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THE EXTERNAL COST OF COAL-FIRED POWER GENERATION:

The case of Kusile

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TABLE OF CONTENTS

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ABBREVIATIONS AND ACRONYMS

AAIC	Anglo American Inyosi Coal
AfDB	African Development Bank
AMD	acid mine drainage
AQIA	air quality impact assistant
BP	Beyond Petroleum
CCS	carbon capture and storage
CER	certified emissions reduction
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxideequivalent
CSP	concentratedsolar power
DME	Department of Minerals and Energy
DWAF	Department of Water Affairs and Forestry
EIA	(US) Energy Information Administration
EIA	environmental impact assessment
EPA	(US) Environmental Protection Agency
ESP	electro-static precipitator
ERF	exposure response functions
ETSU	East Tennessee State University
EU	European Union
EU ETS	European Union Emissions Trading Scheme
FGC	flue gas conditioning
FGD	flue gas desulphurisation
GDP	gross domestic product
GHG	greenhouse gas
GLC	ground level concentration
GNI	gross national income
GNP	gross national product
GWP	global warming potential
HC	hydrocarbon
IPA	impact pathway approach
IPCC	International Panel on Climate change

IRP	Integrated Resource Plan
MPG	Mpumalanga Provincial Government
N_2O	nitrous oxide
NEEDS	New Energy Externalities Developments for Sustainability
NMR	net marginal revenue
NMVOC	non-methane volatile organic compound
NOx	nitrogen oxide
OHS	occupational health and safety
ORNL	Oak Ridge National Laboratory
Pb	lead
PDG	Palmer Development Consulting
PM	particulate matter
PPI	purchasing power parity
PRTP	pure rate of time preference
R&D	research and development
RE	renewable energy
REFIT	renewable energy feed-in tariffs
RfF	Resources for the Future
SARB	South African Reserve Bank
SCC	social damage cost of carbon
SO_2	sulphur dioxide
SUR	seemingly unrelated regression
UNSD	United Nations Statistics Division
VOLY	value of life year
VRESAP	Vaal River Eastern Subsystem Augmentation Project
VSL	value of statistical life
WCA	World Coal Association
WTP	willingness-to-pay
ZLED	zero liquid effluent discharge

The external cost of coal-fired power generation: the case of Kusile

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1. INTRODUCTION

Electricity generation, transmission and distribution in South Africa are handled almost exclusively by Eskom, a public utility established in 1923. According to Eskom, electricity production capacity in South Africa has been reached (see http://www.eskom.co.za/c/article/53/new-build-programme/) because of the development of the economy and the fact that South Africa has not recently augmented its power generation capacity. Eskom, supported by the South African government, has therefore embarked on a process to build more coal-fired power stations (Department of Energy, 2009).Putting action to words, Eskom commenced with the construction of two new coal-fired power stations, namely the Kusile power station in Emalahleni, situatedin the province of Mpumalanga, and the Medupi power station in Lephalale, Limpopo.Supporting these new power generation facilities necessitates the construction of new coal mines, as well as the expansion of existing coal mines.

The country's seeming abundance of coal, which is a questionable perception (see Annex 0), tends to suppress the direct costs of electricity generation.More importantly, coal-fired power stations contribute to widespread indirect costs, referred to as externalities[1].These externalities include the contribution to climate change, the effect of emissions, such as particulate matter (PM) with a diameter of less than 10 µm(PM_{10}), sulphur dioxide (SO_2) and oxides of nitrogen (NOx), on the health of South Africans, and the effect of coal mining and power generation on water consumption and available water supplies. Furthermore, coal mining and related activities are associated with many forms of environmental degradation, such as habitat loss. It also has a negative impact on the transportation network, as it increases the number of heavy trucks travelling on the road network, in particular, but also road haulage requirements that further contribute to climate change, as well as road maintenance and other problems.The majority of these additional costs are indirectly paid for by society atlarge.

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[1] An externality is a coincidental, but often unavoidable, side-effect of an activity. In the generation of coal-fired power, the objective is electricity production, yet, as a side effect, emissions are also produced.

In a perfectly functioning market, the marginal social cost of electricity generation (through coal-fired power plants) would equal the marginal social benefit of electricity generation (through coal-fired power plants).The marginal social costs are assumed to measure all of the additional costs associated with generating another unit of electricity, including costs of all current and future extraction, pollution, health, the transport network, habitat and any other costs.Similarly, the marginal social benefits are assumed to measure all of the additional benefits associated with generating another unit of electricity, where these benefits include increased safety, the ability to undertake various activities at night, increased storage capabilities, employment and any other benefits[2].

Unfortunately, markets are seldom perfect. When it comes to health and environmental costs, markets generally fail, since these costs are borne by individuals within society rather than the decisionmakers or the entity responsible for the pollution and environmental degradation.In this study relatively conservative estimates of the externality cost of coal-fired power generation are provided, because some impacts are excluded, as will be discussed below. Despite its conservativeness, the results of the analysis point to rather large externality costs. Full externality costs range from R0.97/kWh to R1.88/kWh.

Noting that electricity prices in South Africa are set to rise from R0.52/kWh in 2011/12 to R0.65/kWh in 2012/13 (Republic of South Africa (RSA), 2011), it is rather clear that, even after the next price increase, the true cost of electricity generation will not be borne directly by users of electricity. Rather, society as a whole will continue to carry the true cost. Although increasing electricity prices by 250% or 389% – using R0.65/kWh as the base – might be efficient in terms of the current market for electricity, such an increase would in all likelihood in the short-term be damaging to the country’s economic development prospects, as it will not allow the economy enough time to make the required adjustments. However, recalling that the additional costs are associated with coal-fired power generation and not electricity generation per se, the results of the analysis provide strong evidence of the need for Eskom to invest in alternative (renewable) energy sources, and for government to support those investment initiatives.

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[2] In terms of these benefits, the generation source is immaterial as these benefits, with the exception of employment, can be garnered through the availability of electricity. However, the direct cost of employment in the coal industry is accounted for within the direct costs of accessing coal, while employment at power generation facilities is accounted for within the direct costs of electricity. Any additional employment opportunities are likely to be due to the availability of electricity. Therefore employment benefits are not an important externality with respect to coal-fired power generation.

The remainder of the discussion in this synthesis outlines the background to the study, provides a breakdown of the previously reported external costs within four broad categories and presents a further set of electricity tariff proposals based on the results of the analysis. The categories considered include health, climate change, water and coal mining.

2. BACKGROUND, PROBLEM STATEMENT AND STUDY LIMITATIONS

As previously stated, Eskom recently embarked on the construction of two coal-fired power stations (Medupi and Kusile).The site preparation activities for the Medupi power station started in May 2007 (Eskom, 2011).The power station will have a maximum installed capacity of 4 764MW (six 794 MW units).The first unit is expected to be completed in 2012, while the station is expected to reach its full capacity by 2015.The Kusile power plant will be similar in size and its first unit is scheduled to be operational by 2014, while the remaining units will be ready by 2018. Both these power plants have a projected lifespan of 50 years.

The Medupi and Kusile power stations will use a variety of new technologies in all stages of the electricity generation process, ie cooling, combustion and pollution abatement. Due to water scarcity concerns and limited water availability at the locations, both will be dry-cooled stations, unlike the historically installed capacity in the country (African Development Bank, 2009).Another innovation of the two new power plants is the instalment of a flue gas desulphurisation (FGD) mechanism.This process is responsible for removing oxides of sulphur (SO_2) from the exhaust flue gases in coal power stations (NCC Environmental Services, n.d.).

Despite these encouraging technological developments, the Kusile and Medupi power plants are expected to increase South Africa's coal consumption by about 1,7 GT[3], or approximately 10% of the remaining coal reserves in South Africa (see Annex 0 for more details).As a result of the combustion of coal and coal mining in itself, the development of these two power plants causes additional emissions.Thus, these new power plants raise concerns about the impact of coal mining and its ancillary activities on water quality, air quality and the health of people living in these areas, as well as on air pollution and the contribution to global climate change.

The question therefore is: with special reference to Kusile, what is the externality cost of coal-fired power generation?We will address this question by considering the impact of Kusile on air pollution-

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[3] 17 million tons per year per plant x 50 years x 2 plants

related human health, climate change, water consumption and a selection of the externalities related to mining.While we have undertaken to be as inclusive as possible, some external effects could not be included, mainly because necessary data is often lacking.With respect to health, this study covers a large proportion of the pollution-related causes of disease, with the exception of cancer.Research on the relationship and causality between ambient pollution levels and the prevalence of certain cancers has yet to give conclusive results – although radionuclides and heavy metals are considered to be the main culprits.Still, they had to be excluded for the reasons mentioned above.Particles with diameters smaller than 2.5 µm ($PM_{2,5}$) are included in the broader PM_{10} definition and are, to avoid double-counting of pollutants, not included separately in the cost analysis.

This analysis considers Kusile and its health impacts due to air pollution in isolation.Consequently, despite expert assessment that this may be a significant contributor to the health impacts of the power station, issues of occupational health and safety (OHS) related to the operation of Kusile are not considered. The OHS issues related to mining activities, which often form part of the electricity generating life cycle, are well researched (Van Horen, 1997; Ross & Murray, 2004; Hermanus, 2007), but the analyses have not been extended beyond the mining sector. From the small body of literature available on the topic, clear links have been made between exposure to electromagnetic fields and leukaemia (Theriault *et al.*, 1994). Effects due to exposure to PM and workplace accidents have not been discussed in the literature. For this reason it is not yet possible to include the OHS cost due to power plant operations. Although fly ash from ash dumps and coal storage piles contribute significantly to the ambient PM concentrations, nothing is known about the characteristics of these ash dumps.For this reason, the health cost related specifically to ash dumps cannot be calculated either.The exclusion of these impacts is likely to reduce the health cost estimate of the Kusile plant.

The main concern with the determination of the global damage cost due to Kusile's contribution to climate change is the estimation of the anticipated CO_2 emissions.As the power plant is not yet operational, no verifiable data exists.We therefore had to rely on published estimates, based on an annual coal consumption of 17 million tons.

The main limitations to the estimation of the externality cost of water are directly linked to the fact that water is not a traded commodity, and that its tariffs are set through an administrative process.That implies that the scarcity value (or the opportunity cost) of water is not reflected in the water tariff.Complicating matters are the fact that Kusile is not yet operational, therefore no verifiable data is available.The opportunity cost of water has therefore been estimated based on published data and assumptions with respect to growth.While both the data and the assumptions have been evaluated through a process of expert engagement, they cannot be verified and benchmarkedyet.Additionally, the impact of Kusile's power generation on water quality (effluent) could only be discussed qualitatively as this is a subject under the ambit of Eskom's Zero Liquid Effluent Discharge (ZLED) Policy.An evaluation of this policy was not found, therefore,its effectiveness could not be assessed.

For coal mining, although the scope of impacts investigated was broad, noise pollution, damages to roads and the impact of ash lagoons on water resources had to be excluded, because reliable datafor these could not be found. The external cost estimates can therefore be considered as lower-bound estimates because of these exclusions.

3. THE EXTERNALITY COST OF COAL-FIRED POWER GENERATION: A SECTORAL OVERVIEW

3.1 Health

The combustion of coal during the electricity generation process produces a number of by-products, including carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), total mass of suspended particulate matter (PM), oxides of nitrogen (NO_x), sulphur dioxide (SO_2), mercury (Hg) and a wide range of carcinogenic radionuclides[4] and heavy metals.While the chemical nature of PM is important, it is the diameter of these particulates that matter, as that affects lung penetration. Various epidemiological studies found that the aforementioned pollutants contribute to the incidence of mortality (ie cases of bronchitis, asthma and lung cancer, hospital admissions related to respiratory, cardiac, asthma and coronary obstructive pulmonary disease, and asthma-related emergency room visits). While there is a clear link between exposure to this potent mix of pollutants and deteriorating health, a pollutant-by-pollutant analysis could greatly overestimate the health impact of air pollution. For this reason, a number of other methods used to evaluate the health effects and the monetary value of those health effects have been developed, although most applications have made use of data from the USA or Europe. However, a number of studies have been conducted in South Africa.

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[4] Radionuclides are (natural or produced) atoms with unstable nucleuses. They possess excess energy that they shed in a process known as radioactive decay

A summary of those studies and the approach used are presented in Table 1. The numbers contained in Table 1 have been adjusted for inflation, so that they are comparable to the results presented in this study. This study relied heavily on the environmental impact assessment (EIA) conducted. While the EIA has been reviewed, all possible errors contained in it were therefore carried forward into this study.

Table 1: Summary of South African coal-generation externality studies adjusted for inflation

Study	Method	Actual externality (year of valuation, c/kwh)	Inflation adjusted externality (2006, c/kwh)
Dutkiewicz & De Villiers, 1993	Top-down damage cost	0.64	3.23
Van Horen, 1997	Bottom-up damage cost	2.23 – 12.45	6.99 – 39.07
Spalding-Fecher & Matibe, 2003	Bottom-up damage cost	1.40 – 9.30	2.73 – 18.12

Source: Thopil & Pouris, 2010

In the evaluation of the health impacts of Kusile,the impact pathway approach was followed, which is also referred to as the bottom-up damage cost approach.This method has been used in a variety of studies(see Van Horen, 1997; Vrhovcak*et al.*, 2005; and Sakulniyompornet *al.*, 2011), as it follows the real-world sequence of events and associated consequences. In principle, this approach boils down to evaluating emissions, the expected dispersion pattern of those emissions, the likely health impact arising from those emissions and calculating the cost of the resulting health effects. However, due to limited, and in fact mostly unavailable data, a transfer cost method is also applied. This method takes estimates from other sources and transfers them to the local environment via purchasing power parity and income elasticity. It should be noted that transferring values in this way could either understate or overstate the costs, since the exact basket of goods contained in gross national income is likely to differ between South Africa and other developed countries, while the income elasticity used in the analysis could either be too low or too high[5].In order to analyse whether the elasticity in South Africa is overestimated or underestimated, detailed information on the preferences of individuals in South Africa and other developed countries would be needed, as would a thorough analysis of the market structures of the various nations.Individual preferences are not easily measured, making it difficult to calculate where the South African elasticity lies in relation to the elasticity in other developed nations.

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[5] For example, if the income elasticity is higher than that used in the analysis, our results would be an underestimate of the externality costs. On the other hand, if South Africans tend to purchase a less energy-intensive basket of goods, our results would be an overestimate of the externality costs.

At this time, the height of Kusile's emission stacks is not known. It was therefore decided to make use of three alternative heights, 150m, 220m and 300m.The various emissions, dispersion expectations and health effects related to these stack height alternatives are outlined in Annex 1, and these numbers are used to calculate the external health costs, expressed in R/kWh. While it would make intuitive sense that greater stack heights would be associated with lower costs, greater stack heights result in a greater dispersion of pollutants due to higher wind exposure.Therefore, higher stack heights result in greater cost estimates.In this case, however, the situation is not as clear-cut, as will be noted below.

SinceKusile's net electricity output is estimated at 32.3TWh[6], the unit externality costis estimated to be about 0.7c/kWh, which is slightly lower than the studies referred to in Table 1.The main reason for this is that this study was confined to the zone of maximum ground level concentration (GLC). The maximum GLC has been defined as the area within a 25 km radius of the power plant, which is relatively low in population density, whereas the other studies have considered the impact on the entire country. It should also be noted that the cost increases with stack height (see the difference between scenario A2 and C2), but that under the scenario of the highest stack (scenario E2), the dispersion of the pollutants is so wide that some of it falls outside the GLC, and hence the reduction in cost.

Table 2:The annual health cost of Kusile

Stack scenario	Total cost (R million)	Unit externality cost (c/kWh)
Scenario A2 (150 m)	211.2	0.7
Scenario C2 (220 m)	213.3	0.7
Scenario E2 (300 m)	182.8	0.6

3.2 Climate change

This portion of the study considers the social damage cost of the Kusile power plantas it relatesto climate change. In essence, this cost is determined by two factors, namely the emission load of the power station (tCO_2/year) and the unit value of carbon dioxide (\$/tCO_2).While the emission load of the power station is provided by various sources as 30 million tons of CO_2 per annum, based on an annual consumption of 17 million tons of coalonce fully operational(African Development Bank, 2009; Synergistics, 2011), it is the estimate of the unit value of CO_2 that is the source of considerable debate. Here we develop a range of such unit values, based on a number of published (peer reviewed) studies (see Table 3).

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[6] Six units each with a net electricity outage of 723 MW times 8 760 hours times a load factor of 85%

Table 3: The social cost of carbon: 1995 $\$/\text{tC}$[a, d]

	Mode	Mean	Median	Min	Max	Used	No uncertainty, with equity	Uncertainty, no equity	Uncertainty and equity
Tol, 2005: 1% PRTP[b]	4.7	51	33		165				
Tol, 2005: 3% PRTP	**1.5**	16	7		**62**				
Stern, 2007 and 2008						**314**[c]			
Tol, 2009: 1% PRTP	49	120	91		410				
Tol, 2009: 3% PRTP	25	50	**36**		205				
Anthoff *et al.,* 2009				0	121k		14	61	**206**

[a] It should be noted that these values are in $\$/\text{tC}$; to convert the numbers to $\$/\text{t CO}_2$, divide the values by 3.667 (the molecular weight ratio of CO_2 to carbon)

[b] PRTP = pure rate of time preference

[c] 2000 value

[d] The values in bold red are used later on in this study

Alternative views with respect to the value of carbon abounds in the grey (non-peer reviewed) literature, such as those available from Bell and Callan (2011), and Ackerman and Stanton (2011).It is especially the latter that drew much attention, as their study estimates the social cost of carbon to lie between $\$28/\text{tCO}_2$ and $\$893/\text{tCO}_2$.The authors, however, assumed a fixed consumption discount rate of 1.5% per year, while also assuming a relatively high per capita growth rate for the first century.The result of those assumptions is a net negative rate of discounting[7], which is problematic, but would explain the high damage cost values.Given that concern, we focused our attention on the range of values depicted in Table 3.Adjusting these values for inflation and the exchange rate, and combining them with the emissions load, provides an estimate of Kusile's contribution to global climate change damage cost (see Table 4).From this table it is evident that the social damage cost ranges from 0.5c/kWh to 76c/kWh,whereas 10c/kWh to approximately 17c/kWh was the most likely range.

Table 4: Kusile's annual contribution to global damage cost (in ZAR2010 terms)

	Unit	Low	Median	Market	High	Very high	Stern
	1995 $\$/\text{tC}$*	2	36	-	61	206	314**
Value of a ton of carbon	**2010 $\$/\text{tCO}_2$**	0.80	14.33	15.00	24.29	82.02	112.01
	2010 R/tCO_2	5.83	109.80	104.93	177.79	600.42	819.91
Total damage cost	**R million**	174.88	3 147.84	3 294.00	5 333.84	18 012.63	24 597.40
	R/kWh	0.005	**0.097**	**0.102**	**0.165**	0.558	0.762

Notes:

* Series taken from Table 3; to convert a tC to tCO_2 one has to divide by 3.667(the molecular weight ratio of CO_2 to carbon)

** 2000 values

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[7] This point was highlighted by Reyer Gerlagh, personal communication. Negative discounting implies a net appreciation in the value of money over time.

3.3 Water

From a supply point of view, South Africa's water availability is rather limited.Average annual rainfall is 497mm, which is much lower than the global average of 860mm per annum[8](Turton, 2008).Furthermore, only 8% of the country's rainfall remains in catchment areas, such as dams and rivers, which are controlled by the water authorities,ie a large amount of the precipitation is lost through evapotranspiration and deep seepage (Van Heerden*et al.*, 2008).The water resources in the country are also distributed unevenly, as more than 60% of river flows come from 20% of the land area (Department of Water Affairs and Forestry (DWAF), 1997).Finally, groundwater is scarce, since most of the country is underlain by hard rock formationsthat lack major water aquifers.All of these water issues add to the risk of major shortages in the case of overexploitation (DWAF, 1997).

Given that water is a limiting factor to development (Blignaut & Van Heerden, 2009), one might wonder about the society-wide cost of coal-fired water consumption at the Kusile power station.This is an important question, as water's administered prices[9] do not capture the social welfare impacts,because externalities are not factored into those prices(Spalding-Fecher & Matibe, 2003).To measure the external cost, the shadowprice is estimated. The shadow price is an indicator of the opportunity cost of water to societyofcoal-fired electricity generation.Shadowprices are usually relevant in the event that real prices cannot represent the actual loss of welfare to society (Moolman*et al.*, 2006).The way in which the shadow price was estimated reveals the net marginal revenue (NMR) of water, the additional revenue generated by using one cubic metre of water, in accordance with Moore and Dinar (1995) and Moore (1999). The higher the NMR, the more efficiently the water is used. The difference between NMR estimates across technologies represents the opportunity cost of using one technology instead ofthe other.In this study, six models were estimated in order to calculate the differences between the chosen technology for the two power plants (baseline) and five alternative options. The models are as follows (with Table 5 providing their respective water consumption values):

- Baseline: dry-cooling process, with FGD, as proposed for Medupi and Kusile
- Alternative 1: dry-cooling process without FGD

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[8] For comparison purposes in the same geographic area as South Africa, the annual average rainfall of Botswana is 400 mm and that of Namibia is 254 mm.

[9] Water is not traded in the market. The water price, or better still, the water tariff, neither reflect the scarcity of water nor the socioeconomic cost of erroneous allocation of water to suboptimal applications. The water tariff therefore does not have any signalling power. To aggravate matters, the water tariff is only in rare cases reflective of the full cost of delivering the water – although that is an ideal the government is aspiring to. The water tariff, therefore, cannot be used in any form of economic analysis.

- Alternative 2: conventional wet-cooling South African power plant using Eskom's average (2010) water consumption figures
- Alternative 3: concentratedsolar power (CSP) with parabolic trough
- Alternative 4: wind
- Alternative 5: forest residue biomass

Table 5: Water requirements for each of the alternatives

Technology	Water requirement	Source
Baseline: Dry cooling process with 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

Notes:
* Carbon capture and storage (CCS) is a new technology that has not been tried or implemented yet
**Dry-cooling CSP is assumed here for comparison purposes (to the baseline)

Based on the numbers provided in Table 5, it is estimated that Kusile (baseline scenario) will consume approximately 26.15 million m^3 of water per annum[10].The estimated water NMR for the various alternatives is provided in column 1 of Table 6, enabling the estimation of the opportunity cost (column 6), which ranges between R0.66/kWh and R1.31/kWh.

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[10] Based on the fact that Kusile has six units, each with a capacity of 794 MW. First the figure was multiplied by 8 760 hours of the year to convert it to MWh, then multiplied by 0.95 to allow for downtime, and then multiplied by 0.66 m^3.

Table 6: Annual opportunity cost of water for Kusile

		-1	*-2*	*-3*	*-4*	*-5*	*-6*
		λ NMR of water	**Difference**	**Water volume**	**Net generation output**	**Society-wide loss or gain***	**Opportunity cost****
		R/m^3	*R/m^3*	*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

Notes:

* Societal loss is calculated as the difference (column 2) times the water volume (column 3), divided by one million.

** Opportunity cost is calculated as the societal loss (column 5) divided by the net generation output of the baseline (column 4) (32.3TWh), times 1000.

3.4 Mining

Not only does the process of generating electricity (using coal) contribute to negative environmental sideeffects, but so doescoal mining activities and the transportation of coal. Some of these impacts relate to human health (from air pollution), climate change, water quality and biodiversity. The entire life cycle of coal-based electricity supply is therefore associated with negative environmental and human health impacts. This necessitates the consideration of all stages in the coal fuel cycle when assessing the coal-based electricity supply externality cost, including coal mining, processing and transportation (Bjureby *et al.*, 2008; Mishra, 2009; Epstein *et al.*, 2011).

In this study, we quantified the external costs of mining and transporting coal to the Kusile coal-fired power station in Emalahleni, based on the data transfer method.In other words, we adopted, adjusted and transferred published external cost estimates associated with various coal mining-related activities in order to estimate the costs in this portion of the study. While this research technique has its limitations in that it is not based on primary data, it is generally accepted that it provides a first-order assessment of the most plausible range of impacts.Conducting primary research on a mine and power plant currently under constructionis not possible, as there is no inventory of data availableyet.Therefore, there was no option other than to make use of the best available published data.The major concern arising from the use of this technique is that one carries forward all errors from previous studies. This potential problem is mitigated by using published literature, as far as possible, and focusing on range estimates, instead of point estimates, of the externality cost.

The specific impacts that were considered here, together with the sources of data that enabled computation of the external costs of coal mining and transportation, are presented in Table 7, with the results in Table 8.The annual external damages of mining coal and transporting it to Kusile for electricity generation purposes range between R6 538 million and R12 690 million.Based on an annual usage of coal of 17million tons, this translates to an externality value of between R385 and R746 per ton.While based on Kusile's net power generation output (32.3 million MWh) the estimated damage cost (R6 538 million and R12 690 million) translates into an externality cost of between 20.2c/kWh and 39.3c/kWh sent out.

Table 7: Coal mining and transportation impacts investigated in this study and sources of data

Impact investigated	Method	Data requirements	Data source
Coal mining climate change impacts	Benefit transfer	1. Social cost of carbon 2. Methane emission factor 3. Coal mined for Kusile 4. Methane global warming potential	1. Blignaut, 2011 2. Cook, 2005; Lloyd and Cook, 2005 3. Wolmarans and Medallie, 2011 4. IPCC, 2001
Coal transportation climate change impacts	Benefit transfer	1. Total diesel consumption 2. Carbon emission factor for diesel and diesel oxidation factor 3. Social cost of carbon	1. Synergistics Environmental Services and Zitholele Consulting, 2011 2. IPCC, 1996 3. Blignaut, 2011
Accidents: mortality and morbidity (occupational and public)	Benefit transfer	1. Fatalities and injuries during coal mining and transportation 2. Monetary valuation estimates for mortality 3. Monetary valuation estimates for morbidity 4. Coal produced in various years	1. Department of Minerals and Energy, 2008 and 2010 2. NEEDS, 2007; AEA Technology Environment, 2005 3. Van Horen, 1997 4. World Coal Association (WCA), 2006, 2007, 2008 and 2009
Water pollution	Benefit transfer	1. Coal mined for Kusile 2. Water pollution damage cost	1. Wolmarans and Medallie, 2011 2. Van Zyl *et al.*, 2002
Water consumption	Benefit transfer	1. Annual water requirements for mining coal for Kusile power station. 2. Opportunity cost of water	1. Pulles *et al.*, 2001, Wassung, 2010 2. Inglesi-Lotz and Blignaut, 2011
Human health impact due to air pollution	Benefit transfer	1. Emission factors for various classic air pollutants 2. Damage cost estimates	1. Stone and Bennett, n.d. 2. NEEDS,2007; Sevenster *et al.*, 2008; AEA Technology Environment, 2005
Loss of agricultural and other ecosystem goods and services	Opportunity cost	1. Land use 2. Market price of maize and value of ecosystem goods and services in grasslands	1. Wolmarans and Medallie, 2011 2. Blignaut *et al.*, 2010

Table 8: Annual damage cost related to coal mining for the Kusile power plant

Damage estimated	Units	Central estimate	High estimate
Global damage cost: coal mining	R (million)	477.0	722.4
Global damage cost: coal transportation		2.4	3.9
Human health damages due to accidents		0.7	1.3
Human health damages due to air pollution		10.5	15.0
Water pollution damages		6.1	7.7
Water consumption		5 964.2	11 862.4
Loss of agricultural potential		76.4	76.4
Loss in ecosystem goods and services		1	1
Total	R (million)	**6 538.28**	**12 690.11**

4. RESULTS

While several past studies consider the external costs of coal-fired power generation and coal mining, for example, Van Horen (1997),Spalding-Fecher, *et al*. (2000), Blignaut and King (2002), and Spalding-Fecher and Matibe (2003), they are neither up to date nor do they focus on the externality cost of a specific power station. These are problems that could be addressed. The externality cost of the Kusile power plant was considered, with a focus on air pollution-related health impacts, climate change, water consumption and externalities related to coal mining.It should be noted that primary research was not conducted and, therefore, this study relied heavily on data transfer and literature reviews, applyingthat information to the current situation.While this method is not perfect, there is no factual data on the Kusile power plant yet, as it is still under construction. To mitigate the problem of reverting to secondary data, we used – for the most part – peer-reviewed sources.Both the sources and the research method were scrutinised by an external panel during an expert workshop.

Following the research conducted, the estimated social damage cost (or externality cost) of Kusile is presented in Table 9 below.Externality costs range from R31.2billion to R60.6billion a year. Expressed in unitary terms, the externality cost ranges from R0.97 to R1.88/kWh.[11] The water effect dominates these externality costs – approximately 70% of the external costs are water-related. Given that the nationwide average electricity tariff was R0.41/kWh in 2010 (RSA, 2011), an externality inclusive tariff could, potentially, range between R1.38/kWh and R2.29/kWh, although the lower figure is closer to the now defunctrenewable energy feed-in tariffs (REFIT) for biomass, which was announced at R1.181/kWh. In percentage terms,the aforementioned externality costs range between 237% and 459% of the 2010 tariff.

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[11] The table provides comparative information with respect to the relative externality costs of water. For illustrative purposes, we have calculated the values, excluding water costs.

Table 9: Estimated annual externality cost of Kusile

	Net output	Externality cost			
	GWh	**Low (R million)**	**R/kWh (Low)**	**High (R million)**	**R/kWh (High)**
Health	32 301	182.8	0.006	213.3	0.007
Climate change	32 301	3 148	0.097	5 334	0.165
Water	32 301	21 305	0.660	42 357	1.311
Mining	32 301	6 538	0.202	12 690	0.393
Total		**31 174**	**0.97**	**60 594**	**1.88**
Total excluding water for generation purposes*		**9 869**	**0.31**	**18 237**	**0.56**

* For illustrative purposes only

While these estimates areinteresting, the initial problem to be examined here was the additional cost associated with coal-fired power generation, and not electricity generation per se.The results therefore provide strong evidence for the need to invest in alternative electricity-generation technologies, and for Government to support those investment initiatives.Translating the research problem in light of these results leads one to the question: what quantity of renewable electricity generation could be purchased if, rather than investing in coal-fired power generation, the monetary values of coal-fired power generation externalities were to be invested in renewable electricity generation? A preliminary answer to this question, recalling the caveats associated with the various externality calculations, is presented in Table 10.Using the capital costs associated with various renewable electricity options, as depicted in the Integrated Resource Plan 2010–2030 (RSA, 2011), it is possible to determine the amount of power generation that could be purchased.[12]

Conclusions of this nature aretentative at best, since an analysis of this sort is limited to hypothetical cases – renewable power plants of this magnitude have not yet been developed in South Africa, and the future cost and productive capabilities of these technologies are not certain.

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[12] It is likely that the capital costs of these technologies will decline over time. Teske (2011), for example, estimates that the reduction could range from 25 to 60%, as developments in the renewable electricity generation sector advances. These reductions are an important consideration, as the results shown in Table 10 are proportionately much more sensitive to changes in capital cost than they are to operating costs. Any possible reduction in the unit cost of renewable power generation technologies in the future due to ongoing research and development is therefore likely to have a favourable impact on the results.

Table 10: Opportunity cost of Kusile[1, 2, 3, 4]

	MW capacity and MWh generated that would equal a total annual cost of:		Time it would take to equal Kusile's output	MW capacity and MWh generated that would equal a total annual cost of:		Time it would take to equal Kusile's output
	R31 174 million			R60 594 million		
	MW	**MWh**	**Number of years**	**MW**	**MWh**	**# years**
Wind	9 881	25 100 975	1.3	19 206	48 790 295	0.7
Concentrated photovoltaic (PV)	3 923	9 209 235	3.5	7 625	17 900 550	1.8
PV (crystalline silicon)	7 135	12 125 835	2.7	13 869	23 569 724	1.4
Forest residue biomass	3 967	29 540 823	1.1	7 712	57 420 298	0.6
Municipal solid waste	1 919	14 290 024	2.3	3 730	27 776 390	1.2
Concentrated solar power, parabolic trough with nine hours storage	2 882	11 032 313	2.9	5 602	21 444 178	1.5

Notes:

1 Assuming that the capital costs are repaid in five years and that there are no resource and/or technological constraints.

2 While it is unlikely that, in reality, the focus will be exclusively on one technology, this is done here (as opposed to a bundle of technologies) for demonstration purposes.

3 Given the ongoing R&D in renewable energy technologies, the unit costs are likely to come down, reducing the time it will take to reach the capacity of Kusile.

4 While it might be argued that it is currently unlikely that there are sufficient resources to invest in these technologies to the extent indicated, with R&D and improvements in efficiencies, this might become plausible soon.Also, in reality, a bundled approach using a suite of technologies is arguably the best way going forward.

As the externality cost (shown in Table 9) is dominated by water, two estimates of the impacts of these costs are calculated based on the information in Table 10: an extremely conservative estimate, based on 30% of external costs, and a full estimate, based on the full external costs. Using these extremities, the time it would take to equal Kusile's capacity would rise from between 3.5 years (biomass) and 11.4 (CSP) for the lower limit, to 1.9 years (biomass) and six years (CSP) under the full-cost scenario. In other words, at its worst, it would be possible to develop no less than 500% of Kusile's proposed power generation capacity,assuming that renewable electricity generationcapacity was funded from only 30% ofKusile's external costs.

5. CONCLUSION

This study has examined the external costs of coal-fired power generation, making use of the proposed Kusile power plant to inform the analysis. External costs capture the indirect costs of economic activities, and in the case of coal-fired power generation, those costs include potential health damage, potential damages as a result of its contribution to climate change, concerns with regard to water quality and the opportunity cost of water consumption, transport network damages and other environmental damages associated with mining, to name the costs that could, for the most part, be included in this analysis. Importantly, external costs are not meant to capture direct costs, such as the capital cost of the investment. Although there are opportunity costs associated with these direct costs, these funds could be used for other activities, as direct costs funnel into other productive economic activities, such as construction and employment, and therefore these direct costs do not constitute any part of the analysis.

The primary methodology for the analysis was based on data transfer, and this data – mostly costs, in this case – was adjusted for both inflation and exchange rate differences.The chosen methodology was required, because the analysis is primarily hypothetical.The Kusile plant has not yet been completed, and therefore, it is not possible to directly measure emissions and other impacts associated with power generation at the plant.In other words, there is no data available from the plant.Generally, data from existing power stations and studies related to coal externalities were used to inform the analysis.

The results of the analysis point to economically significant external costs ranging from between R31.2 billion and R60.6 billion a year.Depending on inclusion and exclusion choices within the analysis, taking cognisance of the fact that operating a power plant without water is not possible, the external costs range from R0.31/kWh to R1.88/kWh. Given that the average tariff in 2010 was R0.41/kWh, and the proposed tariff for 2012/13 is R0.65/kWh, these externality costs represent a minimum of 76% of the 2010 tariff, or 48% of the 2012/13 proposed tariff.If it were possible to shift these external costs to investments in alternative(renewable) energy sources, these investments would likely be recouped from the damage cost of Kusilewithin three and a half years, but at worst within about 10 years. In other words, over its lifespan, the opportunity cost of Kusile is, at its most conservative, an installed capacity of 24 000 MW (4 800 x 5[13]), but could be as high as 68 600 MW (4 800 x 14.28[14]). Recalling that the additional costs are associated with coal-fired power generation, and not electricity generation per se, the results of the analysis provide strong evidence of the need for Eskom to invest in alternative (renewable) energy sources, and for Government to support those investment initiatives.

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[13] Estimated as Kusile's lifespan of 50 years, divided by a conservative estimate of the time it would take to replace Kusile's capacity of 10 years

[14] Estimated as Kusile's lifespan of 50 years, divided by the plausible time it would take to replace Kusile's capacity of three and a half years under the "with water" scenario

6. REFERENCES

Ackerman, F. & Stanton, E.2011.*Climate risk and carbon prices: Revising the social cost of carbon*. Portland Oregon: Economics for Equity and Environment.

AEA Technology Environment. 2005. Damages per tonne emission of $PM_{2.5}$, NH_3, SO_2, NOx and VOCs from each EU25 member state (excluding Cyprus) and surrounding seas. Available at: http://www.cafe-cba.org/assets/marginal_damage_03-05.pdf (accessed on 14 August 2011).

African Development Bank (AfDB). 2009. Executive summary of South Africa: Environmental impact assessment for the Medupi power plant project of Eskom.Available at: http://www.afdb.org/fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/ESIA%20Ex%20Summary%20of%20Medupi%20Coal%20Power%20Plant%20July%201%20revised%20Final-ram-1.pdf (accessed on 7 August 2011).

Anthoff, D., Tol, R. & Yohe, G. 2009. Risk aversion, time preference, and the social cost of carbon.*Environ.Res. Lett.,***4:**024002; doi:10.1088/1748-9326/4/2/024002.

Bell, R.G. & Callan, D. 2011.More than meets the eye: the social cost of carbon in US Climate Policy, in plain English. Policy brief.Washington DC: Resources Institute (WRI).

Bjureby, E., Britten, M., Cheng, I., Kaźmierska, M., Mezak, E., Munnik, V., Nandi, J., Pennington, S., Rochon, E., Schulz, N., Shahab, N., Vincent, J. & Wei, M. 2008. The true cost of coal: How people and the planet are paying the price for the world's dirtiest fuel. Available at: http://www.greenpeace.org/australia/en/what-we-do/climate/resources/reports/the-true-cost-of-coal/ (accessed on 3 July 2011).

Blignaut, J. & Van Heerden, J. 2009. The impact of water scarcity on economic development initiatives. *Water SA***35(4):** 415–420.

