbonised future not only has far lower water consumption, but also costs less and creates more jobs: Research by the Council for Scientific and Industrial Research highlights that a decarbonised energy future would require four times less water, by 2050, than a Base Case that relies heavily on coal and nuclear. A decarbonised future would further cost less and create up to 331 000 jobs in the energy sector by 2050 (CSIR, 2017).

Coal power disproportionately affects marginalised communities located around coal mines and power stations: Studies on the health impacts in coal mining communities have found that community members have: 70% greater risk of developing kidney disease; 64% greater risk of developing chronic obstructive pulmonary disease (COPD), such as emphysema; and are 30% more likely to report high blood pressure (hypertension) (Genthe et al., 2013). Not only do marginal communities carry a disproportionate exposure to the negative effects of coal mining and coal power generation, but are also disproportionately more vulnerable to the same effects (Holland, 2017).

In light of the above, it is imperative that the final Integrated Resource Plan for Electricity considers a range of water-related externalities and impacts in determining and costing South Africa's future electricity supply mix. Such considerations include:

- Water use, across the full life-cycle of coal, with consideration of regional water availability
- Water infrastructure and management costs for different supply options
- Appropriate valuation of water for generation to ensure water efficiency is considered in supply options
- Water treatment costs, including capital and operation costs, for different supply options, with appropriate consideration of the long-term treatment requirements for acid-mine drainage
- The impact of different options on water quality and our water resources
- The downstream impacts of acid mine drainage
- Impacts on critical water resources such as our strategic water source areas
- Impacts due to the deposition of air pollutants on our water resources
- Water-related climate change externalities
- The knock-on effects of degradation of our water resources (especially acid-mine drainage) on ecosystems, crop production, health, and livelihoods of those reliant on the water
- Environmental justice in view of disproportionate negative effects of externalities on marginalised communities

Inadequate consideration of the above results in a misrepresentation of total costs of coal-fired power generation. Conversely, internalising these considerations would justify a rapid transition away from coal to water-efficient renewable energy. This is critical in light of the water crisis we confront.

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1.1. Coal mining and coal power generation in South Africa

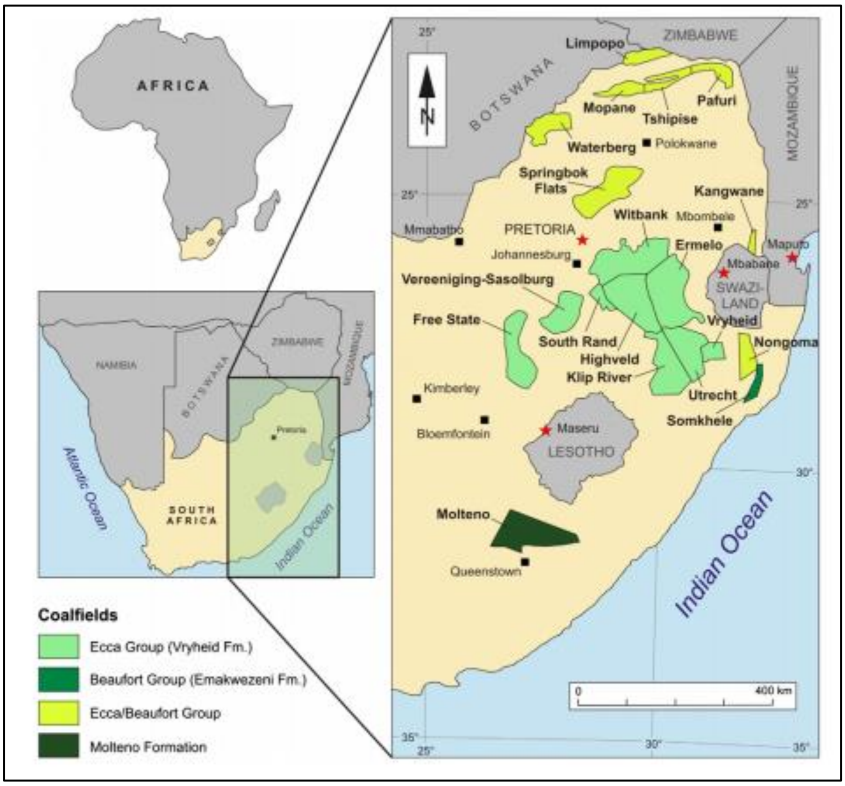
South Africa's coal reserves are estimated at around 30 billion tonnes. South Africa is home to 3.5% of global coal resources; produces 3.3% of total global annual production; and accounts for 6% of global exports. This ranks South Africa as 6th in the list of coal-exporting nations (Engelbrecht, 2010).

In 2014, South Africa produced 260Mt of coal. Of this, 182.7 Mt were sold internally, whereas 69.6 Mt were exported (CoM, 2017). This amounts to roughly a 7:3 ratio of local use to export. Thus, the majority of coal produced is used domestically (CoM, 2017). Domestically, coal is consumed mainly for the generation of electricity by Eskom (110 million tons in 2014) and the production of synthetic fuels and chemicals by Sasol (40 million tons in 2014). The remaining 21 million tons are consumed mainly in boilers and furnaces for industrial and domestic heat-production (CoM, 2017)

In general, higher grades of final product are delivered to export markets, with the lower grade product used by Eskom power stations. In order to produce coal for the domestic and export markets, a significant amount of the mined coal requires beneficiation (washing), which produces 45 million tons of discards that are dumped and pumped to slimes dams (Hartnady, 2010).

It is generally accepted that there are around 19 coalfields in South Africa spanning over 9.7 million hectares (Hancox and Götz, 2014). This is represented in Figure 1. However, coal production is concentrated in large mines. The majority of coal production has come from six or seven coalfields (Hancox and Götz, 2014); and the largest eight mines account for 61% of total output.

Figure 1: Map of South Africa's coal-fields (Hancox and Götz, 2014)

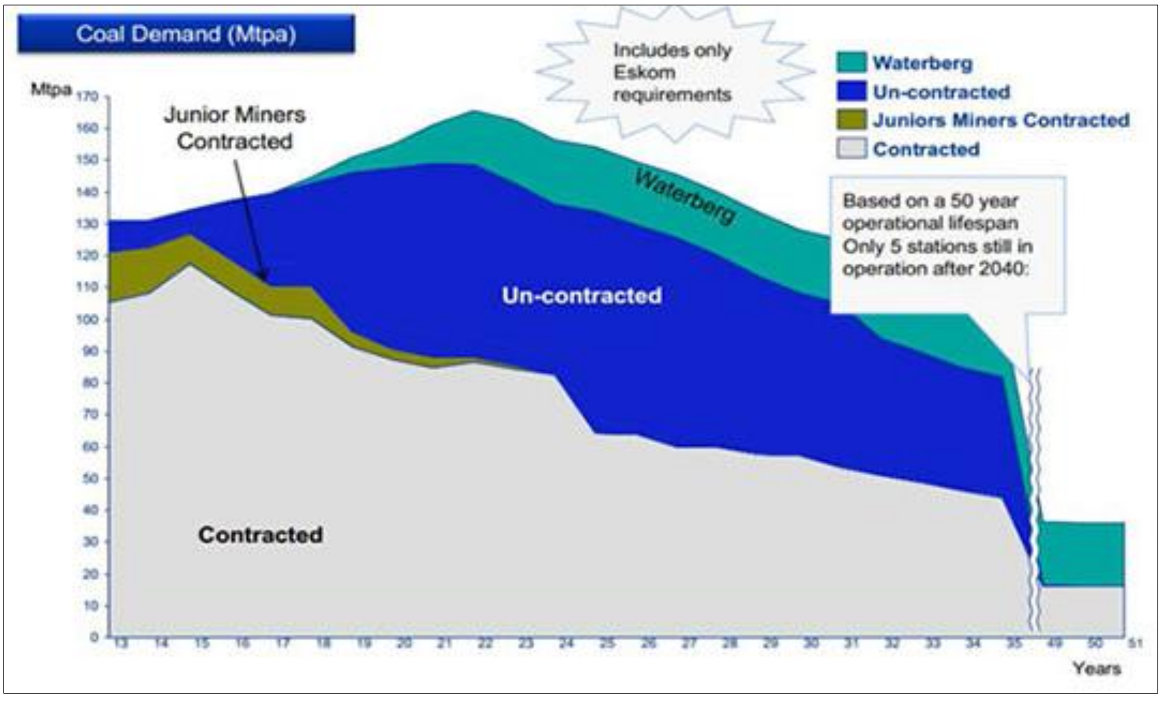


The majority of South Africa's coal reserves are located on the north-eastern part of the country. Traditional areas of extraction such as Witbank are reaching the end of their productive life. As such increasing focus is moving to the Waterberg and Limpopo province (CoM, 2017). The South African Coal Roadmap (South African National Energy Development Institute [SANEDI], 2011) estimates that the "remaining run-of mine coal resources in the Witbank, Highveld and Ermelo coalfields is estimated to be around 12, 000 Mt (combined reserves across all three coalfields)."

Studies on coal production rates in South Africa, applying the Hubbert method, estimate a peak in production rate at about 284 Mt per year in 2020 (Jeffrey, 2005). At this stage, approximately half (12 Gt) of economically-recoverable coal resources (about 23 Gt) would have been exhausted. Thereafter, the annual production rate will decline. Models on coal reserves and production in South Africa estimate that due to natural limits of the resource, coal will be exhausted by 90% by 2050 (Hartnady, 2010).

South Africa is still predominantly reliant on coal for electricity generation. Approximately 89% of South Africa's electricity is generated by coal-fired power stations. Eskom operates 15 power stations, with two currently under construction. In the year to end-March 2015 Eskom bought 122 Mt of thermal coal. In 2008 South Africa, committed to a 'peak, plateau and decline' (PPD) emissions trajectory, which requires emissions to peak by 2020-2025, stabilise for up to ten years, and then decline in absolute terms (Department of Environmental Affairs [DEA], 2011). South Africa's climate change commitments, framed in its Nationally Determined Contributions (NDC) requires an even sharper decline in coal production (and consumption) than anticipated declines in production due to natural limits of the resource (or peak production rates). This sharp decline is highlighted in Figure 2.

Figure 2: Eskom's future coal supply in terms of the South African Coal Roadmap (SANEDI, 2011)

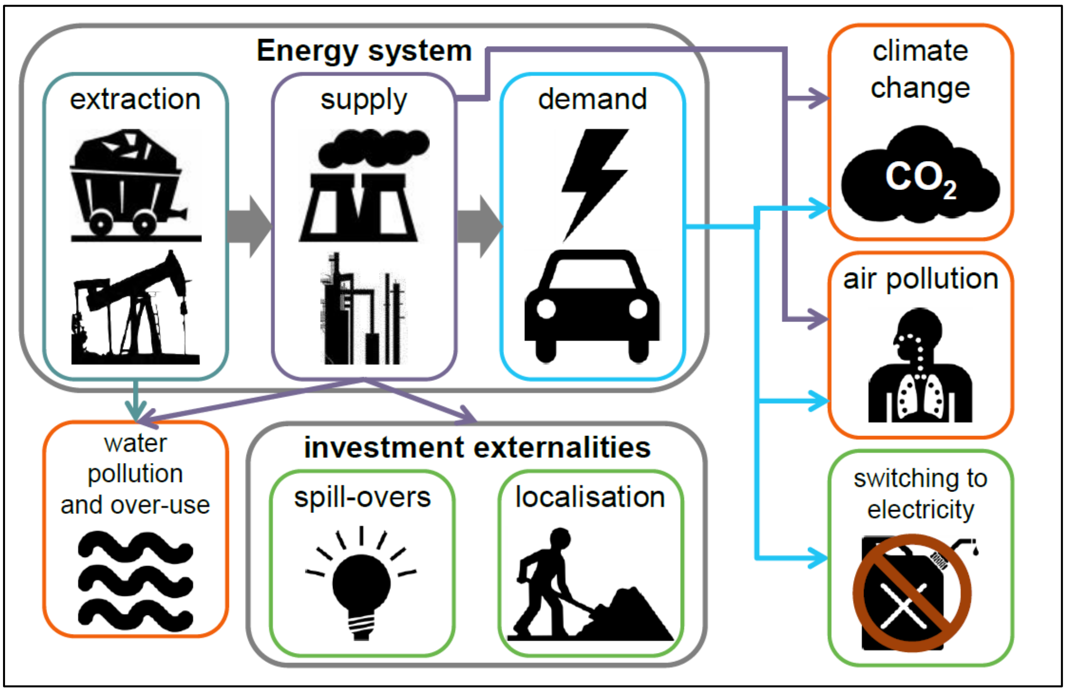


1.2. Externalities in coal mining and coal power generation

A negative environmental externality is a cost imposed on the environment and society due to the activities of a polluter; resulting in social, health, environmental degradation and other negative impacts. These costs are not paid for by the polluter. Rather, poor and marginal communities disproportionately carry the burden of these negative impacts. In the case of electricity supply, externalities occur when negative social and environmental impacts are not reflected in the costs of producing electricity or the price paid by electricity customers (National Research Council, 2009). The electricity sector is a major source of externalities. These may arise at the extraction (mining and transport), supply and demand stages, as represented in Figure 3. The main categories of negative externalities in the electricity sector relate to:

- Climate change: greenhouse (GHG) emissions caused predominantly by combustion of hydrocarbons such as coal cause climate change. Climate change negatively impacts on people across the globe and future generations. This, in turn, imposes costs related to, amongst others, the need to adapt to climate change and impacts of increased extreme weather events.
- Air pollution: sulphur dioxide (SO_2), nitrogen oxides (NO_X) and particulate matter (PM) all cause respiratory problems and are among the most damaging air pollutants from electricity generation.
- Water pollution and over-use: mining and burning coal for coal power generation uses significant volumes of water and pollutes water (Vivid Economics, 2014).

