Aggregation and Internalisation of Electricity Externalities in South Africa

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Abstract:

Energy-environmental impacts associated with non-renewable electricity generation have attained critical importance in South Africa. These impacts are quantified in order to obtain a monetary cost relative to local electricity prices. The methodology used to perform the analysis is the Impact Pathway Approach. Numerous energy-environmental external impacts have been evaluated in this study. The primary externality contributors were found to be green-house gas (GHG) emissions and public health effects from coal combustion. Other minor but important contributors to externalities are also identified and mentioned within the paper. Aggregated central externality costs were found to range from 5.86-35.36 SA c/kWh (1.31-7.95 US c/kWh), with central externalities estimates at 13.43 SA c/kWh (3.02 US c/kWh). These central estimates were found to be 68.5% of average electricity prices during the year 2008. Conversion of externality costs from South African currency to US currency has been made with purchasing power parity exchange rates for the year 2008. This study provides sufficient methodological parity for countries with similar electricity generation backgrounds in Southern Africa and Africa as well as other developing countries, considering South Africa generates roughly 45% of the electricity on the African continent.

Keywords: Electricity, Externalities, Coal, Nuclear, South Africa.

1. Introduction

South Africa is currently undergoing extensive changes in the electricity generation sector because of the introduction of key renewable energy initiatives. The renewable energy initiative undertaken by the South African government has seen the participation of numerous independent power producers keen on exploiting the vast availability of natural resources. The generic incentive to employ renewable electricity generation schemes stems from the availability of resources and the lack of carbon emissions. However there are increasing number of studies internationally, analysing the external costs of renewable electricity generation schemes (Milan et. al, 2012; Gomez et. al., 2012; Collins et. al., 2012; Chien and Lior, 2011). Inspite of the emphasis on renewable technologies, non-renewable technologies still play a significant part in the electricity generation mix as highlighted in multiple impact assessment studies (Czarnowska and Frangopoulos, 2012; Hainoun et. al., 2010). South Africa is currently in the process of building and integrating renewable technologies to the national grid and within the next two to three years impact assessments of renewable generation mechanisms will be required. To gauge the impacts across multiple generation mechanisms, it becomes essential to quantify the impacts from current electricity generation technologies.

The primary and secondary objectives of this paper are to quantify the external costs in the South African electricity industry and to investigate the relative impact of external costs when compared to local electricity prices. Additionally, the final objective aims to scrutinise the policy implications of external costs and pricing for the electricity generation industry.

The paper begins with a tabular comparison of some of the major electricity externality studies performed. The comparison is adjusted in time and currency to give a better relative judgement. The assessment also enables to place South African external costs, which are evaluated in this paper, relative to other international studies. The following section provides a briefing of the methodologies used to evaluate the various external costs that were considered after which the results are presented, analysed and discussed.

The final part of the paper looks at the relative increases of South African electricity prices with other major economies. Electricity prices have increased by 27% on average since 2006/07 which is differential to international trends. Mention is also made of the national government's initiative to generate renewable electricity by inviting independent private entities to procure rights to generate electricity for the national grid. This scenario makes the South African electricity sector distinctive and worth mentioning as a unique case.

2. Literature review

South Africa generates 95% of electricity from non-renewable electricity generation mechanisms, primarily coal based generation and secondarily nuclear generation. Large abundance of coal reserves has historically made South Africa rely on non-renewable generation to support the increasing demand of electricity and also for extensive electrification programmes post-democracy. South Africa produces 92.75 % of its electricity from 13 (10 base load and 3 peak load) coal power plants (Eskom, 2011). 5% is generated from the single nuclear power plant located at Koeberg on the west coast. This setting presents a skewed dependence on non-renewable electricity generation, predominantly on coal. Low-cost and abundant availability of coal is considered the primary reason for such a scenario. Such high dependence on conventional coal-fired electricity generation does not present a positive representation for the energy security of South Africa. The dependence on coal-fired electricity also contributes to socio-environmental impacts that are categorised as externalities in this paper. These externalities are classified based on their point of impact as:

- Public impacts – the public health concerns caused during the process of electricity generation on a local and regional level.
- Occupational impacts – the effects on the occupational wellbeing of personnel involved during the process of mining for fuel and generation of electricity.
- Environmental impacts – those impacts on the environment caused from the generation of electricity, which includes emissions of greenhouse gases and scarce resource usage.

Electricity externality studies started gaining prominence during the 1980s and 1990s when European and North American countries initiated interest in alternative fuel sources for electricity generation, as opposed to conventional mechanisms. Externality valuations play an important role in providing decision-making entities the ability to provide judgement on future policy choices. In economic terms, an externality is a cost or benefit resulting from an economic transaction that is borne or received by parties not directly involved in a transaction.