Blignaut, J., Mander, M., Schulze, R., Horan, M., Dickens, C., Pringle, K., Mavundla, K., Mahlangu, I., Wilson, A., Mckenzie, M. &Mckean, S.2010. Restoring and managing natural capital towards fostering economic development: Evidence from the Drakensberg, South Africa. *Ecological Economics***69:** 1313–1323.

Blignaut, J.N. 2011.The opportunity cost of Medupi and Kusile power stations. Unpublished study. Pretoria, South Africa.

Blignaut, J.N. & King, N.A. 2002. *The externality cost of coal combustion in South Africa. Bridging the economics/environment divide conference proceedings*. Pretoria: Forum for Economic and Environment.

Cook, A. 2005. Task 6.1 greenhouse methane emissions for South African coal mining models for predicting methane gas release from coal seams. Available at: http://www.coaltech.co.za/chamber%20databases/coaltech/Com_DocMan.nsf/0/4D52D96EF7F0202942257409001D7E

38/$File/Task%206.1%2020Methane%20emissions%20and%20Models.pdf (accessed on 21 June 2011).

Dennen, B., Larson, D., Lee, C., Lee, J. &Tellinghuisen, S. 2007. *California's energy-water nexus: Water use in electricity generation*. Santa Barbara: Donald Bren School of Environmental Science & Management University of California.

Department of Energy. 2009. Digest of South African energy statistics 2009. Available at:http://www.energy.gov.za/files/media/explained/2009%20Digest%20PDF%20versio n.pdf (accessed on 4 July 2011).

Department of Energy. 2011. *Water – 2010 input parameter data (externality)*. Pretoria, South Africa: South African Department of Energy.

Department of Minerals and Energy. 2008. *Annual report 2007/2008*. Available at: http:// www.info.gov.za/view/DownloadFileAction?id=93533 (accessed on 28 June 2011).

Department of Minerals and Energy. 2010. *Annual report 2009/2010*. Available at: http:// www.dmr.gov.za/AnualReport/Documents/DME%20Annual%20Report%2009_10%20hr.pdf (accessed on 28 June 2011).

Department of Water Affairs and Forestry (DWAF). 1997. *Overview of water resources availability and utilisation in South Africa*. Pretoria, South Africa: Department of Water Affairs and Forestry (DWAF).

Dutkiewicz, R.K. &De Villiers, M.G. 1993. Social cost of electricity production. Engineering research. Report for the National Energy Council. Pretoria.

Epstein, P.R., Buonocore, J.J., Eckerle, K., Hendryx, M., Stout III, B.M., Heinberg, R., Clapp, R.W., May, B., Reinhart, N.L., Ahern, M.M., Doshi, S.K. &Glustrom, L. 2011. Full cost accounting for the life cycle of coal.*Ann. N.Y. Acad. Sci***1219:** 73–98.

Eskom. 2011. *Eskomintegrated report 2011.* Johannesburg, South Africa: Eskom.

Hermanus, M.A. 2007. Occupational health and safety in mining – status, new developments and concerns. *The Journal of the Southern African Institute of Mining and Metallurgy*, **107 (August):** 531–538.

Intergovernmental Panel on Climate Change(IPCC). 1996. *IPCC guidelines for national greenhouse gas inventories: Reference manual, Volume 3*. Cambridge: Cambridge University Press.

IPCC. 2001. Climate change 2001. In *Third assessment report of the International Panel on Climate Change* (eds. R.T. Watson & Core Writing Team). Geneva: Cambridge University Press.

Lloyd, P. & Cook, A. 2005.Methane release from South African coalmines. *The Journal of the South African Institute of Mining and Metallurgy***105:** 1–8.

Macknick, J., Newmark, R., Heath, G. &Hallett, K. 2011.*A review of operational water consumption and withdrawal factors for electricity generating technologies*. Washington DC: National Renewable Energy Laboratory (NREL), US Department of Energy.

Mishra, S.K. 2009. Estimation of externality costs of electricity generation from coal: an OH-MARKAL extension dissertation.Unpublished doctoral thesis. Canada: The Ohio State University. Available at:http://etd.ohiolink.edu/view.cgi/Khadka%20Mishra%20Shruti.pdf?%20osu12597033 37 (accessed on 8 July 2011).

Moolman, C., Blignaut, J. &Van Eyden, R. 2006. Modelling the marginal revenue of water in selected agricultural commodities: A panel data approach.*Agrekon***45(1):** 78–88.

Moore, M. & Dinar, A. 1995. Water and land as quantity rationed inputs in California agriculture: Empirical tests and water policy implications. *Land Economics***74(4):** 445–461.

Moore, M. 1999. Estimating irrigators' ability to pay for reclamation water. *Land economics***75(4):** 652–578.

NCC Environmental Services. n.d. Environmental management for Eskom. Available at: http://www.natureconservation.co.za/index.html?id=38 (accessed on 7 July 2011).

New Energy Externalities Developments for Sustainability(NEEDS). 2007. Final report on the monetary valuation of mortality and morbidity risks from air pollution. Deliverable for WP6 of RS1b of the New Energy Externalities Developments for Sustainability (NEEDS) project.IER, University of Stuttgart.

Pulles, W., Boer, R. & Nel, S. 2001. A generic water balance for the South African coal mining industry. Water Research Commission Report No. 801/1/01.

Republic of South Africa (RSA). 2011. Integrated Resource Plan 2010–2030. *Government Gazette*. Pretoria: Government Printers.

Ross, M.H. & Murray, J. 2004. Occupational respiratory disease in mining. *Occupational Medicine***54(5):**304–310.

Sakulniyomporn, S., Kubaha, K., &Chullabodhi, C. (2011). External costs of fossil electricity generation: Health-based assessment in Thailand. *Renewable and Sustainable Energy Reviews***15:** 3470–3479.

Sevenster, M., Croezen, H., Van Valkengoed, M., Markowska, A. &Donszelmann, E. 2008. External costs of coal: Global estimate. Available at: http://www.cedelft.eu/publicatie/external_costs_of_coal/878?PHPSESSID=f138219238c72e8038a0a5694354af1d (accessed on 1 July 2011).

Spalding-Fecher, R., Khorommbi-Matibe, D., Afrane-Okese, Y., Eberhardt, R., and Davis, M. 2000. *Macroeconomic reforms and sustainable development in southern Africa: Electricity* *production and the environment*. Development Bank of Southern Africa (DBSA)/World Wide Fund for Nature (WWF).

Spalding-Fecher, R. &Matibe, D. 2003.Electricity and externalities in South Africa. *Energy Policy***31:** 721–734.

Stern, N. 2007.*The economics of climate change: The Stern review*. Cambridge: Cambridge University Press.

Stern, N. 2008. The economics of climate change. *Am. Econ. Rev*.**98:**1–37.

Stone, A. & Bennett, K. n.d.A bulk model of emissions from South African diesel commercial vehicles. Energy Research Institute (ERI), University of Cape Town. Available at: http:// www.erc.uct.ac.za/Research/publications-pre2004/01Stone-Bennett_Diesel_emissions.PDF (accessed on 13 June 2011).

Synergistics Environmental Services &Zitholele Consulting. 2011. Environmental impact assessment, water use license and a waste management licence for the proposed New Largo Colliery. MDEDET Ref: 17/2/3N-41.

Synergistics.2011.New Largo Colliery – Draft environmental scoping report.Report number S0403/NLC/SR02. Johannesburg: Synergistics.

Teske, S. (Ed.) 2011. *The advanced energy [r]evolution:Asustainable energy outlook for South Africa.* Brussels and Amsterdam: European Renewable Energy Council and Greenpeace.

Theriault, G., Goldberg, M., Miller, A., Armstrong, B., Guénel, P., Deadman, J., Imbernon, E., To, T., Chevalier, A., Cyr, D. & Wall, C. 1994. Cancer risks associated with occupational exposure to magnetic fields among electric utility workers in Ontario and Quebec, Canada, and France: 1970–1989. *American Journal of Epidemiology***139(6):**550–572.

Thopil, G.A. & Pouris, A. 2010. An overview of the electricity externality analysis in South Africa within the international context. *South African Journal of Science*, **106(11):**1–6. Available at:http://0-search.sabinet.co.za.innopac.up.ac.za/WebZ/Authorize?sessionid=0&bad=ejour/ ejour_badsearch.html&portal=ejournal&next=images/ejour/sajsci/ sajsci_v106_n10_11_a15.pdf(accessed on 10 July 2011).

Tol, R. 2005. The marginal damage costs of carbon dioxide emissions: An assessment of the uncertainties. *Energy Policy***33(16):**2064–2074.

Tol, R. 2009. The economic effects of climate change.*Journal of Economic Perspectives***23(2):** 29–51; doi: 10.1257/jep.23.2.29.

Turton, A. 2008. Three strategic water quality challenges that decision-makers need to know about and how the CSIR should respond. CSIR conference: Science Real and Relevant. Pretoria, South Africa.

Van Heerden, J., Blignaut, J. &Horridge, M. 2008.Integrated water and economic modelling of the impacts of water market instruments on the South African economy. *Ecological economics***66:** 105–116.

Van Horen, C. 1997. Cheap energy – at what cost?Externalities in South Africa's electricity sector. In *Counting the social costs: electricity and externalities in South Africa*(ed. C van Horen). Cape Town: Elan Press and UCT Press.

Van Zyl, H., Raimondo, J. &Leiman, T. 2002.*Energy supply sector – coal mining. WWF – Macroeconomic reforms and sustainable development in South Africa*.

Vrhovcak, M.B., Tomsic, Z., &Debrecin, N. 2005. External costs of electricity production: case study Croatia. *Energy Policy***33:** 1385–1395.

World Coal Association (WCA). 2006. Coal facts. Available at: http://www.worldcoal.org/resources/coal-statistics/ (accessed on 18 August 2010).

WCA. 2007. Coal facts. Available at: http://www.worldcoal.org/resources/coal-statistics/ (accessed on 18 August 2010).

WCA. 2008. Coal facts. Available at: http://www.worldcoal.org/resources/coal-statistics/ (accessed on 18 August 2010).

WCA. 2009. Coal facts. Available at: http://www.worldcoal.org/resources/coal-statistics/ (accessed on 18 August 2010).

Wolmarans, M. &Medallie, M. 2011.New Largo Colliery environmental scoping report. Report No. S0403/NL/SR02.

ANNEX 0: BACKGROUND

Coal and coal-fired power generation in South Africa

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1. INTRODUCTION

Coal has been the backbone of the development of South Africa’s mining and industrial sectors since 1870, when coal was first used in a Kimberley diamond mine.Since then, coal production rose to approximately 30 million tons in the 1950s and 115 million tons in 1980, following the oil crisis, rising international coal demand and soaring domestic electricity demand (Department of Energy, 2010; Statistics South Africa, 2010).Between 1980 and 2007, coal production rose drastically by 116% to 248 million tons in 2007 (Statistics South Africa, 2010).It is estimated that coal production in 2010 stood at 255 million tons, making South Africa the fifth largest coal producer in the world (World Coal Association (WCA), 2010).About three quarters of the coal produced are consumed in the domestic economy, while a quarter is exported to, mostly, East Asia and the European Union (Energy Information Administration (EIA), 2010a; EIA, 2010b).This makes South Africa the world’s fifth largest coal exporter (WCA, 2010).In 2008, coal exports earned the country a revenue of R42.4 billion while local sales amounted to R30.1 billion (Department of Mineral Resources, 2010).

Given the seeming abundance of coal, it is not surprising that coal is South Africa’s main source of energy, providing over 70% of the country’s primary energy and 93% of its electricity (Department of Energy, 2010; WCA, 2010).The bulk of the country’s coal reserves (70%) is found in only three of the country’s 19 official coal fields (Highveld, Emalahleni and Waterberg).TheEmalahleni and Highveld coalfields combined provide over 80% of South Africa’s total coal output.The coal is almost entirely bituminous with very little anthracite.Although the coal is laid down in thick level seams at shallow depths, making its extraction easier and relatively cheaper, it is for the most part of low quality and has a high ash content (Department of Energy, 2010).

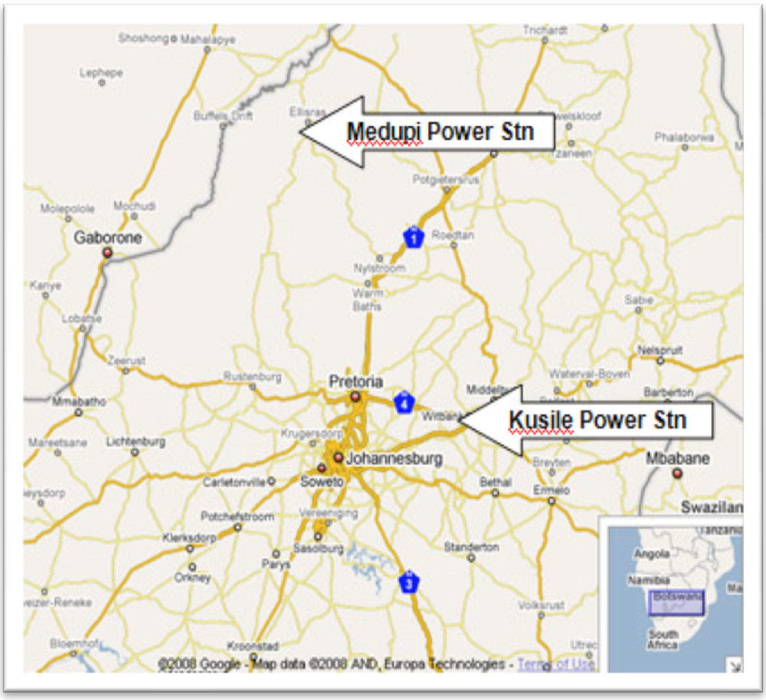
There is a considerable debate regarding South Africa’s coal reserves.Initially it was anticipated that the reserve is about 55Gt, but it has recently been downscaled to 40Gt.This number is currently contested.A recent survey by the Department of Energy indicates that the reserve is potentially only 31Gt, with a useable component of only 23Gt, of which about 8Gt has already been consumed (Hartnady, 2010).Given the prevailing uncertainties, the amount of useable coal reserve is therefore estimated to be between 15Gt and 17Gt (Hartnady, 2010).This is farfrom the initial estimates.The country will therefore have to brace itself for a period of coal scarcity.

Owing to the development of the economy, and the fact that South Africa has not recently invested in augmenting its power generation supply capacity, the maximum production capacity of the existing power stations has been reached.Eskom, supported by the South African government, intends to build more coal-fired power stations in order to meet the country's growing demand for electricity (Department of Energy, 2009).Eskom already has ten coal-fired power stations, which receive coal from 22 coal mines.Twelve of these mines are opencast, five are underground and the other five have both opencast and underground facilities (Department of Mineral Resources, 2010; Wassung, 2010).Eskom estimates that over the next decade, 40 new coal mines will be needed to produce sufficient amounts of coal to fuel future electricity demand (SAinfo, 2009).Eskom has commenced with the construction of two new coal-fired power stations, the Kusile power station in Emalahleni and Medupi in Lephalale in Limpopo.This increase in coal-fired power generation capacity necessitates the construction of new and the expansion of existing coal mines.

2. PROFILES OF MEDUPI AND KUSILE POWER STATIONS AND THEIR SUPPORTING COAL MINES

The site preparation activities for the Medupi power station started in May 2007 (Eskom, 2011).The power station will have a maximum installed capacity of up to 4 764megawatts (MW) (6 x 794 MW units) (Eskom, 2011).The first unit is expected to be completed in 2012, while the overall station is expected to reach its full capacity by 2015.The overall lifespan of the power plant is 50 years (Eskom-Medupi power station, n.d.).

Medupi is located in Lephalale (Figure 1).The area used to be the Naauw Ontkomen farm and was bought by Kumba Coal (Pty) Ltd (now Exxaro Coal (Pty) Ltd) (Eskom-Medupi power station, n.d.).It lies in the Mokolo River Catchment that drains into the Limpopo River, and the specific site where the power plant is situated measures 883ha.The area is relatively flat, approximately 920m above sea level.Also, 87% of the water in the catchment was previously used for agricultural activities, game and cattle grazing (Eskom-Medupi power station, n.d.)as well as for industrial, mining, power generation and domestic water supply (African Development Bank (AfDB), 2009).



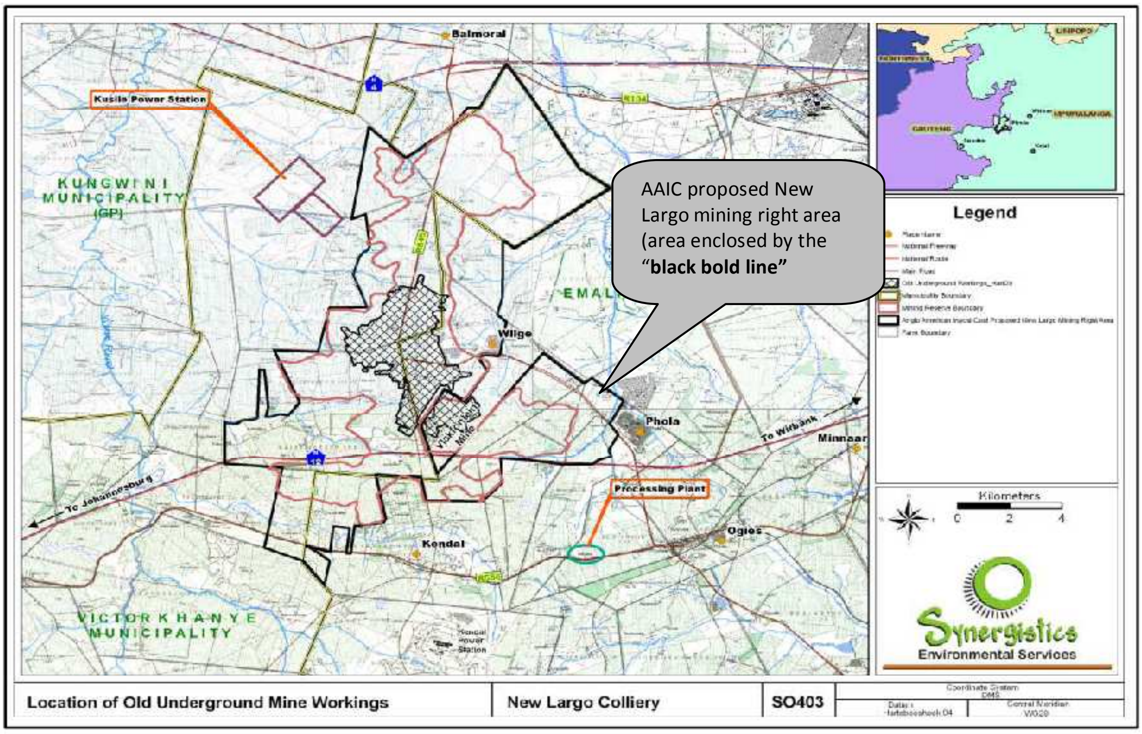
Source: Kruger, 2008

Figure 1: Locations of Kusile and Medupi power plants

The proposed Kusile power plant also has a projected lifespan of 50 years (Action Sierra Club, n.d.).Kusile consists of six units of approximately 800MW electricity generation capacity each, giving an aggregate estimated supply of 4 800MW.The first unit is scheduled to begin operation in 2014, while the remaining ones will be ready by 2018.The power station is located on the Hartbeesfontein and Klipfontein farms in Emalahleni, Mpumalanga (Figure 1), and extends over 1 355ha (NCC Environmental Services, n.d.).The overall host site of the power plant (5 200ha) is located west of the R545, between the N4 and N12 highways.The area was previously used for agricultural activities and cattle grazing (Frontiers Insight, n.d.).Water required for the Kusile power plant will be supplied from the Vaal River system (and not the catchment area) via the Vaal River Eastern Subsystem Augmentation Project (VRESAP) of the Department of Water and Environmental Affairs (previously the Department of Water Affairs and Forestry (DWAF)) (Ninham Shand,2007). From the Vaal River water sources used locally in 2000, 64.5% was used for irrigation and by urban and rural consumers, while the rest was used for mining and power generation (DWAF, 2004).

The Medupi and Kusile power stations will use a variety of new technologies in all stages of the electricity generation process,iecooling, combustion and pollution abatement.Unlike conventional cooling methods used in most power stations, both will be dry-cooled stations due to the water scarcity and limited water availability at the location (AfDB, 2009).Another innovation that will be used in the two new power plants is a flue gas desulphurisation (FGD) mechanism.This process is responsible for removing sulphurdioxide (SOx) from the exhaust flue gases in coal power stations.It uses limestone as feedstock and produces gypsum as a by-product (NCC Environmental Services, n.d.).

It is estimated that Medupi and Kusile will each require approximately 17million tons of coal annually (AfDB, 2009; Eskom, 2011; Synergistics, 2011).Exxaro is committed to supply Medupi with its coal requirements, while Anglo American Inyosi Coal (AAIC) is contracted to supply the required coal to Kusile for 47 years (Eskom, n.d.).This supply will be extracted from the New Largo reserve in support of the Zondagsfontein East No2 seam, as well as the Zondagsfontein East No4 seam and the Zondagsfontein West resources (Eskom, n.d.)(Figure 2).



AAIC proposed New Largo mining right area (area enclosed by the "**black bold line**"

Source: Wolmarans and Medallie, 2011

Figure 2: Location of Kusile power station, AAIC proposed mining area and Phola coal-processingplant

The proposed colliery is called the New Largo Colliery and it will be an opencast coal mine. It will have a capacity of processing at least 12.7 million tons of raw coal per year (Wolmarans & Medallie, 2011).Additional coal will be sourced elsewhere (eg from Zondagsfontein East No 4 seam, Zondagsfontein East No2 seam and Zondagsfontein West resources (Eskom, n.d.)) to meet Kusile's coal requirements when it is fully operational (Synergistics, 2011).

The main activities during coal mining are topsoil stripping prior to mining, drilling and blasting of overburden, loading and haulage of coal from the mine pit, crushing and coal beneficiation (coal washing), depending on the quality of coal.Both virgin coal and previously undermined areas situated in the centre of the coal reserve area will be mined.The virgin coal situated in the northern section of the reserve area is said to be of such quality that beneficiation will not be necessary.AAIC plans to mine this coal first and transport it to Kusile without washing (Synergistics,2011).The virgin coal is expected to last until 2023.Coal from old underground mine workings as well as low-quality coal south of the coal reserve area is therefore projected to be mined after 2023 and will require beneficiation.It is estimated that of the coal fed into the beneficiation plant, 15% will be removed as coal discards.This implies a total production of discards of approximately 84 million tons over the 50-year life of the New Largo Colliery (Wolmarans & Medallie, 2011).Phase 1 of the development of the New Largo Colliery is expected to commence in November 2012. The delivery of the first coal to Kusile is planned for June 2015.The colliery is expected to be in full production by 2023 (Wolmarans & Medallie, 2011).In the early years of operation, until the new colliery is built, Kusile will use coal from the Phola coal-processing plant as well as from other parties, such as the Vlakfontein Colliery (Synergistics, 2011).

The Phola coal-processing plant is located approximately 20km southeast of the Kusile power station (see Figure 2) and is owned by Anglo American and BHP Billiton.It hasthe capacity to beneficiate 16 million tons of coal per annum, which is mainly exported.The middlings coal (secondary product) will be supplied to Kusile via a proposed Phola-Kusile coal conveyor.The conveyor will be approximately 21km long, depending on the route chosen, and will be designed to transport about 10.4 million tons of coal per annum, over the lifespan of Kusile (Synergistics, 2011).Construction of the conveyor is planned to begin in August 2012, with the delivery of the first coal in October 2013.

3. CONCLUSION

The Kusile and Medupi power plants are expected to increase South Africa's coal production by a great margin (17 million tons per year x 50 years x 2 plants = 1700 million tons; about 10% of South Africa's coal reserves of between 15 and 17 Gt).The development of these mines and the encompassing additional emissions from these coal-fired power plants are, however, a source of a number of major concerns.These concerns cover the impact of coal mining and its ancillary activities on water quality, air quality and the health of people living in this area, as well as air pollution and the contribution to global climate change.These issues contribute to the so-called externality cost of coal-fired power generation and are the topic of the annexures to follow.

4. REFERENCES

Action Sierra Club. n.d. South African Kusile 4 800-MW coalfired power project background information and fact sheet. Available at: http://action.sierraclub.org/site/DocServer/ Kusile_Power_Project_Factsheet.pdf?docID=5541(accessed on 7 July 2011).

African Development Bank (AfDB). 2009. Executive summary of South Africa: environmental impact assessment for the Medupi power plant project of Eskom.Available at: http://www.afdb.org/ fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/ESIA%20Ex%20 Summary%20of%20Medupi%20Coal%20Power%20Plant%20July%201%20revised%20Final-ram-1.pdf(accessed on 7 August 2011).

Department of Energy. 2009. Digest of South African energy statistics 2009. Available at: http://www.energy.gov.za/files/media/explained/2009%20Digest%20PDF%20 version.pdf (accessed on 4 July 2011).

Department of Energy. 2010. South African energy synopsis 2010. Available at: http://www.energy.gov.za/files/media/explained/2010/South_African_Energy_Synopsis_ 2010.pdf (accessed on 13 July 2011).

Department of Mineral Resources. 2010. Operating and developing coal mines in the Republic of South Africa. Available at: http://www.dmr.gov.za/Mineral_Information/New/D2-2010%20%20part%201.pdf(accessed on 13 July 2011).

Department of Water Affairs and Forestry (DWAF). 2004. Internal strategic perspective: Upper Vaal Water Management Area. Report number: P WMA 08/000/00/0304. Available at: http://www.orangesenqurak.org/UserFiles/File/National%20Water%20Departments/DWEA-DWAF/Upper_Vaal_ISP.pdf (accessed on 2September 2011).

Energy Information Administration (US) (EIA). 2010a. Country analysis brief. Available at: http://www.eia.gov/countries/country-data.cfm?fips=SF(accessed on 1July 2011).

Energy Information Administration (US)(EIA). 2010b. South Africa country analysis brief. Available at: http://www.eia.gov/ EMEU/cabs/South_Africa/pdf.pdf(accessed on 5July 2011).

Eskom. 2011. Eskom integrated report 2011. Johannesburg, South Africa: Eskom.

Eskom. n.d. Kusile power station. Available at: http://www.eskom.co.za/c/article/58/kusile-power-station(accessed on 7 July 2011).

Eskom-Medupi power station. n.d. Medupi power station.Available at: http://www.eskom.co.za /c/article/57/medupi-power-station/ (accessed on 7July 2011).

Frontiers Insight. n.d. Kusile power station. Available at: http://www.frontiersinsight.com/ company_page.php?company=14837(accessed on 6 July 2011).

Hartnady, C.J.H. 2010.South Africa's diminishing coal reserves. *South African Journal of Science*,**106(9/10)**,doi: 10.4102/sajs.v106i9/10.369.

Kruger, J. 2008. Construction of Kusile power station gets underway.*PM Forum*. Available at: http://www.pmforum.org/blogs/news/2008/08/construction-of-kusile-power-station.html(accessed on 7 August 2011).

NCC Environmental Services. n.d. Environmental management for Eskom.Available at: http://www.natureconservation.co.za/index.html?id=38(accessed on 7 July 2011).

Ninham Shand. 2007. Proposed coal-fired power station and associated infrastructure in the Witbank area: Final environmental impact report. Report No 4284/401281. Available at: http://recruitment.eskom.co.za/content/WitbankEIR.pdf(accessed on 2 September 2011).

SAinfo. 2009. South Africa needs 40 new coal mines. Available at: http://www.southafrica.info/news/business/832012.htm (accessed on 11 March 2011).

Statistics South Africa. 2010. National accounts: Mineral accounts for South Africa: 1980–2007. Available at: http://www.statssa.gov.za/Publications/D04052/D040522007.pdf(accessed on 13 July 2011).

Synergistics.2011.New Largo Colliery – Draft environmental scoping report.Report number S0403/NLC/SR02. Johannesburg: Synergistics.

Wassung, N. 2010. Water scarcity and electricity generation in South Africa. Part 1: Water use in the coal-to-electricity process. Unpublished master's dissertation. Stellenbosch: University of Stellenbosch.

Wolmarans, M. &Medallie, M. 2011. New Largo Colliery environmental scoping report. Report No. S0403/NL/SR02.

World Coal Association. 2010.Coal facts.Available at: http://www.worldcoal.org/resources/coal-statistics/(accessed 1 September 2011).

ANNEX 1

The health costs of coal-fired power generation in South Africa

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1. INTRODUCTION

The growth and development of any developing nation necessitates the increased use of electricity. With this increased need of and reliance on electricity, questions regarding the potential effects of the additional usage have also begun to surface – in the developing as well as the developed world. Consequently, over the past three decades, there has been a drive towards identifying and quantifying the effects of electricity generation and the impact of a growing electricity sector. While studies have been conducted sporadically over this time period, recent concerns regarding greenhouse gases and their role in climate change have reawakened interest in this field, particularly as a means of comparing different electricity-generating technologies.

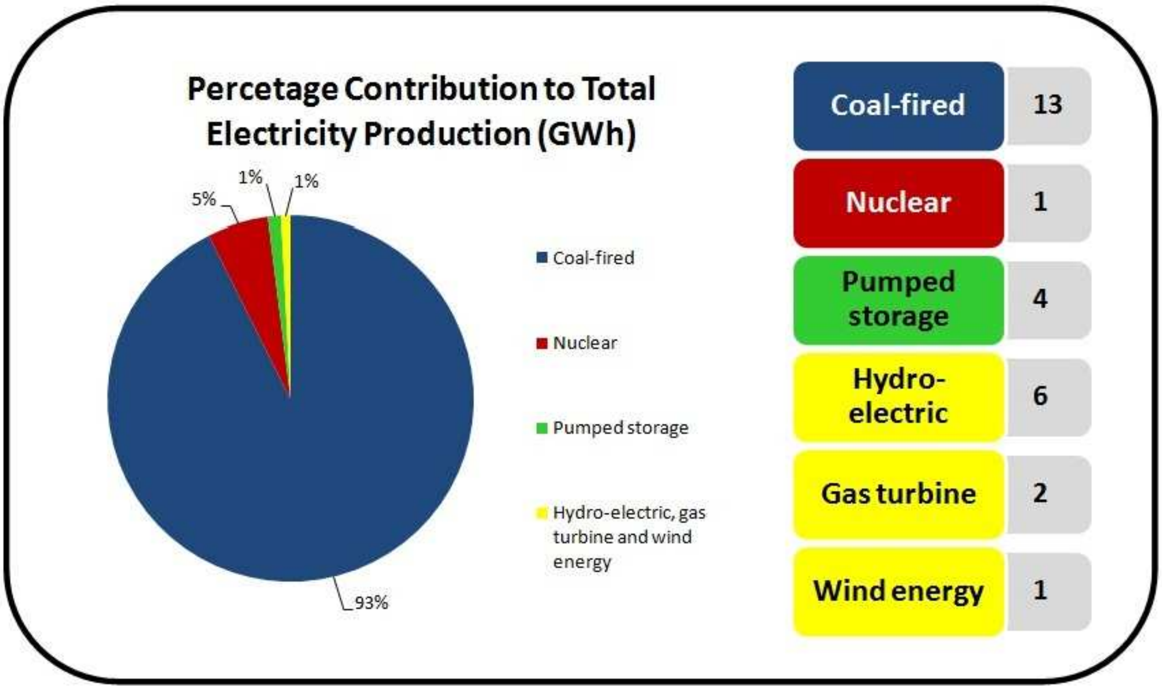
Rapid growth and development in South Africa has called for the significant expansion of the electricity-generating capacity of the nation. Faced with this challenge, the national power utility – Eskom – has commissioned a number of new power plants to be constructed over the next five years. The construction of two new coal-fired power stations, Medupi and Kusile, is underway, despite national and international calls for cleaner technologies to be implemented. This poses a question on the effect of additional coal-fired power stations in South Africa, specifically the health impacts and costs associated with these impacts. By using the impact pathway approach (IPA), this study attempts to quantify the health costs associated with the Kusile power plant, situated in the Highveld region.

This study is divided into five sections, the first of which deals with the background pertaining to electricity generation in South Africa. This is followed by a review of literature on the issues surrounding the externalities related to electricity generation. In the next section, a detailed discussion of the methodology and data requirements is presented, followed by the empirical analysis. The study concludes with a summary of the results and a brief discussion of the limitations of this analysis, as well as possible future extensions to the methodology discussed in this study.

2. BACKGROUND: THE ELECTRICITY SECTOR IN SOUTH AFRICA

Electricity production in South Africa is almost wholly overseen by the national power utility, Eskom. Eskom supplies over 94% of the electricity in the country and generates over 92% of its electricity from coal (Department of Energy, 2010:26). The reliance on coal for electricity generation will increase substantially, particularly because of the construction of two additional 4 800 megawatts (MW) coal-fired power stations – Kusile and Medupi – which is currently underway (Department of Minerals and Energy, 2010). For more detail on the characteristics of the coal sector in South Africa, see Annexure 0. Figure 1 shows Eskom's current electricity generation portfolio. Note that although there are a large number of hydro and gas turbines, these account for less than 1% of total electricity generated in 2010 (Eskom, 2011b). Interestingly, the electricity supplied by the national energy utility accounts for 45% of the electricity used on the African continent. Eskom (2011a) reports that the electricity supplied to other African countries averaged around 13 000 gigawatt hours (GWh) annually over the past five years.

Eskom's reliance on coal-fired electricity generation as a means of supplying South Africa with its growing electricity needs is coupled with an enormous demand for and use of coal. Of the total coal mined locally, 75% is consumed within South Africa and close to 60% is sold directly to the national energy utility (Department of Energy, 2009). The coal is combusted to create heat, which is used to turn purified water into steam. The steam, which at this point is piped to the turbines at extreme temperatures and pressure, propels the blades of the turbines. These turbines are linked to generators, where they spin magnets within wire coils, resulting in electricity generation.



Source:Eskom, 2011b

Figure 1:Percentage contribution of each power generation technology to total national electricity production (left); and the number of plants in South Africa operating on the different generation technologies (right)

The combustion process produces large quantities of gaseous and solid waste (by-products). These by-products are mainly released into the air in the form of gaseous emissions, or disposed of in large ash dumps or sludge and slurry ponds. The gaseous emissions released by the plant into the atmosphere contain a potent mixture of pollutants. Various studies have shown these pollutants to have adverse effects on human health through air (Van Horen, 1996; Dominici *et al*., 2006; Pope III *et al*., 2009) and water (Van Horen, 1996) pollution, effects on biodiversity (Turpie *et al*., 2004; Zvereva *et al*., 2008), effects on buildings (Van Horen, 1996; Charola *et al*., 2007; Schreurs, 2011) and global climate change (Turpie *et al*., 2004). To add fuel to the fire, so to speak, it has been found that burning coal produces one and a half times the CO_2emissions of oil combustion and twice the amount of CO_2emissions produced during the combustion of gas to produce the same amount of energy (Epstein *et al*., 2011). This holds true for many of the other pollutants produced during the combustion process as well.

With regard to solid waste, ash dumps have been found to contribute to air pollution, particularly in the form a particulate matter, when dust (fly ash) from ash dumps is carried into the atmosphere by the wind. Sludge and slurry pools have also been linked to ground water contamination, which has a variety of health and environmental consequences (Epstein *et al.*, 2011). With this in mind, coal-fired power plants in South Africa are a major contributor to atmospheric pollution levels in the country. This also applies to coal-fired power plants in an international context, in their respective countries. Multiple studies – both internationally and locally – have sought to quantify the socioeconomic and environmental damages associated with coal-fired electricity generation. This is the focus of this annex to the report, with specific reference to health costs.

3. LITERATURE REVIEW

The role of electricity generation in the developing world is seen as vital to any nation's development. With an increasing number of power generation options and a drive towards the use of renewable energy sources, concerted efforts are being made to find fuels that are not only sustainable in their use, but also have a decreased negative impact on society in general. In light of this, there has been an influx in the literature concerned with attaching value – monetary or otherwise – to the externalities caused by the electricity generation processes of various types of power plants. Externalities arise when the social and marginal costs of electricity generation, for example, are not the same, causing the market structure to not fully account for the potential social benefits or costs associated with the activities within the process. The individual's welfare is affected without compensation for or reflection in the cost of the goods or services provided by that specific process (Baumol & Oats, 1988; Pearce & Turner, 1990). One such externality relates to the human health impact of these processes and, more importantly, the costs associated with these health impacts. With the majority of South Africa's electricity being generated by coal combustion, the focus of this study is on the externalities associated with coal-fired power plants specifically.

The combustion of coal during the electricity generation process produces a number of by-products (pollutants), including carbon dioxide (CO_2), carbon monoxide (CO), methane (CH_4), suspended particulate matter (PM), oxides of nitrogen (NO_x), sulphur dioxide (SO_2), mercury (Hg), and a wide range of carcinogenic chemicals and heavy metals (Levy*et al.*, 2009). PM refers to the total mass of airborne particles. While the chemical nature of the particulate is important, it varies significantly, prompting most researchers to report and use the diameter of the particles, as this will affect the ability of the PM to penetrate the lungs, where it could potentially have adverse health effects (Norman *et al.*, 2007). Depending on the size, PM is typically classified into one of three fractions: $PM_{2.5}$, PM_{10} and PM > PM_{10}: particles with a diameter of less than 2.5 µm, less than 10µm or greater than 10µm, respectively. In epidemiological studies, $PM_{2.5}$ and PM_{10} are most often selected as exposure metrics, which enable the quantitative assessment of health effects (Norman *et al.*, 2007).