Figure 3: Positive and negative externalities in energy systems (Vivid Economics, 2014)[1]



Externalities are also closely linked to subsidies. Incentives for fossil fuels are embedded into coal-fired power production in the form of hidden subsidies. Stefanski (2016) uses a novel approach of using country carbon emission values, related to the amount of energy produced from fossil fuels, to estimate the real price (including subsidies and taxes) of fossil fuels in each country. According to Stefanski (2016), in 2010, South Africa spent $26 billion (USD) (or R319 billion) on net subsidies for fossil fuels.

There is a robust body of research addressing externalities related to coal power generation in South Africa, with notable contributions being: Dutkiewicz and De Villiers (1993), Van Horen (1997), Spalding-Fecher and Matibe (2003), Spalding-Fecher (2005), Thopil and Pouris (2010), Edkins, et al. (2011). More recently, a considerable body of research has come from the University of Pretoria, from work by Blignaut (2011), Blignaut (2012), Nkambule and Blignaut (2012), Inglesi-Lotz and Blignaut (2012), Riekert and Koch (2012), Myllyvirta (2014) and Holland (2017). Notably, Greenpeace Africa have commissioned a considerable body of research (Business Enterprises, 2011) and have written

[1] Red rings relate to negative externalities and green rings relate to positive externalities

extensively on externalities of coal power generation in South Africa (Greenpeace Africa, 2012a; Greenpeace Africa, 2012b). This report relates mainly to water impacts and externalities of coal power. However, considerations related to health and climate change externalities require brief discussion.

1.2.1. Health impacts and externalities

Coal-fired power plants in South Africa have considerable health impacts resulting in premature death and increased illness (Holland, 2017; Riekert and Koch, 2012; Myllyvirta, 2014). This, in turn, creates a substantial externalised economic burden related to human health. Although health damage costs are difficult to value, two main approaches are commonly used, namely the willingness-to-pay and the cost-of-illness approach. The willingness-to-pay approach considers an individual's preference for avoiding or mitigating risks of illness and death. The cost-of-illness considers a range of factors, such as the health service costs and loss of wages associated with an illness. The cost-of-illness approach is regarded as more extensive.

Research by Holland (2017) provides a detailed analysis of the health impacts and associated costs of just one type of air pollutant ($PM_{2.5}$) emitted from Eskom's coal-fired power plants. The study finds that air pollution from coal-fired power plants is responsible for approximately 2239 equivalent attributable deaths and thousands of cases of respiratory diseases. This translates to a quantifiable total economic cost of air pollution from coal-fired generation in the region of $2.37 billion (USD) (R29 billion) per year. This includes 'health impacts related to premature death, chronic bronchitis, hospital admissions for respiratory and cardiovascular disease, and a variety of minor conditions leading to restrictions on daily activity' (Holland, 2017). The key findings related to impacts from air pollution from coal-fired power plants are outlined in Table 1 below.

Table 1: Annual health impacts linked to coal-fired generation in South Africa (Holland, 2017)

	Cases	**Value (Millions USD)**
Equivalent attributable deaths		
Lung cancer	157	
Ischaemic heart disease	1,110	
Chronic obstructive pulmonary disease	73	
Stroke	719	
Lower respiratory infection	180	
Total equivalent attributable deaths	2,239	2,121.99
Chronic bronchitis (adults cases)	2,781	64.64
Bronchitis in children aged 6 to 12	9,533	2.19
Equivalent hospital admissions	2,379	2.79
Restricted Activity Days (all ages)	3,972,920	132.72
Asthma symptom days (children 5---19yr)	94,680	1.44
Lost working days	996,628	47.05
Total costs		2,372.78

The report further estimates the health impacts of individual Eskom power stations based on respective emissions. The findings highlight the following attributable deaths per power station:

- Medupi: 364 death per year
- Matimba: 262 deaths per year
- Kendal: 210 deaths per year
- Lethabo: 204 deaths per year
- Matla: 192 deaths per year
- Tutuka: 192 deaths per year

Research by Riekert and Koch (2012) investigates the annual health damage cost associated with coal-fired power generation at Kusile. The study is limited to the health impacts relating to inhalation of air pollution from electricity generation,[2] and only calculates costs associated with SO_2, NO_2, and PM_{10}. It thus excludes impacts associated with exposure to harmful substances that have seeped from coal combustion waste facilities into ground or surface water sources.[3] The following health issues were considered in the health damage cost calculation: chronic bronchitis in adults, respiratory hospital admission, cardiovascular hospital admissions, emergency room visits, acute bronchitis in children, asthma attacks in children, asthma attacks in adults, restricted activity days in adults, and days with acute respiratory symptoms. The study finds that the health-related externality cost of Kusile is approximately 1c/kWh.

The largest impact on health from coal mining stems from acid-mine drainage. Metal concentrations associated with acid-mine drainage can bio-accumulate in animals and humans through drinking contaminated water, ingesting contaminated plants, or through dermal absorption in air and water. The known impacts of toxicity of individual contaminants associated with acid-mine drainage include:

- Aluminium: respiratory and neurological ailments, neurotoxic effects, bone diseases in renal patients, and a potential causal link to Alzheimer's disease;
- Manganese: neurotoxic effects; and
- Sulphates: diarrhoea (Riekert and Koch, 2012)

Although many reports assess health risks associated with individual metal exposure, there are no comprehensive studies on the cumulative health impacts stemming from the multiple pollutants associated with acid-mine drainage, or an evaluation of associated health damage costs.

1.2.2. Climate change impacts and externalities

Blignaut (2012)[4] estimates the global damage cost of coal-fired power generation for Kusile and Medupi based on their expected CO_2 emissions.[5] The global damage cost of power generation was calculated by multiplying the expected annual CO_2 emissions by a range of social damage costs (R/tCO_2), which were estimated based on a review of various studies. The findings (shown in Table 2) are based on a range of social damage cost estimates (low-Stern).

Table 2: Eskom's additional annual contribution to global damage cost as a result of Medupi and Kusile (R million in 2010) (Blignaut, 2012)

	CO_2-emissions	**Low**	**Median**	**Market**	**High**	**Very high**	**Stern**
Medupi	30 million t	174.88	3 147.84	3 294.00	5 333.84	18 012.63	24 597.40
Kusile	30 million t	174.88	3 147.84	3 294.00	5 333.84	18 012.63	24 597.40
Both	60 million t	349.76	6 295.68	6 588.00	10 667.67	36 025.25	49 194.79

Table 2 indicates that the combined total global damage cost due to the expected CO_2 emissions from Medupi and Kusile (in ZAR 2010 terms) is likely to be between R6.3-10.7 billion each year.

Nkambule and Blignaut (2012) further estimate the global damage cost due to the mining and transportation of the coal required by Kusile. They utilised data by Lloyd and Cook (2005) to estimate the amount of methane that will be released during mining (26,962 - 350 506 t/yr), which they converted to an equivalent release of CO_2 and multiplied

[2] It excludes impacts due to mining.
[3] This omission was due to a lack of reliable information.
[4] Research by Blignaut has investigated a range of externalities relating to coal power, including health, climate change, water use, and mining respectively.
[5] i.e. it excludes CO_2 emissions associated with the mining and transportation of coal

by a range of social damage costs, as per the methodology used to calculate the global damage cost due to coal power generation. They further estimated the carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4) emissions due to the transportation of coal via road, assuming 7 751 935 litres of diesel will be consumed each year.

Their findings, summarised in Table 3, suggest that the global damage cost due to the mining and transportation of the coal required by Kusile will most likely be between the range of R479 million and R776 million (assuming a mean methane release rate) and R888 million and R1 438 million per year (assuming a high methane release rate). More than 99% of this cost is due to the anticipated methane releases during coal mining, with the remainder due to the CO_2, N_2O and CH_4 emissions to be released during the transportation of the coal to Kusile.

Table 3: Overall annual global damage cost due to coal mining and coal transportation associated with Kusile (2010 values) (Business Enterprises, 2011)

Overall global damage	**Coal mining: CH4 emission factor**	**Units**	**Market**	**Median**	**High**	**Very high**	**Stern**
Coal mining and coal Transportation	Low	R mil	71	67	114	386	527
	Mean	R mil	479	458	776	2622	3580
	High	R mil	888	847	1438	4857	6 633

It is important to note that the cost estimates in respect of both coal power generation (Blignaut, 2012)[6] and coal mining and transportation (Nkambule and Blignaut, 2012)[7] reflect the total global damage cost relating to climate change. Therefore, the estimates do not distinguish between costs that relate to water resources and those that do not. Nevertheless, although the overall impact of climate change on water resources is uncertain (CSIR, 2009), water resources are at the epicentre of projected climate change impacts (Kusangaya, et al., 2013) and the impacts of climate change on people will predominantly relate to water (Stern, 2007). Further, the impacts of water contamination due to coal mining interact in complex ways and compound the effects of climate change on our water resources (Udall, 2018).

The major climate related risks to South Africa's water resources include: increased incidence of drought due to a decrease in rainfall in many areas; increased incidence of floods as the incidence of very heavy downpours increases; and the increased risk of water pollution, linked to erosion, disasters, algal blooms and saltwater intrusion due to rising sea levels.[8] These climate change impacts on water resources will have both direct and indirect effects on the socio-economic and biophysical environments, such as the risk of food shortages due to a reduction in available irrigation water, or an increase in household poverty due to rising food prices (Kusangaya, et al., 2013).

1.3. Externalities and the Integrated Resource Plan for Electricity

The Draft Integrated Resource Plan for Electricity (Draft IRP) (Department of Energy [DOE], 2016a) provides cost estimates for different fuel sources or energy portfolios, and, in this process, pays lip-service to the idea of externalities. For instance, the Draft IRP (DOE, 2016a) touches on the cost of the damage to society stemming from air pollution and associated health impacts[9]. The Draft IRP (DOE, 2016a) defines externalities as:

> *[a] cost imposed on society due to the activities of a third party, resulting in social, health, environmental, degradation or other costs. These costs may be beneficial (e.g. a mine builds a fire break between its operations and the neighbouring farm from which the farmer then directly benefits in terms of safety and security)"…"For the purpose of these statements, overall cost to society is defined as the sum of the*

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[6] Reflected in Table 1.

[7] Reflected in Table 3.

[8] Climate change and water resources: Altered water availability and increased societal risks (unauthored), accessed from the SA Risk and Vulnerability Atlas at: http://rava.qsens.net/case-studies/climate-change-and-water-resources.doc/view

[9] Notably nitrogen oxide, sulphur oxide, mercury, and particulate matter.

imputed monetary value of costs to all parties involved. Externality costs were calculated for different types of pollutants based on the estimated cost of damage caused by those pollutants.

However, these calculations do not take into account the full cost of coal power generation; with evaluation of the full life cycle of coal from mining to energy generation. There are a wide range of externalities that are not considered in total system costs. These include, *inter alia*, water consumption, cost to treat polluted water, CO_2 emissions, climate change impacts, health impacts associated with, *inter alia*, air pollution and acid-mine drainage, ecosystem impacts and rehabilitation costs, decommissioning costs, and water management costs. In comparison, the Shale Gas Strategic Environmental Assessment undertaken by the Council for Scientific and Industrial Research (CSIR) provides a broader outline and approach to externalities. The study provides a detailed examination of different potential impacts and externalities of a shale gas industry in the Karoo. Table 4 compares these externalities.

