THE EXTERNAL COST OF COAL-FIRED POWER GENERATION:

The case of Kusile

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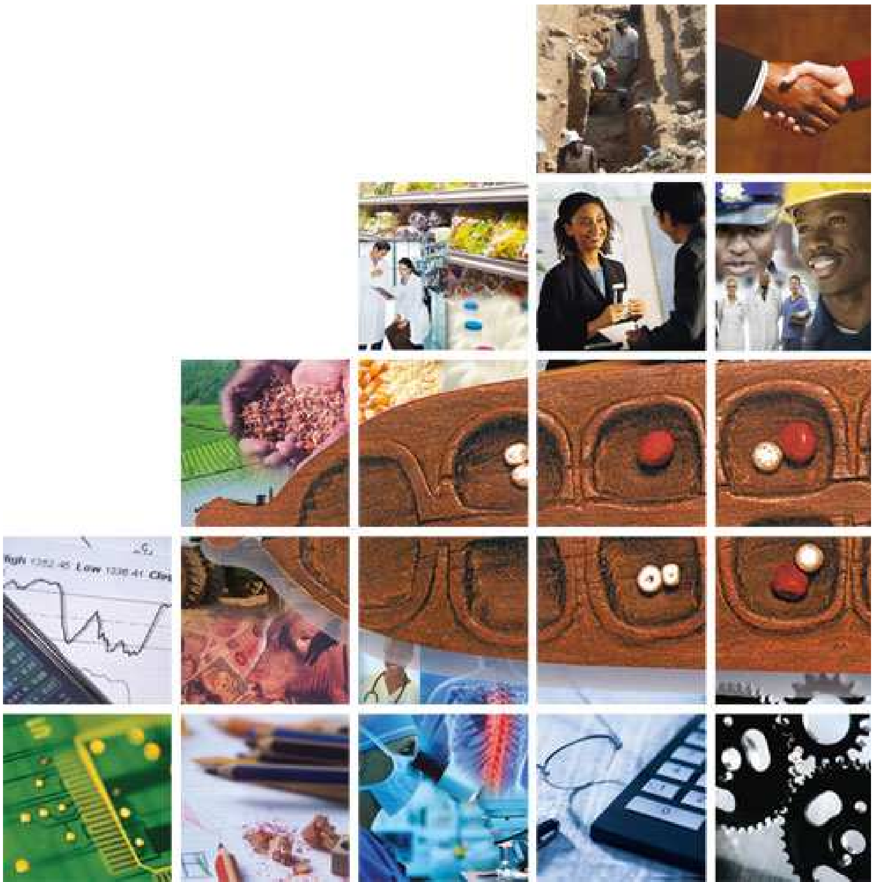

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ABBREVIATIONS AND ACRONYMS

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	concentrated solar 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, situated in 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 at large.

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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 decision-makers 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 benchmarked yet. 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 data for 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.

Since Kusile's net electricity output is estimated at 32.3TWh[6], the unit externality cost is 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 plant as it relates to 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 coal once 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 \$/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 \$/tC; to convert the numbers to \$/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/tCO_2 and \$893/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 \$/tC*	2	36	-	61	206	314**
Value of a ton of carbon	**2010 \$/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 evapo-transpiration 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 formations that 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 shadow price is estimated. The shadow price is an indicator of the opportunity cost of water to society of coal-fired electricity generation. Shadow prices 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 of the 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: concentrated solar 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 side effects, but so does coal 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 construction is not possible, as there is no inventory of data available yet. 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 17 million 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, applying that 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 R31.2 billion to R60.6 billion 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 defunct renewable 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 are interesting, 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 are tentative 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 generation capacity was funded from only 30% of Kusile'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 Kusile within 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

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