Significant associations have been found between the levels of outdoor air pollution and the number of morbidity and mortality outcomes, with various epidemiological studies showing that these pollutants contribute to the incidence of mortality (cases of bronchitis, asthma, and lung cancer, hospital admissions related to respiratory, cardiac, asthma, coronary obstructive pulmonary disease, and emergency room visits related to asthma) (Norman *et al*., 2007; Levy *et al*., 2009; Epstein *et al*., 2011). While there is a clear link between exposure to this potent mix of pollutants and deteriorating health, attributing the incidence of different epidemiological outcomes to specific pollutants has been criticised, mainly due to strong correlations found between the various pollutants in high concentrations (Sarnat*et al*, 2001). An analysis should therefore not be conducted on individual pollutants. A pollutant-by-pollutant approach could greatly overestimate the health impact of air pollution (Künzli *et al*., 2000).

Another important, yet unexplored, issue is that of the occupational health and safety (OHS) implications of working in an operating electricity-generating facility. The OHS issues related to mining activities, which often form part of the electricity-generating life cycle, are well researched (Van Horen, 1996; Ross & Murray, 2004; Hermanus, 2007), but the analyses have not been extended beyond the mining sector. From the small body of literature available on the topic, clear links have been made between exposure to electromagnetic fields and leukaemia (Theriault *et al.*, 1994). Effects due to exposure to PM and workplace accidents have not been discussed in the literature. For this reason, including the OHS cost due to power plant operations is not yet possible.

Various studies have attempted to attach some monetary value to the health and other costs described above. A number of methods for evaluating the impacts of the externalities associated with coal-fired electricity generation have therefore also been developed. The definitions and effects of the externalities related to electricity generation are mostly standard across the board. It is on the issue of valuation that many of the studies take different directions.

Two fundamental approaches exist when looking at the valuation of externalities, namely, the abatement cost approach and the damage cost approach. The abatement cost approach considers the cost of controlling or justifying damage as a proxy for the actual damages caused. Use of the abatement cost approach is criticised for its assumption that policy-makers have an accurate idea of the damage or avoidance costs (Thopil & Pouris, 2010). This method requires a smaller amount of data than other methods, and is therefore also subject to lower levels of accuracy (Owen, 2004). Internationally, many of the early externality studies employed this method. There have, however, not been any local studies that use this method of valuation. The study by Schuman and Cavanagh (1982) provides a good example of the abatement cost methodology.

A far more popular approach, the damage cost approach, is used both internationally and locally. Here, actual costs and benefits of the externalities are used. Actual damage is quantified as opposed to valuing the damage that could have occurred (Thopil & Pouris, 2010). The damage cost approach is further split into the top-down and bottom-up approaches. The top-down approach uses aggregate data, which makes it impossible to conduct site-specific impact valuations. Some examples of top-down studies are Hohmeyer (1988), Faaij *et al*. (1998), Ottinger *et al*. (1991) and Pearce *et al*. (1992). The second damage cost approach, the bottom-up approach, is concerned with tracking polutants from their initial source and monetising the effects using valuation techniques (Thopil & Pouris, 2010). This is also known as the impact pathway approach (Rowe *et al*., 1994; Oak Ridge National Laboratory & Resources for the Future, 1995; European Commission, 1999; Klaassen & Riahi, 2007; Rafaj & Kypreos, 2007). Sections 3.1 and 3.2 below critically evaluate some of the electricity externality studies conducted both internationally and locally.

3.1. International electricity externality studies

The bulk of literature pertaining to the externalities associated with the electricity sector is focused on the developed world, with large-scale studies conducted in both the United States (Rowe et al., 1994; Oak Ridge National Laboratory & Resources for the Future, 1995) and Europe (Hohmeyer, 1988; Friedrich & Voss, 1993; East Tennessee State University (ETSU), 1995; Ottinger et al., 1991; Pearce *et al*., 1992). Table 1 (Thopil & Pouris, 2010) provides a price-adjusted summary of the findings of some of the most notable international externality studies conducted using different market valuation techniques. In most cases, the external costs are expressed as a range of values. Included in each range is a value for the health cost associated with the combustion of coal for electricity generating purposes. Selected studies are discussed and evaluated in more detail below.

Table 3: Selected external studies of coal-fired electricity using different approaches

Study	Method	Country (region)	External cost (us cents/kWH)
Schuman & Cavanagh, 1982	Abatement cost	United States	0.07–54.64
Hohmeyer, 1988	Top-down damage cost	Germany	12.42–28.33
Ottinger *et al*., 1991	Top-down damage cost	United States	4.04–10.99
Pearce *et al.*, 1992	Top-down damage cost	United Kingdom	3.31–17.89
Faaij *et al*., 1998	Top-down damage cost	The Netherlands	4.93
ORNL & RfF, 1995	Bottom-up damage cost	United States	0.14–0.60
European Comission, 1995	Bottom-up damage cost	UK/Germany	1.21–2.96
Rowe *et al*., 1994	Bottom-up damage cost	United States	0.38
Bhattacharyya, 1997	Bottom-up damage cost	India	1.68
Faaij *et al*., 1998	Bottom-up damage cost	The Netherlands	4.76
European Commission, 1999	Bottom-up damage cost	European Union	1.04–89.80
Maddison, 1999	Bottom-up damage cost	UK/Germany	0.38–0.88
Rafaj & Kypreos, 2007	Bottom-up damage cost	Global average	9.08
Klaassen & Riahi, 2007	Bottom-up and top-down	Global average	4.84

Source:Thopil and Pouris, 2010

Since the abatement cost approach is not favoured in the literature, only the study conducted by Schuman and Cavanagh (1982) will briefly be mentioned. From Table 1, it can be seen that the cost estimates of this study were relatively high compared to those done in later years, using different methods. This is largely due to the many data gaps that the authors had to overcome. It was conducted in the USA and the methodology looked at the cost of installing specific technologies to control for a specific pollutant, with the aim of complying with the federal National Ambient Air Quality Standards. Although the cost estimates are high, Schuman and Cavanagh (1982) provided a foundation on which many subsequent studies are based and which many studies have improved upon, particularly with regards to data.

Among the earliest authors to consider the top-down approach was Hohmeyer (1988). Owing to considerable data limitations, the Hohmeyer study was criticised for its narrow range of external costs and the lack of primary valuation of the externalities considered. Hohmeyer relied on estimates from the literature for impact valuations. It must, however, be pointed out that the estimates calculated by Hohmeyer were highly significant. In subsequent work, Hohmeyer expanded substantially on the externalities considered. The top-down approach did not, however, allow for site-specific evaluation and could not distinguish between the various processes within the electricity-generation cycle.

The use and development of the bottom-up approach originated from a need to address the shortcomings of earlier studies and methodologies. It was now possible to look at specific sites and evaluate the various stages of the fuel cycle. Many also considered the bottom-down approach to be more intuitive, since it closely follows the natural cycle of electricity generation. The Oak Ridge National Laboratory (ORNL) and Resources for the Future (RfF) (1995) study provided some of the earliest work using the bottom-up approach. The focus of the study was the impacts of air pollution on human health and non-environmental damages. The damage cost estimates are low due to the exclusion of many environmental impacts. This highlights the need for an extensive evaluation of the impacts associated with electricity generation. Following the ORNL and RfF study, the RCG/Tellus initiative (Rowe*et al*., 1995) applies the bottom-up approach to the state of New York. While not improving on the results of the ORNL and RfF study, the RCG/Tellus initiative developed a useful computerised modelling tool called EXMOD. This model would later be used by Van Horen (1996) in a South African context.

In order to address differences in the modelling approach and data used in the USA and Europe, the European Commission and the USA Department of Energy launched the EC/US Fuel Cycles Study in 1991 (Thopil & Pouris, 2010:3), later the ExternE program. The earlier ExternE studies (European Commission, 1995 and 1999) made substantial advances in the methodologies associated with the valuation and provided interesting insight into the data and pathway requirements for environmental externality valuation.

3.2. LOCAL ELECTRICITY EXTERNALITY STUDIES

Most of the studies in Table 1 focus on the full life cycle of electricity generation, starting with an evaluation of the fuel procurement activities and ending with the final use of electricity. Work by Spalding-Fecher and Matibe (2003) and Spalding-Fecher (2005) call for a greater focus on the positive externalities (benefits) associated with electrification of households, particularly in developing nations. Few large-scale studies have been conducted in developing countries, with most of these studies focusing solely on the additional social cost of electricity generation. A point of contention is what technique should be adopted when attempting to put a monetary value on these externalities.

On the domestic front, Thopil and Pouris (2010) provide a useful summary of the history and findings of electricity externality analysis in South Africa. Electricity externalities in South Africa were first addressed and quantified by Dutkiewicz and De Villiers (1993) in a study done for the Department of Minerals and Energy (DME). A top-down cost approach was followed by the authors on the entire life cycle of the electricity-generation process. The costs determined in this study fell in the lower range of international studies. It was concluded that adding an evaluation of the aesthetic effects (for example, noise pollution) could improve the analysis.

The study by Van Horen (1996) is considered to be the most extensive electricity externality study to date in South Africa. The emphasis of this study was coal and nuclear power, with the aim of comparing the external costs accompanying the different forms of electricity generation. The study followed a bottom-up damage cost approach. An externality tool, known as EXMOD, developed by the RCG/Tellus study in the state of New York (Rowe *et al*., 1994) was applied. It was concluded that the greatest contribution to the external cost of coal power was the release of greenhouse gasses (GHG) and, to a lesser extent, the health impact of air emissions. Van Horen highlights some areas that require further investigation, including the use of more relevant dose-response functions and the inclusion of the cost of air pollution stemming from ash dumps.

Following the study by Van Horen (1996), Spalding-Fecher and Matibe (2003) expanded on the findings of Van Horen, which included the incorporation of updated power generation infrastructure data and the addition of the external benefits (positive externalities) associated with the electrification of households in South Africa through, for example, the decreased inhalation of smoke from fuel-burning fires indoors. Spalding-Fecher and Matibe (2003) suggest some improvements and extensions to their study. From a health perspective, the authors suggest finding impact pathways of air pollution more suited to a South African context and local dose-response functions.

Table 2 provides a summary of the external cost calculations in the studies by Dutkiewicz and De Villiers (1993), Van Horen (1996) and Spalding-Fecher and Matibe (2003). Once again, while not explicitly stating the health cost associated with coal-fired electricity generation, Table 2 provides a range of values pertaining to the human health externality cost. In their analysis, Thopil and Pouris (2010) also provide inflation-updated values of the cost calculations in each of the South African studies. This will provide a good benchmark for comparing the results of this analysis.

Table 4: Summary of South African coal-generation externality studies adjusted for inflation

Study	Method	Actual externality (year of valuation, c/kWh)	Inflation adjusted externality (2006, c/kWh)
Dutkiewicz & De Villiers, 1993	Top-down damage cost	0.64	3.23
Van Horen, 1996	Bottom-up damage cost	2.23–12.45	6.99–39.07
Spalding-Fecher & Matibe, 2003	Bottom-up damage cost	1.40–9.30	2.73–18.12

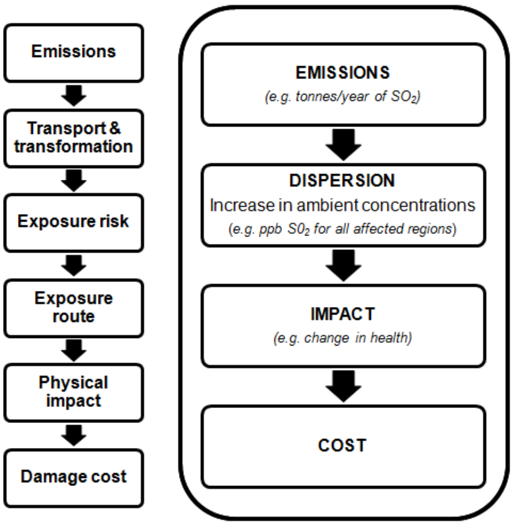
Source:Thopil & Pouris, 2010

4. RESEARCH APPROACH

The quantification of the health impacts caused by coal combustion has been addressed in numerous studies (Van Horen, 1996;Spalding-Fecher & Matibe, 2003;Hainoun *et al.*, 2009). While very few studies use similar models to their predecessors, one common strand is that these models are often based on the impact pathway approach (IPA) (Rowe *et al.*, 1994; European Commission, 1999; Klaassen & Riahi, 2007;Rafaj & Kypreos, 2007). Also known as the bottom-up damage cost approach, the IPA follows pollutants from their initial source, estimates the impacts of these (quantification) and provides monetary estimates of these impacts using valuation techniques (Van Horen, 1996). The sequence followed by the IPA corresponds closely with the real-world sequence of events in electricity generation and their consequences. Van Horen (1996) points out that the use of a reasonably successful IPA-based model will yield much more realistic results than other approaches such as the regulators’ revealed preference approach or top-down damage cost approaches (Hohmeyer, 1988; Pearce *et al.*, 1992; Faaij *et al.*, 1998).

The IPA is generally regarded as the benchmark model for the evaluation of the environmental externalities related to electricity generation (Rowe *et al.*, 1995) and will be used in this study to evaluate and quantify the health externalities related to coal-fired electricity generation. Rowe *et al.* (1995) point out that, although very useful in the analysis of environmental externalities, the IPA has a number of limitations. Firstly, the approach is data-intensive and professional judgements regarding the data to use have to be made. The results can be sensitive to these judgements. Furthermore, the IPA has mostly been applied to areas where data is readily available and where impact pathways are easily established. Van Horen (1996), and Spalding-Fecher and Matibe (2003) both mention the need to revise the impact pathways and dose-response funtions in South Africa. However, Van Horen (1996) points out that although the data requirements for the IPA are extensive, the large body of relevant information availible in South Africa makes an evaluation using the IPA possible.

In order to quantify the health impacts caused by the pollutants released by a coal-fired power plant, information on the four major steps in the IPA is required. Figure 2 provides a summary of the steps in the IPA. Van Horen (1996) summarisesthese steps as follows: determining the quantities of pollution emitted by power stations, tracking the dispersion and ultimate deposition of these pollutants, evaluating the human health response to various exposures (doses) of pollution, and the valuation of increased morbidity and mortality. It is only once monetary values have been linked to morbidity and mortality that the bridge between market cost and social cost can be – at least partially – adressed. More detail on the exact procedure followed in each step will now be provided.



Source:Hainoun, Almoustafa and Aldin (2009)

Figure 2: Calculation steps of Impact Pathway Approach

4.1. Emissions

In this step, details concerning the technical specifications of the power plant are needed, as well as a list of the airborne releases and the quantities released during the combustion process. One could see this step as an identification step, which aims to identify all the technical properties associated with a power plant and the amount of pollutants released using the specific technology.

As a starting point, details regarding the chemical composition of the coal will be needed. In South Africa, low-quality coal is used in the electricity-generation process. Since this quality of coal would not have any other economic use (Van Horen, 1996), it is safe to assume that the ash and sulphur content will vary significantly within a single ton of coal. The coal is alsosourced from different mines, depending on the location of the power plant. This will contribute to low uniformity between the chemical compositions of various batches of coal. The coal typically has a high ash content and low sulphur content (Department of Energy, 2010). Data on the specific composition of the coal used in different power plants would be needed in order to determine the proportions of the various pollutants in the emissions originating from the specific coal used.

Since the exact composition of the emissions cannot be precisely determined, in epidemiological studies $PM_{2.5}$ and PM_{10} are most often used to represent human exposure to air pollution (Norman *et al.*, 2007). For the sake of completeness, however, the analysis will consider nitrates, sulphates, carbon monoxide, $PM_{2.5}$, PM_{10}, radionuclides and heavy metals, such as mercury, when determining the health costs associated with coal-power emissions, provided sufficient emission data is available for these pollutants. There are some indirect externalities related to the GHGs present in emissions, but the effect of climate change on human health (through food security and the like) is a global rather than a regional problem (Hainoun*et al.*, 2009) and therefore falls beyond the scope of this study. However, its impact is covered by the global damage cost of CO_2, which is the focus of Annex 2.

It should be borne in mind that low-quality coal provides very little in terms of usable energy, while it has a proportionately higher pollutant content compared to higher quality coal. Furthermore, since the low-quality coal does not provide much in terms of energy, more is needed to produce the desired amount of electricity. The issue of coal quality inconsistencies is being addressed by the national utility (Eskom, 2011a). Subsequently, Eskom’s electricity-generating activities, specifically those related to coal, contribute substantially to atmospheric pollution levels at regional, national and international level. Eskom, therefore, appears to be making a concerted effort to reduce the prevalence of pollutants in emissions released from its coal-fired power plants. While many of Eskom's coal-fired plants have been fitted with pollutant-reducing technologies, such as bag filters, electro-static precipitators (ESPs) and flue gas conditioning (FGC) or flue gas desulphurisation (FGD) (Eskom, 2011b), plans are in place over the next five financial years to further reduce harmful pollutant-ridden emissions (Eskom, 2011b).

Various pollution management technologies will serve to reduce the pollutant concentration of the gaseous emissions released by electricity-generating facilities, which alters the incidence of health damage caused by the emissions. Details of these technologies and their reduction potential are required for the emission calculations (Wassung, 2010).

4.2. Dispersion

Once it has been established what is being emitted from a coal-fired power station, and how much, the next step is to determine where the pollutants will deposit. The dispersion of pollutants will be determined by the physical emission characteristics of the plant (height of chimney stacks, speed, volume, temperature of gas emissions and ash dump characteristics) and the atmospheric conditions (wind patterns, mixing heights, atmospheric stability) (Van Horen, 1996). Changes in ambient concentrations of the various pollutants are determined using atmospheric dispersion models. The dispersion models are used in a local context (considering an area of up to 50 km away from the source of the emissions). Beyond this distance (at the regional level), the pollutants are depleted from the air through chemical transformation, dry deposition and precipitation. While the Gaussian plume model is often used to estimate the local dispersion of primary pollutants (emitted at the source) that are influenced by stack parameters and weather data, Spalding-Fecher and Matibe (2003) critisise this model for not suiting the unique conditions of the Highveld area. The Gaussian plume model will therefore not be used in this analysis.

4.3. Impact

Once it has been determined where the pollutants will deposit, the health implications of these deposits can be calculated. In other words, an estimation of the physical impacts of exposure to the pollutants is performed. To link the incidence of health damages to pollutant concentrations, exposure response functions (ERFs) are used. ERFs relate the quantity of the pollutant that affects a receptor to the physical impact to that receptor (Rabl, 2011). In general, epidemiological studies report the incidence of illness in terms of relative risk. Calculations are therefore required to acquire the ERFs from the relative risk values (Sakulniyomporn *et al.*, 2011). ERFs in this analysis are assumed to be linear in structure, with no threshold value. The expected cases are therefore given by Sakulniyomporn *et al*. (2011) as follows:

$$ERF\big(r, C(r,Q)\big) = SERF(r) \times C(r,Q) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$SERF = IRR \times Baseline \times F_{POP} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

where $C(r,Q)$ represents the average incremental change in ground-level concentration (μgm^{-3}) at the position of vector *r* and emission rate *Q*.

The slope, S*ERF*, is calculated from equation (2). *IRR* refers to the increment of relative risk (percent/μgm^{-3}), which represents the additional health risk from increases in pollutant concentrations. The baseline rate is the nominal rate of occurrence of the considered disease and F_{POP} denotes the fraction of the population at risk of the said disease, typically based on age-specific groups.

In the environmental externality studies performed in South Africa (Van Horen, 1996; Spalding-Fecher & Matibe, 2003), the authors stress the absence of dose-response functions that have been specifically calculated for the South African population. While no new estimations for South Africa have been done, there has been a growth in the body of literature partaining to the epidemiological consequences of air pollution in the developing world. The selected ERFs rely on published epidemiological studies, which, although scarce for the developing world, have values that correspond well with one another; making it more acceptable to use these values in this study as well (Sakulniyomporn *et al.*, 2011:3476).

Currently available risk factor estimations are not found to be appropriate for the South African context. An adjustment similar to that of Van Horen (1996) – who adjusts the probabilities of the low, central and high estimates of the risk factors – will therefore be used. This will account for the fact that although human responses to specific pollutants will be close to identical, *centeris paribus*, the socioeconomic environment in which an individual finds himself or herself will contribute to and alter epidemeological resonses to different pollutants.

4.4. Cost (valuation)

Monetisation of various health effects provides a useful means for aggregating impacts of a different physical nature and measurement into a single monetary value. Owing to its intangible nature, the idea of valuing health impacts or health damage costs is a difficult one to approach (Sakulniyomporn *et al.*, 2011). Popular measurement techniques include the willingness-to-pay and cost-of-illness approaches (Van Horen, 1996). Under the willingness-to-pay approach, the individual’s preference for avoiding or reducing the risk of death or illness is considered. The cost-of-illness is a more extensive measure in that it considers, among others, health service expenditure and loss of wages or income from reduced working hours caused by illness.

As yet, no unit health costs have been identified for South Africa. If local values cannot be obtained, the procedure followed by Hainoun *et al*. (2009) will be followed. The authors suggest that for nations where costs are not readilly available, the unit costs determined in other nations could be multiplied by the ratio of purchasing power parity gross national product (PPPGNP) between the two nations. This adjustment accounts for the income differences between countries. Although it may not provide the exact health cost, a good estimate of the cost range will be found. This essentially makes use of a benefit transfer approach to find monetary values of mortality and morbidity due to ambient pollution levels. The calculation required for this procedure is as follows:

$$U_{V\,(SA)} = U_{V\,(Reference\ country)} \times \left(\frac{PPP_{SA}}{PPP_{Reference\ country}}\right)^{\gamma} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(3)$$

where U_V refers to unitary value in a specific country, PPP is the gross national income (GNI) per capita, adjusted for purchasing power parity, and γ represents the income elasticity.

Ethical debates surrounding the valuing of health damage cost are well documented, with the main point being the failure of most measures to account for income distributions and the aggravated health effects and costs on low-income individuals compared with high-income individuals. There is also a growing call for cost to be expressed along an income distribution to better show the equity implications. This will require income data for the affected populations, which can be used to construct and calculate an income-weighted health damage cost. Lastly, a monetary value of the total impact is found by multiplying the number of cases by the unit cost of the specific case (for example, ZAR per asthma attack) and summing over the range of chosen health outcomes. By assigning a monetary value to the health costs, one is better able to compare the effects of different health impacts, which often have different units.

5. DATA AND EMPIRICAL ANALYSIS

In order for the IPA to be followed, a large quantity of data is required. The data is both quantitative and qualitative, and draws from a number of scientific and social fields. It is because of the wealth of data needed to conduct this type of analysis that many developing world studies do not exist. Table 3 provides a descriptive summary of the data requirements for the IPA. The data and their sources will be addressed in the calculation steps of this section.

Due to the detailed scientific knowledge required to construct and estimate the pollution dispersion model, it was decided to make use of dispersion calculations published in the environmental impact assessment (EIA) conducted for Kusile prior to the construction phase of the plant (Ninham Shand, 2007). Similarly, existing ERFs have been sourced from the literature. This is in line with the data transfer method (or benefit transfer method), which makes use of existing data calculations to perform calculations in a new, often related, study. The procedure for the data transfer method, firstly, requires the researcher to identify existing studies or values that will be transferred into the current study. Secondly, the appropriateness of the existing values is evaluated to ensure that the information or values are suitable for the new study. This will require the characteristics of the populations or situations to be very similar. Thirdly, the quality of the studies that are to be transferred must be assessed, since this will affect the quality of the current study. Lastly, the values may be adjusted to better suit the context of the current study. This may require additional information or research (Boyle & Bergstrom, 1992). There are, however, some drawbacks to this method. King and Mazzotta (2000) caution the researcher not to extrapolate beyond the scope of the transfer studies and to do a thorough analysis of the quality and relevance of the transfer studies. Use of the data transfer method is common in the developing world where data limitations would otherwise result in many analyses not being done (Sakulniyomporn *et al.*, 2011).

Table 5: Descriptive summary of the data required for the IPA

Data	**Specifications**	
Plant	Chimney (stack)	Number Height (m) Diameter (m) Gas temperature (ºK) Exit velocity (m/s)
	Fly ash	Surface area (m^2) Amount (tonnes) Wind speed and direction
	Location	Rural/urban Latitude Longitude
Emission	$PM_{2.5}$	Emission rate (tonnes per annum)
	PM_{10}	
	SO_2	
	NO_X	
	CO	
	Radionuclides	
	Heavy metals (notably, Hg)	
Population	Regional population density	
	Local population density	
	Household/individual income	
Historical metrological	Wind speed (m/s)	
	Temperature (ºK)	
	Measurement height (m)	
Exposure response functions	Sourced from various toxicological and epidemiological studies or previously calculated incident rates (risk factors)	

Source: Hainoun*et al.*, 2009

5.1. Technical and emmission characteristics

Since the Kusile plant is yet to be completed, emission data and the like have to be estimated or based on the experience of existing coal-fired power stations. For the purpose of this study, the Kendal power station, in close proximity to Kusile, will be used as the preferred source for unavailable data. The main operational features and specifications of Kendal, as well as the proposed specifications of Kusile, are summarised in Table 4.

Table 6:Technical specifications for Kendal and Kusile power plants

Name	Province	Capacity	Cooling system	Pollution control technology	Year
Kendal	Mpumalanga	4 116 MW	Indirect dry	ESP [2]	1993
Kusile	Mpumalanga	4 800 MW [1]	Direct dry	ESP [2], FGD [3]	2014–18

[1] Actual capacity of Kusile

[2] Electrostatic precipitator for controlling dust

[3] Flue gas desulphurisation for controlling SO_2

Source: Wassung, 2010

In order to determine the dispersion and effect of the pollutants, information regarding the stack properties of Kusile is needed. The EIA provides proposed information on the stack parameters of Kusile, as well as the stack parameters of Kendal, for comparative purposes. These parameters are summarised in Table 5. Note that the three stack height configurations are considered for Kusile.

Table 7: Stack parameters

Name	Capacity	Number of stacks	Stack height (m)	Diameter (m)	Exit velocity (m/s)	Temperature (ºK)
Kendal	4 116 MW	2	275	13.51	24.08	399
Kusile	5 400 MW [1]	2	150, 220, or 300 [2]	12.82	26.00	403

[1] Proposed capacity used in EIA calculations

[2] Three stack height scenarios were considered in EIA calculations

Source: Thomas and Scorgie (2006:4.7,5.3)

From Tables 4 and 5, it can be seen that two different capacity values are used for Kusile. This reflects the difference between the actual capacity (4 800MW) and the calculation capacity (5 400 MW), as used in the EIA. This discrepancy is easily addressed, particularly with regards to the total emissions of the plant. Since the volume of emissions is linearly related to the capacity of the plant, multiplying the emission data with the ratio of the two capacities (4800/5400=0.8889) will give the actual emission data for Kusile. These emissions will contribute to the overall ambient pollution levels in the area and therefore have to be included in the dispersion model. The emission volumes for Kusile are given in Table 6.

Table 8:Emissions (in tonnes per annum) for current operating conditions for 2003

Power station	Capacity	SO_2	NO_X	NO	NO_2	Particulates
Kendal (2003)	4 116 MW	321441	NQ [5]	73282	2293	3495
Kendal (proposed 2009)	4 116 MW	336084	NQ [5]	76620	2398	3654
Kusile (proposed: EIA) [1]	5 400 MW [3]	364082	87361	55835	1747	7947
Kusile (proposed: actual) [2]	4 800 MW [4]	323628	77654	49631	1553	7064

[1] Assuming 0% control efficiency for SO_2

[2] Figures determined through calculation: [Kusile (proposed: EIA) values]*(4800/5 400)

[3] Proposed capacity used in EIA calculations

[4] Actual capacity of Kusile

[5] Not quantified

Source: Thomas and Scorgie, 2006

Kendal and Kusile are, therefore, similar in most regards. One major difference relates to the cooling system employed in the plant. While the difference in operation is important, it has little effect on the emission profiles of the two plants. While both plants use ESPs for dust control, Kusile has an additional abatement technology in the form of a FGD system. The SO_2 emission volumes given for Kusile are estimated volumes given the absence of SO_2 abatement technologies. This is important for comparative purposes, but will not be used in the calculation of the health impacts, since FGD technology will be used in the Kusile plant. The FGD system has been incorporated into the EIA calculations with the assumption that it is 90% effective in reducing SO_2 emissions. This is consistent with the findings of the air quality impact assessment (AQIA) (Ninham Shand, 2007). Since there are no significant differences in the technical specifications of the two plants, it is possible to use emission and technical data for Kendal as proxies for the currently non-existent Kusile plant.

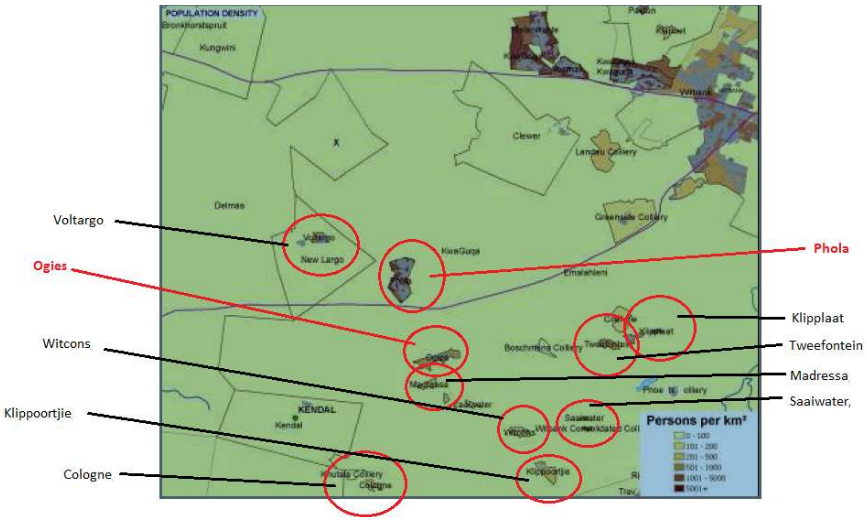
5.2. Dispersion and the modelling approach

Modelling the dispersion patterns of the air (and the pollutant contained in the air) around Kusile requires sophisticated dispersion software such as the CALMET/CALLPUFF modelling system. Although not used in this analysis, CALMET/CALLPUFF was used in the AQIA report (Thomas

&Scorgie, 2006), as found in the EIA (Ninham Shand, 2007). The software consists of three components (Scire *et al.*, 2000): CALMET, CALPUFF and CALPOST. CALMET is a diagnostic meteorological model, which generates hourly wind and temperature data. The data is used by CALPUFF, a multi-layer, multi-species, non-steady-state Lagrangian Gaussian puff model, to model movement and variation in pollutant levels (dispersion). Lastly, CALPOST summarises the results of the simulation (Sakulniyomporn *et al.*, 2011). The dispersion results from the AQIA report are used to identify the at-risk communities surrounding the site of Kusile.

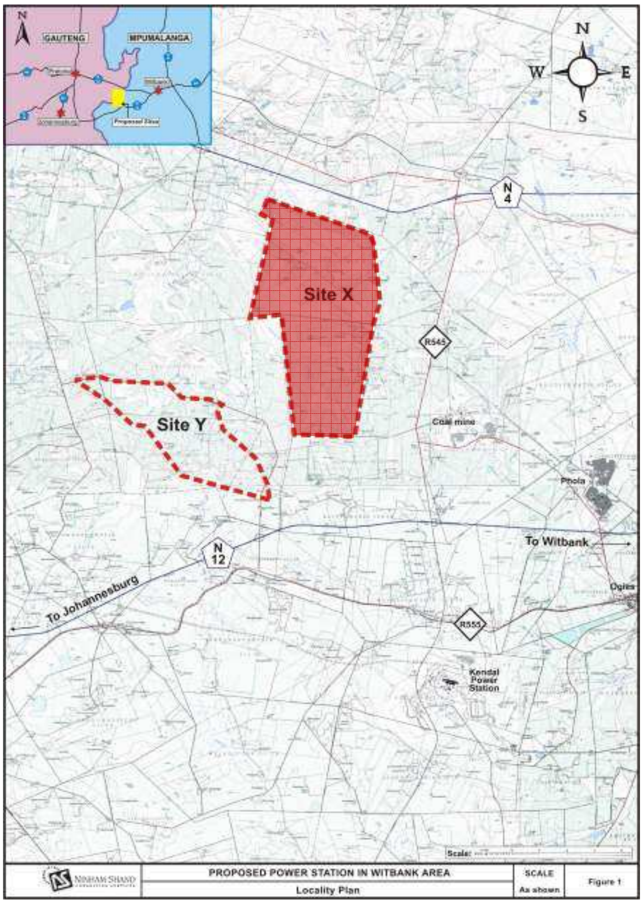
5.2.1. Dispersion area

From the AQIA contained in the EIA, a number of residential areas have been identified in close proximity to Kusile. The towns of Phola and Ogies are located 10 to 18 km east of the site, while numerous smaller areas (including, but not limited to Voltargo, Cologne, Klippoortjie, Madressa, Witcons, Saaiwater, Tweefontein and Klipplaat) are also in close proximity to the power plant (Figure 3). The largest residential area within 30 km of the Kusile site is Emalahleni (Witbank) (Ninham Shand, 2007). The EIA considered numerous sites – sites X and Y (Figure 4) emerging as the most preferred – with site X finally being selected as the operational site. Two ambient air quality monitoring stations are operated by Eskom in the region: Kendal 2 and Kendal B, which are situated within the zone of maximum ground level concentration (GLC) and in close proximity to site X respectively (Ninham Shand, 2007). The zone of maximum GLC has been defined as the area within a radius of 25 km of the power plant.



Source: Thomas and Scorgie, 2006

Figure 3:Communities within close proximity of the Kusile power plant and their respective population densities



Source: Ninham Shand, 2007

Figure 4:Location of the Kusile power plant (site X)

5.2.2. Dose

In order to assess the potential impacts of an additional electricity generation facility, it is important to identify existing sources of air pollution in the same region and to establish a baseline measure of the ambient pollution levels in the region. The cumulative effect of these exiting sources is first modelled, followed by a second simulation, including the power station. One is then able to ascertain how much Kusile will contribute to the levels of atmospheric pollution and to determine the magnitude of the response to the additional pollutants. Ninham Shand (2007) identified the following sources that are currently contributing to abient air pollution concentrations in the region:

- Emissions from various Eskom power stations
- Stack, vent and fugitive emissions from industrial operations
- Fugitive emissions from mining operations, including mechanically generated dust emissions and gaseous emissions from blasting and spontaneous combustion of discard coal dumps
- Vehicle entrainment of dust from paved and unpaved roads

- Vehicle tailpipe emissions
- Household fuel combustion (particularly the use of coal)
- Biomass burning (veld fires)
- Various other fugitive dust sources, for example, agricultural activities and wind erosion of open areas

For the purpose of this study, only the costs associated with SO_2, NO_2 and PM_{10} are considered, since these pollutants are the major contributors to pollution-related health issues. Particles with a diameter smaller than 2.5 µm ($PM_{2,5}$) are included in the broader PM_{10} definition and are therefore not included in the cost analysis to avoid doublecounting of pollutants. In order to assess whether pollutant concentrations exceed health thresholds, it is important to define limits or standards for the various pollutants. Various such standards exist in both the national and international context. In assessing compliance with the various air quality standards, Ninham Shand (2007) highlights the fact that air quality guidelines vary significantly. South African standards are under debate, with proposals being made to align local standards with international best practice. Table 7 provides a brief summary of the various local and international air quality standards.

Table 9:Air quality limits used to assess current and future pollution-level compliance (human health-related limits only)

Authority	**Annual average concentrations (µg/m^3)**		
	SO_2	**NO_2**	**PM_{10}**
SA standards (Air Quality Act)	50	94	60
RSA SANS limits	50	40	30
Australian standards	52	56	-
European Community	20 [1]	40 [3]	20
World Bank: General Environmental Guidelines	50	-	50
World Bank: Thermal Power Guidelines	80 [2]	100 [2]	50
United Kingdom	20	40	40
United States Environmental Protection Agency	80	100	50
World Health Organisation)	50	40	- [4]

[1] Limit to protect health and ecosystems

[2] Ambient air quality in thermal power plants

[3] Not to be exceeded more than 18 times a year

[4] WHO issues linear dose-response relationships for PM_{10} concentrations and various health endpoints (no specific guideline given)

Source: Thomas and Scorgie, 2006

Table 8 summarises the exceedence values for SO_2, NO_2 and PM_{10}. Although hourly, daily and annual average health standard exceedence data is available, only the annual average exceedence findings are shown in the table, since the cumulative annual health effect and cost of air pollution are considered. Although there are numerous other pollutants, such as CO_2, radionuclides and heavy metals, which could contribute to the health impact of air pollution. The set of common health impacts that were identified and used in this study requires the use of only a selection of pollutants (SO_2, NO_2 and PM_{10}). This, however, does not deny the epidemiological importance of other pollutants.

Data availability and quality necessitates the use of only the most common health impacts associated with air pollution (see section 5.3.2) and their corresponding pollutants. The base case (not taking Kusile into account), as well as three scenarios based on three different stack heights, is considered. Scenario A2 bases its calculations on a stack height of 150m, while scenarios C2 and E2 used stack heights of 220m and 300m, respectively.

Furthermore, only scenarios where abatement technologies have been included are used in this analysis, as Eskom has stated that the Kusile power plant will also make use of FGD technology. This is in line with the power utility's commitment to reduce its overall emissions profile (Eskom, 2011b). Since there are numerous local and international air quality studies, Table 8 also includes the most and least strict standards, in addition to the standard decided on in the EIA.