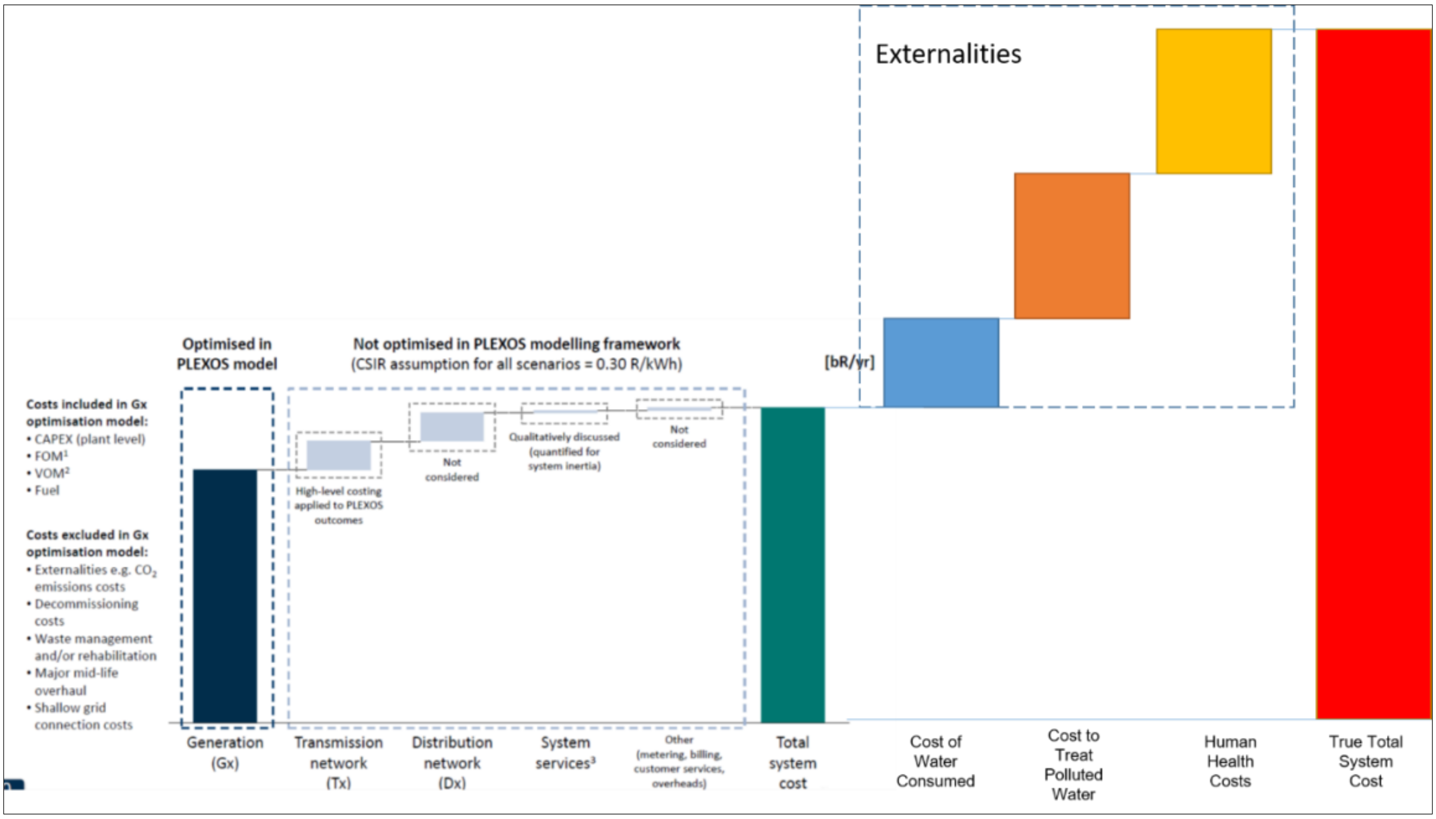
Table 4: Comparison of externalities considered in the Draft Integrated Energy Plan, the Draft IRP and the Shale Gas Strategic Environmental Assessment

Draft Integrated Energy Plan (DOE, 2016b)	Draft IRP 2016 (Department of Energy, 2016a)	Shale Gas Strategic Environmental Assessment (Scholes, et al., 2016)
▪ Air Pollution (nitrogen oxide, sulphur oxide, particulate matter and mercury), ▪ Climate Change (caused by excess CO_2 emissions) ▪ Water use	▪ Air Pollution (nitrogen oxide, sulphur oxide, particulate matter and mercury), ▪ CO_2 emissions	▪ Air Quality and GHG Emissions ▪ Earthquakes ▪ Water Resources (Surface and Underground) ▪ Impacts on Waste Planning and Management ▪ Biodiversity and Ecological Impacts ▪ Impacts on Agriculture ▪ Impacts on Tourism Impacts on the Economy ▪ Impacts on Social Fabric ▪ Impacts on Human Health ▪ Impacts on Sense of Place Values ▪ Impact on Visual, Aesthetic and Scenic Resources ▪ Impacts on Heritage ▪ Noise Generated by Shale Gas-Related Activities ▪ Electromagnetic Interference ▪ Impacts on Infrastructure and Spatial Planning

Overall, the inadequate consideration of externalities in the costing of fuel sources in the IRP (DOE, 2016a) results in a misrepresentation of the total costs of coal-fired power generation. These externalities can dwarf the IRP (DOE, 2016a) system costs which are presented to decision-makers. A schematic of these costs is shown in Figure 4.[10]

[10] The externalities included in the schematic are water consumption costs, the cost to treat polluted water, and human health costs.

Figure 4: Schematic of the impact of including externalities on total system costs (adapted from CSIR, 2017)



1.4. The water-energy nexus and externalities

Energy planning typically fails to consider and model both current and future water constraints. On one hand, water scarcity may impact on the viability and long-term sustainability of particular energy projects. On the other hand, energy processes impact on water resources and water quality, and constrain the water available for other uses (World Bank, 2017). Thus, understanding and considering the interrelationship between water and energy is imperative in building sustainable energy systems. *As* Olsson (2015) highlights:

> *[w]ater and energy are inextricably linked. As a consequence both have to be addressed together. This is the water-energy nexus (a nexus is a connection or series of connections within a particular situation or system). Too often energy planners have assumed that they have the water they need and water planners have assumed that they have the energy they need.*

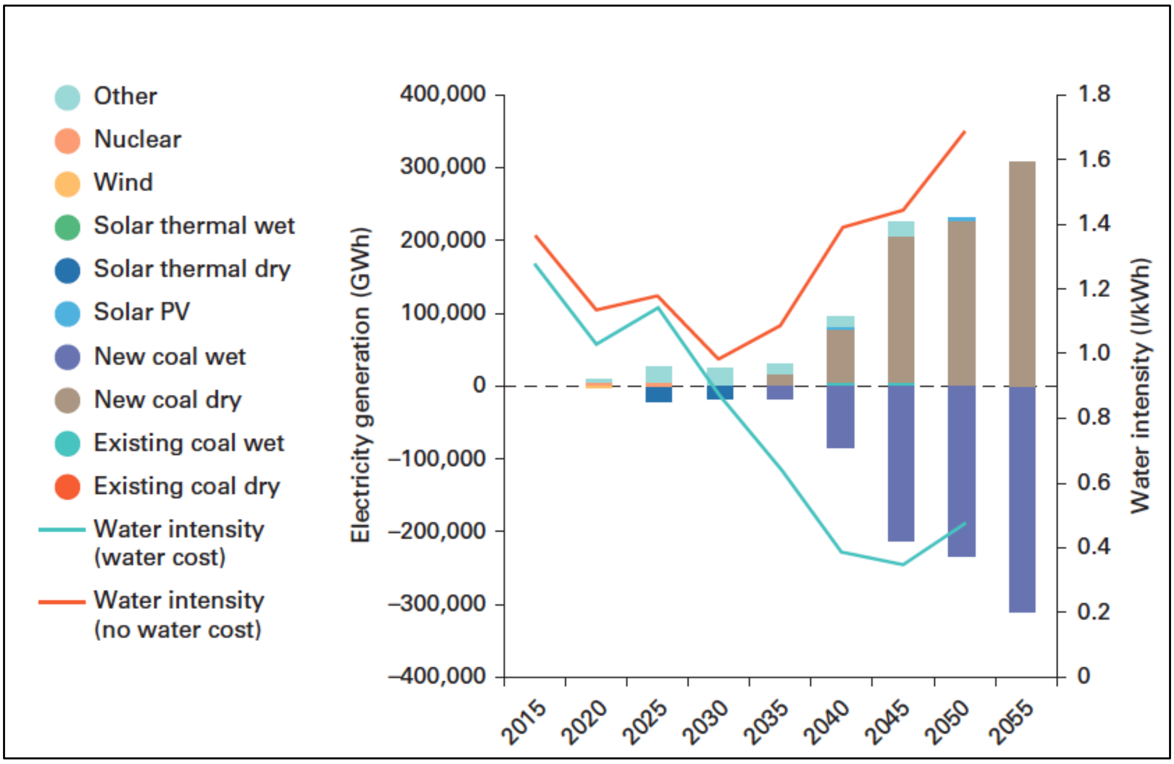
The particular challenges related to the water-energy nexus in South Africa include, *inter alia*, water scarcity alongside a strict water allocation regime; the fact that most of South Africa's water has already been allocated; the predominant reliance on coal-power generation; and climate change uncertainties (World Bank, 2017).

There have been a number of studies that seek to explore the water-energy nexus in South Africa. A study undertaken by the World Bank in partnership with the Energy Research Centre (ERC) sought to account for water constraints in ERC's energy planning tools. An aim was to develop a water-smart energy model that reflects the interdependence of water and energy, through incorporating water supply[11]and infrastructure costs into the SATIM energy model, running energy-water model simulations, and developing scenarios.

[11] By developing marginal water supply cost schedules.

The study finds that 'not including water costs in the energy model increases the cumulative water consumption for the power sector by 77% and the whole energy system by 58%'. After incorporating the true costs of water supply into the model, the water intensity of the power sector is reduced to only a quarter of the 2050 'no water cost' level. This is represented in Figure 5. In essence, where no cost is reflected, the model chooses more water-intense technologies. Notably, including the costs of water increases total system costs by only 1%.

Figure 5: Difference in electricity generation by type and water intensity for reference (water cost) and reference (no water cost) (World Bank, 2017)



In 2012, based on the findings of a significant body of research (Business Enterprises, 2011), Greenpeace Africa published a report titled "*Water hungry coal – Burning South Africa's water to produce electricity*". The report makes the following recommendations:

- the South African government should immediately prioritise renewable energy over water intensive coal-fired electricity; and
- as part of a just transition away from coal, Kusile should be cancelled, there should be no further investments in coal-fired power stations, and Eskom should shift these investments towards renewable energy instead (Greenpeace Africa, 2012).

The above highlights that the cost and availability of water are critical considerations for energy planning. Notably, consideration of the inter-relationship between water and energy provides a strong justification for increased renewable energy supply.

2. Water-related impacts and externalities of coal mining and coal power generation

There are a number of key considerations related to water impacts and externalities that are of critical importance for electricity planning. These include water use, water treatment costs, water infrastructure costs and the impacts on water resources and water quality of different electricity supply options.

Nkambule and Blignaut (2011) investigate the external costs of coal-fired power generation using Kusile as a case study. Table 5 summarises the findings that are relevant to water resources.

Table 5: Summary of estimated annual externality costs relating to water resources for Kusile (Nkambule and Blignaut, 2011)

	Low estimate for Kusile (R million)	R/kWh (low)	High estimate for Kusile (R million)	R/kWh (high)
Climate change (power generation) [12]	3 148	0.097	5 334	0.165
Climate change (mining and transportation)[13]	479	0.015	776	0.024
Water use (power generation)	21 305	0.66	42 357	1.311
Water use (mining)	5 964	0.18	11 862	0.37
Water pollution damages (mining)	6.1	0.0002	7.7	0.0002
Total	30 902	0.95	60 337	1.86

The table above indicates that, at the time of the study, the external costs of coal-fired power, with respect to water resources, were estimated to be between R0.95- R1.86 per kWh produced.

As mentioned previously, research by Blignaut (2011) investigate a range of externalities relating to coal power; including climate change, and human health due to the inhalation of air emissions. However, it is worth noting that the vast majority of the external costs of coal power relate to water use and water resources. Further, it is important to note that these values exclude several impacts relating to water resources that were omitted from the study, largely due to a lack of reliable information (Business Enterprises, 2011). These include:

- the impacts of pollutants, other than sulphates, on water quality (especially due to seepage and spillage from mining and power station waste facilities);
- the downstream impacts of acid mine drainage; and
- impacts due to the deposition of air pollutants (sulphur, nitrogen, mercury) in water resources

As these will have significant impacts on water resources (especially acid-mine drainage), as well as indirect impacts on ecosystems, crop production, health, and livelihoods of those reliant on the water, the total external costs of coal mining on water resources are likely to be considerably higher.

[12] This estimate is not limited to climate change impacts on water resources alone, but instead reflects an all-encompassing global damage cost. However, this estimate is still of interest, as water impacts are at the epicenter of climate change's projected impacts.
[13] As above.

2.1. Water use

Coal power generation requires significant volumes of water. South Africa's current water needs are shown in Figure 6. Mining and power generation consume 5% and 2% of South Africa's water, respectively (DWA, 2013). Although water use for power generation may be relatively small at a national scale, it is far more significant on a regional level. Water supply for electricity generation is supported by major transfer basins. There is thus significant regional variability in both water availability and associated costs of water supply infrastructure. For instance, power generation accounts for 37% of water use in the Upper Olifants. This regional and spatial component of water and energy resources can significantly impact on energy planning (World Bank, 2017).