The concept of externalities in the general sense was first mentioned by the economist Alfred Marshall, and then developed and analysed in further detail by Arthur Cecil Pigou (1920). Externalities have been defined in multiple forms and have also been termed external effects, external diseconomies, third-party effects and spill-over effects (Lin, 1976). Externalities were initially mentioned and classified as exceptions to the standard. As societies grew in material wealth, the incidence of external effects grew more into a standard than an exception, thereby requiring extended attention (Mishan, 1965).

Pearce and Turner (1990) refer to externalities as the phenomenon which occurs when the social or economic actions of an individual or a group affect another individual or group (not necessarily in that order) in an unintentional and uncompensated manner. This effect can be either positive or negative and often goes unaccounted. The positive external effects are often ignored from an action-oriented approach (because they are harmless), but are accounted for economically to enhance policymaking. On the other hand, negative externalities affect the society both aesthetically and economically, essentially making their internalisation highly critical to the economy. Electricity externality valuation is mainly performed using two kinds of techniques: abatement cost methods and damage cost methods.

Abatement cost method (ACM) uses estimations of costs to control or evade a particular environmental externality. ACM assumes policy-makers to have accurate values for the damage or avoidance cost before an externality has occurred (Pearce et al., 1992). The damage (opportunity) cost method (DCM) uses the actual costs and benefits of the externalities and of non-market externality evaluation within itself where necessary. This methodology values the actual damage rather than estimating what the damage might have been. Hence the DCM is more associated to the real world scenario. One such situation would be evaluating the damages caused to both material and non-material assets by uncontrolled emission of pollutants from a power plant. The DCM is further divided into the 'top-down' and the 'bottom-up' approaches (Sundqvist, 2004). A large number of externality analysis studies have been performed over the past couple of decades (Scuhmann and Cavanagh, 1982; Hohmeyer, 1988; Ottinger et. al, 1991; Pearce et. al, 1992; Faaij et. al, 1998; Rowe et. al, 1995; Van Horen, 1996; Bhattacharya, 1997; Madisson, 1999; European Commission, 1999; Rafaj and Kypros, 2007; Klassen and Riahi, 2007). As the years have advanced, the scope of the area under evaluation has progressed from local to international to global zones. A summary and comparison of a selected few electricity externality studies are made in Table 1.

Table 1. Selected externality studies of coal-fired electricity using different approaches[a]

Study	Method	Country	External cost (US cents/kWh)
Schumann Cavanagh (1982)	Abatement cost	US	0.07–53.48
Hohmeyer (1988)	Top-down damage cost	Germany	5.55–11.63[b]
Ottinger et al. (1991)	Top-down damage cost	US	4.39–10.70
Pearce et al. (1992)	Top-down damage cost	UK	3.24–17.51
Faaij et al. (1998)	Top-down damage cost	The Netherlands	4.83
Oak Ridge National Laboratory and Resources for the Future (1994–1998)	Bottom-up damage cost	US	0.13–0.58
European Commission (1995)	Bottom-up damage cost	UK/Germany	1.19–2.9
Rowe et al. (1995)	Bottom-up damage cost	US	0.37
Van Horen (1996)	Bottom-up damage cost	South Africa	1.09–6.08
Bhattacharya (1997)	Bottom-up damage cost	India	1.63
Faaij et al. (1998)	Bottom-up damage cost	The Netherlands	4.66
European Commission (1999)	Bottom-up damage cost	EU	1.02–87.88
Maddison (1999)	Bottom-up damage cost	UK/Germany	0.38–0.86
Rafaj and Kypreos, (2007)	Bottom-up damage cost	Global average	13.50
Klaassen and Riahi, (2007)	Bottom -up and top-down combination	Global average	15.72-43.49[c]

[a]Adapted from Van Horen (1996) and Sundqvist (2004). Values used in Sundqvist have been adjusted for 2011 from 1998 using a US 2010 Consumer Price Index of 1.5 US$ (World bank, 2013).

[b] Values given in Van Horen were converted back to 1994 US$ using a conversion rate $0.273/R1 and adjusted using CPI for the year 2011.
[c] Conversion factor US$ 1.3 = €1 (2010 rates).