Table 10:Exceedence results for Kusile

Case	**Location**	**Annual average concentrations (µg/m^3)**					
		SO_2		**NO_2**		**PM_{10}**	
		5 400MW	**4 800MW**	**5 400MW**	**4 800MW**	**5 400MW**	**4 800MW**
Base case	GLC Max [1]	44	44	8	8	83	83
	Phola	29	29	5.9	5.9	5.8	5.8
Scenario A2 (150m)	GLC Max [1]	51	50.2	10	9.8	84	83.9
	Phola	36	35.2	9.9	9.5	28	25.5
Scenario C2 (220m)	GLC Max [1]	51	50.2	10	9.8	84	83.9
	Phola	36	35.2	9.4	9.0	30	27.3
Scenario E2 (300m)	GLC Max [1]	50	49.3	10	9.8	84	83.9
	Phola	35	34.3	9	8.7	28	25.5

Case	**Location**	**Annual average concentrations (µg/m^3)**					
		SO_2		**NO_2**		**PM_{10}**	
		5 400MW	**4 800MW**	**5 400MW**	**4 800MW**	**5 400MW**	**4 800MW**
Air quality standards							
Minimum	Value	80		100		60	
	Description	US EPA, WB, TPG		US EPA		SA standards	
Maximum	Value	20		40		20	
	Description	UK, EC		UK		EC	
EIA	Value	50		40		40	
	Description	SA		SA, WHO, EC, UK		SANS, EC, UK	

[1] Within a 25 km radius of the Kusile power plant

Source:Thomas and Scorgie, 2006

To establish which scenarios and which pollutant species exceed the given air quality standards, the difference between the annual average concentrations and the quality limits are calculated. These values are reported in Table 9, with the positive values indicating that the ambient air concentration of the relevant pollutant exceeds the air quality limits. These positive values will be used to find the number of people affected by various pollution-related illnesses, by making use of incident rates, as sourced from the literature (Sakulniyomporn *et al.*, 2011).

Table 11:Exceedence of annual average pollutant concentrations

Case	**Location**	**Annual average concentrations (µg/m^3)**								
		SO_2			**NO_2**			**PM_{10}**		
		Min	**Max**	**EIA**	**Min**	**Max**	**EIA**	**Min**	**Max**	**EIA**
Base case	GLC max [1]	-36	**24**	-6	-92	-32	-32	**23**	**63**	**43**
	Phola	-51	**9**	-21	-94	-34	-34	-54	-14	-34
Scenario A2 (150m)	GLC max [1]	-30	**30**	**0**	-90	-30	-30	**24**	**64**	**44**
	Phola	-45	**15**	-15	-91	-31	-31	-34	**6**	-14
Scenario C2 (220m)	GLC max [1]	-30	**30**	**0**	-90	-30	-30	**24**	**64**	**44**
	Phola	-45	**15**	-15	-91	-31	-31	-33	**7**	-13
Scenario E2 (300m)	GLC max [1]	-31	**29**	-1	-90	-30	-30	**24**	**64**	**44**
	Phola	-46	**14**	-16	-91	-31	-31	-34	**6**	-14

[1] Within a 25 km radius of the Kusile power plant

The baseline SO_2 calculation shows that, given the most strict air quality standards, the concentration of sulphur dioxide is non-compliant, even without the contribution of Kusile. The FGD technology does little in terms of decreasing the overall future baseline exceedance, specifically because the current baseline scenario –excluding Kusile – exceeds air quality standards (Ninham Shand, 2007). The exceedence occurs at Phola and the GLC maximum, which indicates a significant risk to the residential population of Phola, in particular. The predicted NO_2 concentration exceeds none of the criteria. In general, it can be seen that the non-exceedance NO_2 values for the three scenarios compare very closely to those of the baseline values, suggesting that existing sources of nitrogen dioxide are the main contributors to ambient levels of the gas. It would seem that particulate matter has a more prominent effect. Air quality limits in the GLC zone for all four scenarios are exceeded on every level. Furthermore, all three Kusile scenarios exceed the most stringent air quality limit at Phola as well. Therefore, PM_{10} could contribute significantly to the incidence of disease (illness) related to this pollutant. Table 10 shows the additional pollutants contributed by Kusile above the baseline scenario. Only the actual capacity (4 800MW) emissions are considered.

Table 12:Additional pollutants added by Kusile to the baseline conditions

Case	Location	Annual average concentrations (µg/m^3)		
		SO_2	NO_2	PM_{10}
Scenario A2 (150m)	GLC maximum	6	2	1
	Phola	6	4	20
Scenario C2 (220m)	GLC maximum	6	2	1
	Phola	6	3	22
Scenario E2 (300m)	GLC maximum	5	2	1
	Phola	5	3	20

[1] Negative values expressed as zero additional contribution by Kusile

Finally, Ninham Shand (2007) makes some additional health conclusions. The elevated SO_2 concentrationsidentified in the study have significant potential health risks, particularly when coupled with elevated levels of particulate in the air. Although there is a potentially high risk in the Phola residential area, there were infrequent exceedances of the reference level, hence, the health effects will be dependent on whether the individuals exposed to the pollution are sensitive to the impacts of SO_2 at the time of exceedance. Nonetheless, the SO_2 levels are cause for concern. The potential health impacts for various heavy metals were also considered in the EIA. It was found that the cancer risk due to heavy metal inhalation ranged between 1:45million and 1:10million (Ninham Shand, 2007). For mercury (Hg) specifically, the highest annual, highest daily and annual average concentrations did not exceed even the most stringent of international health standards (Ninham Shand, 2007). It is therefore concluded that the health cost associated with heavy metal exposure will not significantly contribute to the overall health cost to society of coal-fired electricity generation by the Kusile plant.

5.2.3. Population within the dispersion area

The largest residential populations within the dispersion area considered are found at Phola and Ogies, although only Phola will be considered on an individual level, since it represents the most significant residential area – both in terms of population density and exposure potential – within the impact area of Kusile. Given its location and the wind dispersion results, Phola not only represents the most densely populated area, but also gives a good estimate of the effect on the most atrisk population within the impact boundary. Detailed population data on the impact area could not be found and hence calculations had to be made on the aggregate data for the Emalahleni local municipality, where Kusile is situated. Mpumalanga Provincial Government (MPG) (2011) reports that the Emalahleni local municipality covers an area of 2 677.67 km^2, with the total population estimated to be 299 206. Since data for Phola is unavailable, the study relies on the population density reported by the EIA. This value is given as between 1 000 and 5 000 people per km^2 for the town as a whole. For calculation purposes, a high and low value of 5 000 people per km^2 and 1 000 people per km^2, respectively, will be used. The resulting cost calculations for Phola will therefore represent a high and low estimate of the health impact. The Phola residential area covers approximately 6 km^2, as estimated from a map of the area.

The zone of maximum GLC covers an area within a 25 km radius of the plant. Both Phola and Ogies fall within this area. Therefore, any cost estimation of the zone of maximum GLC will represent the total cost of the impact area. In order to calculate the population within this area, the average population density of the Emalahleni local municipality was calculated (112 persons per km^2), which compares well with the value of 100 persons per km^2 given in the AQIA for the majority of the maximum GLC zone (Thomas & Scorgie, 2006). Multiplying the average population density with the total area covered by the zone of maximum GLC gives the total affected population at 219 403.

5.3. Impact analysis

This section focuses on the additional number of human health effects due to exposure to ambient pollutants. The dose-response criteria for a number of common pollution-related ailments are considered, as well as the social costs associated with these health issues.

5.3.1. Selection of ERFs

While epidemiological and toxicological studies for South Africa are scarce, the data transfer method was once again employed to find appropriate values for the incidence rates of various illnesses. These values are provided by Sakulniyomporn *et al*. (2011), based on a study conducted in Thailand. The study considers a number of developing and developed world epidemiological exposure response function (ERFs) studies and calculates the incidence rate accordingly.

5.3.2. Dose-response

The scope of health issues related to air pollution is a broad one, resulting in a very large number of health concerns linked to air pollution. Since it is not feasible to include every single ailment, only the following health issues are considered (Sakulniyomporn *et al*., 2011):

- 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
- Days with acute respiratory symptoms

The response of populations to various pollutants is well documented for the developed world. In a developing context, however, fewer studies have attempted to quantify these responses. Response to various pollutants is measured in terms of incident rates or risk factors (Van Horen, 1996; Sakulniyomporn *et al*., 2011), where, for example, if the risk factor for mortality due to inhalation of specimen X is 3.3×10^{-6}, this means that one person in 3.3×10^{-6} will die for every 1 μgm^{-3} increase in the concentration of specimen X. Table 11 provides a summary of the incident rates used in this study. The values found by Sakulniyomporn *et al*. (2011) are used to address the concerns raised by Van Horen (1996) and Spalding-Fecher and Matibe (2003) regarding the ERFs used in their studies.

Table 13: Summary of incident rates for selected health issues

Health endpoint	Pollutant species	Incident rate (case/person year µg/m^3)		
		Central	**Low**	**High**
Premature mortality	PM_{10}	6.882E-06	4.515 E-06	9.304 E-06
	SO_2	8.864 E-06	4.404 E-07	1.740 E-05
Morbidity				
Chronic bronchitis in adults (≥25 years)	PM_{10}	1.411 E-05	1.296 E-06	2.794 E-05
Respiratory hospital admission	PM_{10}	4.543 E-05	2.271 E-05	6.814 E-05
	SO_2	1.262 E-05	NQ[1]	2.271 E-05
	NO_X as NO_2	NQ[1]	NQ[1]	2.019 E-05
Cardiovascular hospital admissions	PM_{10}	4.717 E-05	2.621 E-05	6.814 E-05
Emergency room visits	PM_{10}	4.112 E-05	1.121 E-05	7.476 E-05
Acute bronchitis in children (<25 years)	PM_{10}	4.406 E-05	1.944 E-05	7.229 E-05
Asthma attacks in children (<15 years)	PM_{10}	5.984 E-04	3.672 E-04	8.432 E-04
Asthma attacks in adults (≥15 years)		8.742 E-05	4.259 E-05	1.323 E-04
Restricted activity days in children (≥18 years)	PM_{10}	5.800 E-02	2.900 E-02	9.100 E-02
Days with acute respiratory symptoms	PM_{10}	3.000 E-01	2.200 E-01	7.400 E-01

[1] Not quantified

Source: Sakulniyomporn *et al.*, 2011

5.3.3. Health damage cost

In order to calculate the health cost associated with coal-fired electricity generation at Kusile, monetary values must be linked to each of the identified health concerns. Once this has been done, an aggregate health cost can be found, which will be expressed in terms of cents per kWh (c/kWh). Presently, no cost values have been determined for South Africa, therefore prompting the use of the benefit transfer technique. Calculations of the U_V, the unitary value, for each disease will be calculated using values determined in the United States (US), which has a wealth of research on the topic.

From equation (3), the purchasing power parity (PPP) values for South Africa and the USA are required. The 2010 PPP values are used in this study. These values are published by the World Bank and are expressed in terms of gross national income (GNI) based on PPP, in other words, GNI converted to international dollars using purchasing power parity rates. The PPP values are given as \$10 280 and \$47 020 for South Africa and the USA respectively. The ZAR/US\$ exchange rate for 2010 is quoted as the middle rate for 2010, as provided by the South African Reserve Bank (SARB). The SARB gives this value as R7.3222/1US\$. For the purpose of simplicity, the income elasticity (γ) is given a value of 1. Mortality and morbidity costs given in Sakulniyomporn *et al.* (2011) are converted back to their original 2005 US$ values, updated to 2010 US$ values and used to calculate the unitary cost estimations for South Africa. The unitary costs for mortality and morbidity are given in Table 12.

Table 14: The unitary costs of health impacts

Category	Health endpoint	SA cost per case (2010 ZAR)	Type of estimation
Mortality	Premature mortality	15 630 356.64	Willingness-to-pay
Morbidity	Chronic bronchitis in adults (≥25 years)	687 051.78	Willingness-to-pay
	Respiratory hospital admission	37 973.66	Cost-of-illness
	Cardiovascular hospital admissions	4 065.68	Cost-of-illness
	Emergency room visits	1 410.48	Cost-of-illness
	Acute bronchitis in children (<25 years)	895.11	Cost-of-illness
	Asthma attacks in children (<15 years)	99.48	Cost-of-illness
	Asthma attacks in adults (≥15 years)	105.70	Willingness-to-pay
	Restricted activity days in children (≥18 years)	168.14	Willingness-to-pay/ Cost-of-illness
	Days with acute respiratory symptoms	31.61	Willingness-to-pay

Source: Sakulniyomporn *et al.*, 2011

5.4. Final external cost calculation

The incident rates give an indication of the number of people that will be affected, given the additional ambient pollutants. Therefore, using the incident rates, population data and additional pollutant contributions from Kusile, the total number of affected people (additional disorders) is determined for each health impact. Equation (4) shows the calculation procedure (Vrhovcak *et al.*, 2005):

$$Additional\ disorders = conc \times density \times area \times \exp\ \_res \text{……………………………(4)}$$

where *conc* refers to the concentration of pollutants, *density* and *area* refer to the population density and surface area (m^2) of the area in question, and *exp_res* refers to the incident rates. Cost calculations will only be done using the central estimates of the incident rates. Table A1 (see Appendix A) provides a summary of the number of affected people in each of the stack scenarios.

The first procedure in the calculation of the total final health cost due to coal-fired electricity generation is found by multiplying the cost for each impact by the corresponding number of cases. Summing the costs will give an estimate of the total health cost associated with operations at Kusile for each of the three stack scenarios. Table A2 (see Appendix A) presents these final cost estimates.

As Kusile's net electricity sent out is estimated at 32.3TWh, the unit externality cost, expressed as R/kWh, is estimated and provided in Table 15. Based on the above information, the health-related externality cost of Kusile is estimated to be approximately 1c/kWh, which is marginally lower than the estimates of the other studies as depicted in Table 2, mainly because of the fact that this study was confined to the GLC, which has been defined as the area within a radius of 25 km of the power plant, which is relatively low in population density, whereas the other studies have considered the impact on the entire country. This health cost represents an additional cost over and above the current electricity price of 41c/kWh. Note that greater stack height corresponds with greater dispersion of pollutants. This is normally associated with more people being exposed and a higher cost (as the increase from A2 to C2 testifies). Given the height of E2, however, some of its emission load falls outside the GLC and hence the reduction in value.

Table 15:The total annual health cost of Kusile

Cost	Central exceedance estimate								
	Scenario A2 (150 m)			Scenario C2 (220 m)			Scenario E2 (300 m)		
	GLC	Phola (low)	Phola (high)	GLC	Phola (low)	Phola (high)	GLC	Phola (low)	Phola (high)
Total (R '000)	211 235	21 635	108 173	213 314	23 298	116 488	182 827	20 801	104 003
R/kWh	0.007	0.001	0.003	0.007	0.001	0.004	0.006	0.001	0.003

6. DISCUSSION AND CONCLUSION

While a large number of health impacts have been included, the list is by no means exhaustive. A review of epidemiological literature, however, suggests that the list presented in this study covers a large proportion of the pollution-related cases of disease, with the exception of cancer. Research on the relationship and causality between ambient pollution levels and the prevalence of certain cancers have yet to give conclusive results and can therefore not be included in the analysis. The considerable data limitations on Kusile prompted the use of benefit transfer techniques in order to find estimates of the costs. Once the plant is operational, the proxy data can be replaced with actual data to give a more accurate account of the health damage cost approach

With any study making use of the data transfer method, there is the concern that the original data is not of good quality, or that it may be biased in some way or another (Boyle & Bergstrom, 1992). With the use of data from an EIA, there is heightened concern, specifically since the EIA is commissioned by a party or parties with certain interest in the project being assessed. Since the EIA is conducted for proposed projects, a quantitative assessment of the quality of the study cannot be done. Therefore, it is common practice for the EIA to be subjected to extensive rounds of public and private input, as well as an independent review of the document. The draft EIA conducted for Kusile was subjected to public scrutiny (Ninham Shand, 2007) and, regarding air quality, only the potential effect on poultry in the region was questioned. This was addressed by the final EIA. Furthermore, an independent review of the IEA done by Mark Wood Consultants (2007) concluded that "…the specialist studies [including the AQIA] are generally well prepared, are clear and provide the necessary basis for an objective evaluation of the overall impact of the project." Lastly, no major issues were identified in the AQIA documentation. While this does not provide enough justification to classify the EIA as wholly objective and reliable, the EIA numbers are the only numbers available, which neccesitated the use of these numbers in this study. Any errors or ommissions in the EIA data will therefore be carried over into this analysis.

This analysis considers Kusile and its health impacts due to air pollution in isolation. Consequently, issues of occupational health and safety (OHS) related to the operation of Kusile are not considered. While the issue of OHS has received much attention in the mining sector, the specific issues related to OHS in an electricity-generating facility have not been addressed in the literature. Therefore, while it is important to take cognisance of such issues, they are not analysed in this study. While fly ash from ash dumps and coal storage piles contribute significantly to the ambient particulate matter concentrations, nothing is known about the characteristics of these ash dumps. For this reason, the health cost relating specifically to ash dumps cannot be included here. Exclusion of this specific cost possibly results in a lower health cost estimate for the Kusile plant. Notwithstanding the exclusions and shortcomings of this analysis, the externality costs related to health is approximately 0.7c/kWh.

7. APPENDIX

Table A1:Number of people affected per health impact

Health Endpoint	Pollutant species	Number of people affected								
		Central exceedence estimate								
		Scenario A2 (150 m)			Scenario C2 (220 m)			Scenario E2 (300 m)		
		GLC	Phola (low)	Phola (high)	GLC	Phola (low)	Phola (high)	GLC	Phola (low)	Phola (high)
Premature mortality	PM$_{10}$	2	1	4	2	1	5	2	1	4
	SO$_2$	12	0	2	12	0	2	10	0	1
Morbidity										
Chronic bronchitis in adults (≥25 years)	PM$_{10}$	3	2	8	3	2	9	3	2	8
Respiratory hospital admission	PM$_{10}$	10	5	27	10	6	30	10	5	27
	SO$_2$	17	0	2	17	0	2	14	0	2
	NO$_X$ as NO$_2$	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cardiovascular hospital admissions	PM$_{10}$	10	6	28	10	6	31	10	6	28
Emergency room visits	PM$_{10}$	9	5	25	9	5	27	9	5	25
Acute bronchitis in children (<25 years)	PM$_{10}$	10	5	26	10	6	29	10	5	26
Asthma attacks in children (<15 years)	PM$_{10}$	131	72	359	131	79	395	131	72	359
Asthma attacks in adults (≥15 years)	PM$_{10}$	19	10	52	19	12	58	19	10	52
Restricted activity days in children (≥18 years)	PM$_{10}$	12719	6960	34800	12719	7656	38280	12719	6960	34800
Days with acute respiratory symptoms	PM$_{10}$	65,788	36,000	180,000	65,788	39,600	198,000	65,788	36,000	180,000

Table A2:Final health cost estimated per health impact

Health Endpoint	Pollutant Species	Health damage cost (R)								
		Central exceedence estimate								
		Scenario A2 (150 m)			ScenarioC2 (220m)			ScenarioE2 (300 m)		
		GLC	Phola (low)	Phola (high)	GLC	Phola (low)	Phola (high)	GLC	Phola (low)	Phola (high)
Premature mortality	PM_{10}	23588827	12908174	64540869	23588827	14198991	70994955	23588827	12908174	64540869
	SO_2	182294126	4987709	24938547	182294126	4987709	24938547	151911771	4156424	20782122
Morbidity										
Chronic bronchitis in adults (≥25 years)	PM_{10}	2125883	1163316	5816580	2125883	1279648	6398238	2125883	1163316	5816580
Respiratory hospital admission	PM_{10}	378310	207017	1035086	378310	227719	1138595	378310	207017	1035086
	SO_2	630545	17252	86261	630545	17252	86261	525454	14377	71884
	NO_X as NO_2	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a
Cardiovascular hospital admissions	PM_{10}	42055	23013	115067	42055	25315	126574	42055	23013	115067
Emergency room visits	PM_{10}	12719	6960	34799	12719	7656	38279	12719	6960	34799
Acute bronchitis in children (<25 years)	PM_{10}	8649	4733	23663	8649	5206	26029	8649	4733	23663
Asthma attacks in children (<15 years)	PM_{10}	13054	7143	35717	13054	7858	39288	13054	7143	35717
Asthma attacks in adults (≥15 years)		2026	1109	5544	2026	1220	6099	2026	1109	5544
Restricted activity days in children (≥18 years)	PM_{10}	2138506	1170224	5851120	2138506	1287246	6436232	2138506	1170224	5851120
Days with acute respiratory symptoms	PM_{10}	2097669	1138027	5690136	2079669	1251830	6259150	2079669	1138027	5690136
Total		**213314368**	**21634678**	**108173390**	**213314368**	**23297650**	**116488248**	**182826923**	**20800518**	**104002588**

8. REFERENCES

Baumol, W.J. & Oats, W.E. 1988. *Theory of environmental policy*. Cambridge: Cambridge University Press.

Bhattacharyya, S. 1997. An estimation of environmental costs of coal-based thermal power generation of India. *International Journal of Energy Res*, **21:**289–298.

Blignaut, J.N. & King, N.A. 2002. The externality cost of coal combustion in South Africa. Paper presented at the Forum for Economics and Environment Conference , Cape Town. Available at: https://www.elaw.org/system/files/Economic+costs+of+coal+combustion+in+RSA.pdf (accessed on 12 July 2011).

Boyle, K.J. & Bergstrom, J.C. 1992. Benefit transfer studies: Myths, pragmatism, and idealism. *Water Resources Research*, **28(3):**657–663. Available at: http://0-www.agu.org.innopac.up.ac.za/pubs/crossref/1992/91WR02591.shtml (accessed on 24 August 2011).

Charola, A.E., Pühringer, J. & Steiger, M. 2007. Gypsum: a review of its role in the deterioration of building materials. *Environmental Geology*, **52(2)**:339–352. Available at: SpringerLink: http://0-www.springerlink.com.innopac.up.ac.za/content/41534g34621160n4/ (accessed on 24 August 2011).

Department of Energy. 2009. Digest of South African energy statistics 2009. Available at: http://www.energy.gov.za/files/media/explained/2009%20Digest%20PDF%20version.pdf (accessed on 12 July 2011).

Department of Energy. 2010. South African energy synopsis 2010. Available at: http://www.energy.gov.za/files/media/explained/2010/South_African_Energy_Synopsis_2010.pdf (accessed on 8 July 2011).

Department of Minerals and Energy. 2010. *Annual report 2009/2010*. Available at: http://www.dmr.gov.za/AnualReport/Documents/DME%20Annual%20Report%2009_10%20hr.pdf (accessed on 12 July 2011).

Dominici, F., Peng, R.D., Bell, M.L., Pham, L., McDermott, A., Zeger, S.L. & Samet, J.M. 2006. Fine particulate air pollution and hospital admission for cardiovascular and respiratory diseases. *Journal of the American Medical Association*, **295(10):**1127–1134. Available at: http://0-jama.ama-assn.org.innopac.up.ac.za/content/295/10/1127.full.pdf+html (accessed on 24 August 2011).

Dutkiewicz, R.K. & de Villiers, M.G. 1993. Social cost of electricity production. Engineering research. Report for the National Energy Council. Pretoria.

East Tennessee State University (ETSU). 1995. *Externalities of fuel cycles: 'ExternE' project summary report*. Report no 1. Harwell: ETSU.

Epstein, P.R., Buonocore, J.J., Eckerle, K., Hendryx, M., Stout III, B.M., Heinberg, R., Clapp, R.W., May, B., Reinhart, N.L., Ahern, M.M., Doshi, S.K. & Glustrom, L. 2011. Full cost accounting for the life cycle of coal. *Annals of the New York Academy of Sciences*, **1219(February):**73–98. Available at: Wiley Online Library: http://0-onlinelibrary.wiley.com.innopac.up.ac.za/doi/10.1111/j.1749-6632.2010.05890.x/pdf (accessed on 12 July 2011).

Eskom. 2010. Eskom fact sheet: Ash management in Eskom. 7th revision. Available at: http://www.eskom.co.za/content/CO_0004AshManRev7~1.pdf (accessed on 22 July 2011).

Eskom. 2010. Eskom fact sheet: Particulate emission control at a coal fired power station. 7threvision. Available at: http://www.eskom.co.za/content/CO_0004AshManRev7~1.pdf (accessed on 22 July 2011).

Eskom. 2011. Coal quality. Available at: http://www.eskom.co.za/content/CO_0098CoalQualityRev0.pdf (accessed on 22 July 2011).

Eskom. 2011. Eskom integrated report 2011. Available at: http://financialresults.co.za/2011/eskom_ar2011/downloads/eskom-ar2011.pdf (accessed on 12 July 2011).

European Comission. 1995. *ExternE: Externalities of energy*. Vol. 1-6. Luxembourg.: Office for Official Publications of the European Communities.

European Commission. 1999. *ExternE: Externalities of energy*. Vol. 1-6. Luxembourg: Office for Official Publications of the European Communities.

Faaij, A., Meuleman, B. & Turkenburg, W. 1998. Externalities of biomass-based electricity production compared with power generation form coal in the Netherlands. *Biomass Bionergy*, **14:** 125–147.

Friedrich, R. & Voss, A. 1993. External costs of electricity generation. *Energy Policy*, **21(12):**114–122.

Hainoun, A., Almoustafa, A. & Aldin, M.S. 2009. Estimating the health damage costs of Syrian electricity generation system using impact pathway approach. *Energy*, **35(2010):**628–638.

Hermanus, M.A. 2007. Occupational health and safety in mining – status, new developments and concerns. *The Journal of the Southern African Institute of Mining and Metallurgy*, **107(August):**531–538.

Hohmeyer, O. 1988. *Social costs of energy consumption*. Berlin: Springer Verlag.

Josipovic, M., Annegarn, H.J., Kneen, M.A., Pienaar, J.J. & Piketh, S.J. 2010. Concentrations, distributions and critical level exceedance assessment of SO_2, NO_2 and O_3 in South Africa. *Environmental Monitoring and Assessment*, **171:**181–196. Available at: http://0-

www.springerlink.com.innopac.up.ac.za/content/u023275747844112/fulltext.pdf (accessed on 25 June 2011).

King, D.M. & Mazzotta, M.J. 2000. Methods, Section 8: Benefit Transfer Method. Available at: http://www.ecosystemvaluation.org/benefit_transfer.htm (accessed on 24 August 2011).

Klaassen, G. & Riahi, K. 2007. Internalizing externalities of electricity generation: An analysis with MESSAGE-MACRO. *Energy Policy*, **35:**815–827.

Künzli, N., Kaiser, R., Medina, S., Studnicka, M., Chanel, O., Filliger, P., Herry, M., Horak, F., Puybonnieux-Texier, V., Quénel, P., Schneider, J., Seethaler, R., Vergnaud, J. & Sommer, H. 2000. Publichealth impact of outdoor and traffic-related air pollution: a European assessment. *The Lancet*, **365(9232):**795–801. Available at: http://0-www.sciencedirect.com.innopac.up.ac.za/science?_ob=MImg&_imagekey=B6T1B-43P3TK1-9-3&_cdi=4886&_user=59388&_pii=S0140673600026532&_origin=&_coverDate=09%2F02%2F2000&_sk=996430767&view=c&wchp=dGLbVzW-zSkWW&md5=49f116bda5f5da1d77dd192b47420b84&ie=/s (accessed on 12 July 2011).

Levy, J.I., Baxter, L.K. & Schwartz, J. 2009. Uncertainty and variability in health-related damages from coal-fired power plants in the United States. *Risk Analysis*, **29:**1000–1014. Available at: Wiley Online Library: http://0-onlinelibrary.wiley.com.innopac.up.ac.za/doi/10.1111/j.1539-6924.2009.01227.x/pdf (accessed on 12 July 2011).

Maddison, D. 1999. *The plausibility of the ExternE estimates of the external effects of electricity production*. CSERGE Working Paper GEC 99-04. London: University College London and University of East Anglia.

Mark Wood Consultants. 2007. *Independent review – Eskom's proposed coal-fired power station in the Witbank area*, South Africa: Eskom. Available at: http://recruitment.eskom.co.za/content/AnnexSMarkWRevFeb07.pdf (accessed on 15 September 2011).

Mpumalanga Provincial Government (MPG). 2011. Nkangala District Municipality. Available at: http://www.mpumalanga.gov.za/munic/municipality_nkangala.htm#emalahleni (accessed on 24 August 2011).

Ninham Shand. 2007. *Environmental impact assessment process: Proposed coal-fired power station and associated infrastructure in the Witbank area*. Final environmental impact report. Sandton: Eskom. Available at: http://recruitment.eskom.co.za/content/DEIR~2.pdf (accessed on 15 August 2011).

Norman, R., Groenewald, P., Vos, T., Laubscher, R., Van Walbeek, C., Saloojee, Y., Sitas, F., Bradshaw, D. & Group, SACRAC. 2007. Estimating the burden of disease attributable to smoking in South Africa in 2000. *SAJM*, **97(7):**782–790. Available at: http://0-

www.samj.org.za.innopac.up.ac.za/index.php/samj/article/viewFile/661/156 (accessed on 25 June 2011).

Oak Ridge National Laboratory (ORNL) & Resources for the Future (RfF). 1995. *Estimating the fuel cycle externalities: analytical methods and issues (Reports 2-8)*. Washington: McGraw-Hill Utility Data Institute.

Ottinger, R.L., Wooley, D.R., Robinson, N.A., Hodas, D.R. & Babb, S. 1991. *Environmental costs of electricity*. New York: Oceana Publications Inc.

Owen, A.D. 2004. Environmental externalities, market distortions and the economies of renewable energy technologies. *The Energy Journal*, **25(3):**127–156. Available at: http://0-ceem.unsw.edu.au.innopac.up.ac.za/content/userDocs/Ej2004.pdf (accessed on 12 July 2011).

Pearce, D., Bann, C. & Georgiou, S. 1992. *The social cost of fuel cycles report to the UK Department of Trade and Industry*. London: HMSO.

Pearce, D. & Turner, R.K. 1990. *Economics of natural resources and the environment*. Hemel Hempstead, United Kingdom: Harvester Wheatsheaf.

Pope III, C.A., Ezzati, M. & Dockery, D.W. 2009. Fine-particulate air pollution and life expectancy in the United States. *The New England Journal of Medicine*, **360:**376–86. Available at: http://0-www.nejm.org.innopac.up.ac.za/doi/pdf/10.1056/NEJMsa0805646 (accessed on 24 August 2011).

Rabl, A. 2011. Report no 4: How much to spend for the protection of health and environment: A framework for the evaluation of choices. Available at: http://www.institut.veolia.org/en/cahiers/protection-health/impact-analysis/functions-response.aspx (accessed on 24 August 2011).

Rafaj, P. & Kypreos, S. 2007. Internalisation of external cost in the power generation sector: Analysis with global multi-regional MARKAL model. *Energy Policy*, **35:**828–843.

Ross, M.H. & Murray, J. 2004. Occupational respiratory disease in mining. *Occupational Medicine*, **54(5):**304–310.

Rowe, R., Bernow, S., Bird, L., Callaway, J.M., Chestnut, L.G., Eldrige, M.M., Lang, C.M., Latimer, D.A., Murdoch, J.C., Ostro, B.D., Patterson, A.D., Rai, D.A. & White, D.E. 1994. *New York State environmental externalities cost study, Report 2: methodology*. Albany, New York: RCG/Haigler, Bailly, Inc. & Empire State Electric Research Corporation.

Rowe, R.D., Chestnut, L.G., Lang, C.M., Bernow, S.S. & White, D.E. 1995. The New York environmental externalities cost study: summary of approach and results. Paper presented at the Workshop on: the external costs of energy, Brussels, 30–31 January.

Sakulniyomporn, S., Kubaha, K. & Chullabodhi, C. 2011. External costs of fossil electricity generation: Health-based assessment in Thailand. *Renewable and Sustainable Energy Reviews*, **15:**3470–3479.

Sarnat, J.A., Schwartz, J., Catalano, P.J. & Suh, H.H. 2001. Gaseous pollutants in particulate matter epidemiology: confounders or surrogates? *Environ Health Perspect*, **109(10):**1053–1061. Available at: PubMed Central: http://0-www.ncbi.nlm.nih.gov.innopac.up.ac.za/pmc/articles/PMC1242083/pdf/ehp0109-001053.pdf (accessed on 12 July 2011).

Schreurs, M.A. 2011. Transboundary cooperation to address acid rain: Europe, North America, and East Asia compared. In *Beyond resource wars: Scarcity, environmental degradation, and international cooperation*(Ed. S. Dinar). Cambridge, Massachsetts, United States: MIT Press.

Schuman, M. & Cavanagh, R. 1982. *A model conservation and electric plan for the Pacific Northwest*. Seattle: NCAC.

Scire, J.S., Strimaitis, D.G. & Yamartino, R.J. 2000. *A user's guide for the CALPUFF dispersion model (version 5)*. MA: Earth Tech Inc. Available at: http://www.src.com/calpuff/download/CALPUFF_UsersGuide.pdf (accessed on 20 August 2011).

Spalding-Fecher, R. & Matibe, D.K. 2003. Electricity and externalities in South Africa. *Energy Policy*, **31:**721–734. Available at: Science Direct: Elsevier: http://0-www.sciencedirect.com.innopac.up.ac.za/science?_ob=MImg&_imagekey=B6V2W-46YXJKX-4-3&_cdi=5713&_user=59388&_pii=S0301421502001234&_origin=&_coverDate=06%2F30%2F2003&_sk=999689991&view=c&wchp=dGLzVlb-zSkWb&md5=01c733b3fd0700236650f946ba4b2323&ie=/s (accessed on 25 June 2011).

Spalding-Fecher, R. 2005. Health benefits of electrification in developing countries: A quantitative assessment in South Africa. *Energy for Sustainable Development***, IX(1):**23–32.

Theriault, G., Goldberg, M., Miller, A., Armstrong, B., Guénel, P., Deadman, J., Imbernon, E., To, T., Chevalier, A., Cyr, D. & Wall, C. 1994. Cancer risks associated with occupational exposure to magnetic fields among electric utility workers in Ontario and Quebec, Canada, and France: 1970–1989. *American Journal of Epidemiology*, **139(6):**550–572.

Thomas, R. & Scorgie, Y. 2006. *Air quality impact assessment for the proposed new coal-fired power station (Kendal North) in the Witbank area*. Sandton, South Africa: Eskom. Available at: http://recruitment.eskom.co.za/content/Airqualitypart1.pdf and http://recruitment.eskom.co.za/content/Airqualitypart2.pdf (accessed on 15 August 2011).

Thopil, G.A. & Pouris, A. 2010. An overview of the electricity externality analysis in South Africa within the international context. *South African Journal of Science*, **106(11):**1–6. Available at: http://0-search.sabinet.co.za.innopac.up.ac.za/WebZ/Authorize?sessionid=0&bad=ejour/

ejour_badsearch.html&portal=ejournal&next=images/ejour/sajsci/sajsci_v106_n10_11_a15.pdf (accessed on 10 July 2011).

Turpie, J., Winkler, H. & Midgeley, G. 2004. Economic impacts of climate change in South Africa: A preliminary assessment of mitigated damage costs. In *Sustainable options: Economic development lessons from applied environmetal resource economics in South Africa*(Eds. J.N. Blignaut, &M.P. de Wit, M.P.). Cape Town: University of Cape Town Press.

Van Horen, C. 1996. *Counting the social costs: Electricity and externalities in South Africa*. Cape Town: University of Cape Town Press and Elan Press.

Vrhovcak, M.B., Tomsic, Z. & Debrecin, N. 2005. External costs of electricity production: case study Croatia. *Energy Policy*, **33:**1385–1395.

Wassung, N. 2010. Water scarcity and electricity generation in South Africa, Part 1: Water use in the coal-to-electricity process. Unpublished thesis. Stellenbosch.: University of Stellenbosch. Available at: SUNScholar Research Repository: http://0-scholar.sun.ac.za.innopac.up.ac.za/bitstream/handle/10019.1/5858/wassung_water_2010.pdf?sequence=1 (accessed on 24 August 2011).

Zvereva, E.L., Toivonen, E. & Kozlov, M.V. 2008. Changes in species richness of vascular plants under the impact of air pollution: a global perspective. *Global Ecology and Biogeography*, **17(3):**305–319. Available at: Wiley Online Library: http://0-onlinelibrary.wiley.com.innopac.up.ac.za/doi/10.1111/j.1466-8238.2007.00366.x/pdf (accessed on 24 August 2011).

ANNEX 2

Climate change:
the opportunity cost of Medupi and Kusile power stations

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1. INTRODUCTION

Eskom has embarked on a process of developing two very large coal-fired power stations, namely Medupi and Kusile (see Annex 0 for more details). Given the ongoing global debate regarding climate change, the question could, and should, rightfully be asked: what is the social (including environmental/climate change) damage cost of embarking on this route, and hence the opportunity cost[15] of doing so? This is that will be addressed here.

In order to address this question, the following will be considered: background information on the value of a ton of carbon, Eskom's carbon footprint and its contribution to global social damage cost, and the opportunity cost, from a climate change damage cost perspective, of the two new power plants. It should be noted that this analysis excludes the contribution to climate change of other parts of the coal chain, such as plant construction and the coal-mining operation itself. The latter is being dealt with in Annexure 4. This will include a discussion on the value of renewable electricity generation technologies that can be "bought" by the social damage cost of the two new coal-fired power plants and how many years it will take to establish the same power generation capacity when converting the damage cost into renewable electricity.

2. BACKGROUND: THE VALUE OF A TON OF CARBON

Climate change is one of the most researched yet ill-understood phenomena of our time. Studies on this topic cover a wide range of issues, such as agriculture (Kurukulasuriya *et al.*, 2006; Blignaut *et al.*, 2009; Thornton *et al.*, 2009), health (Tol, 2008; Markandya & Chiabai, 2009; Hutton, 2011), invasive alien plant species (Masters & Norgrove, 2010), and corporate adjustment programmes linked to climate change (Reyers *et al.,* 2011; Tyler & Chivaka, 2011), to mention but a few.