Figure 6: South Africa's current water needs from the National Water Resource Strategy (DWA, 2013)

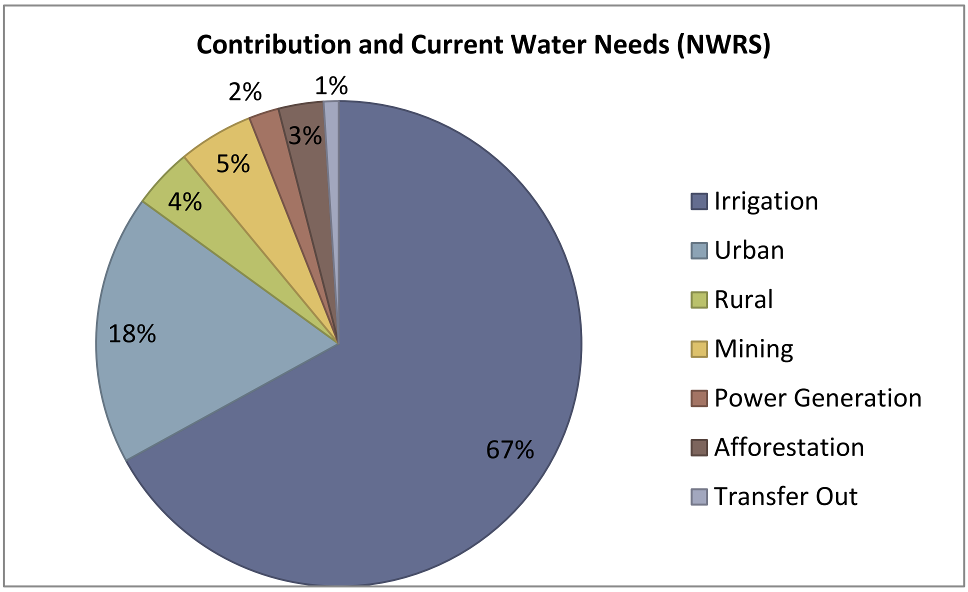
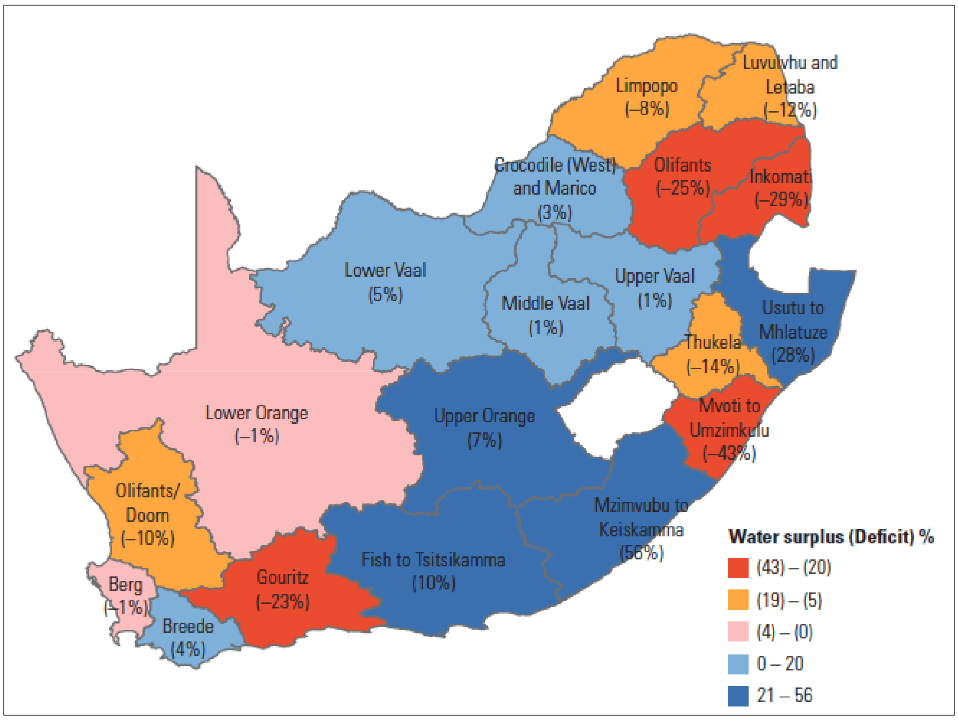
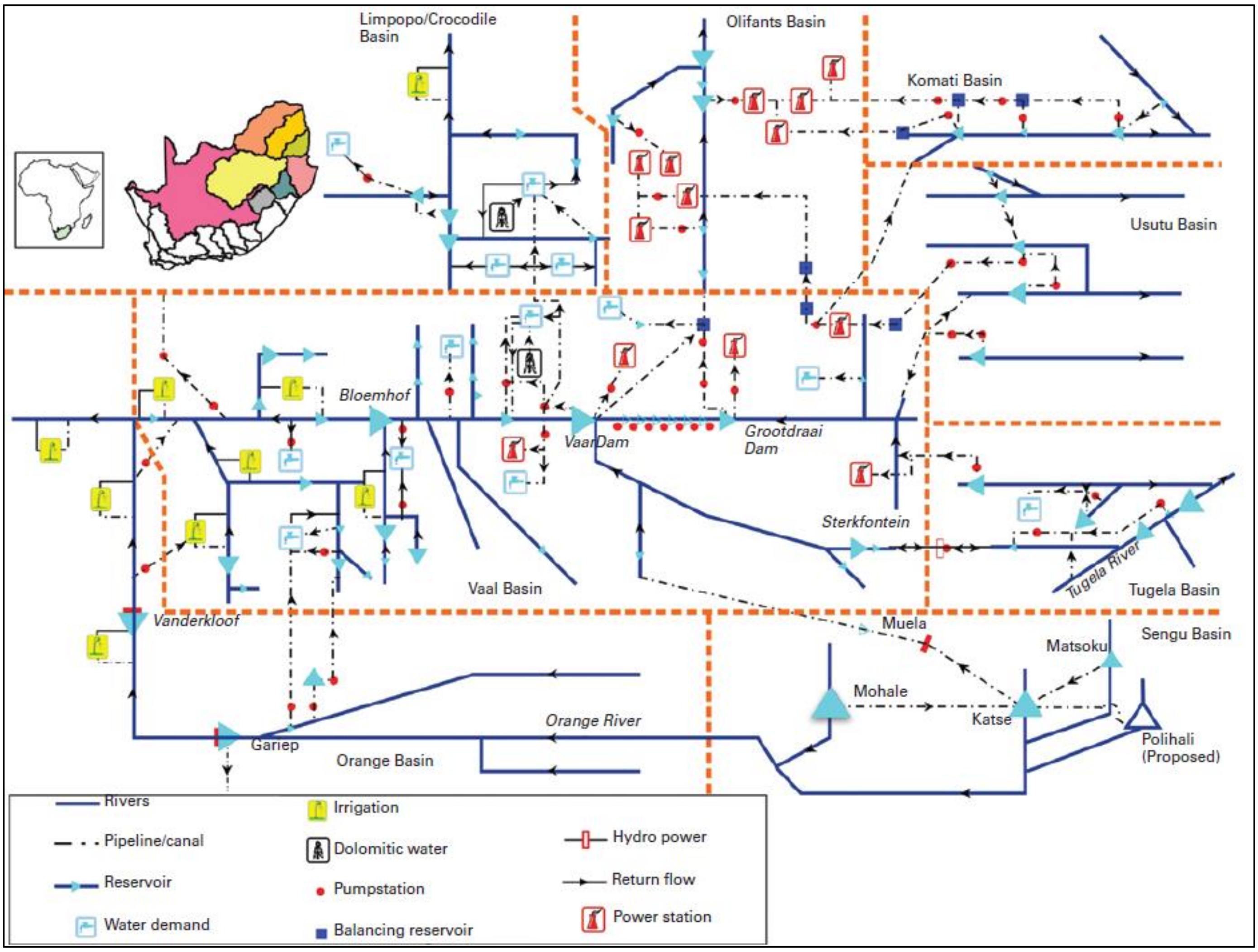


Figure 7: Water management area surplus/deficit in 2008 (DWA, 2008)



Water is used and water resources are impacted across the full life cycle of coal mining and power generation. This includes mining of coal, acid mine drainage that results post mining, washing of coal prior to processing at power stations, burning of coal to generate electricity, and the acid rain that results from burning fossil fuels.

Figure 8: Power sector reliance on water (DWAF, 2006)



2.1.1. Water use in coal mining

Estimated water use in coal mining is shown in Table 6. The total water use per ton of coal is estimated at 469 litres or 0.47 m^3. Per ton, extraction accounts for 160 litres (0.16 m^3), dust control for 42 litres (0.04 m^3), evaporation for 229 litres (0.2 m^3), and coal washing for 38 litres (0.038 m^3). Martin and Fisher (2012) state that water usage for coal washing varies considerably; depending on coal grade, type, and quality. On the upper limits, total water usage for coal washing can rise to 581 litres (0.58 m^3) per ton. In South Africa, coal washing, on the lower limits, accounts for up to 4.8 million cubic metres of the water used in coal mining. At the upper limit of coal washing, this increases to up to 18 million cubic metres of water.

Table 6: Estimated water use in coal mining in 2016 (Martin and Fisher, 2012)

Coal burnt in 2016	114.81 Mt	Water Externality: Cost of Consumed[14]*
Total Water Use in Coal Mining	53.8 mcm[15]	R107.6 million
• Coal Washing	4.8 mcm	R9.6 million
• Extraction	18.4 mcm	R36.8 million
• Dust Control	4.4 mcm	R8.8 million
• Evaporation	26.3 mcm	R52.6 million

Nkambule and Blignaut (2012) using data by Wassung (2010) estimate the opportunity cost of the water consumed during coal mining and transport. They assume that 431 litres of water is used per ton of coal produced (includes water used for extraction, dust control, and evaporation, but excludes water used for coal washing). This figure is multiplied by the coal requirements of Kusile (17 million tons), yielding an annual water requirement of 7.4 million cubic meters. This was then multiplied by the opportunity cost per cubic metre. The results suggest that the estimated opportunity cost of the water used during coal mining will between around R6-12 billion each year for Kusile, as shown in Table 7.

Table 7: Annual water consumption external effect (2010 values) (Business Enterprises, 2011)

Damage estimated	**Units**	**Amount**	**Low estimate**	**High estimate**
Water consumption	Million m^3	7.327		
Society-wide loss	R million		5 964.18	11 862.41

2.1.2. Water use in coal power generation

In 2016 Eskom's consumed approximately 315 million cubic metres of water. In 2017, Eskom used 841 million litres of water per day or up to 10 000 litres of water per second. Water use in coal power generation is dominated by the cooling process. This is summarised in Table 8 (Madhlopa, et al., 2013). Thermoelectric power stations boil water, making steam which turn turbines and generates electricity. Condensers, cooling water, and cooling towers are used to convert the steam back into water. In 2015-2016 reporting year, Eskom generated 215 944 GWh and burnt 114.81 Mt of coal (Eskom, 2016). Using the water usage values of Madhlopa et al. (2013), pre-generation mining and washing would use between 36.4 and 44.9 million cubic metres of water.

Table 8: Estimated water use in energy production (Madhlopa, et al., 2013)

Energy Production Stage	Water use litres/MWh	Water use m^3/MWh	Reference
Pre-generation, mining and washing	183-226	0.2	Martin and Fischer (2012)
Generation, wet cooling	1420	1.4	Eskom (2013b)
Generation, dry cooling	100	0.1	Eskom (2013c)
Generation, indirect dry cooling	80	0.08	Martin and Fischer (2012)
Generation, indirect wet cooling	1380	1.4	Martin and Fischer (2012)

In order to calculate the opportunity cost of the water consumed by Kusile, Inglesi-Lotz and Blignaut (2012) compared its expected water consumption to that of other technology options, as shown in Table 9. The figures indicated in the

[14] Water price of R2 per m^3.
[15] mcm = million cubic meters; 1 cubic meter = 1000 litres

table should be viewed as an approximation. The exact water requirements will differ depending on the specific plant and technologies employed, as is evident from the wide range of values found in literature (Madhlopa et al., 2013).

Table 9: Comparison of water consumption for various energy technologies during power generation (Inglesi-Lotz and Blignaut, 2012)

Technology	Water requirement	Source
Baseline: Dry cooling process with flue gas desulphurisation (FGD)	Dry-cooling = 0.16 m^3/MWh Coal washing = 0.15 m^3/MWh FGD = 0.25 m^3/MWh CCS= 0.1 m^3/MWh Total = 0.66 m^3/MWh	Department of Energy, 2011
Alternative 1: Dry cooling process without FGD	Dry-cooling = 0.16 m^3/MWh Coal washing = 0.15 m^3/MWh CCS*= 0.1 m^3/MWh Total = 0.41 m^3/MWh	Department of Energy, 2011
Alternative 2: Conventional South African power plant (wet-cooling)	1.35 m^3/MWh	Eskom,2011
Alternative 3: Concentrated solar power with parabolic trough	0.296 m^3/MWh	Macknick et al., 2011
Alternative 4: Wind	0.0038 m^3/MWh	Macknick et al., 2011
Alternative 5: Forest residue biomass	0.36 m^3/MWh	Dennen et al., 2007

The table above indicates that concentrated solar power (CSP), wind, and biomass consume considerably less water than coal-fired power with or without dry cooling or flue gas desulphurisation (FGD). Utility scale solar PV was omitted from the Inglesi-Lotz and Blignaut's (2012) study. However, Macknick et al., (2011) find that solar PV consumes approximately 0.098 m^3/MWh during power generation.[16]

With the exception of coal washing, Table 9 only includes the amount of water consumed during power generation. It therefore excludes water used during coal mining (fuel production), such as for dust suppression, coal extraction, and evaporative losses, which was considered by Nkambule and Blignaut (2012). Therefore, had this water use been included, the difference between coal-based power generation and solar or wind power (which, unlike coal, do not require water for fuel production) would be even greater.

Inglesi-Lotz and Blignaut (2012) use the water requirement information in Table 9 to calculate the estimated net marginal revenue (NMR)[17] and hence the opportunity cost for Kusile (baseline) in relation to the other technology options. This is summarised in Table 10. The opportunity costs, as shown below, indicate that, when using dry cooled coal-fired generation (baseline) instead of concentrated solar power (Alt3), the forgone revenue due to water consumption is R0.83 for every kWh of electricity sent out (2011 ZAR). Therefore, for every 32 300 748 MWh that Kusile will send out each year, R26.7 billion is forgone annually due to water use, compared to concentrated solar power. Thus, the opportunity cost for dry-cooled coal power (in terms of water use) is between R0.66/kWh and R1.31/kWh (2011 ZAR), as compared to renewable technologies.

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[17] Inglesi-Lotz and Blignaut (2012) define the net marginal revenue (NMR) as being "the additional revenue generated by using a cubic metre of water. The higher the NMR, the more efficiently water is used, i.e. the greater the marginal value of the water. The difference between the NMRs is the opportunity cost of using one technology above the other."

Table 10: Annual opportunity cost for Kusile (2011 ZAR) (Business Enterprise, 2011)

		-1	-2	-3	-4	-5	-6
		Λ NMR of Water	**Difference**	**Water volume**	**Net generation output**	**Society-wide loss or gain[18]**	**Opportunity cost[19]**
		R/m3	*R/m3*	*m^3*	*MWh*	*R (million)*	*R/kWh*
Baseline		9 717	26 166 365	32 300 748			
Alt1	No FGD	11 149	-1 432	16 254 863	32 300 748	-23 278	-0.72
Alt2	Conventional	3 399	6 318	53 522 111	32 300 748	338 154	10.47
Alt3	Solar	14 667	-4 949	5 405 495	18 237 164	-26 753	-0.83
Alt4	Wind	930 736	-921 018	45 989	12 102 466	-42 357	-1.31
Alt5	Biomass	11 210	-1 493	14 272 563	31 925 470	-21 305	-0.66

2.1.3. Water costs for coal power generation

Water is seldom priced to ensure that the costs and benefits of its use are equal. This, in turn, results in over-use (Vivid Economics, 2014). The Eskom Revenue Application for 2017/18 (Eskom, 2017) contains data for water volumes and water costs for the Eskom power stations. This is shown in Table 11. The average water cost for Eskom is R6 per m^3, whereas South African households pay between R7 and R12 per m^3 of water. According to StatsSA, in 2010, the electricity sector paid even less, at R3.40 per m^3 (StatsSA, 2010), while households paid R8 per m^3 in 2010. This is due to both cheap water provided to Eskom as a Strategic Water User and Eskom's use of raw (untreated) water rather than potable (treated) water provided to households. Eskom notes that most of the cost is incurred before the water reaches the power stations.

Table 11: Water volumes, water cost and treatment costs for the Eskom power stations (Eskom, 2017)

Station	Water Volumes (Million m^3)	Water Cost (R million)	Water Cost (R/m^3 [20])	Water Treatment Costs (R million)
Kusile	2.055	40	19.5	2
Medupi	0.5	125	262.1	0
Medupi	4.4	219	49.2	3
Duvha	22.0	79	3.6	13
Kendal	5.7	72	12.6	38
Lethabo	37.0	30	0.8	40
Majuba	22.1	72	3.3	35
Matimba	4.3	54	12.6	31
Matla	37.5	253	6.7	35
Tutuka	34.2	205	6.0	86
Arnot	25.5	134	5.3	40
Camden	17.9	116	6.5	7
Grootvlei	9.0	29	3.2	24
Hendrina	19.5	122	6.2	17
Komati	15.1	101	6.7	19
Kriel	34.2	305	8.9	39
Total (from Eskom)	284.4	1751	6.2	423

[18] Societal loss is calculated as $\frac{Difference\ (column\ 2)\ X\ Water\ volume(column\ 3)}{1000\ 000}$.

[19] Opportunity cost is calculated as $\frac{Societal\ loss\ (column\ 5)}{Baseline\ (column\ 4)(32.3\ TWh}\ X\ 1000$.

[20] 1 m^3 = 1 kl

Water for power generation in South Africa is under-valued. Eskom pays less for water than many other water users and hence has no incentive to prioritise electricity supply options that use less water. For instance, between 2006 and 2016, Eskom's water consumption per unit of energy has increased from 1.3 litres per kWh (2006) to 1.44 litres per kWh sent out (2016). Thus, rather than becoming more water-efficient as better technology becomes available, Eskom has become less water-efficient. This is particularly problematic in relation to the on-going drought conditions in South Africa, where water restrictions and water-saving interventions have mainly targeted the residential sector. This increase in water is predominantly due to the need to meet air pollution emissions standards which require water intensive FGD plants. According to Eskom, meeting new emissions standards will "require an additional 67 million cubic metres of water per annum by 2025, a 20% increase" (Savides, 2018).

In general, the undervaluing of water distorts the cost estimates of different electricity supply options. If water were better valued, it would further justify a rapid transition away from coal-based energy to water-efficient renewable energy. This would further mean that water currently used for coal power generation could be better allocated to other more sustainable uses.

2.2. Impacts of coal mining on water quality and water resources

Our scarce water resources are impacted throughout the coal life-cycle including direct impacts on water resources during coal mining, acid-mine drainage, impacts of air pollutants on water resources and coal ash contamination of groundwater (Groenewald, 2012). In both underground and surface coal mining, groundwater is pumped out in order to dry the mined area. This has considerable negative impacts on groundwater, reduces water tables and damages ecosystems (Greenpeace, 2012).

2.2.1. Impacts of acid-mine drainage

Acid-mine drainage has the considerable negative impacts; polluting our surface and groundwater with acid, salts and metals. Coal is associated with sulphide-bearing strata. During coal mining, these sulphide minerals oxidise when they come into contact with water and oxygen. This results in decreased pH values and elevated salt concentrations (WWF-SA, 2011). This further increases the solubility and mobility of metals[21] often increasing concentrations to toxic levels (CER, 2016). This acidic water and metals leach into groundwater and is eventually discharged into streams and rivers.

The impacts on aquatic ecosystems are manifold. Metal-related pollution may result in precipitation of ferric hydroxide[22] and oxyhydroxide complexes[23] that form a yellow coating that smothers aquatic life or clogs up streambeds. Precipitated iron consumes dissolved oxygen in water that may result in asphyxiation of biota that are dependent on dissolved oxygen. Notably, reduced pH levels have severe ecosystems impacts including:

- the conversion of dissolved carbonates and bicarbonates into carbonic acid;
- acidification prevents photosynthesis in aquatic plants which depend on bicarbonates;
- harm to aquatic ecosystems due to impacts on ionic balances, damage to cell components or carbonate exoskeleton (WWF-SA, 2011).

Acid mine drainage threatens the capacity of aquatic ecosystems to decompose matter and hence negatively affects nutrient cycles and food chains. Further, increased aluminium concentrations have negative impacts on benthic insects and fish (Liefferink, 2016). Acid mine drainage also has significant consequences for crop production. Increased salinity interferes with the metabolism and nutrient uptake of plants and soil biota. Increased salt concentrations in plants

[21] Including aluminium, beryllium, cadmium, copper, cobalt, chromium, mercury, manganese, nickel, lead, vanadium and zinc, arsenic, cobalt, iron, magnesium, nickel, and uranium.
[22] Fe(OH3)
[23] FeO (OH)

result in shrinking and collapse of cells (plasmolysis). Certain crops including apples, oranges, and potatoes are particularly intolerant to increased salinity. Increased concentrations of certain metals associated with acid mine drainage may further be phytotoxic to plants. Aluminium, for instance, is toxic to plants - resulting in cell damage and limiting nutrient uptake. Water contaminated with acid-mine drainage can thus have a severe impact on crop yield (WWF-SA, 2011).

Acid mine drainage processes, resulting from the slow filling of voids and backfill material with water, typically commence decades after mining has ceased. Acid mine drainage will continue until oxidisation processes cease, which could persist for decades or even centuries (CER, 2016). The impacts of acid mine drainage and mining effluent across South African catchments is summarised in Table 12 (based on Yibas et al., 2014).

Table 12: Summary of catchments impacted by acid mine drainage and mining effluent (Yibas et al., 2014)

Quaternary Catchment	**River Name and Description**
B20B	**Koffiespruit in the upper Wilge River**: Cosmopolitan algae species dominate the aquatic system with no mining impact indicators.
B20G	**Grootspruit flowing into the Saalboomspruit**: severely impacted by acid mine drainage causing high levels of metals and low pH values which, in conjunction with metal precipitation impacting the habitat of algal species. Acidophilic (Microspora quadata) algal species dominate the aquatic system.
B20H, B20F, B20E	**Wilge River**: water is mesotrophic due to agriculture and sewage effluent impacts. Cosmopolitan algae species are dominant in the aquatic system.
Wilge Summary: B20G impacted by mining.	
B11K	**Klip River**: the river is severely impacted by acid mine drainage causing high levels of metals and low pH values which, in conjunction with metal precipitation impact the substrate habitat of algae species. Acidophilic (Ulothrix punctate) algae species dominate the aquatic system.
B11L	**Olifants River upstream of the confluence with the Klip River**: algal species indicating mining effluent was scarce.
B11J	**Groot Olifants upstream of confluence with Klein Olifants River**: indication of low mining effluent with nutrient enrichment (eutrophication) and industrial effluent. Algal species indicating mining effluent was scarce, but eutrophication indicator species were extremely high suggesting nutrient enrichment. **Groot Olifants River downstream of the Riverview sewage works**: Algae indicate high nutrient enrichment (eutrophication).
B11H	**Spookspruit:** Indication of low mining effluent with nutrient enrichment and industrial effluent. Algal species indicating mining effluent was scares.
B11J	**Brugspruit**: the river is severely impacted by acid mine drainage and sewage effluent. Algae species dominating the aquatic system were indicators of brackish water with a high electrolyte content and presence of mining effluent.
B11E, B11D, B11C	**Steenkoolspruit:** Indication of presence of mining effluent with nutrient enrichment (eutrophication) and industrial effluent. Algal species indicating mining effluent was common.
Olifants Summary: B11E, B11D, B11C, B11J and B11K impacted by acid mine drainage and mining effluent. Nutrient enrichment from the sewage works dominates some benthic assemblages.	
B12E	**Klein Olifants River upstream of confluence with the Olifants River**: indication of low mining effluent with nutrient enrichment (eutrophication) and industrial effluent. Algal species indicating mining effluent was scarce.
B12D	**Tributary of the Klein Olifants River downstream of industries (e.g. Columbus Steel) and mining**. Algal species indicating mining effluent was scarce.
Klein-Olifants Summary: B12E shows low mining effluent.	

Figure 9: Acid-mine drainage decanting in the environment in Mpumalanga[24]

Figure 10: Acid-mine drainage impacting the aquatic ecosystem in Mpumalanga[25]

[24] Photo courtesy of Ashton Maherry

[25] Photo courtesy of Ashton Maherry - The iron precipitates can clearly be seen in the soil.

2.2.2. Impacts of coal ash contamination

Coal ash is the non-combustible residue produced during the burning of coal. The ash is essentially the non-carbon mineral matter that is naturally present in coal, and the ash residuum concentrates the coal's constituents that are not burned and lost as a gas. As a result, coal ash has many of the same elemental constituents as the parent coal, but at much higher concentrations. Coal ash often contains high, and potentially toxic, concentrations of many substances that can pollute any water that comes into contact with the ash. That polluted water is commonly called leachate, and it tends to be alkaline (high pH) and enriched in numerous substances, especially sulphate, boron, iron, aluminium, and zinc as well as toxic heavy metals, such as antimony, arsenic, barium, cadmium, chromium, lead, manganese, mercury, molybdenum, selenium and vanadium. The great majority of toxic metals found in coal are retained in the solid waste after combustion. For example, for trace metals, arsenic, cadmium, chromium, lead, antimony and selenium, 97%, 97.2%, 99%, 97.5%, 97.7% and 91.5% of the total mobilisation of each of these metals, respectively, is retained and concentrated in the coal ash (Sabbioni, et al., 1984).

Coal ash leachate will commonly escape the ash and enter and contaminate natural groundwater and surface water systems. Because of the vast quantities of coal ash produced, historically-poor disposal practices, and widespread evidence of environmental damage from coal ash leachate to water resources, the United States Environmental Protection Agency (EPA) recently increased regulatory requirements for ash handling, disposal, containment, remediation, and environmental monitoring, to ensure against the devastating impacts of contamination from coal ash (EPA, 2011). Numerous researchers have observed, worldwide, the adverse environmental impacts caused by the leaching of coal ash to groundwater and surface waters from both old and new ash deposits. Leaching takes place from both old and new sites, and peak leaching of hazardous chemicals occurs many decades after disposal and can persist for hundreds of years (Sandhu, et al., 1993). Thus, ash disposal sites are potential sources of groundwater and surface water contamination for many decades after ash deposition has ceased. The major environmental harms from coal ash include: leaching of potentially toxic substances into soils, groundwater and surface waters; hindering effects on plant communities; and the accumulation of toxic elements in the food chain (Rowe, et al., 2002).

Many researchers have documented the negative effects of coal ash on the physiology, morphology and behaviour of aquatic organisms and the health of aquatic ecosystems. For example, researchers have documented extensive damage to fish populations from selenium leaching from coal ash landfills and surface impoundments throughout the United States. Research has also documented the potential harm from coal ash contamination in drinking water to human health. Some of these health impacts include cancer and damage to the nervous systems and other organs, especially in children (Physicians for Social Responsibility, 2010).

Serious contamination has been documented at numerous opencast mine sites in the United States where CFB coal ash has been disposed. In a multi-year study of 15 coal ash mine-fills in Pennsylvania, researchers found that coal ash made water quality worse at 10 of the 15 mines (Clean Air Task Force, 2006). At the remaining five sites, there was not enough monitoring data to determine whether adverse impacts were caused by the coal ash. A review of the mine sites where coal ash was disposed revealed that:

- levels of contaminants, including manganese, aluminium, arsenic, lead, selenium, cadmium, chromium, nickel, sulphate and chloride, increased in groundwater and/or surface water after coal ash was disposed of in the mines;
- contaminants increased from background concentrations (measured after mining) to levels hundreds to thousands of times in exceedance of federal drinking water standards; and
- pollution was found downstream from coal ash disposal areas and sometimes well outside the boundary of the mines.