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[15] Opportunity cost refers to the foregone value of the next best alternative not chosen.

While it is possible to do a sectoral analysis to determine the economy-wide impact of climate change, such a bottom-up approach is fraught with difficulty. Most attempts are therefore based on the national or global impacts of climate change and its related damage costs, also called the social damage cost of carbon.

Estimating the social damage cost of climate change has gripped many authors and has led to a wide range of studies (Intergovernmental Panel on Climate Change (IPCC), 1999; IPCC, 2000; Tol, 2005; Stern, 2007; Kuik *et al.,* 2009; Tol, 2009; Stage, 2010; Rafey & Sovacool, 2011). However, the subject has also become the topic of a heated debate pertaining to the use of discount rates, or more accurately, the appropriate pure rate of time preference (PRTP), where PRTP is defined as "the marginal rate of substitution between present and future consumption under the condition that consumption levels in both periods are equal" (Anthoff *et al.,* 2009:2). The choice of PRTP is important, as it drives, to a very large extent, the estimate of the likely impact of climate change on national economies (Dasgupta, 2007; Nordhaus, 2007; Stern, 2007; Stern, 2008; Anthoff *et al*., 2009; Tol & Yohe, 2009)[16]. It is not only the choice of discount rate that influences the estimates, but also the time period, the country focus, the income levels of countries and the distribution of income both within and among countries. It is therefore not surprising that there are very wide discrepancies in the results among these studies, as can be seen from the summary of the studies reviewed by Tol (2009) (see Annexure 1). What is evident from Annexure 1, however, is that there is an agreement among the studies that the region likely to be most adversely impacted upon is Africa (to the effect of between -2% and -5% of GDP).

While Africa's contribution to climate change through anthropogenic induced emissions of carbon dioxide is small, South Africa is considered a main global player in this respect (Blignaut *et al.,* 2005) being the 13th highest carbon dioxide emitter among nations (according to annual emissions in 2008) (United Nations Statistics Division (UNSD), 2011). This is largely as a result of its coal-fired power stations and the production of liquid petroleum from coal. There have been a number of studies attempting to quantify the external cost of the combustion of coal in South Africa, most notably with respect to electricity power generation (see Table 1). Spalding-Fecher and Matibe (2003) estimate the climate change impact of greenhouse gas emissions related to power generation to be about

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[16] A discount rate refers to the time preference value of money. In other words, at what rate does society value the worth of tomorrow's money with respect to today's money. The higher the rate is, the lower society considers the value of tomorrow's money. The pure rate of time preference (PRTP) is a specific form of discounting namely that it is the discount rate at which the consumption rate of both the current and future generations are held constant, ie no reduction or increase in welfare over time. In other words, the time value of money and economic growth per capita are constant.

R7 billion per year. Considering all the negative impacts related to coal-fired power generation, Palmer Development Consulting (PDG) (2003) estimates the impact to be between R75 billion per year and R120 billion per year. Blignaut and King (2002) estimate the climate change-related social damage cost of power generation to be R7.3 billion per year, or approximately 24.6% of Eskom's 2002 sales revenue. Van Zyl *et al.* (1999) consider only the methane emissions from coal mines themselves and estimate the damage cost at approximately R1 billion per year. Given the historic evidence discussed here and summarised in Table 1, the contribution of coal-fired power stations in South Africa to climate change-related damage cost is meaningful, and requires regular attention and subsequent policy intervention to mitigate the impacts, adapt to the reality of climate change and reduce the country's future carbon intensity.

Table 1: Summary of studies conducted on the cost of coal-fired power generation in South Africa

Authors	**Year**	**Areas considered**	**Estimate**
Spalding-Fecher and Matibe	2003	Climate change cost of coal-fired power stations	R7billion per year
PDG	2003	All the negative impacts related to coal-fired power generation	R75billion–R120billion per year
Blignaut and King	2002	Climate change cost of coal-fired power stations	R7.3billion per year
Van Zyl *et al.*	1999	Methane emissions from coal mines	R1billion per year

Determining coal-fired power stations' contribution to climate change-induced damage cost hinges on two factors. The emission factor of a power station (tCO_2/MWh) and the unit value of carbon dioxide. While Eskom's emission factors are published, the social damage cost of carbon (SCC) is not observed and is the subject of much debate. Blignaut and King (2002), for example, base their estimates on Sandor (2001), who indicated the damage cost of CO_2 as between \$5 and \$10/tCO_2 (\$18.3–\$36.6/tC). Subsequently, however, many studies have been published considering the unit value of carbon dioxide.

The study that gained the most attention was that of Sir Nicholas Stern. Stern (2007, 2008), however, was criticised heavily by some for the use of a very low PRTP (0.1%), a choice based largely on philosophical rather than empirical considerations. The outcome of using such a low PRTP is a very high social cost of carbon (\$314/tC, or \$85/tCO_2). This has become a bone of serious contention, because the chosen unit value has a major impact on the total damage cost when multiplying it with total emissions. However, it explains Stern's predictions that climate change could cost the global economy anything between 5% and 20% of gross domestic product (GDP), a number much higher than most other studies (such as those listed in Annexure 1).

So, what are the alternative views with respect to the unit value of a ton of carbon? After reviewing 28 studies with respect to the damage cost of climate change under varying PRTPs, Tol (2005) found that the "mode is \$2/tC, the median \$14/tC, the mean \$93/tC, and the 95th percentile \$350/tC". He concludes that "the marginal damage costs of carbon dioxide emissions are unlikely to exceed \$50/tC, and probably much smaller" (Tol, 2005:2064). He also states that "[i]f we use a pure rate of time preference of 3% — corresponding to a social rate of discount of 4–5%, close to what most western governments use for most long-term investments — the combined mean estimate is \$16/tC, not exceeding \$62/tC with a probability of 95%," (Tol, 2005:2073). In 2009 he conducted another review, this time of more than 200 studies (see Annexure 2), in which he concludes that "for a standard discount rate, the expected value is \$50/tC, which is much lower than the price of carbon in the European Union, but much higher than the price of carbon elsewhere" (Tol, 2009:29) (it should be noted that these values are for 1995 US\$)[17]. In a conclusion on the debate, Anthoff *et al.* (2009) state that the most likely social cost of carbon is approximately \$41/tC (\$11.18/tCO$_2$), if one ignores uncertainty and equity. If uncertainty and global income differentials are taken into consideration, the value lies somewhere between \$61.6/tC (\$16.8/tCO$_2$) and \$206/tC (\$56.18/tCO$_2$). While this is higher than Sandor's estimate, it is still much lower than Stern's. The range of estimates from a number of studies are summarised in Table 2.

Table 2: The social cost of carbon: 1995\$/Ct[a, d]

	Mode	Mean	Median	Min	Max	Used	No uncertainty, with equity	Uncertainty, no equity	Uncertainty and equity
Tol (2005: 1% PRTP[b])	4.7	51	33		165				
Tol (2005: 3% PRTP)	**1.5**	16	7		**62**				
Stern (2007 & 2008)						**314**[c]			
Tol (2009: 1% PRTP)	49	120	91		410				
Tol (2009: 3% PRTP)	25	50	**36**		205				
Anthoff *et al.* (2009)				0	121k		14	61	**206**

[a] It should be noted that these values are in \$/tC; to convert the numbers to \$/tCO$_2$, divide the values by 3.6667
[b] PRTP = pure rate of time preference
[c] 2000 value
[d] The values in bold red are used later on in this study

The values depicted in Table 2 are well within the range of acceptability. This is emphasised by Bell and Callan (2011), who state the following:

> In 2009 an interagency team of US government specialists, tasked to estimate the SCC, reported a range of values from \$5 to \$65 per ton of carbon dioxide. The choice of a final

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[17] Refer to Table 4 for the conversion to 2010 values.

> figure (or range of figures) is, in itself, a major policy decision, since it sets a likely ceiling for the cost per ton that any federal regulation could impose on the economy to curb CO_2. At \$5 a tonne, government could do very little to regulate CO_2; at \$65, it could do significantly more. Higher SCC numbers, such as the United Kingdom's range of \$41–\$124 per ton of CO_2 with a central value of \$83, would justify, from an economics perspective, even more rigorous regulation.
>
> Using modelling developed by economists and other analyses and tools described in detail in the following sections, the Interagency Working Group (IWG) panel report recommended a range of SCC values — \$5, \$21, \$35, and \$65 (in 2007 dollars) – per ton of carbon dioxide with the intent that these values be used in individual rulemakings across government involving the regulation of CO_2. \$21 is the "central number" and carries the most weight in analysis.

Ackerman and Stanton (2011), however, challenge this range of values. They estimate the social cost of carbon between \$28/tCO_2 and \$893/tCO_2. Their study, however, has not been reviewed and proven yet. It does seem odd, though, that the authors assumed a fixed consumption discount rate of 1.5% per year, while also assuming a higher per capita growth rate for the first century. This implies negative pure discounting[18]. It is obviously a matter of concern, but it would explain the high damage cost values. Given the concern, the estimates in this document are not based on these numbers.

3. ESKOM'S CARBON PROFILE AND CONTRIBUTION TO CLIMATE CHANGE-RELATED GLOBAL DAMAGE COST

Eskom is South Africa's main power-producing utility and it mainly uses coal (see Table 3). It is therefore no surprise that Eskom's carbon footprint is, by own admission, quite severe. Eskom (2011), through the Letter of the Chairman, states the following:

> Due to the coal-centric nature of our generation mix, we are not satisfied with our current performance in this regard. Eskom's CO_2 emissions for the period were 230.3 Mt, an increase of 2.5% on the previous year's 224.7 Mt. We remain committed to reducing our

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[18] This point was highlighted by Professor Reyer Gerlagh, Tilburg School of Economics and Management in The Netherlands, in personal communication. Negative discounting implies a net appreciation in the value of money over time.

> emissions as conveyed in our climate change strategy. Our commitment is to see a reduction by 2030. Subject to the support from the shareholder and the allocation of nuclear and renewables to Eskom, this reduction follows what we anticipate to be our peak at 283 Mt in 2022 to 235 Mt by 2030. This will see our relative CO_2 emissions at 0.68t/MWh compared to the current 0.99t/MWh. No company takes pride in the negative impacts of its business, and Eskom is no different. One of Eskom's objectives is to become a greener energy company.

Eskom's power generation and carbon dioxide emissions profile is provided in Table 3.

Table 3: Eskom's carbon emissions profile[a]

	Unit	2006/7	2007/8	2008/9	2009/10	2010/11
Power generated	GWh	243 928	250 619	241 133	246 566	252 876
Power sales	GWh	218 120	224 366	214 850	218 591	224 446
Power generated by coal (net)	GWh	215 211	222 908	211 941	215 940	220 219
Coal combusted	t (mil)	119.1	125.3	121.2	122.7	124.7
Total CO_2-emissions (as published)[b]	t (mil)	208.9	223.6	221.7	224.7	230.3

Source: Eskom, 2011

[a] Power plants only, ie the profile excludes emissions related to coal mining and the transport of coal, etc.
[b] Calculated figures are based on coal characteristics and the power station design parameters. CO_2emissions are based on coal analysis and tonnages of coal burnt in 2010/11.From 2009 Camden, Grootvlei and the gas turbine power stations, as well as oil consumed during power station start-ups, are included.From 2010, total CO_2 includes the additional contribution from the Underground Coal Gasification pilot project (flaring) and Komati power station.

Using the above information (Table 3), in conjunction with the global assessment of the social damage cost of carbon (Table 2), it is possible to estimate Eskom's contribution to this. This is depicted in Table 4 and Figure 1 using a range of damage cost estimates starting at \$2/tC (\$0.55/tCO_2) up to Stern's estimate of \$314/tC (\$85.63/tCO_2). Most of these values are for 1995 US\$; they are therefore first converted into \$/tCO_2, and then adjusted to 2010 values using the inflation rate of the USA. The range therefore becomes \$0.8/tCO_2 to \$112/tCO_2. As an additional benchmark, an average market rate of \$15/CO_2 is added, derived from considering carbon prices within the EU ETS programme, CER prices and prices in the voluntary carbon market.

Applying these values to the published emissions profile of Eskom converts to an estimated contribution to global damage cost. Eskom's contribution to global damage cost related to climate change is estimated to be between \$183 million (R1.3billion) and \$28.8 billion (R188 billion) in 2010/11. Arguably the most likely range, using the median, market and high rates (which are the rates flanking the market rate), is between \$3.5 billion (R25.3 billion) and \$5.5 billion (R41 billion) – or between 28% and 45% of Eskom's 2010/11 turnover. Using the high rate of \$24.29/tCO_2 (or about

R170/tCO_2), it translates into an accrued damage over the time period concerned (2006/07–2010/11) of R197 billion in 2010 values. This value could be as high as R907 billion if one accepts Stern's estimate.

Table 4: Eskom's contribution to global damage cost through its CO_2 emissions

	Emission load: million tCO_2		**Very low**	**Median**	**Market**	**High**	**Very high**	**Stern**
		1995$/tC	2	36	-	61	206	314*
		1995$/$tCO_2$	0.55	9.82	-	16.64	56.18	85.64*
		2010$/$tCO_2$	0.80	14.33	15.00	24.29	82.02	112.01
2006/07	208.9	**$/m**	166	2 994	3 134	5 074	17 135	23 399
2007/08	223.6	**$/m**	178	3 205	3 354	5 430	18 338	25 042
2008/09	221.7	**$/m**	177	3 178	3 326	5 385	18 185	24 833
2009/10	224.7	**$/m**	179	3 221	3 371	5 458	18 431	25 169
2010/11	230.3	**$/m**	183	3 301	3 455	5 594	18 890	25 796
2010/11	Damage cost: R million		1 342	**25 287**	**24 165**	**40 946**	138 277	188 826
2010/11	Eskom's turnover: R million		90 485	**90 485**	**90 485**	**90 485**	90 485	90 485
2010/11	Global damage cost as percentage of turnover		1.5%	**27.9%**	**26.7%**	**45.3%**	152.8%	208.7%

* Year 2000 value

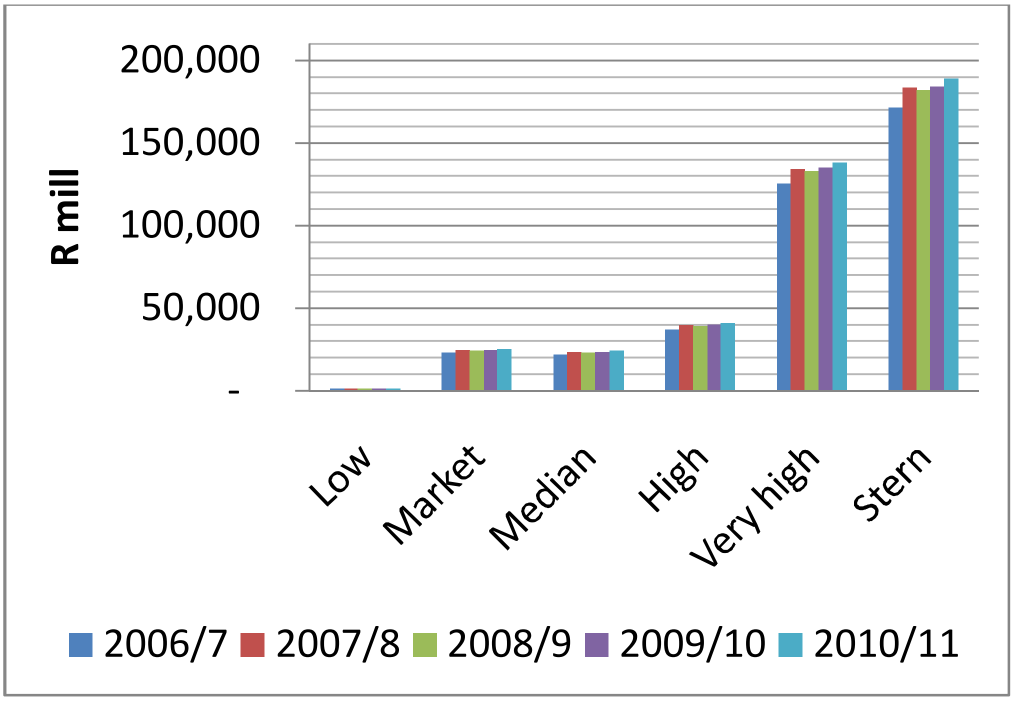

Figure 1: Eskom's contribution to global damage cost related to climate change, based on various estimates of the unit value of a ton of carbon and Eskom's own estimates of its CO_2 emissions

4. THE OPPORTUNITY COST OF TWO POWER PLANTS: A CLIMATE CHANGE DAMAGE COST PERSPECTIVE

Eskom has reached the supply limit of its current power generation facilities and had to commit to an infrastructure expansion programme. This programme includes the addition of two large coal-fired power stations, Medupi and Kusile, each with a gross capacity of 4 800 MW. It is anticipated that they will consume about 17 million ton of coal each annually and contribute to an additional CO_2 load of 30 million ton each (African Development Bank (AfDB), 2009; Synergistics, 2011).[19] The combined CO_2 emissions of these two new power stations are therefore approximately 60 million ton, or 26% of the 2010/11 emission load of Eskom (230.3 million ton). Eskom's contribution to the global damage cost as a result of these two power stations, using the unit values as described above, is shown in Table 5. While the estimated damage cost range is between R350 million and R49 billion, the most likely range (ie the median, market and high range) is between R6.3 billion and R10.7 billion per year. (The market rate is used as a gauge and the values around it, and hence the very low and the very high values, such as that of Stern, which are heavily contested are excluded.)

Assuming a net generation capacity of 8 677 MW and a load factor of 85%, this translates to a damage cost of between R0.10 and R0.17/kWh, or R0.56/kWh when using the very high estimate or R0.76/kWh when using the Stern values, and should be compared to an average electricity price for South Africa of about R0.41/kWh (RSA 2011). When considering a damage cost of R0.17/kWh, and a total combined net electricity generated of 64.6TWh[20] for Kusile and Medupi combined, and emissions of 60 million tons, then this implies a damage cost per ton of CO_2 of R183.

Table 5: Eskom's additional annual contribution to global damage cost as a result of Medupi and Kusile: R million (in ZAR 2010 terms)

	CO_2emissions	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

Given the anticipated damage cost due to the two additional new coal-fired power stations, the question can rightfully be asked what the opportunity cost thereof is. In other words, how much

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[19] It should be noted that the power plants will introduce flue gas desulphurisation (FGD) technology. This increases the demand for both coal and water (see Annexure 3) as what otherwise would have been the case, but to the benefit of reduced sulphur emissions. CO_2 emissions are therefore higher due to the increase in coal consumption, but with the added benefit of reduced sulphur emissions.

[20] A gross capacity of 723 MW per unit times 12 units, times 8 760 hours a year, times a load factor of 85%.

power using renewable power generation technologies does either R6.3 billion or R10.7 billion a year buy? To answer this question, we use the power generation unit costs as published in the 2011 Integrated Resource Plan (IRP) of South Africa (given in Table 6) for a range of different technologies. It should be noted that it is likely that the capital costs of these technologies will decline over time – some estimate this to be as much as between 25% and 60% – as developments within the renewable electricity generation sector advances (Teske, 2011). This will, in all likelihood, improve matters all-round.

Table 6: Unit cost of a range of different power generation technologies in South Africa: 2010

	Load factor	Present value of capital cost	Fixed operating and maintenance cost	Variable operating and maintenance cost
	%	Rmil/MW	R/MW/yr	R/MWh/yr
Wind	29	14.445	266 000	0.0
Concentrated PV	26.8	37.225	502 000	0.0
PV (crystalline silicon)	19.4	20.805	208 000	0.0
Forest residue biomass	85	33.270	972 000	31.1
Municipal solid waste	85	66.900	2 579 000	38.2
Concentrated solar power, parabolic trough with 9 hours storage	43.7	50.910	635 000	0.0

Source: Republic of South Africa, 2011

Taking the respective load factors into account, as well as the capital cost and the fixed and variable cost for the different technologies as provided in Table 6, it is possible to determine the annual required cost of operating these technologies. The power generation capacity (MW) and power generation output (MWh) that either R6.3 billion or R10.7 billion a year can buy is presented in Table 7.

The global damage cost due to climate change of Medupi and Kusile could buy between 388 MW (municipal solid waste) and 3 381 MW (wind) every year, on a capacity basis assuming that the capital can be paid over five years. Alternatively, the opportunity cost is an additional generation output, after considering load factors, of between 1.9 TWh (concentrated photovoltaic)(CPV) and almost 10.1 TWh (biomass). This implies that after between seven (biomass) and 38 years (concentrated photovoltaic), the combined damage cost of Medupi and Kusile would have bought an equivalent generation capacity using renewable power generation technologies. This does not suggest that only one technology should be used; a technology bundle is probably more beneficial, especially when considering resource restrictions, such as biomass availability. This analysis does indicate that the environmental pay-back period of all the alternative technologies considered here, when internalising externalities, are well within the lifespan of Medupi and Kusile, which is estimated to be 50 years (Action Sierra Club, n.d.). The lower the cost of the technologies become, the shorter the environmental pay-back periods are likely to be.

Table 7: Opportunity cost, due to climate change, of Medupi and Kusile[1, 2, 3, 4]

	MW capacity and MWh generated that would equal a total annual cost of: R6 296 million		Time it would take to equal Medupi and Kusile's output	MW capacity and MWh generated that would equal a total annual cost of: R10 667 million		Time it would take to equal Medupi and Kusile's output
	MW	**MWh**	**# years**	**MW**	**MWh**	**# years**
Wind	1 995	5 069 266	14	3 381	8 589 589	8
CPV	792	1 859 850	38	1 342	3 151 413	23
photovoltaic(PV)(crystalline silicon)	1 441	2 448 872	29	2 442	4 149 478	17
Forest residue biomass	801	5 965 915	12	1 358	10 108 911	7
Municipal solid waste	388	2 885 941	25	657	4 890 066	15
Concentrated solar power, parabolic trough with 9 hours' storage	582	2 228 030	32	986	3 775 273	19

Notes:

1 Assuming that the capital costs are repaid in five years and that there are no resource and/or technological constraints.

2 While it is unlikely that, in reality, the focus will be exclusively on one technology, ie investing either R6.3 billion or R10.7 billion in one technology only, we do this here (as opposed to a bundle of technologies) for demonstration purposes.

3 Given the ongoing research and development (R&D) in renewable energy (RE) technologies, the unit costs are likely to come down, reducing the time it will take to reach the capacity of Medupi and Kusile.

4 While it might be argued that it is currently unlikely that there is sufficient resources to invest in 1 300 ME of biomass-based technology, or 660 MW of MSW technologies annually on an ongoing basis, with R&D and improvements in efficiencies, this might become plausible soon. Also, in reality, a bundled approach is arguably the best way going forward, ie using a suite of technologies.

5. CONCLUSION

Eskom, South Africa's primary power utility, has embarked on a capital expansion programme that, at its core, implies the development of two large-scale coal-fired power plants, Medupi and Kusile. This is despite concerns and international pressure not to do so in the wake of the ongoing debate and active effort to mitigate and offset carbon dioxide emissions. The question therefore is, at what (climate change damage) cost are these two power plants being built?

It is anticipated that the two power plants will emit about 60 million tons of CO_2 annually (excluding CO_2 emissions from construction, transport and coal mining). When considering a range of global damage costs of between \$0.8/tCO_2 and \$112/tCO_2, the estimated damage cost is between R350 million and R49 billion per year. The most likely range is between R6.3 billion and R10.7 billion per year. This converts to a damage cost of between R0.10 and R0.17/kWh when assuming a net combined generation capacity of 8 677 MW and a load factor of 85%.

After considering the cost of renewable electricity generation technologies as per the IRP (RSA, 2011:54), it was estimated that, for the most part, it would be possible to develop the same amount of installed capacity as the two power plants utilising the damage cost only in under 20 years. That implies that over the 50 year lifespan of Medupi and Kusile, their installed capacity could have been more than doubled. From the above it is self-evident that the climate change-related opportunity cost of Medupi and Kusile is equal to 21 700 MW of renewable electricity alternatives (8 677 MW * 50 years/20 years). This is just more than half of South Africa's current installed capacity and it exceeds the 17.8 GW capacity for renewables discussed in the IRP (RSA, 2011:6). While benchmarking this opportunity cost is difficult, it seems extraordinarily high. This is especially so in the wake of a decline in coal reserves (Annex 0), and a variable climate and the urgent need to invest in renewable alternatives. The question therefore is: can the country afford forgoing the opportunity to invest in 21 700 MW of renewable alternatives?

6. ANNEXURES

Annexure 1: Estimates of the welfare impact of climate change (expressed as an equivalent income gain or loss in per cent GDP)*

Study	Warming °C	Impact percentage of GDP	Worst-off region		Best-off region	
			Percentage of GDP	Name	Percentage of GDP	Name
Nordhaus (1994a)	3.0	-1.3				
Nordhaus (1994b)	3.0	-4.8				
		(-30.0 to 0.0)				
Fankhauser (1995)	2.5	-1.4	-4.7	China	-0.7	Eastern Europe and the former Soviet Union
Tol (1995)	2.5	-1.9	-8.7	Africa	-0.3	Eastern Europe and the former Soviet Union
Nordhaus and Yang (1996)[a]	2.5	-1.7	-2.1	Developing countries	0.9	Former Soviet Union
Plambeck and Hope (1996)[a]	2.5	2.5	-8.6	Asia (w/o China)	0.0	Eastern Europe and the former Soviet Union
		(-0.5 to -11.4)	(-0.6 to -39.5)		(-0.2 to 1.5)	
Mendelsohn, Schlesinger and Williams (2000)[a, b, c]	2.5	0.0[b]	-3.6[b]	Africa	4.0[b]	Eastern Europe and the former Soviet Union
		0.1[b]	-0.5[b]		1.7[b]	
Nordhaus and Boyer (2000)	2.5	-1.5	-3.9	Africa	0.7	Russia
Tol (2002)	1.0	2.3	-4.1	Africa	3.7	Western Europe
		(1.0)	(2.2)		(2.2)	
Maddison (2003)[a, d, e]	2.5	-0.1	-14.6	South America	2.5	Western Europe
Rehdanz and Maddison (2005)[a, c]	1.0	-0.4	-23.5	Sub-Saharan Africa	12.9	South Asia
Hope (2006)[a, f]	2.5	0.9	-2.6	Asia (w/o China)	0.3	Eastern Europe and the former Soviet Union
		(-0.2 to 2.7)	(-0.4 to 10.0)		(-2.5 to 0.5)	
Nordhaus (2006)	2.5	-0.9 to 0.1				

Notes:

* Where available, estimates of the uncertainty are given in parentheses, either as standard deviations or as 95 percent confidence intervals.

[a] The global results were aggregated by the current author.

[b] The top estimate is for the "experimental" model, the bottom estimate for the "cross-sectional" model.

[c] Mendelsohn *et al*. only include market impacts.

[d] The national results were aggregated to regions by the current author for reasons of compatibility.

[e] Maddison only considers market impacts on households.

[f] The numbers used by Hope (2006) are averages of previous estimates by Fankhauser and Tol; Stern *et al*. (2006) adopt the work of Hope (2006).

Source: Tol, 2009

Annexure 2: The social cost of carbon (measured in $/tC)

	Sample (unweighted)				**Fitted distribution (weighted)**			
		Pure rate of time preference				**Pure rate of time preference**		
	All	**0%**	**1%**	**3%**	**All**	**0%**	**1%**	**3%**
Mean	105	232	85	18	151	147	120	50
Standard deviation	243	434	142	20	271	155	148	61
Mode	13	-	-	-	41	81	49	25
33rd percentile	16	58	24	8	38	67	45	20
Median	29	85	46	14	87	116	91	36
67th percentile	67	170	69	21	148	173	142	55
90th percentile	243	500	145	40	345	339	272	112
95th percentile	360	590	268	45	536	487	410	205
99th percentile	1500	-	-	-	1687	667	675	270
N	232	38	50	66	-	-	-	

Source: Tol, 2009

7. REFERENCES

Ackerman, F. & Stanton, E. 2011. *Climate risk and carbon prices: Revising the social cost of carbon*. Portland, Oregon: Economics for Equity and Environment.

Action Sierra Club. n.d. *South African Kusile 4 800-MW coal-fired power project background information and fact sheet*. Available at:P http://action.sierraclub.org/site/DocServer/Kusile_Power_Project_Factsheet.pdf?docID=5541 (accessed on 7 July 2011).

African Development Bank Group (AfDB). 2009. Executive summary of South Africa: Environmental impact assessment for the Medupi power plant project of Eskom.Available at: http://www.afdb.org/fileadmin/uploads/afdb/Documents/ Environmental-and-Social-Assessments/ESIA%20Ex%20Summary%20of%20Medupi %20Coal%20Power%20Plant%20July%201%20revised%20Final-ram-1.pdf (accessed on 7 July 2011).

Anthoff, D., Tol, R. & Yohe, G. 2009. Risk aversion, time preference, and the social cost of carbon. *Environ. Res. Lett.,* **4:**024002; doi:10.1088/1748-9326/4/2/024002.

Bell, R.G. & Callan, D. 2011. More than meets the eye: The social cost of carbon in US Climate Policy, in plain English. Policy brief. Washington DC: Resources Institute (WRI).

Blignaut J.N., Mabugu, R.M. & Chitiga-Mabugu, M.R. 2005. Constructing a greenhouse gas emissions inventory using energy balances: The case of South Africa: 1998. *Journal of Energy in Southern Africa,* **16(3):**105–116.

Blignaut, J.N. & King, N.A. 2002. *The externality cost of coal combustion in South Africa. Forum for Economic and Environment. Bridging the Economics/environment divide conference. Published peer-reviewed conference proceedings.Forum for Economic and Environment, first conference held in Cape Town:* 71–86.

Blignaut, J.N., Ueckermann, L. & Aronson, J. 2009. Agriculture production's sensitivity to changes in climate in South Africa*. South African Journal of Science,* **105:**61–68.

Dasgupta, P. 2007. Commentary: The Stern review's economics of climate change. *National Institute Economic Review*, **199:**4–7; DOI: 10.1177/002795010719900102.

Eskom. 2011. *Annual report 2010/11*. Johannesburg: Eskom.

Hutton, G. 2011. The economics of health and climate change: Key evidence for decision-making. *Globalization and Health*, **7:**18; doi:10.1186/1744-8603-7-18.

Intergovernmental Panel on Climate Change (IPCC). 1999. *Economic impact of mitigation measures*. Geneva: IPCC.

Intergovernmental Panel on Climate Change (IPCC). 2000. *Sectoral economic costs and benefits of GHG mitigation*. Geneva: IPCC.

Kuik, O., Brander, L. & Tol, R. 2009. Marginal abatement costs of greenhouse gas emissions: A meta-analysis. *Energy Policy*, **37:**1395–1403; doi.org/10.1016/j.enpol.2008.11.040.

Kurukulasuriya, P., Mendelsohn, R., Hassan, R., Benhin, J., Deressa, T., Diop, M., Mohamed Eid, H., Fosu, K., Gbetibouo, G., Jain, S., Mahamadou, A., Mano, R., Kabubo-Mariara, J., El-Marsafawy, S., Molua, E., Ouda, S., Ouedraogo, M., Se´ne, I., Maddison, D., Niggol Seo, S. & Dinar, A. 2006. Will African agriculture survive climate change? *World Bank Econ. Rev.*, **20:**367–388.

Markandya, A. & Chiabai, A. 2009. Valuing climate change impacts on human health: Empirical evidence from the literature. *Int. J. Environ. Res. Public Health*, **6:**759–786; doi:10.3390/ijerph6020759.

Masters, G. & Norgrove, L. 2010. *Climate change and invasive alien species*. CABI Working Paper 1.

Nordhaus, W.D. 2007. A review of the Stern review on the economics of climate change. *Journal of Economic Literature*, **45(3):**686–702.

Palmer Development Consulting (PDG). 2003. *Review of the effectiveness of energy subsidies and related taxation policies in South Africa*. Pretoria: National Treasury and Department of Minerals and Energy.

Rafey, W. & Sovacool, B.K. 2011. Competing discourses of energy development: The implications of the Medupi coal-fired power plant in South Africa. *Global Environ. Change,* doi:10.1016/j.gloenvcha.2011.05.005.

Reyers, M., Gouws, D. & Blignaut, J. 2011. An exploratory study of motivations driving corporate investment in voluntary climate change mitigation in South Africa. *SAJEMS*, **14(1):**8–14.

Republic of South Africa (RSA). 2011. Integrated Resource Plan 2010–2030. *Government gazette*. Pretoria: Government Printers.

Sandor, R. 2001. How I see it: The case for coal. *Environmental Finance*, **March:** 12.

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

Stage, R. 2010. Economic valuation of climate change adaptation in developing countries. *Ann. N.Y. Acad. Sci.*, 1 185:150–163.

Stern, N. 2007. *The economics of climate change: The Stern review*. Cambridge: Cambridge University Press.

Stern, N. 2008. The economics of climate change. *Am. Econ. Rev.*, **98:**1–37.

Synergistics. 2011. New Largo Colliery – draft environmental scoping report. Report number S0403/NLC/SR02. Johannesburg: Synergistics.

Teske, S. (Ed.) 2011. *The advanced energy [r]evolution: A sustainable energy outlook for South Africa*. Brussels and Amsterdam: European Renewable Energy Council and Greenpeace.

Thornton, P.K., Van de Steeg, J., Notenbaert, A. & Herrero, M. 2009. The impacts of climate change on livestock and livestock systems in developing countries: A review of what we know and what we need to know. *Agricultural Systems,***101:**113–127.

Tol, R. 2005. The marginal damage costs of carbon dioxide emissions: An assessment of the uncertainties. *Energy Policy*, **33(16):**2064–2074.

Tol, R. 2008. Climate, development and malaria: an application of FUND. *Climatic Change*, **88:**21–34; DOI: 10.1007/s10584-007-9253-4.

Tol, R. 2009. The economic effects of climate change. *Journal of Economic Perspectives*, **23(2):** 29–51; DOI: 10.1257/jep.23.2.29.

Tol, R. & Yohe, G. 2009. The Stern review: A deconstruction. *Energy policy*, **37:** 1032–1040; doi:org/10.1016/j.enpol.2008.11.008

Tyler, E. and Chivaka, R. 2011. The use of real options valuation methodology in enhancing the understanding of the impact of climate change on companies. *Business Strategy and the Environment*, **20:**55–70; DOI: 10.1002/bse.668.

United Nations Statistics Division (UNSD). 2011. *Millennium Development Goals indicators: Carbon dioxide emissions (CO_2)*. Available at: http://mdgs.un.org/unsd/mdg/Series Detail.aspx?srid=749&crid (accessed on 8 August 2011).

Van Zyl, H., Raimondo, J. & Leiman, A. 1999. *Working Paper 6: Energy supply sector – Coal mining.* WWF macroeconomic reforms and sustainable development in South Africa.

ANNEX 3

Estimating the opportunity cost of water For the Kusile and Medupi coal-fired electricity power plants in South Africa

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1. INTRODUCTION

Accessible and affordable water of high quality is considered to be one of the scarcest natural resources on our planet. The World Water Council (n.d.) argues this point by stressing that although the global population tripled during the 20th century, the water consumption increase was sixfold. Increasing industrialisation, including the need for more power generation, and urbanisation only add to the already burdened conditions. The most common form of power generation is also by means of coal combustion. Such combustion has various implications for water quality and quantity. Except for the direct consumptive use of water, there is also the water use requirement for coal mining, and water pollution. In this annex to the report,the focus is mainly on the consumptive use of water for power generation. The other side effects of coal mining are considered in Annex 4.

While it is important to take note of the negative side effects of coal-fired power stations, electricity in and by itself plays an extremely important role in any economy: firstly, as a supplier of an essential input to all other economic sectors and, secondly, as an employer and service provider for households. However, in South Africa, this sector has benefited greatly from the abundance of coal reserves. Therefore, the fact that the vast majority of electricity in the country is produced by coal-fired power stations is not surprising. Eskom, the country's power utility, has, however, reached its power generation supply ceiling and has therefore embarked on an infrastructure expansion programme. As part of this programme, two coal-fired power stations, Medupi and Kusile, will be added to the country's existing capacity. The overall electricity output capacity of these two plants will be about 9 528 MW (4764 MW x 2), with coal requirements of approximately 34 million tons (17 million each) per annum (Eskom, 2011) (see Annex 0 for more details).

Appreciating the concerns about water quantity, these two stations will apply dry-cooling technology in order to reduce their water consumption. They will require 0.66 m^3 of water per MWh generated (this includes water demanded for flue gas desulphurisation (FGD) and coal washing)

(Department of Energy, 2011). This is considerably lower than Eskom's average consumption rate in 2010 of 1.35m^3/MWh (Eskom, 2011). This means that the two power plants, once fully operational, will require approximately 52.3 million cubic metres per annum.[21] This amount of water will represent 14% of the total water consumption of Eskom, while Kusile and Medupi will produce 23% of the power. Medupi and Kusile will therefore, compared to older coal-fired power stations, produce more power and consume less water, and this can directly be ascribed to the technology applied by them.

However, given that water is a limiting factor to development (Blignaut & Van Heerden, 2009), the question is: What is the society-wide cost of this water consumption? This is an important question, as water's administered prices do not capture society's welfare impact due to externalities (Spalding-Fecher & Matibe, 2003). To measure this, the shadowprice is estimated as an indicator of the opportunity cost of water to society when engaging in coal-fired electricity generation.Shadow prices are usually relevant when real prices cannot represent the actual loss of welfare to society (Moolman*et al.*, 2006).