The damage posed by coal ash placed in opencast mines stems from the large volume of waste placed in these mines and the ash's contact with water. Since groundwater or mine pools at mine sites are often highly acidic due to AMD, the interaction of the alkaline (high pH) ash with the acidic (low pH) mine water can mobilise hazardous chemicals from the ash. In addition, the production of contaminated leachate in the mine environment often leads to uncontrolled off-site flows of polluted water. Opencast mines present a highly fractured underground environment where the travel of leachate is facilitated by the cracks and voids in the subsurface environment. Thus contamination at highly fractured mine sites can often be severe and very difficult to remediate due to the massive quantities of overburden and multiple pathways for the flow of pollution.

2.2.3. Estimates of water quality impacts

Nkambule and Blignaut (2012) estimate the damage costs of coal mining on our water quality in South Africa. Owing to limited available information, they utilised data from a study by Van Zyl et al (2002) that focussed on sulphate pollution, as it was considered to be the best available indicator of acid mine drainage. They estimated the damage cost imposed on other water users in the Emalahleni catchment from sulphate pollution by coal mining to be between R0.11 and R0.19/t of saleable production (in 1999 ZAR).[26] Nkambule and Blignaut (2012) inflated these values and multiplied them by the annual coal requirements of Kusile to yield an estimated damage cost of between R4.5 million and R7.7 million each year. This is shown in Table 13.

Table 13: Annual water pollution impacts due to coal mined for Kusile (2010) (Business Enterprises, 2011: 129)

Damage estimated	Units	Low estimate	Average estimate	High estimate
Water pollution impacts	R million	4.5	6.1	7.7

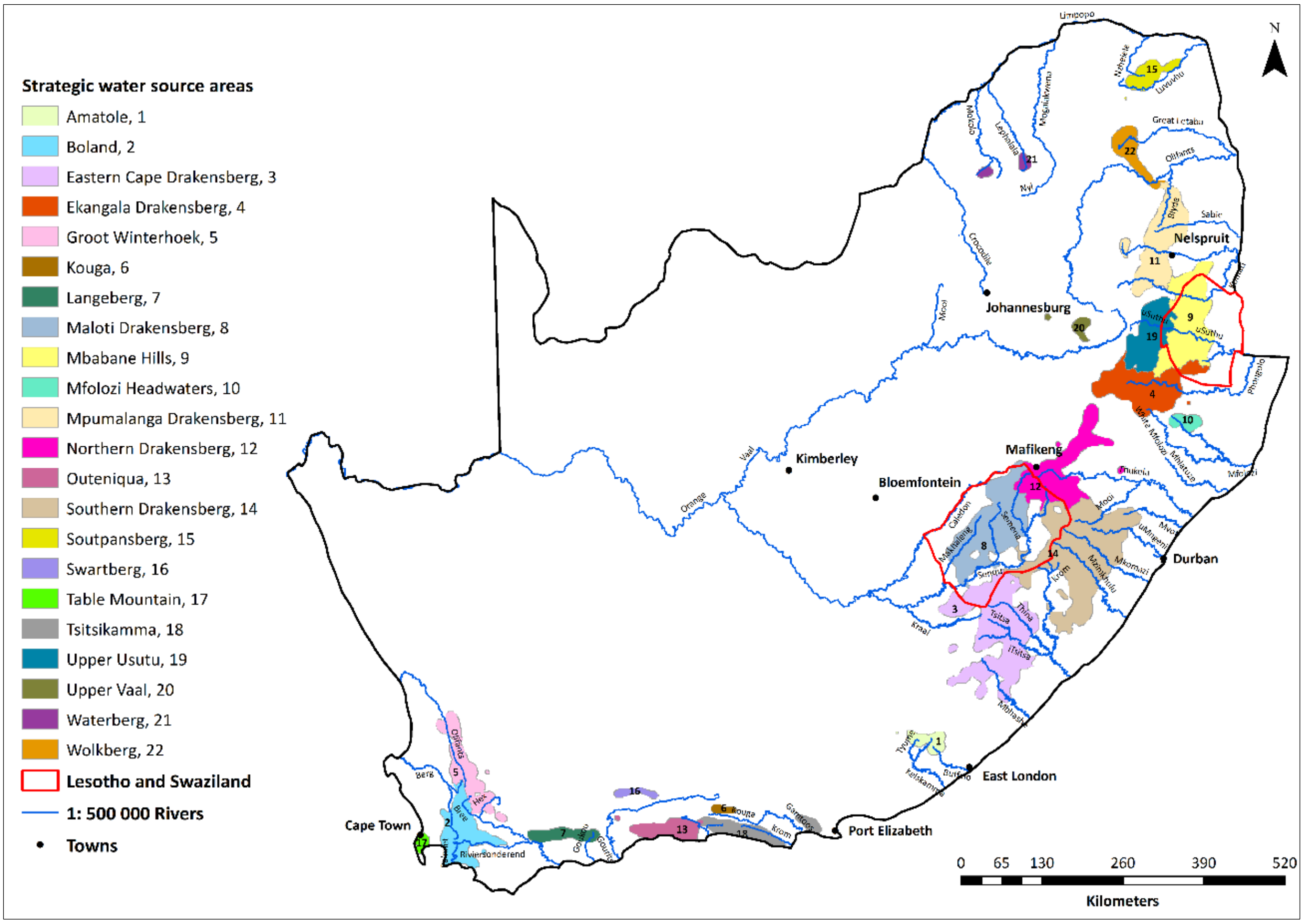
The above estimates for water quality impacts should be viewed as conservative, as they do not include sulphate, pollutants other than sulphate and do not evaluate downstream impacts. Research by Pretorius (2009) suggests that acid mine drainage is a significantly larger external cost.

2.2.4. Coal mining in our strategic water source areas

South Africa's water security is put under considerable threat when coal mining activities coincide with the source areas of our urban water supply. These areas are known as Strategic Water Source Areas (DWA, 2013). South Africa's 22 strategic water source areas extend across only 8% of South Africa's land surface, but contribute up to 50% of our runoff, support at least 60% of South Africa's population and 67% of our economy (Nel, et al., 2017). The 22 strategic water source areas are shown in Figure 10. Only 13% of our Strategic Water Source Areas are formally protected. There is a considerable overlap between coal mining and our Strategic Water Source Areas in Mpumalanga and Limpopo. For instance, about 45% of the Enkangala Drakensberg water source area overlaps with coal fields in Ermelo, Vryheid, Highveld and Utrecht (CSIR, 2017).

[26] Ibid.

Figure 11: Map of South Africa's 22 strategic water source areas (Nel, et al., 2017)



2.3. Water treatment costs

The capital and operational costs to treat water polluted by coal mining and coal-power generation are considerable. These costs are not considered in current costing of coal in electricity planning. A number of studies attempt to quantify water treatment costs associated with coal-fired power. Research by Pretorius (2009) suggests that the cost of acid mine drainage should be around R0.38/kWh (2009 ZAR). This is significantly higher than the water pollution cost estimate by Inglesi-Lotz and Blignaut (2012) of R0.0002/kWh, which focused on treatment costs related solely to sulphate pollution.

A number of examples highlight the costs and problems associated with treating acid mine drainage. A water pollution control works constructed in 1997 by the Department of Water Affairs and Forestry to deal with an abandoned mine in the Brugspruit area cost around R26.5 million.[27] The treatment works treats polluted water with sodium hydroxide to counter acidity. Since its construction, the plant has had a number of problems related to insufficient maintenance and theft of electricity cables, resulting in untreated decant flowing into the Brugspruit (WWF-SA, 2011).

The eMalahleni Water Reclamation Project[28], implemented by Anglo Coal and BHP Billiton, is a further example of the substantial costs of treating acid mine drainage. The plant cost an estimated R1.4 billion in investment capital for Phase 1 and Phase 2 (Naidu, 2012). The Water Research Commission estimates the eMalahleni treatment cost to be

[27] It has a capacity of 10 000m³/day.

[28] This plant uses reverse osmosis to turn 25 000 m³ of mining effluent into potable drinking water each day.

1.5 USD per cubic metre which is sold to the municipality at $1 USD per cubic metre (Bhagwan, 2012). The Reconciliation Strategy for the Olifants River Water Supply System highlights the following, in relation to the eMalahleni Water Reclamation Project:

> *The treatment and re-use of acid mine drainage water has already been implemented with a reverse osmosis plant with a capacity of 9 million m^3 /a. (25 Ml/d). To provide additional capacity to meet the additional yield of 22 million m^3 /a, is expected to cost approximately R75 million with a URV of R6.31 /m^3* (Department of Water and Affairs, 2011).

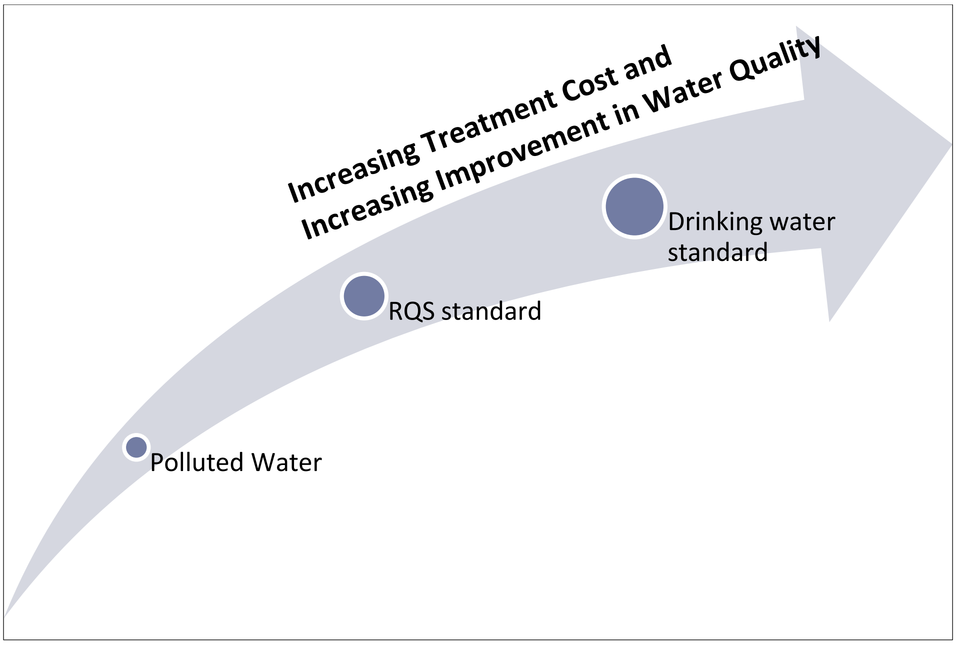
The Evaluation of Scenarios Report (Department of Water Affairs, 2012) for the Upper Olifants provides for an average treatment cost for acid-mine drainage at R10.72 per m^3 to be released back in the river system.

Naturally, the cost of treating mine water increases depending on the water quality sought. Mine water can be treated to different sulphate concentrations based on the purpose of the treated water (Van Zyl et.al, 2001). The acceptable sulphate concentrations, depending on purpose, are as follows:

- Irrigation: 2000 mg/l
- Coal processing plant: 1000 mg/l
- General industrial use: 500 mg/l
- Discharge to public streams: 500 mg/l
- Potable use: 200 mg/l
- Cooling water in power stations: 20-40 mg/l

Treating water to potable quality is far more costly. For instance, van Zyl et al. (2001) estimates that the capital cost to treat mine water effluent in the Upper Vaal to potable quality (sulphate concentrations of less than 200 mg/litre) would cost R528.5 million with a running cost of R55.7 million per year. In order to treat the water to the lower irrigation quality, would require a capital cost of R68.223 million and running costs of R11.93 million per year. This is based on a cost of R75 million for a 15 Ml/day sulphate removal plant, and R8.55 million for a 15 Ml/day pre-treatment plant.[29]

Figure 12: Schematic showing the increase in treatment costs and the increasing improvement in water quality

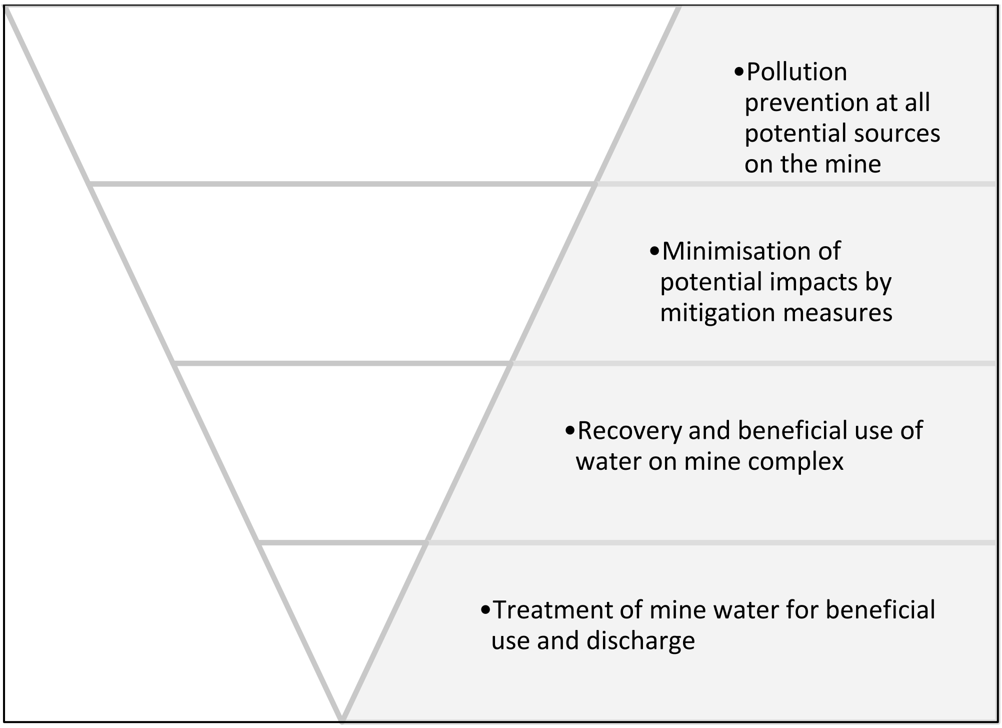


[29] These costs are significantly less than the investment costs stated by Anglo American (Bhagwan, 2012).