The main purpose of this annexis to estimate the opportunity cost of water for the two prospective power plants. In order to do so, the shadow priceof water has to be estimated for electricity generation, based on the technology to be used by the two power plants, and should then be compared with the shadow pricesof water, assuming that alternative technologies were employed. To do so, a literature review will first be conducted, followed by a profile of the water sector in South Africa. This will be followed by the research method, the data and the results. The final section discusses the findings and concludes this annex.

2. LITERATURE REVIEW

Literature on the environmental concerns related to the selection of different power generation technologies has been increasing over the last few years (Roth & Ambs, 2004; Feeley, *et al.*, 2008; King*et al.*, 2008). Electricity-generation power plants have an impact on the environment while being constructed, as well as while operating (generating electricity, using fuel). Spalding-Fecher and Matibe (2003) summarise the main externalities by classifying them in three categories as in Van

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[21] The number is a summation of the water requirement for both power plants. Their gross capacity of electricity is estimated to be 9 528MW, that is two power plants with six units each, and each unit has a capacity of 794MW.First the figure was multiplied by 8760 hours of the year to convert it to MWh, then multiplied by 0.95 to allow for downtime and then multiplied by 0.66m^3.

Horen (1996). Water quality issues are considered unlikely to be serious (Class 3). Water consumption and pricing are classified as being potentially serious, but not readily measurable (Class 2). Its seriousness is exacerbated by climate change-related issues, as the frequency and severity of climate-related events are likely to affect water provisioning in the future. Feeley *et al*. (2008)also argue that in the future, the competition for water will increase among water-intensive sectors such as agriculture, power generation and the residential sector. The changes in the composition of water will also be challenging for policy-makers, since this will have an impact on various aspects, such as the health of the local population and food security (Rygaard*et al.*, 2009).

An additional concern is the appropriate rates and tariffs paid for water by coal-fired power stations. Spalding-Fecher and Matibe (2003) raise the question of whether the administered water prices include the opportunity cost of water. The real costs of water should be based on the capital costs of the infrastructure, added to the operation and maintenance costs. They suggest that to achieve accuracy in the pricing of water, the opportunity cost (or shadow price) for each catchment area should be estimated. While this is not yet considered in the country, the opportunity cost of water for industries such as agriculture has been estimated (Moolman*et al.*, 2006). It has, however, not been done for the power industry. An attempt to do this will be made in this annex.

In the literature, there are three main directions towards an improvement of the water requirements for power generation. Firstly, there are studies that suggest technological advancements in order to reduce the water intensity of the current techniques of electricity generation (Feeley & Ramezan, 2003; Feeley *et al.*, 2008). Secondly, a number of studies recommend a combination of innovative technologies with regard to fossil fuel-fired power plants with a switch to renewable technologies (Larson *et al.*, 2007; Sovacool & Sovacool, 2009). Thirdly studies such as that of Von Uexkull (2004) support the notion that the only solution for the future of power generation is the switch to cleaner renewable energy technologies that are also benefiting water users. The benefits of doing so from a water perspective will be considered. Before embarking on this, the water sector in South Africa will be discussed in general.

3. THE WATER SECTOR IN SOUTH AFRICA

Water is an important consideration for all developing countries that experience shortages linked to poverty and other social challenges (Asthon & Haasbroek, 2002; Van Heerden*et al.*, 2008). On the other hand, water is considered an important natural capital resource that is becoming scarcer by the day (Aronson*et al.*, 2006), affecting the economy's growth and development. With the increasing global population, the growing water demand has become an important challenge. This predicament was mainly addressed through supply-side mechanisms (Smakhtin *et al.*, 2001),but demand-side options have also recently become available (Ashton & Seetal, 2002).

From a supply point of view, South Africa is considered a water-limited country. The average annual rainfall is 497 mm, which is much lower than the global average of 860 mm per annum[22](Turton, 2008). Only 8% of the country's rainfall is caught in dam outlets and rivers that are controlled by water authorities, and a large amount of the precipitation is lost through evapotranspiration and deep seepage (Van Heerden*et al.*, 2008). The water resources in the country are also distributed unevenly. More than 60% of the river flow comes from 20% of the land area (Department of Water Affairs and Forestry (DWAF), 1997). The groundwater is scarce, since most of the country is underlain with hard rock formations that lack major water aquifers. This fact also adds to the risks of major shortages in the case of overexploitation (DWAF, 1997).

As Blignaut and Van Heerden (2009) point out, the balance of water resources remaining for development is declining and more than 98% of the country's water has already been allocated (Turton, 2008). This decline can be attributed to demographic and socioeconomic pressures, the change in climate and the allocation of water to higher value-added industries such as the electricity sector (Blignaut*et al.*, 2009). It is expected that the available water resources will not be sufficient to meet the future water requirements, especially with the current rates of population and economic growth (Eberhardt & Pegram, 2000). This is confirmed by the fact that the country has started importing water with several catchments already in deficit (Wassung, 2010).

This increasing scarcity necessitates an investigation as to the opportunity cost of water where the opportunity cost is defined as the cost of any activity in terms of the best alternative forgone. In this case, any new development will eliminate the possibility of water use for other developments, as well as possibly seize vital water resources that have been allocated already. It is therefore important to consider to whom the water resources are allocated, and who the main consumers of water in South Africa are. According to Source: Statistics SA, 2006
Figure 5, irrigation agriculture is the biggest consumer of water in the country, consuming 62% of the water reserves. Large-scale farms use 95% of the irrigation water (Schreiner & Van Koppen, 2002). The domestic sector comes second, consuming 23% of the water. The mining and bulk industrial

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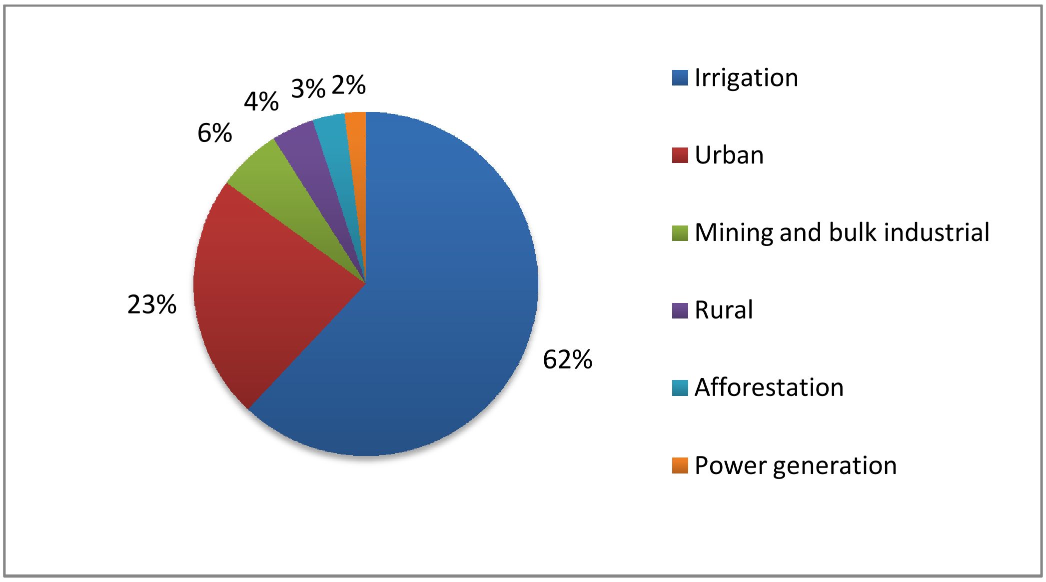
[22] For comparison purposes in the same geographic area as South Africa, the annual average rainfall of Botswana is 400 mm and of Namibia 254 mm.

sectors, in combination with power generation, are responsible for 8% of the water consumption (Statistics South Africa, 2006).



Source: Statistics SA, 2006

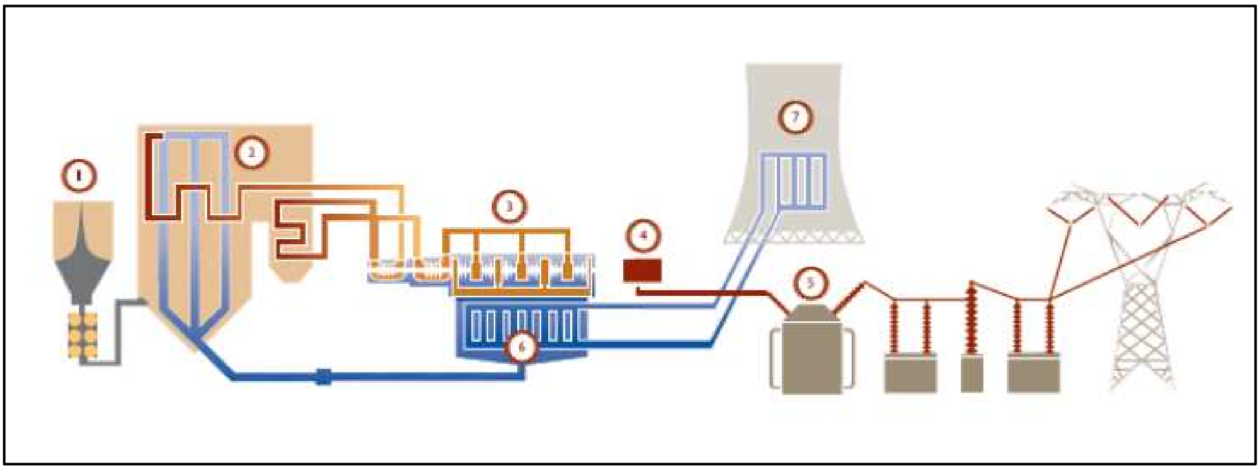
Figure 5: Water consumption per sector in South Africa in 2000

Aiming to reduce water consumption in the agricultural sector would have negative effects on the economy and society in its entirety. Blignaut *et al.*(2009) argue that drastic changes in the main water consumption will have significant implications for food security, future irrigation techniques, the methods of agricultural production, the future of land reform and the rural economy in general. However, the water use and good-quality characteristics of water in the residential sector are connected to livelihoods, health and socioeconomic development, since it cannot be substituted (Blignaut & Van Heerden, 2009). In contrast to the agricultural sector, not much water, relatively speaking, is used in the power generation sector. How is this water used? The next section will provide an answer to this question.

4. WATER USAGE IN A COAL-FIRED POWER PLANT

Having discussed the water-related concerns linked to coal combustion and the status quo of water in the country, it is imperative at this point to investigate the water requirements of coal-fired power plants and to compare the traditional technologies used by the old Eskom power plants with the two new ones. Coal-fired plants burn fuel to produce either hot air or steam in order for the turbines to generate power. This creates gases and other by-products, including air pollutants. To produce steam, large quantities of water are required from lakes, rivers, water catchments or groundwater aquifers. Usually, surface water is used for plant cooling and groundwater for the various other processes (King*et al.*, 2008; Wassung, 2010). Spalding-Fecher and Matibe,2003) mention that although Eskom's contribution to economy-wide water consumption is only 2% (Statistics SA, 2006), the requirements of certain power plants can be quite substantial in relation to the local water resources and catchments.

During the combustion of coal, the majority of water is required for two main processes: first, the internal steam cycle, and second, the cooling process. Processes that consume less water are, for example, pollution control measures. As Wassung (2010) explains (see Figure 2), "demineralised water is piped above a boiler (2) where the coal is burnt, and the heat turns the water to steam. The steam then turns a turbine (3) to generate electricity (4). As the steam passes through the turbine, it is fed into a condenser (6), which transforms the steam back into water".



Note: (1) fuel; (2) boiler; (3) steam turbines; (4) generator; (5) transmission; (6 &7) cooling systems

Source: Wassung (2010) from Eskom poster

Figure 6: Coal combustion process at a power plant

All thermoelectric power stations need a cooling process for the power generation machinery. As explained in Eskom (2010), "the turbines at coal-fired power stations are steam-driven. The steam is produced using highly purified water – demineralised water. This water needs to be recovered due to the high costs involved in its production and also to save water. When the spent steam leaves the turbine, it is at a very low pressure and high volume. The temperature is at ±40°C. Steam cannot be compressed.Therefore, the only way to recover the spent steam is through condensation, ie changing the steam (vapour) into a liquid".

In South African power plants, cooling is achieved by using water through three types of systems (Eskom, 2010): wet-cooling (the most conventional type), direct and indirect cooling systems. Only a small number of power plants in South Africa use dry-cooling systems, namely Matiba, Kendal and Majuba – they are considered the largest ones of this kind in operation internationally (Eskom, 2010). The country's only nuclear plant, Koeberg power station, uses a completely different cooling system. Kusile and Medupi are designed to have dry-cooling systems because of the scarcity of water resources.

Both wet and indirect dry-cooling systems function with condensers, cooling water and cooling towers. Condensation is achieved as a result of the temperature difference between the water that flows through the condenser tubes and the steam on the outside. Afterwards, the cooling water flows into a tower where the heat from the water is removed by an upward draft of air. After cooling, the water returns to the condenser. In a wet cooling system, the upward movement of air results in an immense loss of water (King*et al.*, 2008). Eskom (2001; n.d.) estimates that approximately 80 to 85% of the water consumed is lost due to evaporation.

The indirect dry-cooling system operates in a similarly way to a car radiator: "Heat is conducted from the water by means of A-frame bundles of cooling elements arranged in concentric rings inside the tower. Cooling water (clean water) flowing through these elements cools down as the cold air passes over them and returns to the condenser. This is referred to as a closed system, as there is no loss of water due to evaporation." (Eskom, 2010). On the other hand, the dry-cooling system does not make use of cooling towers. "The heat is conducted from the steam to the metal of the heat exchanger. Air passing through the exchanger is supplied by a number of electrically driven fans. The air removes the heat, thus condensing the steam back into water, which will be used once again to produce steam in the boiler." (Eskom, 2010). Operating the power plant in this way, however, implies the use of power and hence the net capacity available for transmission is less than the gross capacity of the power plant. For Kusile and Medupi, this use, among others, is captured by the difference between their gross capacity of 794 MW and their net capacity of 723 MW.

The difference in water requirements between direct and indirect dry-cooling systems is substantial. The water needed for the dry-cooling process is 0.160 m^3/MWh of electricity sent out. In addition to this, water for coal washing (0.150 m^3/MWh) and, if necessary, carbon capture and storage (CCS) (0.100m^3/MWh) should be added. This brings the total requirement to 0.410 m^3/MWh (Department of Energy, 2011). A process known as flue gas desulphurisation (FGD)[23] – remoing the sulphur content from the gaseous emissions – will increase this requirement (an extra 0.250 m^3/MWh is needed) to 0.66 m^3/MWh. This requirement, although considerable, is almost half the average of South African power stations of 1.35 m^3/MWh of electricity sent out in 2010 (Eskom, 2011). Figure 3 illustrates the inputs and outputs of a coal-fired power generation process.

Coal ➔	Coal combustion	➔ Electricity
Chemicals/materials ➔	↓	➔ Emissions to air
Water ➔	Coal combustion product	➔ Emissions to water
Energy and fuel ➔		➔ Emissions to land

Source: Heath *et al.,*2009

Figure 7: Inputs and outputs of coal-fired power generation

It can be seen that water is considered an input and also an externality of the generation in the form of pollution. With regard to water as input for generation purposes, the use of a dry-cooling process can lower the effect on the region's water quantity as explained above. The use of a flue gas desulphurisation (FGD) process is also an assisting factor to the water situation. However, the use of FGD will generate considerable volumes of effluent from the gypsum washing and dewatering process. This wastewater would have a high heavy metal, nitrate and chloride content. Having mentioned that, the quality of water should be taken into account (see Figure 3, outputs of coal-fired generation).

According to Ninham Shand (2007), the new power stations will not influence substantially the quality of the regional water supply because they will operate under Eskom's Zero Liquid Effluent Discharge (ZLED) policy. This policy was first adopted in 1987 in order to prevent the pollution of water resources. The main purpose of this policy is to ensure that the quality of water discharged into the receiving bodies should be at least as good as before it was used (Spalding-Fecher & Matibe, 2003). Pather (2004) states as follows: "cascading the water from higher quality to lower quality uses enables extensive re-use. Where possible, water is lost only through evaporation, retaining the accompanying dissolved and suspended solids." However, the ZLED policy will only become effective

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[23] The FGD process is a technology aiming at removing the SO_2 emissions that are mainly responsible for acid rain and causes substantial deterioration of water quality.

when the all the power units are fully operational. The overall expected result from this is no conscious discharge of pollutants into existing water resources or riparian zones. It should be noted that ZLED is a policy implemented through different technologies, depending on the specific power plant. No formal evaluation of the policy has been published yet.

5. RESEARCH APPROACH AND MATERIALS

5.1. Methodology

To determine the true scarcity value of the water, one has to estimate its shadow price and, in doing so, compare the shadow prices of water using different technologies. The way in which we propose to estimate the shadow price reveals the net marginal revenue of water, ie the additional revenue generated by using a cubic metre of water. The higher the net marginal revenue (NMR), the more efficiently water is used, ie the greater the marginal value of the water. The difference between the net marginal revenues is the opportunity cost of using one technology above the other. This approach has successfully been applied within the agriculture sector in Moore and Dinar (1995), Moore (1999) and Moolman *et al.*, (2006). According to Moolman *et al*. (2006), for example, the NMR of sugar cane is several orders of magnitude lower than mangoes. The opportunity cost, from a water perspective, of planting sugar cane is the difference between mangoes and sugar; that is the forgone value (opportunity cost) of using water on sugar rather than on mangoes.

The main focus of this annex is the opportunity cost of water in the Kusile and Medupi power plants. To do so, and in accordance with Moore (1999), a panel data analysis is used. The logic behind the use of a revenue function lies in the literature that estimates water as a fixed input (Moore, 1999). Owing to the fact that water prices are set as administrative prices, they serve neither a rationing nor an allocating function (Moore, 1999; Rausser & Zusman, 1991). Two earlier studies (Moore & Dinar, 1995; Kanazawa, 1993) confirmed the hypothesis that water is a quantity-rationed input and revenue function models water appropriately. According to Moolman*et al.*(2006), the marginal revenue function for water is obtained from the total revenue function. The revenue function is estimated by using a production function approach. The total revenue of electricity is a function of the price of the product (electricity), the quantity of water consumed for the generation of electricity and a number of other variables, such as the total expenses for the use of necessary coal per power plant. In our case, the total revenue is calculated by multiplying the price of electricity with the quantity of the net electricity sold per power plant and, hence, neither of them can be included as an explanatory variable. Therefore, the total revenue function is defined as follows:

Equation 1

$$\mathbf{TR = TR(water, total\ expenses)}$$

where TR is the *total revenue* calculated by multiplying the net quantity of electricity supplied with the price of electricity, *water* is the water used in electricity generation, and *total expenses* is the overall costs of each power plant for coal (price of coal times the quantity of coal) plus other operational costs when we estimate the model assuming coal-fired power plants; or total expenses is the sum of fixed and variable costs with regard to the electricity generation of alternative options, such as solar, wind or biomass. The total revenue function is estimated using a quadratic functional form as proposed by Moore (1999). This form is defined as follows:

Equation 2:

$$\begin{aligned}\mathbf{TR} = \boldsymbol{\alpha} + \sum_{\mathbf{i=1}}^{\mathbf{m-1}} \boldsymbol{\beta}_{\mathbf{i}}\mathbf{totalexpenses}_{\mathbf{i}} + \boldsymbol{\beta}_{\mathbf{w}}\mathbf{water} \\ + \sum \boldsymbol{\beta}_{\mathbf{ij}}\mathbf{totexpenses}_{\mathbf{i}} * \mathbf{totalexpenses}_{\mathbf{j}} + \boldsymbol{\beta}_{\mathbf{ww}}\mathbf{water}^{\mathbf{2}} \\ + \sum \boldsymbol{\beta}_{\mathbf{w\ totalexpenses_i}}\mathbf{water}_{\mathbf{i}} * \mathbf{totalexpenses}_{\mathbf{i}}\end{aligned}$$

Equation 3

$$\sum_{\mathbf{i=1}}^{\mathbf{m-1}} \boldsymbol{\beta}_{\mathbf{i}}\mathbf{totalexpenses} = \boldsymbol{\beta}_{\mathbf{i}} * \mathbf{totalexpenses}_{\mathbf{i}} + \boldsymbol{\beta}_{\mathbf{j}} * \mathbf{totalexpenses}_{\mathbf{j}}$$

Equation 4

$$\sum \boldsymbol{\beta}_{\mathbf{ij}}\mathbf{totalexpenses} * \mathbf{totalexpenses}_{\mathbf{j}} = \boldsymbol{\beta}_{\mathbf{i}} * \mathbf{toalexpenses}_{\mathbf{i}}^{\mathbf{2}} + \boldsymbol{\beta}_{\mathbf{j}} * \mathbf{totalexpenses}_{\mathbf{j}}^{\mathbf{2}}$$

Equation 5

$$\sum \mathbf{water} * \mathbf{totalexpenses} = \boldsymbol{\beta}_{\mathbf{w\ totexc,med}}\mathbf{w}_{\mathbf{med}} * \mathbf{totexc}_{\mathbf{med}} + \boldsymbol{\beta}_{\mathbf{w\ totexc,kus}}\mathbf{w}_{\mathbf{kus}} * \mathbf{totexc}_{\mathbf{kus}}$$

where *i* denotes Kusile power plant or its hypothetical (renewable) equivalent and *j* denotes Medupi power plant or its hypothetical (renewable) equivalent.

The marginal revenue function of water determines the unit cost as the opportunity cost. As noted above, the marginal revenue function for water is derived as in Moore and Dinar (1995):

Equation 6

$$\boldsymbol{\lambda\,(\mathbf{totexc},\mathbf{w}) = \beta_{w} + 2\,\beta_{ww}\mathbf{w_i} + \sum \beta_{w\,totexc}\mathbf{totexc_i}}$$

Equation 7

$$\boldsymbol{\sum \beta_{w\,totexc}\mathbf{totexc_i} = \beta_{w\,totexc_{med}}\mathbf{totexc_{med}} + \beta_{w\,totexc_{kus}}\mathbf{totexc_{kus}}}$$

5.2. Data

Since neither of the two power plants is currently operating, only projected information on the variables can be used. Hence, the data used is based on collected information from various reports describing the two power stations and assumptions in order to estimate the time series for a period of 20 years.

Six models will be estimated to calculate the differences between the chosen technology for the two power plants (baseline) and five alternative options. The models are as follows:

- Baseline: dry-cooling process, with FGD, as proposed for Medupi and Kusile
- Alternative 1: dry-cooling process without FGD
- Alternative 2: conventional wet-cooling South African power plant using Eskom's average (2010) water consumption figures
- Alternative 3: concentratedsolar power (CSP) with parabolic trough
- Alternative 4: wind
- Alternative 5: forest residue biomass

For each of these models the assumptions are as follows:

Total revenue=price of electricity x quantity of electricity sold (net quantity of electricity)

- **Price of electricity:** The real average price for Year 1 is assumed to be the same as the average 2010 price, which was equal to R0.416/kWh (Eskom, 2011). For the rest of the sample, the base case scenario of the Integrated Resource Plan (IRP) of Electricity 2010 (RSA, 2011) is followed. It is noted here that according to this estimation, the real average price for electricity will decrease slightly after it reaches the ceiling of R1/kWh. We use the IRP time series, although it might not be necessarily viable.

- **Quantity of electricity:** In the Medupi power plant, only one unit is assumed to be operational in Year 1. According to the Eskom annual report of 2008 (Eskom, 2009), an extra two units will be operational in Year 2, another one in Year 3 and another two in Year 4.In the Kusile power plant, one unit will be operational every eight months, according to Eskom(Eskom, n.d). For this study, the frequency of the data is annual, so the assumption is that one extra unit becomes operational every year. The gross capacity per unit is 794MW for Medupi and Kusile (Eskom, 2011), but their net capacities (after deductions for internal use) is 723MW (Eskom, personal communication). Furthermore, the amount of electricity that can finally be supplied by each unit is equal to its net capacity times its load factor (85%).

  For the solar and wind alternatives, the net production of electricity is calculated as the gross quantity produced multiplied by their load factors: 43% and 29%, respectively (RSA, 2011). For biomass, the net production takes into account that 10% of the production is used within the power plant and from this only 85% (load factor) is finally sent out for consumption.

Total expenses for coal=price of coal times quantity of coal

- **Price of coal:** The information is derived from the Quantec database (Quantec, 2011) and the series is called *Local sales: Coal (Unit: Rand/ton)*. For the first year, the price of coal is assumed to be equal to the average 2010 price (January to December) and for Year 2, the estimated average price of coal for 2011. For Year 3 to Year 7 it will be a two-year moving average, From there onwards until the end of the sample, we assume that the price of coal will increase by 2% every year, thus capturing the increasing resource shortage.

- **Quantity of coal:** According to the report by the African Development Bank (AfDB) (2009), the coal requirement will be 17 million tons per annum once the overall project is functioning. Hence, it can be assumed that one functioning unit will require 2.8 million tons per annum. In the first years the requirements will be dependent on the number of operational units. After that it remains the same.

Operational, fixed and variable costs

- **Coal-fired:** Other operational costs are also taken into consideration for the baseline and the first two alternatives (coal-fired technology). In Eskom'sannual report for 2011, the operational costs per kWh for 2010 were said to be 28.23 cents, to which we added the amortisation costs of the new power plants.[24] Hence, the operational cost ratio is multiplied with the amount of electricity produced for each year.

- **Solar:** The fixed operating and maintenance cost for this type of technology is R635 000 MW per year (RSA, 2011), to which we added amortisation costs, assuming a technology of concentrated solar power (CSP) parabolic trough with nine hours of storage capacity. This ratio is multiplied with the amount of electricity sent out by the hypothetical solar power plant.

- **Wind:** The fixed operating and maintenance cost for this type of technology is R266 000 MW per year (RSA, 2011) plus amortisation costs. This ratio is multiplied with the amount of electricity sent out by the wind power plant.

- **Forest residue biomass:** The fixed operating and maintenance cost for this type of technology is R972 000 a year (RSA, 2011) plus amortisation costs. The variable operating and maintenance costs for such a technology are R31.1/MWh a year. This ratio is multiplied with the amount of electricity sent out.

Water requirements

The water consumption differs substantially from technology to technology. Table presents the assumed water requirement ratios per unit of electricity produced for the different alternatives. We multiply these by taking into account that a power plant is not used at its full capacity, ie there is an underutilisation of 5%.

Table 16: Water requirements for each of the alternatives

Technology	Water requirement	Source
Baseline: Dry cooling process with 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

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[24] The amortization costs present the linear depreciation of the capital cost over 50 years.

Technology	Water requirement	Source
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

Notes:
* Carbon capture and storage (CCS) is a new technology that has not been tried or implemented yet
**Dry-cooling CSP is assumed here for comparison purposes (to the baseline)

6. EMPIRICAL RESULTS

The study uses a panel data set for 20 years, not linked to calendar years, with two cross-sections, namely Kusile and Medupi. The only restriction in the estimation is that, according to theory, the marginal revenue function of water (Equation 7) should be positive. Hence, as Moolman *et al.* (2006) suggest, the function should have a negative slope and a positive intercept. Limited cross-section heterogeneity is present, so pooled effects are also considered, but based on Moore and Dinar (1995), we should allow for variation in some of the factors of the components of the estimation and hence we proceed with a seemingly unrelated regression (SUR). The problem of hetereroskedasticity in the estimation was corrected by using White's cross-section heteroskedastic structure on the error term. The results of the baseline estimation are presented in Table 2.

Table 17: Baseline results

Dependent variable: total revenue				
Total pool (balanced) observations: 40				
Variable	**Coefficient**	**Standarderror**	**t-Statistic**	**Problem**
WATER	0.00100	0.00049	2.02546	0.0512
$WATER^2$	-1.17E-10	0.00000	-3.35963	0.0020
TOTALEXPENSES_KUS	-0.74343	0.67089	-1.10812	0.2761
TOTALEXPENSES_MED	-0.86218	0.72696	-1.18601	0.2444
$TOTALEXPENSES\_KUS^2$	-0.00013	0.00003	-4.02579	0.0003
$TOTALEXPENSES\_MED^2$	-0.00013	0.00003	-4.12669	0.0002
TOTALEXPENSES_KUS*WATER_KUS	0.00000	0.00000	4.25711	0.0002
TOTALEXPENSES_MED*WATER_MED	0.00000	0.00000	4.50861	0.0001
Rsquared	0.989	Mean dependent variable		26883.950
Adjusted Rsquared	0.986	SD dependent variable		9251.171
SE of regression	1078.609	Akaike info criterion		16.982
Sum squared resid	37228729.000	Schwarz criterion		17.319
Log likelihood	-331.632	Hannan-Quinn criterion		17.104
Durbin-Watson stat	1.084			

The adjusted Rsquared of 0.986 gives the indication that the model is a good fit to the data. The coefficient of water squared should be negative, based on economic theory, because it determines the slope of the marginal revenue function. In this estimation, the coefficient is equal to -1.17e-10 and statistically significant at the 1% level of significance confirming our *a priori* expectations. All the coefficients of the interaction variables (the ones containing water) that affect the intercept of the marginal revenue function are also all significant at the 1% level of significance and their combination yields a positive intercept. The function, therefore, is in accordance with economic theory.

It is now possible to firstly construct the *lamda* functions for both power plants and subsequently substitute the figures for Year 15 of our sample. The reason why Year 15 is chosen is because it is towards the end of the sample and the two power plants will have reached their full capacity (after Year 6, both plants are expected to be fully operational). From this point of the analysis onwards, we will proceed by discussing only one power plant because in Year 15 the two power plants will be identical. So, the *lamda* function of the baseline scenario is as follows:

Equation 8

$$\lambda = 0.001001 + (-2.34\mathrm{E} - 10) * \mathrm{water} + 2.87\mathrm{E} - 07 * \mathrm{totalexpenses_i} + 2.87\mathrm{E} - 10 * \mathrm{totalexpenses_j}$$

By substituting the values for water and total expenses for power plant *i* (Kusile) and *j* (Medupi), we find that λ is equal to R0.0097mil/m^3. With exactly the same approach as in the previous section, we estimate the models for the five alternatives. A summary of the total revenue regressions for all the alternatives considered is presented in Table 3.

Table 18: Summary of total revenue functions of alternatives

Dependent variable: total revenue	Alternative 1 Without FGD	Alternative 2 Conventional	Alternative 3 Solar	Alternative 4 Wind	Alternative 5 Biomass
WATER	-0.000791	-0.00024	-0.003372	-0.388829	-0.004101
WATER^2	-1.57E-10	-1.44E-11	-4.13E-10	-1.13E-06	-1.14E-10
TOTALEXPENSES_i	1.43E+00	1.28E+00	3.02E+00	7.92E+00	7.53E+00
TOTALEXPENSES_j	1.27575	1.434426	3.165621	8.164694	8.007294
TOTALEXPENSES_i^2	-0.000132	-1.26E-04	-3.36E-04	-1.98E-03	-6.36E-04
TOTALEXPENSES_j^2	-0.000126	-1.32E-04	-0.000351	-0.00207	-0.000692
TOTALEXPENSES_i*WATER_i	3.29E-07	9.97E-08	9.41E-07	1.77E-04	6.68E-07
TOTALEXPENSES_j*WATER_j	3.28E-07	1.00E-07	9.48E-07	1.79E-04	6.81E-07

Note: *i* denotes a power plant equivalent to Kusile and *j* equivalent to Medupi

Based on the above estimations, Table presents the λ (*lamda* – net marginal revenue) calculated for each alternative in column 1, column 2 shows the difference between each alternative with the baseline. Column 3 presents the water consumption for the baseline and each alternative in cubic metres, while column 4 shows the net generation output of electricity in MWh. Column 5 presents the overall societal loss or gain by alternative, while column 6 shows the opportunity cost or the forgone revenue per unit of electricity expressed in R/kWh.

Table 19: Shadow prices for each of the alternatives

		-1	*-2*	*-3*	*-4*	*-5*	*-6*
Year 15 **(=from Year 4 onwards)**		**λ** **NMR of water**	**Difference**	**Water volume**	**Net generation output**	**Society-wide loss or gain***	**Opportunity cost****
		R/m3	*R/m^3*	*m^3*	*MWh*	*Rmillion*	*R/kWh*
Baseline		9 717		26 166 365	32 300 748		
Alternative 1	No FGD	11 149	-1 432	16 254 863	32 300 748	-23 278	-0.72
Alternative 2	Conventional	3 399	6 318	53 522 111	32 300 748	338 154	10.47
Alternative 3	Solar	14 667	-4 949	5 405 495	18 237 164	-26 753	-0.83
Alternative 4	Wind	930 736	-921 018	45 989	12 102 466	-42 357	-1.31
Alternative 5	Biomass	11 210	-1 493	14 272 563	31 925 470	-21 305	-0.66

Notes:

* Societal loss is calculated as the difference (column 2) times the water volume (column 3), divided by a million.

** Opportunity cost is calculated as the societal loss (column 5) divided by the net generation output of the baseline (column 4) (32,3 TWh) times 1 000

From this table (and especially column 2), we can see that only the conventional generation of electricity has net marginal revenue (NMR)lower than the baseline, as could have been expected. The negative signs in column 2 show that for every cubic metre that is used, the forgone revenue is R1 432 (alternative 1), R4 949 (alternative 3), R921 018 (alternative 4) and R1 492 (alternative 5). Column 6 shows the opportunity cost in R/kWh. For example, in the case of using solar instead of a dry cooling coal-fired generating process, for every kWh of electricity sent out, the forgone revenue is equal to R0.83, which subsequently can be converted to R26.7 billion per annum if the production of electricity is equal to 32.3 million MWh per annum. Hence, embarking on a non-renewable pathway equates to a significant societal loss (between R21billion and R42billion per year) and opportunity cost (between R0,66/kWh and R1,31/kWh). It should be noted that converting to dry-cooling implies a societal gain of R340billion per annum relative to conventional coal-fired power stations.

7. DISCUSSION AND CONCLUSION

South Africa is a country that is characterised as being prone to suffering from chronic water shortages. With about 98% of South Africa's available water already allocated, all new water allocations should only be made after taking the greatest degree of care that the water is put to best socioeconomic use. Amidst the already impaired water conditions of the country, the electricity sector uses large amounts of water for generation purposes. Eskom’s new infrastructure programme includes the building of two new power stations, Medupi and Kusile, which will be fully operational in the next five to six years.

Water, however, is not traded in the market. The water price, or better still, the water tariff (since it is an administered price) reflectsneither the scarcity of water nor the socioeconomic cost of erroneous allocation of water to suboptimal applications. The water tariff, therefore, does not have any signalling power. To aggravate matters, the water tariff is only in rare cases reflective of the full cost of delivering the water – although that is an ideal Government is aspiring to. The water tariff, therefore, cannot be used in any form of economic analysis. However, the real economic value of water should be sought locked in an industrial or economic process.

To determine the true scarcity value of water, one has to estimate its shadow price and, in doing so, compare the shadow prices of water using different technologies. The way in which we estimated the shadow price reveals the net marginal revenue of water, i.e. the additional revenue generated by using a m^3 water. The higher the net marginal revenue (NMR), the more efficiently water is used. The difference between the net marginal revenues is the opportunity cost of using one technology above the other.

The baseline presents the chosen technology for the two power plants: a dry cooling process with FGD. The other alternatives include dry cooling process without FGD (Alternative 1), conventional wet-cooling process (Alternative 2), solar (Alternative 3), wind (Alternative 4) and biomass (Alternative 5). By using a production function approach, it was possible to estimate the opportunity cost of water. The only alternative that performs worse than the baseline, as expected, is the traditional wet-cooling process used by the majority of South African power stations. The renewable forms of electricity generation selected for comparison (solar, wind and biomass) use substantially lower amounts of water and hence the results show high opportunity costs of not considering the alternatives, ranging from R0,66/kWh (biomass) to R0,83/kWh (solar) to R1,31/kWh (wind).

8. REFERENCES

African Development Bank (AfDB). (2009). Executive summary of South Africa: Environmental impact assessment for the Medupi power plant project of Eskom.Available at: http://www.afdb.org/fileadmin/uploads/afdb/Documents/Environmental-and-Social-Assessments/ESIA%20Ex%20Summary%20of%20Medupi%20Coal%20Power%20Plant%20July%201%20revised%20Final-ram-1.pdf (accessed on 7 August 2011).

Aronson, J., Blignaut, J. & Milton, J.C. 2006. Natural capital: the limiting factor. *Ecological Engineering,* **28:**1–5.

Ashton, P. & Seetal, A. 2002. Challenges of water resource management in Africa. African Renais-Science Conference.Durban, South Africa.

Asthon, P. & Haasbroek, B. 2002. Water demand management and social adaptive capacity: A South African case study. In *Hydropolitics in the developing world: A southern African perspective*(Ed. A.H. Turton). African Water Issues Research Unit (AWIRU) and International Water Management Institute (IWMI).

Blignaut, J. & Van Heerden, J. 2009. The impact of water scarcity on economic development initiatives. *Water SA,* **35(4):**415–420.

Blignaut, J., Ueckerman, L. & Aronson, J. 2009. Agriculture production's sensitivity to changes in climate in South Africa. *South African Journal of Science,* **105:**61–68.

Dennen, B., Larson, D., Lee, C., Lee, J. & Tellinghuisen, S. 2007. *California's energy-water nexus: Water use in electricity generation.* Santa Barbara: Donald Bren School of Environmental Science and Management University of California.

Department of Energy. 2011. *Water – 2010 input parameter data (externality).* Pretoria, South Africa: South African Department of Energy.