Figure 13, above, is a schematic showing the increase in treatment costs and the accompanying improvement in water quality. The decision to treat water to irrigation quality is typically based on economic demands rather than on environmental considerations. Accordingly, returning mine water to potable quality would considerably increase treatment costs and hence the externality costs of coal mining, and coal electricity generation would be greater.

With such costly treatment requirements, it does not make economic sense to continue mining and polluting water resources where it subsequently requires costly treatment to return to potable water quality. It is far more cost-effective to prevent pollution or not pollute in the first place. This is supported by international best practice. The International Network for Acid Prevention (INAP) provides a best practice hierarchy of mine water management, represented in Figure 14. According to this hierarchy, treatment of mine water should be the last step in mine water management - with pollution prevention being the first step. Conversely, in South Africa, treatment is unfortunately often the first response; whereas prevention and mitigation are ignored.

Figure 13: Overall hierarchy of mine water management (adapted from INAP, 2009)



2.4. Impacts and costs of legacy of coal mining

It is evident that even if South Africa ceased coal mining today, the historical impacts of coal mining would require treatment and associated costs for decades to come. South Africa has around 5 906 derelict and ownerless mines. These create considerable health and safety risks and pollute water resources and agricultural land. According to a study by the Council for Geoscience and the Department of Mineral Resources, closure of derelict and ownerless mines (including long-term treatment of acid-mine drainage) would cost up to R60 billion (WWF-SA, 2011).

Treating mine water in the Western Basin was estimated to cost as much as R12 billion in 2016 (Crowley and Henderson, 2016). Comparatively, in Australia, it is estimated that treatment of acid mine drainage from active mines would cost R1.6 billion, and R5.3 billion for abandoned mines (Short, 2016). Similar expenses were reported in Canada and the United States (Mudder and Harvey, 1998). In South Africa, it is estimated that plant construction costs for treating water pollution from abandoned mines could be around R5 billion, with annual operational costs estimated at several million. Guidelines by the Department of Mineral Resources estimate that the cost to rehabilitate is approximately R50 000 per hectare. Anglo American estimates that waste disposal costs, using the three main mine water treatment technologies, can reach up to 25-30% of the life cycle costs (Naidu, 2012).[30]

An estimated R60 is held in financial provisions for mine rehabilitation. However, it is evident that financial provisions made by mining companies is inadequate.[31] Further, a recent report by the Centre for Environmental Rights and Intellidex analysed disclosures by eleven listed mining companies related to their financial provision for environmental rehabilitation. The report highlights that:

> *Neither the law, nor the accounting standards governing company disclosures, ensure the necessary transparency and accountability about financial provision for environmental rehabilitation. The information disclosed by mining companies, about the costs of rehabilitation of the environmental damage that they cause, and about the money that they are obliged to set aside to fix it, is inconsistent, unclear, in some cases unreliable, and not comparable between companies. It is therefore impossible for shareholders or taxpayers to hold companies or regulators to account* (Intellidex, 2018).

Over the last decade, the Department of Water and Sanitation invested around R120 million to investigate and deal with historical water pollution caused by abandoned mines. This is only a fraction of the amount required (Schwab, 2002). In the last five years, the Department of Mineral Resources has spent only around R42 million on rehabilitating five of the 5 906 derelict and ownerless mines. By comparison, Australia spends approximately $80 million (USD) annually on treating acid-mine drainage.

[30] Ion exchange, reverse osmosis/ion exchange, and passive treatment.
[31] WWF-SA (2012). *Financial Provisions for Rehabilitation and Closure in South African Mining: Discussion Document on Challenges and Recommended Improvements*

3. Related socio-economic considerations

3.1. Employment potential of different electricity supply options

The Draft IRP (DOE, 2016a) highlights that 80 000 people were employed in the energy sector in 2016. According to Eskom's financial statement, it currently has 47 658 employees (Eskom, 2017). Not all employees work at coal-fired power stations. Eskom figures of employment per power station are outlined in the Table 14 below. According to the '*Chamber of Mines Facts and Figures'* (CoM, 2017), in 2016, there were 77 506 people employed in the coal mining sector. In the same year, only 28% of coal produced in South Africa was sold domestically.

Table 14: Eskom station employment figures (extract from SAP, July 2017)

BU	*Employment*
GX Arnot	677
GX Camden	324
GX Duvha	696
GX Grootvlei	427
GX Hendrina	644
GX Kendal	668
GX Komati	331
GX Kriel	701
GX Kusile	247
GX Lethabo	628
GX Majuba	508
GX Matimba	476
GX Matla	659
GX Medupi Unit 6	293
GX Tutuka	649

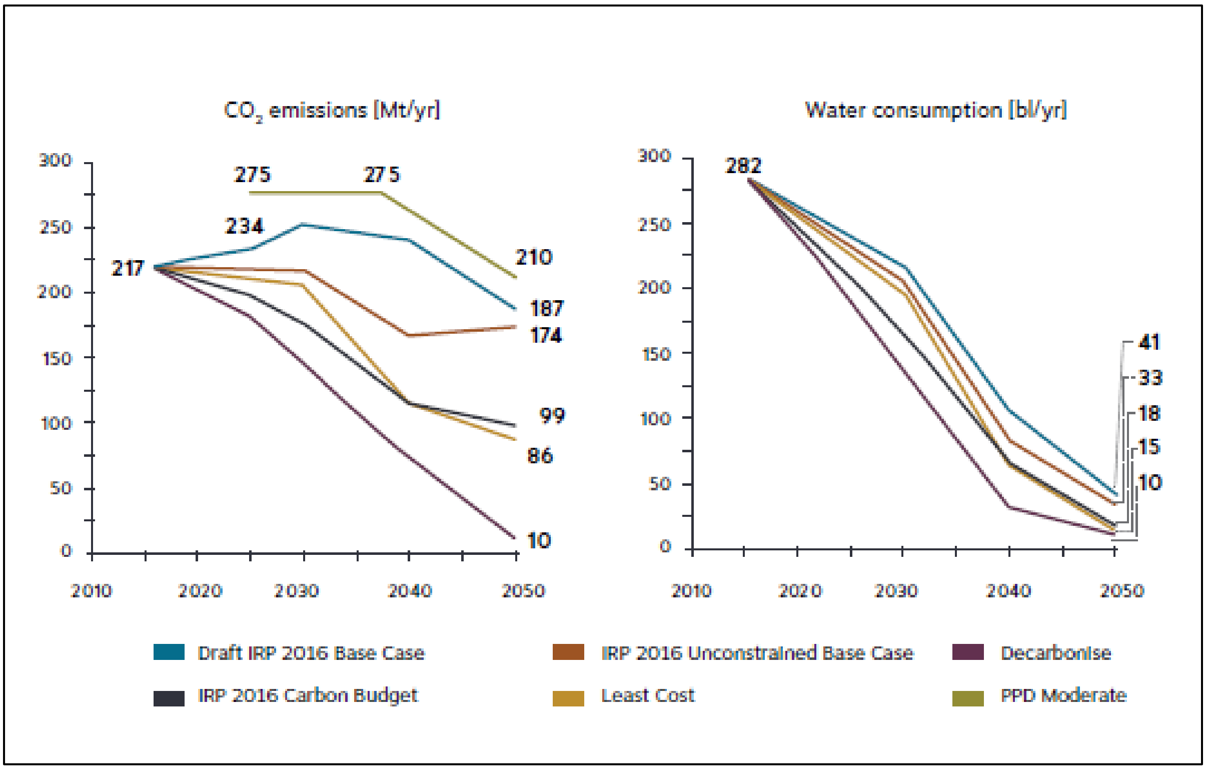
In contrast, full-time employment in South Africa's fourth bidding round for all renewable energy was estimated at 26 246 jobs (Deign 2016).[32] The South African Renewable Energy Council reports that the Renewable Energy Independent Power Producer Procurement Programme (REIPPP) has created 26 790 jobs, with 24 838 in construction and 1 952 in operations. The 64 active projects have committed to creating 57 627 jobs in their lifetimes (Meier, 2017). The Minister of Energy has stated that the total 112 projects procured through the REIPPP "will create 114 266 job years over the construction and 20-year operations period" (Omarjee, 2018).[33] Research by the Council for Scientific and Industrial Research (CSIR) highlights that, between 2020 and 2050, wind projects could result in the creation of:

- 470 000 direct full-time equivalent jobs in the construction phase and 185 000 direct full-time equivalent jobs in the operation and maintenance phase;
- 515 000 indirect full-time equivalent jobs in the construction phase and 198 000 indirect full-time equivalent jobs in the operation and maintenance phase; and
- 523 000 induced full-time equivalent jobs in the construction phase and 383 173 full-time equivalent jobs in the operation and maintenance phase.
- This amounts to a total of over 2 274 173 direct, indirect, and induced jobs in the wind energy sector alone.

[32] Internationally 9.8 million people were employed in renewable energy sectors in 2016 (IRENA, 2017)
[33] McDaid (2016) provide a detailed analysis of the REIPPP related to job creation, localisation and socio-economic development potential

The CSIR, as part of formal inputs into the Draft IRP (DOE, 2016a) modelled and developed two scenarios; a "least cost" mix and a decarbonised future. The decarbonised future scenario is one with a 95% reduction in CO_2 emissions by 2050, where no new coal power stations are built and existing coal power stations are decommissioned over time (CSIR, 2017). According to the study, the decarbonised future not only has far lower water consumption, but also costs less and creates more jobs than coal and nuclear. As shown in Figure 15, current water consumption for power generation is 282 billion litres per year. By 2050, water consumption declines dramatically for all energy-mix scenarios. Nevertheless, the decarbonised scenario shows the lowest water consumption, of 10 billion litres per year.

Figure 14: CO_2 emissions and water consumption for the different energy-mix scenarios (CSIR, 2017)



The job creation numbers of the CSIR study are shown in Figure 16. According to the study, concentrated solar power (CSP) results in the highest number of direct and supplier job-years per gigawatt installed for capital expenditure. In terms of operating jobs, coal (including coal mining) has the highest amount of annual jobs, followed closely by CSP, solar PV, and wind. Gas and nuclear result in the least amount of jobs. However, it is arguable that the study inflated the job creation figures for coal mining and coal generation, as it underestimated the impacts of automation on job losses (CSIR, 2017).

Figure 15: Capital and Operating direct and indirect jobs per energy type (CSIR, 2017)

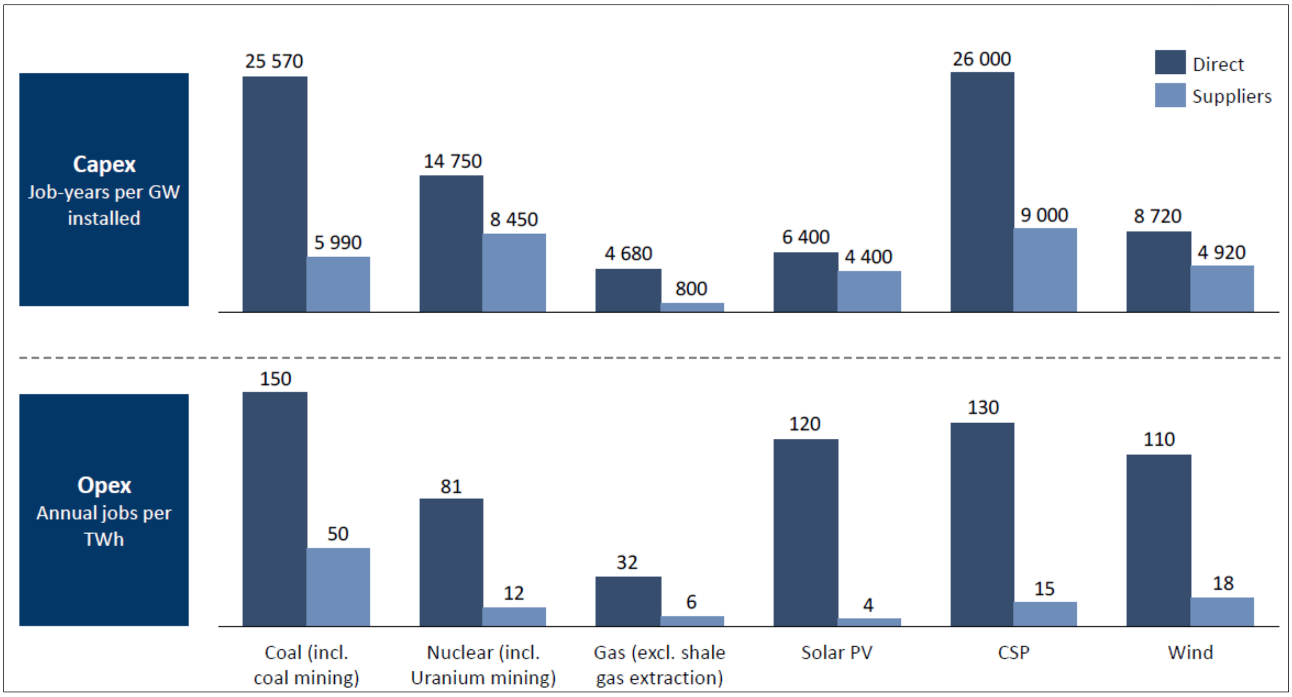


Table 15: Summary of job creation per energy-mix scenario for 2016, 2030, 2040 and 2050 (CSIR, 2017)

Scenario	Jobs in 2016	Jobs in 2030	Jobs in 2040	Jobs in 2050
IRP 2016 Base Case ($\frac{1}{3}$ coal, $\frac{1}{3}$ nuclear and $\frac{1}{3}$ solar PV, wind and gas)	80 000	93 000 - 153 000	185 000 - 241 000	252 000 - 295 000
IRP 2016 Carbon Budget (Nuclear, renewables and gas replace coal)	80 000	100 000 - 142 000	191 000 - 216 000	235 000 - 253 000
Unconstrained Base Case (No new nuclear, some new coal, PV, wind and gas)	80 000	96 000 - 146 000	199 000 - 234 000	248 000 - 281 000
CSIR Least Cost (No new nuclear or new coal, 75% renewables by 2050)	80 000	101 000 - 149 000	234 000 - 258 000	310 000 - 325 000
CSIR Decarbonised (95% decarbonisation by 2050)	80 000	112 000 - 144 000	242 000 - 252 000	331 000

The CSIR Decarbonised and the Least Cost (no new nuclear, no new coal, 75% renewables by 2050) scenarios create the most jobs in the energy sector (highlighted in Table 15). In the long-term, the Decarbonised scenario creates 331 000 jobs by 2050.

The Total System Cost (total cost of power generation including capital, fixed, and variable operations and maintenance costs and fuel) for the different energy-mix scenarios are shown in Table 16. The current system cost is R229 billion per year. The CSIR decarbonised and the CSIR least cost is significantly cheaper than the Draft IRP (DOE, 2016a) Base Case (comprising of $\frac{1}{3}$ coal, $\frac{1}{3}$ nuclear and $\frac{1}{3}$ solar PV/wind/gas. A Decarbonised future would have a total system cost of R579 billion per year. The CSIR Least-Cost scenario consists of 8% coal (existing), 0% nuclear, 0% biogas and 0% CSP, with wind comprising 38% and solar PV 36%, with a total system cost of R529 billion per year. In comparison, the Draft IRP (DOE, 2016a) Base Case, which includes the commissioning of Kusile and Medupi will cost the most, at R683 billion per year.

Table 16: Total System Cost for the different energy-mix scenarios using expected costs (billion Rands per annum) (CSIR, 2017).[34]

Scenario	Total system cost (R'B/year in 2016)	Total system cost (R'B/year in 2030)	Total system cost (R'B/year in 2040)	Total system cost (R'B/year in 2050)
CSIR Decarbonised (95% decarbonisation by 2050)	229	355	465	579
CSIR Least Cost (No new nuclear or new coal, 75% renewables by 2050)	229	353	444	529
IRP 2016 Base Case ($\frac{1}{3}$ coal, $\frac{1}{3}$ nuclear and $\frac{1}{3}$ solar PV, wind and gas)	229	382	548	675
IRP 2016 Carbon Budget (Nuclear, renewables and gas replace coal)	229	399	526	664
Unconstrained Base Case (No new nuclear, some new coal, PV, wind and gas)	229	369	489	596

3.1.1. The disproportionate burden of externalities on marginalised communities

It is widely accepted that negative externalities associated with coal-power generation disproportionately disproportionately affect marginalised and poor communities located around coal mines and power stations. Studies that have investigated the health effects in coal mining communities have found that community members have:

- a 70% greater risk of developing kidney disease
- a 64% greater risk of developing chronic obstructive pulmonary disease (COPD) such as emphysema; and
- are 30% more likely to report high blood pressure (hypertension)

Holland (2017) highlights that "air pollution most affects those whose underlying health condition is worst" and "who are most disadvantaged". In relation to health externalities of coal-fired power plants in South Africa, he notes that "impacts may well be most severe on the more disadvantaged members of society" (Holland, 2017). In relation to water-related externalities of climate change, Kusangaya, et al. (2013) highlights that poor communities are most vulnerable to impacts and risks, as they lack the finances, skills, and technologies to address these problems. Genthe et al. (2013) in their health risk assessment study in the Upper Olifants noted that poor marginal communities, that "partially depend on river water for potable and domestic use, are exposed to immune-compromising metals that

[34] Red shading indicates the most expensive, and Green indicates the cheapest

increase their probability of infection from water borne diseases caused by the excess microbial pathogens in the contaminated surface water".

A multi-component epidemiological study of the Lower Olifants Catchment assessed the impacts of environmental pollution, including coal mining and air pollution, on communities. It highlights that communities most exposed to health risks are "poor", with "extreme levels of unemployment and "very low economic opportunities". In conclusion, not only are marginal communities carrying a disproportionate exposure to the negative effects of coal mining and coal power generation, but are also disproportionately more vulnerable to the same effects (CSIR, 2014).

The disproportionate burden of water related impacts and externalities of coal power is in direct conflict with section 27 of our Constitution, which provides that everyone has the basic human right of access to sufficient and safe water.

4. Conclusion and recommendations

There are several ways to internalise external costs, including regulation, standards, or setting an explicit price in terms of a tax or trading scheme. Explicit pricing mechanisms are usually more economically efficient. Recently, there have been a number of policy developments that aim to 'internalise the cost' of coal mining; including a proposed Carbon Tax and a proposed environmental levy on the mining sector for mitigation of acid mine drainage. Nevertheless, it is important that externalities are calculated and considered in energy planning and decision-making related to different electricity supply options and mixes.

Notably, although the Draft IRP (DOE, 2016a) models water consumption of different electricity supply options, there are considerable gaps related to water externalities and impacts that require further consideration. In response, the Energy Research Centre submits that in IRP modelling, externalities "should be used as externality adders, added to the costs to various power plants" and should be "added to the base case / modeller's reference case and to all policy cases or scenarios" (ERC, 2010). In relation to water, proper costing of electricity supply options should include, *inter alia*, the following:

- water use, across the life cycle of coal power generation, with particular consideration of regional water availability (with full consideration of climate change impacts on availability);
- water infrastructure and management costs for different supply options;
- appropriate valuation for water used for power generation, to ensure that water efficiency is considered in supply options;
- water treatment costs, including capital and operation costs, for different supply options. This should further consider the long-term nature of acid mine drainage, including downstream impacts, and corresponding treatment requirements;
- the impact of different options on water resources, including the impact on water quality due to seepage and spillage from mining and power station waste facilities;
- impacts on critical water resources such as strategic water source areas and vulnerable, threatened, and critically-endangered aquatic ecosystems;
- impacts due to coal ash contamination and deposition of air pollutants, such as sulphur, nitrogen, mercury, and arsenic on our water resources;
- water-related climate change externalities;
- the knock-on effects of degradation of our water resources (especially acid mine drainage) on ecosystems, crop production, health, and livelihoods of those reliant on the water; and
- equity and justice, in view of the disproportionate negative effects of externalities on vulnerable and marginalised communities

A number of studies have provided cost estimates of the above water-related impacts and externalities in coal power generation. These include the following:

- A report by the World Bank finds that incorporating water supply and infrastructure costs into energy modelling may result in a 75% reduction in water intensity of the power sector by 2050 compared to a 'no water cost' scenario;
- Nkambule and Blignaut (2011) calculate that the external costs of coal-fired power generation with respect to water resources, using Kusile as a case study, were estimated to be between R0.95- R1.86 per kWh produced;
- Nkambule and Blignaut (2011) estimate that the opportunity cost of the water used during coal mining will be between around R6-12 billion each year for Kusile;
- Inglesi-Lotz and Blignaut (2012) estimate that the opportunity cost for dry-cooled coal power (in terms of water use) is between R0.66/kWh and R1.31/kWh (2011 ZAR), as compared to renewable technologies;

- Nkambule and Blignaut (2012) estimate the damage cost imposed on other water users from sulphate pollution, using Kusile as a case study, to be between R0.11 and R0.19/t of saleable production (in 1999 ZAR) or between R4.5 million and R7.7 million each year;
- Research by Pretorius (2009) estimates the cost of acid mine drainage to be around 0.38/kWh (2009 ZAR);
- The Council of Geoscience estimate that the closure of derelict and ownerless mines (including long-term treatment of acid-mine drainage) would cost up to R60 billion; and
- Research by CSIR highlights that the Base Case in the Draft IRP, comprising of $\frac{1}{3}$ coal, $\frac{1}{3}$ nuclear and $\frac{1}{3}$ renewables would require four times the water volumes when compared to a Decarbonised Scenario (CSIR, 2017).

This report highlights that proper and informed decision-making on different electricity supply options in general and choices between renewable energy and coal-fired power in particular, require consideration of the above-mentioned water impacts and externalities. Notably, it is evident that consideration and internalising these costs would further justify a rapid transition away from coal-based electricity to water-efficient renewable energy. Water-related externalities, together with health, climate change and ecosystem externalities, alongside the considerable job potential of renewable energy, and the disproportionate negative impacts of externalities on marginalised communities provide a strong justification for a decarbonised future. This is particularly urgent in light of the deep water crisis confronting South Africa.

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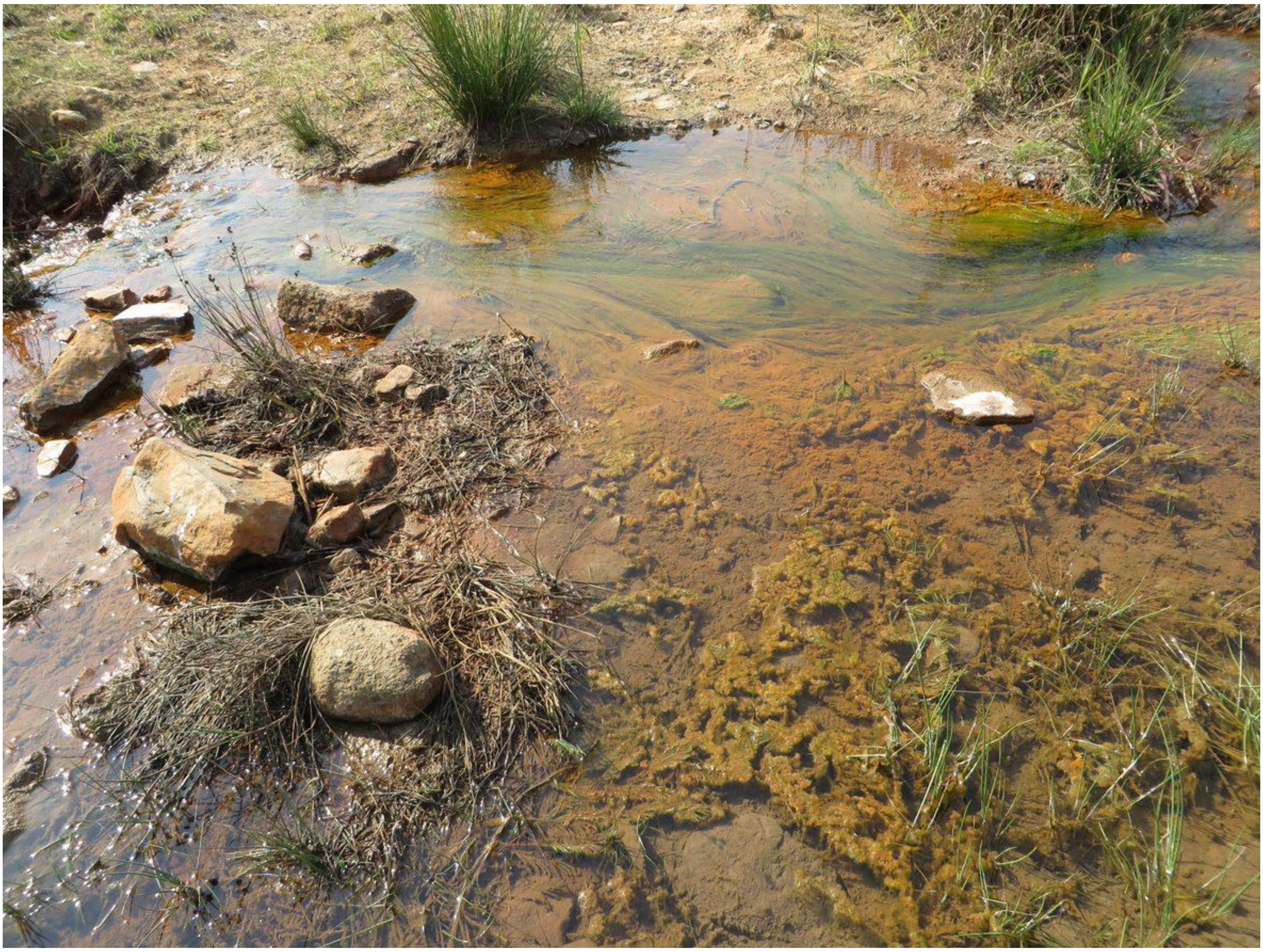

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