Department of Water Affairs and Forestry (DWAF). 1997. *Overview of water resources availability and utilisation in South Africa.* Pretoria, South Africa: Department of Water Affairs and Forestry (DWAF).

Eberhardt, R. & Pegram, G. 2000. *The water sector.* Midrand, South Africa: Development Bank of Southern Africa (DBSA).

Eskom. 2001. *Eskom Environmental report 2000.* Pretoria, South Africa: Eskom.

Eskom. 2009. *Annual report 2008.* Johannesburg, South Africa: Eskom.

Eskom. 2010. Cooling techniques at Eskom power stations.Available at: http://www.eskom.co.za/content/CO_0005CoolingTechnRev7~1.pdf (accessed on 7 July 2011).

Eskom. 2011. *Eskom integrated report 2011.* Johannesburg, South Africa: Eskom.

Eskom. n.d.a. Kusile power station. Available at: http://www.eskom.co.za/c/article/58/kusile-power-station/ (accessed on 7 July 2011).

Eskom. n.d.b. Water management.Available at: http://www.eskom.co.za/c/article/240/water-management/ (accessed on 7 July 2011).

Eskom. n.d.c. Medupi power station.Available at: http://www.eskom.co.za/c/article/57/medupi-power-station/ (accessed on 11 July 2011).

Feeley, T. & Ramezan, M. 2003. Electric utilities and water: Emerging issues and R&D needs. Water Environment Federation, 9th Annual Industrial Wastes Technical and Regulatory Conference. San Antonio.

Feeley, T., Skone, T., Stiegel, G., McNemar, A., Nemeth, M., Schimmoler, B., et al. 2008. Water footprint of bio-energy and other primary energy carriers. *Energy,* **33:**1–11.

Heath, R., Van Zyl, H., Schutte, C. & Schoeman, J. 2009. *First-order assessment of the quantity and quality of non-point sources of pollution associated with industrial, mining and power generation.* Pretoria: Water Research Commission South Africa.

Kanazawa, M. 1993. Pricing subsidies and economic efficiency: The US bureau of reclamation. *Journal of Law and Economics,* **36:**205–234.

King, C., Holman, A. & Webber, M. 2008. Thirst for energy. *Nature Geoscience,* **1:**283–286.

Larson, D., Lee, C., Tellinghuisen, S. & Keller, A. 2007. California's energy-water nexus: Water use in electricity generation. *Southwest Hydrology,* **Sept–Oct:**20–22.

Macknick, J., Newmark, R., Heath, G. & Hallett, K. 2011. *A review of operational water consumption and withdrawal factors for electricity-generating technologies.* Washington DC: National Renewable Energy Laboratory (NREL), US Department of Energy.

Moolman, C., Blignaut, J. &Van Eyden, R. 2006. Modelling the marginal revenue of water in selected agricultural commodities: A panel data approach. *Agrekon,* **45(1):**78–88.

Moore, M. & Dinar, A. 1995. Water and land as quantity-rationed inputs in California agriculture: Empirical tests and water policy implications. *Land Economics,***74(4):**445–461.

Moore, M. 1999. Estimating irrigators' ability to pay for reclamation water. *Land economics,* **75(4):**652–578.

Ninham Shand. 2007. *Proposed coal-fired power station and associated infrastructure in the Witbank area: Final environmental impact report. Report No 4284/401281.* George, South Africa: Eskom.

Pather, V. 2004. Eskom and water. *Proceedings of the 2004 Water Institute of Southern Africa (WISA) Biennal Conference*. Cape Town, South Africa, pp. 659–664.

Quantec. 2011. *Quantec: Mineral statistics*. Pretoria: Quantec.

Rausser, G. & Zusman, P. 1991. Organizational failure and the political economy of water resources management. In *Economics and Management of water and drainage in agriculture*(Eds. A. Dinar & D. ZIlberman). Boston: Kluwer Academic Publishers.

Republic of South Africa (RSA). 2011. Integrated Resource Plan 2010-2030. *Government Gazette.*Pretoria: Government Printers.

Roth, I. & Ambs, L. 2004. Incorporating externalities into a full-cost approach to electric power generation life-cycle costing. *Energy,* **29:**2125–2144.

Rygaard, M., Arvin, E. & Binning, P. 2009. The valuation of water quality: Effects of mixing different drinking water qualities. *Water Research,* **43:**1207–1218.

Schreiner, B. & Van Koppen, B. 2002. Catchment management agencies for poverty eradication in South Africa. *Physics and Chemistry of the Earth,* **27(11–22):**969–976.

Smakhtin, V., Ashton, P., Batchelor, A., Meyer, R., Maree, J., Murray, M., et al. 2001. Unconventional water supply options in South Africa: Possible solutions or intractable problems? *Water International,***26(3):**314–334.

Sovacool, B. & Sovacool, K. 2009. Identifying future electricity-water tradeoffs in the United States. *Energy Policy,* **37:**2763–2773.

Spalding-Fecher, R. & Matibe, D. 2003. Electricity and externalities in South Africa. *Energy Policy,* **31:**721–734.

Statistics South Africa. 2006. *Water resource accounts for South Africa: 1995-2000.* Pretoria, South Africa: Statistics South Africa.

Turton, A. 2008. Three strategic water quality challenges that decision-makers need to know about and How the CSIR should respond. CSIR Conference: Science Real and Relevant. Pretoria, South Africa.

Van Heerden, J., Blignaut, J. & Horridge, M. 2008. Integrated water and economic modelling of the impacts of water market instruments on the South African economy. *Ecological economics,* **66:**105–116.

Van Horen, C. 1996. *Counting the social costs: Electricity and externalities in South Africa*. University of Cape Town Press and Elan Press, Cape Town.

Von Uexkull, O. 2004. Energy and water: The ignored link. *Refocus,* **March–April:**40–44.

Wassung, N. 2010. *Water scarcity and electricity generation in South Africa. Part 1: Water use in the coal-to-electricity process.* Thesis, MPhil degree in Sustainable Development, University of Stellenbosch, School of Public Management and Planning, Stellenbosch, South Africa.

World Water Council. n.d. World Water Council: Water crisis. Available at: http://www.worldwatercouncil.org/index.php?id=25 (accessed on 7 August 2011).

ANNEX 4

The external costs of coal mining: the case of collieries supplying Kusile power station

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1. INTRODUCTION

Cheap coal and electricity are considered to be comparative advantages for the South African industry (Department of Energy, 2010). However, the mining, transportation and combustion of coal for the purposes of electricity generation have harmful environmental and health effects that are not only borne by South African society, but by people around the world. Some of these include the impact of air pollution on human health, the effect of climate change, and the environmental impact on water quality and biodiversity. South African researchers have been investigating a number of these effects and their associated external costs, with the emphasis on the combustion process (Van Horen, 1997; Blignaut & King, 2002; Spalding-Fecher *et al*., 2000; Spalding-Fecher & Matibe, 2003).

In the past, researchers have noted that the entire coal fuel cycle is associated with dire impacts on both the environment and human health. They have therefore called for the consideration of all stages in the life cycle of coal-based electricity supply, including coal mining, processing and transportation (Bjureby *et al*., 2008; Mishra, 2009; Epstein *et al*., 2011). The consideration of all stages, instead of focusing only on coal combustion, is paramount to revealing the true cost of coal-based electricity generation and is necessary to inform public policy and private investment (Bjureby *et al*., 2008; Epstein *et al*.,2011).

More research on the environmental and health costs of coal mining and transportation in South Africa is therefore needed (Munnick et *al*., 2009Both ENDS, 2011). Furthermore, most of the studies are relatively old and need to be updated (for example, Van Horen, 1997; Van Zyl *et al*., 1999; Goldblatt *et al*., 2002). There are also no studies in the country that extensively quantify the external costs of transporting coal to a power station.

This annex to the report wishes to advance the understanding of the measurable and quantifiable external costs of coal mining and transportation by quantifying these costs in relation to the Kusile coal-fired power station, which is currently being constructed in Emalahleni. An overview of the coal mining industry in South Africa and a profile of the collieries that supply the Kusile power station are presented in Annex 0 and will not be discussed here. Section 2 discusses the various externalities associated with coal mining, followed by a review of local and international research on coal mining externalities in Section 3. The research approach and data used in this study are presented in Section 4. The findings of the study are presented in Section 5 and are discussed in Section 6, while the last section concludes the study.

2. THE ENVIRONMENTAL AND HEALTH IMPACTS ASSOCIATED WITH COAL MINING

Coal mining is associated with a number of health and environmental hazards. Generally, coal mining stresses the environment during the extraction, beneficiation and transportation of coal to a power station (Mishra, 2009). Humans can also be negatively affected in the coal fuel chain through exposure to harmful pollutants, and injuries and fatalities. The main impacts associated with coal mining include climate change impacts from greenhouse gas (GHG) emissions, human health burdens due to air pollution, fatalities and injuries due to coal mining and transportation, water pollution, and impacts related to land use (see Table 1).

Table 1: Coal mining and transportation impacts

Activity	**Accidents**		**Air pollution**		**GHG emissions**	**Damage to roads**	**Biodiversity**	**Water quality**
	Morbidity	Mortality	Morbidity	Mortality				
Coal mining	✓	✓	✓	✓	✓		✓	✓
Beneficiation							✓	✓
Coal transportation	✓	✓	✓	✓	✓	✓	✓	

Air pollution in coal mines is mainly caused by emissions of particulate matter, coal dust, burning discard dumps, underground fires (Goldblatt *et al.*, 2002) and methane (CH_4) emissions – a GHG that is released during coal extraction when coal seams are cut (Singh, 2008; National Research Council, 2009). Besides posing a health hazard to the exposed population, the GHGs contribute to global warming. The main operations that produce dust and gases in mines are blasting, drilling, hauling, crushing and transportation. Air pollution is more of a problem in opencast mines than in underground mines, as opencast mines do not only create pollution on the mining premises, but also in the areas surrounding the mines (Singh, 2008). Coal mining is a hazardous activity that is associated with high fatality and mortality rates. Mine workers may suffer injuries or even die from rock falls, material handling, methane explosions or accidents while transporting coal. Another health-related risk emanates from noise pollution,which causes problems such as hearing loss and pneumoconiosis (Goldblatt *et al*., 2002).

Opencast mines can affect water quality through dirty mine water discharges, leachate from discard dumps or acid mine drainage. Surface water sources can be disrupted by surface mines throughincreasing runoff, reducing infiltration, which decreases groundwater recharge, and increasing sedimentation, due to vegetation removal. Surface mines also disrupt large land surface areas, displace people, impact on local biodiversity and erode the soil. Underground mining, on the other hand, may cause surface subsidence, which imposes severe damage to engineering structures (Singh, 2008).

To prepare coal for use in power stations, it is cleaned to reduce impurities. This is usually done using wet cleaning methods. This process can reduce the coal's sulphur content, but leaves behind coal slurry (a mixture of water and fine coal) that is disposed of in slurry dams (Wassung, 2010). The slurry dams are vulnerable to breaching and collapsing during heavy precipitation. As a result, they become significant contributors to water contamination and may even pose a threat to the natural environment. Some of the chemicals used and generated in processing coal are known to be carcinogenic and some cause heart and lung damage (Epstein *et al*., 2011).

Coal transportation also produces a number of negative externalities, primarily in the form of air pollution, global warming, accidents, noise, congestion and damage to roadways (Jorgensen, 2010). The establishment of new roads impacts on local biodiversity. Coal transportation leads to both occupational and non-occupational injuries and deaths. Air pollution is a product of fossil fuel combustion in the engines of trucks and trains. The classic air pollutants emitted during transportation include sulphur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), hydrocarbons (HC), non-methane volatile organic compounds (NMVOC), lead (Pb)and particulate matter ($PM_{2.5}$). These air pollutants cause various health problems, including lung cancer,chronic respiratory disease, lower respiratory illnesses, eye irritation and bronchitis. The GHGs associated with transportation include carbon dioxide (CO_2), which is the main GHG associated with the transport sector, methane (CH_4), which is emitted in small quantities, and nitrous oxide (N_2O). Noise is caused by engines, car alarms, radios and road contact, to mention but a few. Linked to accidents are injuries, death, material damage and lost productivity (Gaffen *et al*., 2000).The state of knowledge on coal mining externalities is reviewed in the following section.

3. LITERATURE REVIEW: EXTERNAL COSTS OF COAL MINING AND TRANSPORTATION

Environmental and health impacts in the life cycle of coal (mining, transport, processing and combustion) have been assessed using a range of methods since 1982 (Mishra, 2009). The literature discloses two broad categories of methods that have been used by researchers to estimate the external costs: the abatement cost approach and the damage cost approach. The abatement cost approach uses the costs of controlling or mitigating damage as a proxy for the damage caused by an externality. On the other hand, the damage cost approach estimates the actual external burdens and assigns a monetary cost to them, using valuation techniques. The damage cost approach can be executed in either a top-down or a bottom-up manner.

The top-down approach estimates external costs of pollutants based on national or regional damages (Sundqvist, 2000). The bottom-up approach – also known as the impact pathway approach – traces pollutants and other burdens from their initial source, quantifies impacts and monetises impacts using valuation techniques, such as the contingent valuation method (for example, through directly eliciting willingness-to-pay or willingness-to-accept) or indirect valuation methods (for example, replacement cost technique, hedonic pricing method, etc.). The bottom-up approach is the most preferred approach, but it is data intensive (Sundqvist, 2002). In most developing countries such as South Africa, primary valuation studies that are linked to the environmental impacts of energy are also lacking. For this reason, researchers adjust monetary estimates of externalities from previous studies and transfer them to new contexts (ie benefit transfertechnique) (Van Horen, 1997; Spalding-Fecher & Matibe, 2003). Various researchers have therefore used a number of approaches to place a value on the impacts of coal mining, depending on the nature of the externality.

A number of international studies have attempted to quantify the external costs of coal mining and transportation (for example, Bjureby *et al*., 2008; Sevenster *et al*., 2008; Yushi *et al*., 2008; Zhu *et al*., 2008;Epstein *et al*., 2011). These studies, which are summarised in Table 2, are discussed in detail below. The aim of the discussion is to understand how the various researchers studied, quantified and monetised the environmental and health effects of coal mining and transportation.

Table 2: Summary of international studies on external costs of coal mining and transportation

Author	**Country**	**Method**	**Impacts investigated**	**Values in (year)**	**Units**	**Value**	**Value 2010-US$**
Yushi *et al.*, 2008	China	Human capital approach Willingness-to-pay Travel cost method	Coal mining: Airborne pollution Soil pollution Biodiversity loss Coal transportation: Emissions, noise Damage to roads Overloading accidents	2005	RMB/t RMB/t	69.47 50.30	**552.33** **399.92**
Epstein *et al.*, 2011	United States	Benefit transfer	Coal mining: Climate change Public healthburden Coal transportation: Public fatalities	2008	$/kWh $/kWh $/kWh	0.03–0.34 4.36 0.09	**0.03–0.35** **4.55** **0.09**
Sevenster *et al.*, 2008	Global	Benefit transfer	Mining and transportation: Air pollution (GHG and classic air pollutants)	2007	€ mil/yr € mil/t[1]	673 0.0073	**539.80** 0.0058
Bjureby *et al.*, 2008	Global	Benefit transfer	Coal mining: Climate change Human health impacts from air pollution Mining accidents	2007	€mil/yr € mil/t[2] €mil/yr € mil/t[2]	674 0.0073 161 0.0017	**540.60** 0.0058 **129.13** **0.0014**

[1&2] Calculated based on global annual coal consumption reported in Sevenster *et al.*, 2008

Yushi *et al*. (2008) estimate the environmental costs of coal mining (airborne pollution, soil pollution, damage to vegetation, etc.) and coal transportation (noise, emissions, damage to roads through overloading, overloading accidents, etc.) in China to be 69.47 and 50.30RMB/t, respectively. The authors, however, were not explicit about the step-by-step process they followed in computing the environmental cost of coal mining. They do mention that they used a combination of approaches, such as willingness-to-pay, the human capital approach and the travel cost method.

Epstein *et al*. (2011) estimate the external costs of coal mining and transportation for the Appalachia region in the United States. Impacts considered include climate change impacts from methane emissions, public fatalities due to coal transportation (rail) and the public health burden in Appalachia. Monetary values were presented in 2008 US$. The monetised impacts were normalised to per kWh of electricity produced. Climate impacts were monetised using estimates of the social cost of carbon. The following values were used: $10, $30 and $100/t of CO_2equivalent (CO_2e), and yielded the following damage costs: 0.03, 0.08 and 0.34 $/kWh. CH_4 was taken to be25 times more potent as a GHG than CO_2. Public health impacts due to mortality were valued using the value of statistical life (VSL). The central estimate used was $7.5 million in 2008 US$. When estimating the public health burden in Appalachia, the authors relied on county-level mortality rates studies for the years 1997–2005. For these years, the authors estimated the excess mortality rates in the coal mining areas of Appalachia in comparison to the national rates outside Appalachia. The excess mortality estimates were then translated into monetary costs using the VSL. This yielded a cost of 4.36$/kWh. Public fatalities due to coal transportation were calculated by multiplying the number of coal-related fatalities with the VSL. This yielded a cost of 0.09$/kWh.

Sevenster *et al*. (2008) estimate the global damage costs for various air pollutants linked to coal mining for European Union (EU) countries and non-EU countries, including South Africa. The damage estimates were for 2007. The pollutants considered were CH_4, CO_2, $PM_{2.5}$,SO_2 and NO_X. The emissions data (kg/t or g/t) was sourced from the EcoInvent 2007 database and the quantities looked almost the same for all the countries considered. Total global annual emissions were calculated by multiplying the amount of pollutant produced per ton of coal supplied at power stations by the amount of hard and lignite coal used in that specific country or region in 2007. For estimating damage costs for GHG, the authors adopted 20€/t of CO_2at 2007 for all countries as the best expert estimate. The estimate is based on marginal abatement costs. For CH_4emissions, a factor of 23 was applied to reflect the impact of methane on global warming as compared to CO_2. To calculate damage cost for local air pollutants, the authors based these estimates on damage costs per ton of emission from the EU-based New Energy Externalities Developments for Sustainability (NEEDS) project. In the NEEDS project, damage costs per ton of a specific local air pollutant were calculated based on value of life year ($VOLY_{EU}$) of €40.000. The authors adjusted this value for purchasing power parity and population ($VOLY_{WEI}$). To estimate damage costs per ton of emissions, they therefore adjusted the original per ton damages from the NEEDS project with the adjustment factor $VOLY_{WE}/VOLY_{EU}$. The damage costs per ton (€/t) obtained were 20, 460, 14.21, 3.53 and 3.25

for CO_2, CH_4, $PM_{2.5}$,SO_2 and NO_X, respectively. After multiplying these values with the amount of each pollutant emitted, an overall damage value of 673€/t was obtained.

Bjurebyet *al*. (2008), like Sevenster *et al*. (2008), conducted a global assessment. The authors quantified the annual external cost of coal mining (ie damages attributable to climate change and human health impacts from air pollution) and mining accidents. The pollutants considered were CH_4, CO_2, $PM_{2.5}$,SO_2 and NO_X. Like in the study by Sevenster *et al.*(2008), global emissions data was sourced from the EcoInvent 2007 database. Annual global damage costs were estimated for the year 2007. Damages attributable to climate change were estimated using the figure 20€/t – a value based on the approximate prevention costs for CO_2. For CH_4, a factor of 23 was applied resulting in 460€/t. To compute annual damage cost attributable to climate change in the year 2007, these values were multiplied by the estimated annual emissions. To estimate human health damages due to air pollution, the authors adjusted damage cost figures from the NEEDS project, using purchasing power parity factors. They then calculated an average value weighted with respect to population. In the NEEDS project, monetary estimatesof the health impacts from emissions of specific air pollutants were derived based on willingness-to-pay. For the damage costs of mining accidents, the authors relied on work conducted by Hirschberg *et al*. (2004). The annual external costs of coal mining and mining accidents were estimated to be €674 million and €161.28 million, respectively.

In summary, the international studies cover three main impacts related to coal mining and transportation, ie climate change impacts from GHG emissions, human health burdens due to air pollution and fatalities due to coal transportation. For climate change impacts, the most recent values used by the researchers range between \$10 and \$100/t of CO_2e based on the approximate prevention costs for CO_2 (2008 values). However, a recent study by Anthoff *et al.*(2009) shows that if one ignores equity and uncertainty, the social cost of carbon is \$41/tC (\$11.18/tCO_2)[25]. If uncertainty is taken into account but equity is ignored, the value becomes \$61.6/tC (\$16.8/tCO_2). Finally, if uncertainty and equity are both taken into consideration, the social cost of carbon becomes \$206/tC (\$56.18/tCO_2). In all of the reviewed studies, the damages are presented for a particular year, so future CO_2 prevention costs are not calculated. The literature indicates that CO_2 prevention costs are likely to double in the next decade and to increase more than ten times by mid-century (NEEDS, 2007). To estimate human health damages due to air pollution, researchers generally estimate the specific air pollutants' quantities obtained from databases and then multiply these numbers with

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[25] To convert \$/tCto \$/tCO_2, the original values in \$/tCwere divided by 3.6667

adjusted damage costs per ton of emission figures from other studies. For fatalities due to coal transportation, they generally estimate fatality rates for transportation and multiply these with the adjusted VSL or VOLY.

Finally, the externality values from the international studies were converted to 2010 US$ for comparative purposes (see last column of Table 2). However, in-depth comparisons are still hindered by the fact that the units of analysis vary between the studies (for example, some report cost per ton and some report cost per kWh). In general, the external costs of coal mining and transportation from the global studies look similar (Bjureby *et al.*, 2008; Sevenster *et al.*, 2008) due to the use of similar methodologies and the consideration of more or less similar externalities. The rest of the 2010 US$ estimates in Table 2 are compared with the outcomes of this study in Section 6.

In Africa, South Africa dominates the African coal industry, producing approximately 99% of coal on the continent (Beyond Petroleum (BP), 2010). Owing to the importance of coal to South Africa, there are studies that have attempted to quantify the external cost of coal mining. Van Zyl *et al*. (2002) estimate the climate change impact of methane emissions produced during coal mining to range between R180 million and R1.260 billion (R0.98–R 6.83/t). The 1990 national methane emissions data was used. The CO_2 damage costs used were R20, R60 and R140 per ton (1999 values) (see Table 3). The authors further estimate the impact of coal mining on the quality of water (ie damage cost estimates for sulphates) in the Emalahleni catchment to be between R8.56 million and R17.13 million (R0.12–R0.23/t). Pretorius (2009), on the other hand, estimates the water damage externality (acid mine drainage) for Eskom’s coal mining needs to be R0.38/kWh.

In contrast to the above local studies, Van Horen (1997) estimated the occupational health effects of coal mining (accidents: morbidity and mortality) to range between R16.8 and R34.5 million (R0.01–R0.02/kWh) (1994 values). Data reported by the Leon Commission of Enquiry on health and safety in South Africa’s gold and coal mines was used to estimate fatality and injury rates for coal mines supplying Eskom’s power stations. It was estimated that for every million tons of coal mined, 1.68 injuries and 0.30 fatalities occurred. The cost-of-illness approach was used to value injuries. Estimates for medical treatment costs and the opportunity costs of not working were obtained through discussions with public health practitioners. To attach an economic value to premature mortality (fatalities), the authors adjusted valuations of a changed probability of death from international studies. The adjustments were conducted to reflect differential levels of income.

Table 3: Summary of South African studies on external costs of coal mining

Author	Impact investigated	Units	Low	Central	High	1990/91	1995/96
Van Zyl *et al*., 2002 (1999 values)	Methane	R million	180	540	1260		
		R/t	0.98	2.93	6.83		
	Sulphate pollution	R million				8.56	17.13
		R/t				0.11	0.19
Van Horen, 1997 (1994 values)	Accidents (occupational)	R million	16.8	24.5	34.5		
		R/kWh	0.01	0.02	0.02		
Pretorius, 2009	Acid mine drainage	R/kWh		0.38			

External costs of road transport are estimated by Gaffen *et al*. (2000). The assessments were conducted at national level for all motor vehicles, so external cost estimates for coal transportation destined for power generation were not distinguished. Due to the lack of emissions data and its subsequent economic valuation, internationally derived figures were also used. Jorgensen (2010) also estimates the external cost of road transportation, focusing mainly on the rail mode. His study highlights the lack of data in South Africa in terms of emissions and valuation studies, among other issues. Coaltech (2009) studies various coal transportation modes that could be used by the coal industry, including coal transportation by road to Eskom's power station. The aim of the study was to test the feasibility and applicability of coal transportation modes at various distances. CO_2 emissions were the only externality quantified for coal transportation (no damage cost estimates were computed, only quantities of CO_2).

In conclusion, local studies highlight the need for more research on coal mining and coal transportation externalities. No studies have been conducted to attempt to quantify the external costs of transporting coal to a power station. In fact, the local studies seem to be relatively old and need to be updated.

4. RESEARCH METHOD AND DATA

The aim of this annex to the report is to quantify the external costs of mining and transporting coal to the Kusile coal-fired power station in Emalahleni. As highlighted above, the impacts associated with coal mining and transportation are manifold and a number of approaches have been used to place a value on the various impacts, depending on the nature of the externality. The specific impacts that are considered in this study, together with the sources of data that will enable computation of the external costs of coal mining and transportation, are presented in Table 4. The impacts investigated in this study are climate change impacts due to GHG emissions during coal mining and coal transportation, the human health effects of classic air pollutants produced during coal transportation and mining, the injuries and deaths suffered by mine workers and the public during coal mining and transportation, the impacts of water pollution due to coal mining, water consumption and the loss of ecosystem services due to coal mining.

Table 4: Coal mining and transportation impacts investigated in this study and sources of data

Impact investigated	Method	Data requirements	Data source
Coal mining climate change impacts	Benefit transfer	1. Social cost of carbon 2. Methane emission factor 3. Coal mined for Kusile 4. Methane global warmingpotential	1. Blignaut, 2011 2. Cook, 2005; Lloyd and Cook, 2005 3. Wolmarans & Medallie, 2011 4. IPCC, 2001
Coal transportation climate change impacts	Benefit transfer	1. Total diesel consumption 2. Carbon emission factor for diesel anddiesel oxidation factor 3. Social cost of carbon	1. Synergistics Environmental Services &Zitholele Consulting, 2011 2. IPCC, 1996 3. Blignaut, 2011
Accidents: mortality and morbidity (occupational and public)	Benefit transfer	1. Fatalities and injuries during coal mining and transportation 2. Monetary valuation estimates for mortality 3. Monetary valuation estimates for morbidity 4. Coal produced in various years	1. Department of Minerals and Energy, 2008, 2010 2. AEA Technology Environment, 2005; NEEDS, 2007 3. Van Horen, 1997 4. WCA, 2006, 2007, 2008, 2009
Water pollution	Benefit transfer	1. Coal mined for Kusile 2. Water pollution damage cost	1. Wolmarans & Medallie, 2011 2. Van Zyl *et al.*, 2002
Water consumption	Benefit transfer	1. Annual water requirements for mining coal for Kusile power station 2. Opportunity cost of water	1. Pulles *et al.*, 2001; Wassung, 2010 2. Inglesi-Lotz & Blignaut, 2011
Human health impact due to air pollution	Benefit transfer	1. Emission factors for various classic air pollutants 2. Damage cost estimates	1. Stone &Bennett, n.d. 2. NEEDS (2007); Sevenster *et al.*, 2008; AEA Technology Environment, 2005
Loss of ecosystem service: (loss of carbon sequestration and loss of agricultural potential)	Opportunity cost	1. Land use 2. Market price of maize and value of ecosystem goods and services in grasslands	1. Wolmarans & Medallie, 2011 2. Blignaut *et al.*, 2010
Impacts not investigated due to lack of data: noise pollution and damage to roads			

4.1 Global warming damage costs

The main GHG associated with coal mining is CH_4, a gas that gets released during coal extraction when coal seams are cut (Singh, 2008; National Research Council, 2009). The GHGs associated with transportation include CO_2, CH_4 and N_2O (Gaffen *et al*., 2000). For coal transportation, though, CO_2 is the principal GHG associated with the transportation sector. CH_4 and N_2O were also investigated.

Coal mining global warming damages

The global damage costs from methane emissions are computed as a product of the annual amount of CH_4 released in meeting Kusile's annual coal requirement and the damage cost estimate for CO_2 adjusted for inflation and to reflect the global warming potential of CH_4 compared to CO_2. The specific equation that was used to determine global warming damage costs due to CH_4 emission during coal mining ($GW_{DC(CH4)}$) is the following:

$$GW_{DC(CH4)} = (EF_{CH4} * Qcoal) * (DC_{CO_2} * GWP_{CH4})$$

where

EF_{CH4} is the emission factor of CH_4 (ie the amount of CH_4 emitted per ton of coal (kg/t));

$Qcoal$ is the amount of coal in tons destined for Kusile per year;

DC_{CO_2} is the damage cost of CO_2 (\$/t CO_2); and

GWP_{CH4} is the global warming potential of CH_4, representing the estimated climate impact expressed as an equivalent release of CO_2.

For the amount of CH_4 emitted per ton of coal in surface mines, estimates from Cook (2005) and Lloyd and Cook (2005) were used. About 17 million tons of coal will be transported to Kusile annually (Wolmarans & Medallie, 2011; Synergistics Environmental Services &Zitholele Consulting, 2011). A range of damage cost estimates for CO_2, computed by Blignaut (2011) is adopted in this study (2010 values) (ie, \$0.80/tCO_2 (low), \$15/tCO_2 (market), \$14.33 tCO_2 (median), \$24.29/tCO_2 (high), \$82.02/tCO_2 (very high) and \$112.01/tCO_2 – Stern (2007 and 2008) base value. The average market rate was computed after considering carbon prices within the European Union Emissions Trading Scheme (EU ETS) programme, prices in the voluntary carbon market and certified emissions reduction (CER) prices. The global warming potential (GWP) for CH_4 used is 23 (Intergovernmental Panel on Climate Change (IPCC), 2001).

Coal transportation global warming damages

To calculate the global damage costs of CO_2 emissions emitted during coal transportation, the following procedure was followed: Firstly, the amount of diesel that is required to transport the

17 million tons of coal to Kusile was estimated. This necessitated determining the amount of coal to be transported by road, based on information contained in the Synergistics Environmental Services and Zitholele Consulting (2011) report, the truck capacity, based on the Coaltech (2009) study, annual distance travelled and the truck's fuel consumption, based on a study by Odeh and Cockerill (2008) and Sinotruk (n.d.).

Secondly, the total amount of diesel consumed was converted to terajoule (TJ). Thirdly, the carbon emission factor for diesel was determined, which – according to IPCC (1996) – is 20.2t C/TJ. In the fourth instance, the carbon content of the diesel used was estimated by multiplying the total amount of diesel consumed (expressed in terajoule) with the diesel carbon emission factor (t/TJ). In the fifth instance, the fact that not all carbon is oxidised during combustion by using the diesel oxidation factor – which is 99% according to IPCC (1996) – is accounted for. In the sixth instance, the estimated total carbon emissions were converted to CO_2 by multiplying the carbon emissions with 3.667, ie 44/12, which is the molecular weight ratio of CO_2 to carbon (Blignaut *et al.*, 2005). Finally, the global warming damage cost of CO_2 emissions during coal transportation was computed as a product of the total CO_2 emissions calculated above, multiplied with the damage cost of CO_2 (\$/t CO_2), as computed by Blignaut (2011).

Hence, the equation that was used to determine global warming damage costs due to CO_2 emission during coal transportation ($GW_{T_{DC}}$) is the following:

$$GW_{T_{DC}} = \left(Fuel_{consump} * EF_C * 3.667\right) * DC_{CO_2}$$

where

$Fuel_{consump}$ is the total diesel consumed expressed in TJ;

EF_C is the carbon emission factor (t/TJ) multiplied by the oxidation factor;

3.667 is molecular weight ratio of CO_2 to carbon (i.e. 44/12); and

DC_{CO_2} is the damage cost of CO_2 (\$/t $C0_2$).

To calculate the global damage costs of CH_4 and N_2O emission, emission factors for CH_4 and N_2O for heavy duty diesel vehicles were multiplied with the annual diesel requirements, and the damage cost of CO_2 was adjusted for CH_4 and N_2O global warming potential, 23 and 310 (IPCC, 2001), respectively.

4.2 Accidents: monetary estimates for mortality andmorbidity

In its annual report for 2009/10, the Department of Minerals and Energy (2010) reported that fatalities and accidents remained high in South Africa's mining industry. Fall-of-ground accounted for most accidents and fatalities, followed by transportation and machinery. Injuries associated with coal as a commodity stood at 332 and 295 in 2008 and 2009, respectively. Fatalities are given as 20 in 2008 and 18 in 2009. In the report, there is no differentiation between occupational and public accidents.

To compute the injury rate and fatality rate for the annual amount of coal needed by Kusile, the following procedure was followed: Firstly, the fatalities and injuries per million tons of coal mined in South Africa from 2006 to 2009 were calculated. This involved dividing the reported injuries in these years by the amount of coal produced in these years, respectively. The mean value was opted for because, over the four-year period, reported injuries and fatalities were not generally decreasing. One year they were up and the next year they were low. For example, reported fatalities were 253, 183, 332 and 295, respectively, in 2006, 2007, 2008 and 2009, while fatalities were 20, 15, 20 and 18, respectively (Department of Minerals and Energy, 2008 and 2010). Secondly, using the average fatality and injury rates of the four years, adjustments were made to account for the fact that coal would be mainly sourced from surface mines and that surface mines have a lower accident rate than underground mines. This was done by adjusting the fatality and injury rates per million tons of coal mined by a quarter. To calculate the total number of people that are likely to die or be injured by Kusile's annual coal requirement, the respective adjusted rates were multiplied by the amount of annual coal needed by Kusile, which is 17 million tons.

The next step was to compute valuation estimates for morbidity and mortality and to multiply these values with the respective number of people that are likely to be injured or die. For morbidity, cost estimates – estimated using the cost-of-illness approach of Van Horen (1997) – from public health practitioners were transferred to this study by adjusting the values for inflation.

For fatalities, due to a lack of valuation studies in South Africa, estimating the economic value for mortality was based on valuation of changed life expectancy, obtained from the NEEDS (2007) and AEA Technology Environment (2005) studies. The values for mortality were adjusted to reflect the disparity in income levels between the European Union and South Africa. This adjustment is essential because, theoretically, individual valuations of the risk of death are dependent on income levels. The income adjustment factor was therefore calculated and used to adjust the values for mortality. The adjusted values were then inflated to ZAR and multiplied by the number of people that are likely to die, yielding the total value for mortality.

4.3 Water pollution

Water pollution from coal mining operations has been characterised as an environmental issue of concern in the Emalahleni area (EO Miners, 2011). Coal mines can affect water quality through mine water discharges, leachate from discard dumps or through acid mine drainage (AMD). AMD is a highly acidic water that is formed when pyrite (a sulphur-bearing mineral) and other sulphide minerals that are present in coal and associated strata react with water and air to form sulphuric acid and dissolved iron (Singh, 2008; Ochieng*et al*., 2010). This acidic run-off dissolves heavy metals such as lead and copper (World Coal Association(WCA), 2010). For these reasons, AMD is characterised by a low pH and high concentrations of sulphate and heavy metals (Neculita *et al*., 2007; Manders *et al*., 2009).

The environmental effects of AMD include the contamination of drinking water,disrupted growth and loss of aquatic animals and plants, and the contamination of agricultural land when mine water is used for irrigation purposes (Singh, 2008). This can enhance the uptake of heavy metals by plants and humans who consume the contaminated agricultural products (Boularbah *et al*., 2006).

AMD is an important and costly environmental problem that is linked to coal mining and gold mining in South Africa (Naicker *et al*., 2003; Council for Geoscience, 2010). Damage cost estimates for water pollution from coal mining in the Emalahleni catchment were computed by Van Zyl *et al*. (2002). As noted above, AMD is characterised by high concentrations of sulphate (Neculita *et al*., 2007; Manders *et al*., 2009), so sulphate was chosen in the study by Van Zyl *et al*. (2002) as the best available indicator of overall salinity and a major concern in the Emalahleni catchment study. The damage cost imposed on other water users in the Emalahleni catchment from sulphate pollution by coal mining was estimated to range between R0.11 and R0.19/t of saleable production (1999 ZAR). These damage cost estimates from sulphate pollution are used in this annex to the report. These estimates are inflated and then multiplied with the annual amount of coal required by Kusile to arrive at an estimate of the annual damage costs that are likely to be imposed by mining coal for Kusile.

4.4 Water consumption

Water is used in a number of activities in coal mines. Primarily, water is used for dust control, extraction and coal washing. It is also lost through evaporation (Pulles *et al*., 2001; Wassung, 2010). Dust occurs on soil and coal stockpiles. It is also present when the coal is hauled along roads (Miller, 2005). Dust is a greater problem in surface mines than it is in underground mines (Pulles *et al*., 2001). To ensure the efficient use of coal for power generation, it is cleaned of contaminants before it is burnt (Miller, 2005).

In view of the fact that the proposed New Largo Colliery is an opencast mine where mining will take place in consecutive long cuts or strips (Synergistics Environmental Services &Zitholele Consulting, 2011), coupled with the fact that the proposed coal mine will use washing as a means of preparing coal for power generation purposes (see Annex 0 for more details), the water requirements of such a mine were considered in this study.

In order to compute the society-wide cost of water consumption by the proposedNew Largo Colliery that will supply coal to the Kusile coal-fired power station, the following procedure was followed. First, the annual water requirements of a surface mine with a beneficiation plant that produces 17 million tons of coal for electric power generation were computed based on figures reported by Pulles *et al*. (2001) and Wassung (2010). Pulles *et al*. (2001) conducted an extensive study of the water requirements of various types of coal mines in South Africa, including the water requirements of surface mines with a beneficiation plant. Wassung (2010) contacted primary sources, such as mine managers, in an effort to confirm whether the 2001 figures reported in Pulles *et al*. (2001) were still correct. They were found to be still valid and were used in the study.

Secondly, it was necessary to establish the opportunity cost of water to society when engaging in coal mining. If time and resources allow, it is imperative for this to be computed, as the administered price of water for coal mining or for coal-fired electricity generation in South Africa in general does not reflect the actual loss of welfare to society (society's welfare impacts) due to the presence of externalities (Spalding-Fecher & Matibe, 2003). So, ideally, in order to estimate the external cost of water underpricing for coal mining, it would be necessary to establish the opportunity cost of water to society when engaging in coal mining. However, since the opportunity cost of water to society when engaging in coal mining has not been computed in South Africa, the opportunity cost of water to society when engaging in coal-fired electricity generation will be used, as the coal produced by the proposed coal mine will be 100% dedicated to coal-fired power generation.

Inglesi-Lotz and Blignaut (2011) estimated the opportunity cost of water to society for the Kusile coal-fired power station. This power station will use a dry cooling process with flue gas desulphurisation. The power generation technology chosen by Kusile was compared to a number of alternative power generation technologies, including solar, wind and biomass. The opportunity cost values computed by Inglesi-Lotz and Blignaut (2011) were used in this study. First, the society-wide loss (opportunity cost) of water use at the Kusile power station computed by Inglesi-Lotz and Blignaut (2011) (ie between R21 305 million and R42 357 million) was divided by the water requirements of the power station (26.166 million m^3) to arrive at the opportunity cost of water per cubic metre. The values that were yielded (in R/m^3) were then multiplied with the annual water requirements of mining coal for the Kusile power station, thereby yielding a society-wide cost (opportunity cost) of water use in the New Largo Colliery for the purposes of supplying the Kusile coal-fired power station.

4.5 Human health damages due to air pollution

Air pollution (classic air pollutants) in coal mines is mainly caused by coal dust and particulate matter generated during coal mining, burning discard dumps and underground fires (Goldblatt *et al*., 2002). The Department of Minerals and Energy (2010) notes that, while occupational health impacts are not easy to quantify, South African miners are exposed to excessive dust. This is the principal cause of death and premature retirement. Although there are studies that provide estimates on dust fallout rate, coal discard and slurry produced (Trusler & Mzoboshe, 2011; Wolmarans & Medallie, 2011), none of the studies in the country have tried to link human exposure to the classic air pollutants produced during coal mining to human health (mortalities and fatalities). The same applies to transportation. Gaffen *et al*. (2000) base motor vehicle air pollution costs on estimates of the cost of air pollution in Santiago, Chile. Jorgensen (2010) has done the same for rail transportation.

To estimate human health damage due to air pollution coming from coal mining and transportation, the following methodology – used by Sevenster *et al*. (2008) and Bjureby *et al*. (2008) – is adopted: Firstly, the amount of classic air pollutants emitted was calculated using emission factors from the literature. For coal transportation, this involved computing the total annual distance travelled by the truck and multiplying it with the emission factor for each pollutant considered. Emission factors were sourced from the study by Stone and Bennett (n.d.).

This was followed by transferring damage cost estimates per ton already linked to air pollutants from the NEEDS project (NEEDS, 2007; Sevenster *et al.*, 2008) and from the AEA Technology Environment (2005) study. The damage cost estimates needed adjustments before they could be multiplied with the estimated emissions. The adjustment was done by first transferring the VOLY estimates for the EU ($VOLY_{EU}$) and adjusting the $VOLY_{EU}$ values for differential levels of income between the European Union and South Africa. An adjustment factor was then obtained ($VOLY_{EU}/VOLY_{SA}$) and was used to adjust all the original damage costs per ton of emission. Finally, to estimate human health damages due to air pollution, the respective adjusted values per ton were multiplied by the estimated emissions. The classic air pollutants that were considered were NO_X, SO_2 and $PM_{2.5}$.

4.6 Loss of ecosystem services due to coal mining

The new opencast mine that is proposed to supply coal to the Kusile power station (the New Largo Colliery) will be utilising coal from the New Largo coal reserve. The New Largo coal reserve signifies the extent of the area that could be mined and covers an area of 6 817 hectares (Wolmarans & Medallie, 2011). The area is mainly used for maize cultivation and grazing. Extraction of the coal resource in this area will therefore lead to loss of farmlands and grasslands. The opportunity cost of coal mining in the study area is therefore the forgone benefits derived from agricultural production and ecosystem services generated by grasslands (ie carbon storage and the carbon sequestration potential of the soils and vegetation cover). Loss of agricultural potential is calculated as a product of the number of hectares of land under maize production, productivity of maize (t/ha) and the market price of maize. Loss in ecosystem goods and services is calculated as the product of the number of hectares under grazing and their value (R/ha).

5. RESULTS

5.1 Global damage costs: coal mining and transportation

The greenhouse gases investigated are CO_2, CH_4 and N_2O. For coal mining, only the global damage cost of CH_4-releases was quantified, while for coal transportation global damage cost of CO_2, CH_4 and N_2O were computed.

Coal mining

The annual quantity of methane released from surface coal mines due to the annual coal requirements of the Kusile power station was estimated to range between 26 962t and 350 506t (Table 5) using methane emission factors of 0.002m^3/t, 0.014m^3/t and 0.026m^3/, as estimated by Cook (2005) and Lloyd and Cook (2005) for South African surface mines. Applying the range of damage cost estimates for CO_2 (\$0.8/tCO_2 to \$112.01/tCO_2) computed by Blignaut (2011), and adjusting these values to reflect that methane has a higher global warming potential than CO_2, yielded damage cost estimates for methane expressed as a CO_2 equivalent of between \$18/tCO_2e and \$2576/tCO_2e (2010 values). Applying these damage values to the quantity of methane released, yielded global damage costs from methane releases of between R4 million and R509 million for low methane releases; between R25 million and R3 562 million for average methane releases and between R47 million and R6 615 million for high methane releases (Table 5). Arguably, the most likely range for the global damage cost using the market, median and high damage rates, and using the mean and high methane emission factor values, is between R477 million and R772 million and between R886 million and R1 435 million, respectively.

Table 5: Annual global damage cost of methane releases during coal mining (2010 values)

Methane releases (tons of CH_4)		Conversions	Low	Market	Median	High	Very high	Stern
		2010\$/tCO_2	0.8	15	14.33	24.29	82.02	112.01
		2010\$$CH_4$/t$CO_{2e}$	18.4	345	329.59	558.67	1886.46	2576.23
Low	26 962	\$ million	0.5	9.3	8.9	15.1	50.9	69.5
Mean	188 734	\$ million	3.5	65.1	62.2	105.4	356.0	486.2
High	350 506	\$ million	6.4	120.9	115.5	195.8	661.2	903.0
Damage cost in R million								
Low		R million	3.6	68.1	65.1	110.3	372.6	508.8
Mean		R million	25.4	**477.0**	**455.7**	**772.4**	2608.3	3561.9
High		R million	47.2	**885.9**	**846.3**	**1434.5**	4843.9	6615.0

Coal transportation

An estimate of the annual diesel requirements of transporting coal to the Kusile coal-fired power station was estimated at 7 751 935litres, based on the annual quantity of coal likely to be transported by road, the distance travelled and with a coal truck being capable of carrying a 31t payload (Coaltech, 2009) and consuming 0.35litres of diesel per km (Odeh & Cockerill, 2008; Sinotruk n.d.). This yielded annual CO_2 emissions of 21 863t. Applying the range of damage cost estimates for CO_2 (\$0.8/tCO_2 to \$112.01/tCO_2) as computed by Blignaut (2011) to the quantity of CO_2 emissions yielded global damage costs from CO_2 emissions of between R0.13 million and R17.94million (Table 6). The most likely range for the global damage cost,using the market, median and high damage rates,is between R2.4 million and R3.89million.

Unlike CO_2, which is based on the carbon content of the diesel, CH_4 and N_2O emission factors depend largely on the combustion technology and emission control technology present in the vehicles. Default emission factors that do not specify vehicle technology are therefore highly uncertain. While the IPCC (1996) provides default emission factors for CH_4 and N_2O for heavy duty diesel vehicles, the United States Environmental Protection Agency EPA (2004) quantified CH_4 and N_2O emission factors for heavy duty diesel vehicles in the USA and compared them to theIPCC rates. The EPA found that the CH_4 and N_2O emission factors for heavy duty vehicles were approximately 10.4% of the IPCC values. Therefore, this study adjusted the original IPCC (1996) emission factors in g/ℓ (the EPA reported the emission factors in g/mile) and then multiplied them with the annual diesel requirements and the damage cost of CO_2 adjusted for N_2O and CH_4 emission factors 310 and 23 (IPCC, 2001) respectively. This yielded global damage costs of N_2O and CH_4 emission of between R0.0001 million and R0.0181million and R0.00024 million and R0.0029million respectively (Table 6).

Table 6: Annual global damage cost of coal transportation (CO_2, N_2O, CH_4) (2010 values)

	Conversions	Low	Market	Median	High	Very high	Stern
Pollutant	$\text{2010\$/tCO}_2$	0.8	15	14.33	24.29	82.02	112.01
CO_2	\$ million	0.02	0.33	0.31	0.53	1.79	2.45
	R million	0.13	2.40	2.30	3.89	13.14	17.94
N_2O	\$ million	0.00002	0.0003	0.0003	0.0005	0.0018	0.0025
	R million	0.0001	0.0024	0.0023	0.0039	0.0132	0.0181
CH_4	\$ million	2.8E-06	0.0001	0.0001	0.0001	0.0003	0.0004
	R million	2.1E-05	0.0004	0.0004	0.0006	0.0021	0.0029
Global damage cost due to coal transportation (R/million)			**2.4**	**2.3**	**3.9**	**13.2**	**18.0**

The global damage cost due to coal transportation ranges between R2.4million and R18million (Table 6), with the most likely range for overall global damage cost (coal mining and transportation) being between R479 million and R766million, and between R888 million and R1 438million respectively (Table 7).

Table 7: Overall annual global damage cost due to coal mining and transportation (2010 values)

Overall global damage	**Coal mining: CH_4 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

5.2 Accidents: monetary estimates for mortality and morbidity

The injury rate for surface coal mines was calculated to be 0.0823 injuries per million tons of coal mined and supplied to power stations for the purpose of power generation, using actual coal mine injuries reported in 2006 to 2009 (Department of Minerals and Energy, 2008 and 2010) and coal production during these years (WCA, 2006, 2007, 2008 and 2009). Applying this rate to the annual coal requirements of the Kusile coal-fired power station translated into 14 injuries per annum. Multiplying these injuries with the inflation-adjusted valuation estimates for morbidity from Van Horen (1997) yielded monetary estimates for morbidity that ranged between R0.3 million and R0.8million (2010 values) (Table 8).

For fatalities, the fatality rate for surface coal mines was calculated to be 0.056 fatalities per million tons of coal mined, translating into one death per annum. For monetary valuation,estimates of the value of a life year lost for the EU were used (VOLY, ie €40 000 and €120000 (2000 values)). Mortality values for the EU, on the other hand, were estimated using the VSL and yielded higher values approximately ranging between €1 and €2million (2000 values) (AEA Technology Environment, 2005). VSL can be viewed as a stream of discounted VOLY. However, there are serious doubts about the validity of this approach (Sevenster *et al.*, 2008). The VOLY lost estimates are therefore used in this study.

The estimates of VOLY for the EU were adjusted for different levels of income between the EU and South Africa, using an adjustment factor (2.8) based on GDP per capita (PPP). This yielded€14 266 as the central estimate and €42 797 (2000 values) as the upper estimate. These values were then adjusted for Euro inflation between 2000 and 2010 and converted to ZAR. Applying these values to the number of deaths yielded monetary estimates for mortality that ranged between R0.14 million and R0.4 million (2010 values) (Table 8). Monetary estimates for morbidity and mortality combined range between R0.69 million and R1.26 million.

Table 8: Annual monetary estimates for morbidity and mortality (2010 values)

Damage estimated	units	Low estimate	Central estimate	High estimate
Morbidity	R million	0.26	0.55	0.84
Mortality	R million		0.14	0.42
Total	R million		**0.69**	**1.26**

5.3 Air pollution: human health damages

The estimated emissions of SO_2, NOx and $PM_{2.5}$ were calculated to be 37t, 289t and 15t, respectively. This is based on emission factors reported in Stone and Bennett (n.d.) for heavy-duty diesel commercial vehicles in South Africa. (The authors developed a bulk emissions model for commercial diesel vehicles by augmenting emissions data for heavy-duty diesel engines that was generated during the South Africa Vehicle Emissions Project.) For monetary valuation,damage cost estimates per ton of pollutant were estimated using the value of a life year for the EU ($VOLY_{EU}$, ie €40 000 and €120000 – 2000 values). Specifically, estimates of VOLY lost due to air pollution, estimated using change of life expectancy, were used in this study. The methodology used in the NEEDS project do not only include mortality effects, but also morbidity effects, so the final estimates of damage cost per ton of the specific pollutants incorporate both mortality and morbidity effects (NEEDS, 2007; Sevenster *et al.*, 2008). Basing the valuations of air pollution mortality on the change of life expectancy, as opposed to a change in the probability of death as noted by Rabl (2006) and NEEDS (2007), is more appealing because of the approach factor in the constraint that humans die only once, regardless of pollution, and because respondents (ie surveyed individuals) have difficulty understanding small probability variations or changes in life expectancy.

The estimates of $VOLY_{EU}$ were adjusted for different levels of income between the EU and South Africa, using an adjustment factor (2.8) based on GDP per capita (PPP). This yielded€14 266 ($VOLY_{SA1}$) as the central estimate and €42797($VOLY_{SA2}$) as the upper estimate (2000 values). The original damage costs per ton of emission were estimated using the central and upper estimates, adjusted using the factor $VOLY_{SA}/VOLY_{EU}$ and adjusted for Euro inflation between 2000 and 2010, and converted to ZAR. The adjusted values per ton of pollutant were then multiplied by the respective estimated emissions to arrive at a damage cost of R10.5 million and R15 million (2010 values) for the central and upper estimates, respectively (Table 9).

Table 9: Annual human health damages due to air pollution (2010 values)

Damage estimated	Units	Central estimate			Upper estimate		
		SO_2	NOx	$PM_{2.5}$	SO_2	NOx	$PM_{2.5}$
Human health damages	R million	1.1	7.7	1.8	1.7	10.1	3.3
Total damages due to air pollution (R million)		**10.5**			**15.0**		

5.4 Water quality

Annual direct damage cost of sulphate pollution from coal mining to various water users in the Emalahleni area was estimated by Van Zyl *et al*. (2002) as R0.11 and R0.19/t of coal for dry and wet seasons, respectively (1999 values). Inflating and multiplying the damage cost estimates with the annual amount of coal required by the Kusile coal-fired power station yielded annual damage cost estimates ranging between R4.5 million and R7.7 million (2010 values) (Table 10). The estimates should be viewed as conservative estimates, as the damage cost estimates do not focus on all pollutants, and downstream impacts were not evaluated.

Table 10: Annual water pollution impacts due to coal mining (2010 values)

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

5.5 Water consumption

The total water requirements of mining a ton of coal were computed by Wassung (2010), based on Pulles *et al*. (2001), to range between 469ℓ/t and 581ℓ/t of coal. On average, coal extraction requires 160ℓ/t, dust control requires about 42ℓ/t and water loss due to evaporation amounts to about 229ℓ/t (Pulles *et al*., 2001), while estimates of water use during coal washing vary greatly depending on the coal beneficiation plant design and the number of washing stages. Coal washing ranged between a low of 38ℓ/t (Pulles *et al*., 2001), and a high of 150ℓ/t (Wassung, 2010), yielding the low and high estimates of 469ℓ/t and 581ℓ/t respectively.

However, since Inglesi-Lotz and Blignaut (2011) incorporated coal washing water requirements into their study when calculating the opportunity cost of water for the Kusile power station, this analysis focuses only on the water requirements for coal extraction, dust control and water loss due to evaporation. This amounted to 431ℓ/t or 0.431m^3/t of coal mined. Multiplying 0.431m^3/t with 17 million tons (coal mined for the Kusile power station) yielded annual water requirements amounting to 7.327 million m^3 (Table 11).

Inglesi-Lotz and Blignaut (2011) computed the society-wide loss (opportunity cost) of water use in the Kusile coal-fired power station to range between R21 305 million and R42 357 million. Dividing these values with the amount of water requirements for the Kusile power station (26.166 million m^3,iea figure that incorporates water use during coal washing) yielded the opportunity cost of water per cubic metre to amount to a low and high value of R814/m^3 and R 1 619/m^3 respectively. Multiplying these values with the annual water requirements of mining coal for the Kusile power station yielded a society-wide cost (opportunity cost) of water use of between R5 964.18 million (R5.96 billion) and 11 862.41 million (11.86 billion) (Table 11).

Table 11: Annual water consumption external effect (2010 values)

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

5.6 Loss of ecosystem services resulting from coal mining

The main land use activities in the area to be occupied by the New Largo Colliery are maize cultivation and grazing. The extraction of the coal resource in this area will lead to loss of farmlands and grasslands. The opportunity cost of coal mining in the study area is therefore the forgone benefits derived from agricultural production and ecosystem services generated by grasslands (ie carbon storage and the carbon sequestration potential of the soil and the vegetation cover).

The area under maize production and grazing or grasslands was estimated to occupy 4 771.9ha and 2 045.1ha respectively, based on the area occupied by the New Largo reserve (6 817ha base). Some 70% of that land is therefore used for cultivation and about 30% for grazing (Wolmarans & Madallie, 2011). Multiplying the area under maize cultivation with the maize yield per hectare (10t/ha) and the market price of maize (R1 600/t) (Blignaut *et al.*, 2010) yielded the forgone benefit from maize cultivation to be R76.4 million (Table 12). Multiplying the hectares under grazing or grasslands with the estimate of the value of ecosystem goods and services generated by grasslands (R510/ha) computed in a study by Blignaut *et al*. (2010) fora fire-prone grassland ecosystem (ie the Maloti–Drakensberg mountain range in South Africa) yielded the value of ecosystem services lost due to coal mining to amount to R1 million.

Table 12: Annual loss of ecosystem services

Damage estimated	Units	Low estimate
Loss of agricultural potential	R million	76.4
Loss of carbon sequestration	R million	1.0
Total	**R million**	**77.4**

6. DISCUSSION

Synthesis

A full-scale coal industry developed in the Emalahleni area soon after 1894. Currently, there are over 40 operating coal mines in the area (Department of Mineral Resources, 2010), while the Council for Geoscience identified more than 118 abandoned coal mines in the catchment (EO Miners, 2011). The area is an important one, contributing a significant portion to South Africa’s coal production and housing a number of power stations and steel industries, all of which require coal. Owing to coal exploitation in excess of 100 years in the area, and considering that coal mining is by its very nature disturbing and destructive to the environment, certain environmental and societal impacts that emanate from coal production have been characterised as important in the area, for instance land degradation and water pollution (EO Miners, 2011).

While various externalities of coal mining in the Emalahleni catchment have been investigated by researchers in South Africa, this study widens the scope of investigated coal mining impacts by incorporating externalities of coal transportation and linking these costs to power generation.

This study discloses that the annual external damages of mining coal and costs of transporting it to Kusile for electricity generation purposes range between R6 538 million and R12 690 million (Table 13). Based on an annual coal usage of 17 million tons, this translates into an externality value of between R385 and R746/t, which is considerably higher than the earlier South African studies (Table 3). This is due to the higher (global) price of carbon and the fact that this study includes more externality aspects. The external effect of water consumption (opportunity costs of water) makes up over 90% of the total cost, followed by global warming damage costs (~6%) and ecosystem services lost due to coal mining (~1%).

Table 13: Summary table of annual damage cost

Damage estimated	Units	Central estimate	High estimate	Percentage of total
Global damage cost: coal mining	R million	477.0	722.4	~ 6
Global damage cost: coal transportation		2.4	3.9	
Human health damages due to accidents		0.7	1.3	< 1
Human health damages due to air pollution		10.5	15.0	< 1
Water pollution damages		6.1	7.7	< 1
Water consumption external effect		5 964.18	11 862.41	> 90
Loss of agricultural potential		76.4	76.4	~ 1
Loss in ecosystem goods and services		1	1	
Total	R million	**6538.28**	**12690.11**	

It is estimated that the net power generation output of Kusile is 32.3 million MWh (net capacity of 723MW per unit x 6 units x 8 760 hours x a load factor of 85%). The estimated damage cost of coal mining of between R6 538 million and R12 690 million translates into an externality cost of between 20.2and 39.3c/kWh. The estimated externality cost is between about 50% and 100% of the current average electricity price, which is approximately R0.41/kWh (2010 value) (RSA, 2011).

To compare the outcomes with a study that does not include water consumption, the external costs – excluding water consumption – were computed. This yielded an external cost estimate of 0.25 to 0.35$/kWh (R1.8/kWh to R2.6/kWh). Comparing this overall external damage cost of coal mining (0.25 to 0.35$/kWh) to that of between 4.67$/kWh and 4.99$/kWh (Table 2), which also excluded water consumption, estimated by Epstein *et al*. (2011) for the Appalachia region in the United States (values inflated to 2010 US$), the computed estimate in this study seems rather low, mainly due to variations in the methods used to value mortality and the exact values used. In the study by Epstein, all public health impacts due to mortality were valued using the VSL that had a very high value of 7.5 million (2008 US$) (ie $6million at 2000 US$), which was by far higher than the values used in this study (original values of between €40 000 and €120 000 – 2000 values) based on VOLY. A closer look at the overall damage cost of coal mining in the study by Epstein also disclosed that due to the high value of mortality used, human health burdens dominate the overall external costs of coal mining, making up over 90% of this cost.

Limitations

The valuation estimates generated in this study are only as good as the input, assumptions and information from which they are derived. It is therefore important to highlight the assumptions and limitations of the valuation exercise.The evaluation of air pollution impacts on human health – although complex – is one important externality to be considered. Generally, quantification of human health impacts is done using modelling tools that incorporate the dispersion and ultimate deposition of pollutants, and the responsiveness of humans to various doses of pollution. In this study, however, the approach adopted was one used by Sevenster *et al*. (2008) and Bjureby *et al*. (2008). It involved transferring and adjusting damage cost estimates per ton of specific pollutant. Therefore no model was developed or used. Although the scope of impacts was broad, a number of externalities were not investigated, for example, noise pollution, damages to roads and the damage caused by ash lagoons on water resources, due to unavailability of data in South Africa. The estimates can therefore be considered as lower bound estimates. Lastly, it is important to highlight the fact that a great deal of effort was made to solicit and use South African-based data to compute most of the external costs.

7. CONCLUSION

The aim of this study was to quantify the external costs of coal mining and transportation related to the Kusile coal-fired power station currently being constructed in Emalahleni. The results of the study disclosed that coal mining and transportation will inflict costs to both the environment and humans of between R6 538 million and R12 690 million per annum, or between 20.24c/kWh and 39.3/kWh sent out. These costs are considered to be a lower bound estimate since a number of externalities were not investigated.

8. REFERENCES

AEA Technology Environment. 2005. Damages per tonne emission of $PM_{2.5}$, NH_3, SO_2, NOx and VOCs from each EU25 member state (excluding Cyprus) and surrounding seas. Available at: http://www.cafe-cba.org/assets/marginal_damage_03-05.pdf (accessed on 14 August 2011).

Anthoff, D., Tol, R. & Yohe, G. 2009. Risk aversion, time preference, and the social cost of carbon.Available at: http://iopscience.iop.org/1748-9326/4/2/024002 (accessed on 11 July 2011).

Beyond Petroleum (BP). 2010. Statistical review of world energy June 2010. Available from: http://www.bp.com/liveassets/bp_internet/globalbp/globalbp_uk_english/reports_and_publications/statistical_energy_review_2008/STAGING/local_assets/2010_downloads/statistical_review_of_world_energy_full_report_2010.pdf (accessed on 7 August 2011).

Bjureby, E., Britten, M., Cheng, I., Kaźmierska, M., Mezak, E., Munnik, V., Nandi, J., Pennington, S., Rochon, E., Schulz, N., Shahab, N., Vincent, J. & Wei, M. 2008. The true cost of coal: how people and the planet are paying the price for the world's dirtiest fuel. Available at: http://www.greenpeace.org/australia/en/what-we-do/climate/resources/reports/the-true-cost-of-coal/ (accessed on 3 July 2011).

Blignaut, J.N. 2011. The opportunity cost of Medupi and Kusile power stations. Unpublished study. Pretoria, South Africa.

Blignaut, J.N. & King, N. 2002. The externality cost of coal combustion in South Africa. Forum for Economics and Environment Conference 2002, Cape Town. Available at: http://www.anthonyturton.com/admin/my_documents/my_files/Economic_costs_of_coal_combustion_in_RSA.pdf (accessed on 8 February 2011).

Blignaut, J.N., Chitiga-Mabugu, M.R. & Mabugu, R.M. 2005. Constructing a greenhouse gas emissions inventory using energy balances: the case of South Africa for 1998. *Journal of Energy in Southern Africa,* **16(3):**21–32.

Blignaut, J., Mander, M., Schulze, R., Horan, M., Dickens, C., Pringle, K., Mavundla, K., Mahlangu, I., Wilson, A., McKenzie, M. & McKean, S. 2010. Restoring and managing natural capital towards fostering economic development: Evidence from the Drakensberg, South Africa. *Ecological Economics*, **69:**1313–1323.

Both ENDS. 2011. The burning issue: The global footprint of coal-fired energy in the Netherlands.Available at: http://www.bothends.org/uploaded_files/Both_ENDS_Briefing_Paper_A_Burning_Issue.pdf (accessed on 13 June 2011).

Boularbah A., Schwartz C., Morel, J.L. 2006. Heavy metal contamination from mining sites in South Morocco: 2. Assessment of metal accumulation and toxicity in plants. *Chemosphere,***63:** 811–817.

Coaltech. 2009. Coaltech transport investigation. Available at: http://www.coaltech.co.za (accessed on 15 August 2011).

Cook, A. 2005. Task 6.1 greenhouse methane emissions for South African coal mining models for predicting methane gas release from coal seams. Available at: http://www.coaltech.co.za/chamber%20databases/coaltech/Com_DocMan.nsf/0/4D52D96EF7F0202942257409001D7E38/$File/Task%206.1%20-20Methane%20emissions%20and%20Models.pdf (accessed on 21 June 2011).

Council for Geoscience. 2010.Mine water management in the Witwatersrand gold fields with special emphasis on acid mine drainage.Available at: http://www.dwaf.gov.za/Documents/ ACIDReport.pdf(accessed on 12 September 2011).

Department of Energy. 2010. South African energy synopsis 2010.Available at: http://www.energy.gov.za/files/media/explained/2010/South_African_Energy_Synopsis_2010.pdf (accessed on 13 July 2011).

Department of Mineral Resources. 2010. Operating and developing coal mines in the Republic of South Africa.Available at: http://www.dmr.gov.za/Mineral_Information/New/D2-2010%20%20part% 201.pdf (accessed on 13 July 2011).

Department of Minerals and Energy. 2010. *Annual report 2009/2010*. Available at: http://www.dmr.gov.za/AnualReport/Documents/DME%20Annual%20Report%2009_10%20hr.pdf (accessed on 28 June 2011).

Department of Minerals and Energy. 2008. *Annual report 2007/2008*. Available at: http://www.info.gov.za/view/DownloadFileAction?id=93533 (accessed on 28 June 2011).

EO Miners. 2011. Test Site 2. Witbank coalfields. Available at: http://www.eo-miners.eu/test_sites/ts_testsite2_witbank.htm (accessed on 18 August 2011).

Environmental Protection Agency(EPA) (US). 2004. Update of methane and nitrous oxide emission factors for on-highway vehicles. Available at: http://www.epa.gov/oms/models/ngm/420p04016.pdf(accessed on 13 May 2011).

Epstein, P.R., Buonocore, J.J., Eckerle, K., Hendryx, M., Stout III, B.M., Heinberg, R., Clapp, R.W., May, B., Reinhart, N.L., Ahern, M.M., Doshi, S.K. & Glustrom, L. 2011. Full cost accounting for the life cycle of coal.*Ann. N.Y. Acad. Sci,***1219:**73–98.

Gaffen, M., Naude, C., Lombaard, P., Maasdorp, G., Taylor, A. & Pretorius, J. 2000. A quantitative analysis of the full cost associated with motor vehicle use in South Africa.Report for the Department of Transport, funded by USAID.

Goldblatt, M., Gelb, S. &Davies, G. 2002. Synthesis report of South African study.WWF macroeconomics and sustainable development in southern Africa.

Hirschberg, S., Burgherr, P. & Hunt, A. 2004. Accident risks in the energy sector: comparison of damage indicators and external costs. In *Proceedings of the 7th International Conference on Probabilistic Safety Assessment and Management (PSAM7 - ESREL'04) Vol. IV. 14–18 June 2004*, pp.2314–2319.

Inglesi-Lotz, R. & Blignaut, J.N. 2011. Estimating the opportunity cost of water for the Kusile and Medupi coal-fired electricity power plants in South Africa. Unpublished study. Pretoria, South Africa.

Intergovernmental Panel on Climate Change (IPCC). 1996. *IPCC guidelines for national greenhouse gas inventories: Reference manual, Volume 3*. Cambridge: Cambridge University Press.

IPCC. 2001. Climate change 2001. In *Third assessment report of the Intergovernmental Panel on Climate Change*(Eds. R.T. Watson & Core Writing Team). Geneva: Cambridge University Press.

Jorgensen, A.A. 2010. Available at: http://www.rra.co.za/?p=16756 (accessed on 25 June 2011).

Lloyd, P. & Cook, A. 2005. Methane release from South African coalmines. *The Journal of the South African Institute of Mining and Metallury,* **105:**1–8.

Manders, P., Godfrey, L. & Hobbs, P. 2009. Acid mine drainage in South Africa. Available at: http://www.csir.co.za/nre/docs/BriefingNote2009 _2_AMD_draft.pdf (accessed on 14 September 2011).

Miller, B. 2005. *Coal energy systems*. Elsevier Academic Press: Burlington MA, USA.

Mishra, S.K. 2009. Estimation of externality costs of electricity generation from coal: An OH-MARKAL extension dissertation.Unpublished doctoral thesis. Canada: The Ohio State University. Available at: http://etd.ohiolink.edu/view.cgi/Khadka%20Mishra%20Shruti.pdf?%20osu12597033 37 (accessed on 8 July 2011).

Munnick, V., Hochmann, G. & Hlabane, M. 2009. The social and environmental consequences of coal mining. South African case study: final draft. Available at: http://www.bothends.org/uploaded_files/2case_study_South_Africa.pdf (accessed on 13 June 2011).

Naicker K., Cukrowska, E. & McCarthy, T.S. 2003. Acid mine drainage from gold mining activities in Johannesburg, South Africa and environs. *Environmental Pollution,***122:**29–40.

National Research Council. 2009. Hidden costs of energy: Unpriced consequences of energy production and use. Available at: http://media.kentucky.com/smedia/2009/10/19/10/HiddenCosts.source.prod_affiliate.79.pdf (accessed on 11 March 2011).

Neculita, C., Zagury, G.J. & Bussiere, B. 2007. Passive treatment of acid mine drainage in bioreactors using sulfate-reducing bacteria: Critical review and research needs. *Journal of Environ. Qual,* **36:**1-16.

New Energy Externalities Developments for Sustainability (NEEDS). 2007. Final report on the monetary valuation of mortality and morbidity risks from air pollution. Deliverable for WP6 of RS1b of the New Energy Externalities Developments for Sustainability (NEEDS) project. IER, University of Stuttgart.

Ochieng, G.M., Seanego, E.S. & Nkwonta, O.I. 2010. Impacts of mining on water resources in South Africa: A review. *Scientific Research and Essays*, **5(22):**3351-3357.

Odeh, N.A. & Cockeril, T.T. 2008. Life cycle analysis of UK coal-fired power plants.*Energy Conversion and Management,***49:**212–220.

Pulles, W., Boer, R. & Nel, S. 2001. A generic water balance for the South African coal mining industry. Water Research Commission Report No. 801/1/01.

Pretorius, K. 2009*. Coal mining and combustion: Internalising the cost for a fair climate change debate*. Federation for a Sustainable Environment.

Rabl, A. 2006. Analysis of air pollution mortality in terms of life expectancy changes: Relation between time series, intervention and cohort studies. *Environmental Health: A Global Access Science Source 2006*, **5:**1. Available at: http://web.me.com/arirabl/Site/Publications_files/ Rabl06%20LE%20framework.pdf (accessed on 14 August 2011).

Republic of South Africa (RSA). 2011. Integrated Resource Plan 2010–2030. *Government Gazette*. Pretoria: Government Printers.

Sevenster, M., Croezen, H., Van Valkengoed, M., Markowska, A. & Donszelmann, E. 2008. External costs of coal: Global estimate. Available at: http://www.cedelft.eu/publicatie/external_costs_of_coal/878?PHPSESSID=f138219238c72e8038a0a5694354af1d(accessed on 1 July 2011).

Sinotruk. n.d. Dump-body trucks Sinotruk. Available from: http://www.sinotruk.by(accessed on 13 August 2011).

Singh, G. 2008. Mitigating environmental and social impacts of coal mining in India. Available from: http://www.ismenvis.nic.in/My_Webs/Digital_Library/GSingh/Mitigating%20Environmental%20and%20Social%20Impacts%20of%20Coal%20Mining%20in%20India.pdf (accessed on 11 July 2011).

Spalding-Fecher, R. & Matibe, D.K. 2003. Electricity and externalities in South Africa. *Energy Policy*, **31:**721–734.

Spalding-Fecher, R., Khorommbi-Matibe, D., Afrane-Okes, Y., Eberhardt, R. & Davis, M. 2000. *Electricity production and the environment*. WWF macroeconomic reforms and sustainable development in Southern Africa.

Stern, N. 2007. *The economics of climate change: The Stern review*. Cambridge, UK: Cambridge University Press.

Stern, N. 2008. The economics of climate change. *Am. Econ. Rev*., **98:**1–37.

Stone, A. & Bennett, K. n.d. A bulk model of emissions from South African diesel commercial vehicles. Energy Research Institute (ERI), University of Cape Town. Available at:http://www.erc.uct.ac.za/Research/publications-pre2004/01Stone-Bennett_Diesel_emissions.PDF (accessed on 13 June 2011).

Sundqvist, T. 2000. Electricity externality studies – Do the numbers make sense?Unpublished doctoral thesis. Sweden: Lulea University of Technology. Available at: http://epubl.ltu.se/1402-1757/2000/14/index-en.html (accessed on 15 August 2011).

Sundqvist, T. 2002. Power generation choice in the presence of environmental externalities. Unpublished doctoral thesis. Sweden: Lulea University of Technology. Available at: http://epubl.ltu.se/1402-1544/2002/26/LTU-DT-0226-SE.pdf(accessed on 15 August 2011).

Synergistics Environmental Services &Zitholele Consulting. 2011. Environmental impact assessment, water use licence and a waste management licence for the proposed New Largo Colliery. MDEDET Ref: 17/2/3N-41.

Trusler, G. & Mzoboshe, S. 2011. The introduction of cleaner production technologies in the South African mining industry: a summary report. WRC report no. 1553/1/11.

Van Horen, C. 1997. Cheap energy – At what cost? Externalities in South Africa's electricity sector. In *Counting the social costs: electricity and externalities in South Africa*(Ed. C. van Horen). Cape Town: Elan Press and UCT Press.

Van Zyl, H., Raimondo, J. & Leiman, A. 1999. Working paper 6: Energy supply sector – coal mining.WWF macroeconomic reforms and sustainable development in South Africa.

Van Zyl, H., Raimondo, J. & Leiman, T. 2002. Energy supply sector – coal mining. WWF macroeconomic reforms and sustainable development in South Africa.

Wassung, N. 2010. Water scarcity and electricity generation in South Africa Part 1: Water use in the coal-to-electricity process. Unpublished master's dissertation. Stellenbosch: University of Stellenbosch.

World Coal Association(WCA). 2006. *Coal facts*. Available at: http://www.worldcoal.org/resources/coal-statistics/ (accessed on 18 August 2010).

WCA. 2007. Coal facts. Available at: http://www.worldcoal.org/resources/coal-statistics/ (accessed on 18 August 2010).

WCA. 2008. Coal facts.Available at: http://www.worldcoal.org/resources/coal-statistics/ (accessed on 18 August 2010).

WCA. 2009. Coal facts.Available at: http://www.worldcoal.org/resources/coal-statistics/ (accessed on 18 August 2010).

WCA, 2010. Coal mining and the environment. Available at: http://www.worldcoal.org/coal-the-environment/coal-mining-the-environment/ (accessed on 13 September 2011).

Wolmarans, M. & Medallie, M. 2011. New Largo Colliery environmental scoping report. Report No. S0403/NL/SR02.

Yushi, M., Hong, S. & Fuqiang, Y. 2008. The true cost of coal. Available at: http://act.greenpeace.org.cn/coal/report/TCOC-Final-EN.pdf (accessed on 25 June 2011).

Zhu, X., Appelquist, L. & Halsnæs, K. 2008. Cost assessment of sustainable energy systems: Cross-country comparison of the case studies under WP7. Available at: http://www.feem-project.net/cases/documents/deliverables/D_07_2%20energy%20costs%20nonEU.pdf (accessed on 16 June 2011).