As can be seen from Table 1, the result of the abatement cost method constituted a wide range of results primarily because it was one of the foremost studies performed and had to overcome numerous data gaps. However, uncertainties exist when the geographical area considered in the study is wide and when factors previously unaccounted for, such as the effects of CO_2, are later accounted for (European Commission, 1999). This disparity can be observed by comparing the results of the ExternE evaluation performed in 1995 and 1999. The costs of the predictive studies are higher than the general average because of the contribution from the developing economies which do not employ desulphurisation or de-nitrification schemes on a large scale. Also, the rate and scale at which the developing countries are expected to switch to renewable schemes are slower than the developed countries. The box plot in Figure 1, which shows the entire range of externality values used in Table 1, helps in understanding the values better. The valuations range from a low of US$ 0.07c/kWh to a high of US$ 87.89c/kWh with a median of US$ 3.24c/kWh. The middle 50% (inter-quartile range) of the values range from US$ 0.98c/kWh to US$ 12.1c/kWh.

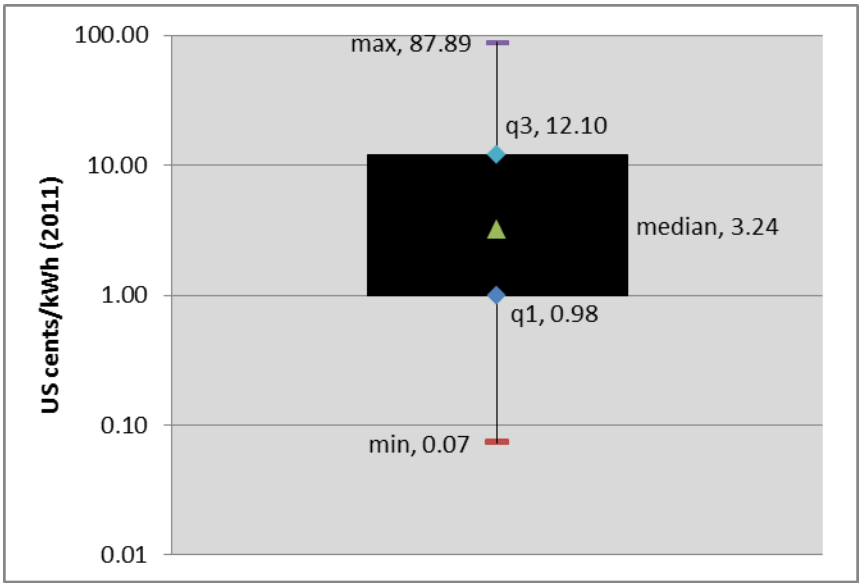


Figure 1. Box plot of external costs in electricity generation

Quantification of external costs in South Africa in this paper is performed for 10 base load coal power plants and one nuclear power plant. All 10 coal power plants are located in the north and north eastern region of South Africa within the provinces of Free State, Mpumalanga and Limpopo, because of the abundant availability of coal resources. The nuclear power plant is located at Koeberg, near Cape Town, in the south western region of South Africa bordering the Atlantic ocean.

The most important factor that needs mention in this analysis is that all external cost (or externality) valuations are performed on data sets for the year 2008. This has been done to avoid distortions in estimates when comparing external costs to local electricity prices. Since local electricity prices in South Africa have increased by 25% to 33 % during the period 2008-2013, comparing external costs with local prices would diminish the significance of external costs. Another reason to choose data sets for the year 2008 was to achieve uniformity in time frame for all evaluations being performed.

3. Methodology

The methodology employed to evaluate externalities in this study is based on the Impact Pathway Approach (IPA) used in the Externalities of Energy (ExternE) study performed in the European Union. The IPA methodology is mostly used during Life Cycle Analysis (LCA) studies. This study is however not a LCA of fuel cycles, but focuses solely on the generational stage of the fuel cycle. The IPA is used to analyse the generational stage of the fuel cycle, as well as the impacts associated during electricity generation. The IPA methodology is broken down into various stages such as identification of impacts, prioritisation of impacts, quantification of burdens, description of receiving environment, quantification of impacts, economic valuation of impacts and finally assessment of uncertainty.

The function used to valuate external costs is deduced in terms of a damage function obtained from quantification of impacts and economic valuation as,

$$\text{Damage} = \text{Impact} \times \text{Cost}$$

where,

Damage = Total monetary external cost

Impact = Total number of cases per externality (impact)

Cost = Monetary value per case of externality (valuation)

The extent of quantification of external costs is largely dependent on the scale of impacts quantified, the availability of local data and the reliability of assumptions made when local data is unavailable. The type of impacts aggregated in this study include a)public health impacts from coal, b)environmental impacts from greenhouse gases (GHG), c)environmental impact from water usage, d)occupational health impacts from coal and e) public and occupational health impacts from nuclear.

The following sections provide a brief description of each impact group and the IPA methodology used. A matrix (indicator grid map) of the damages versus the impacts and other important parameters which include local costs and uncertainty factors are shown in Table 2.

Table 2. Indicator grid map

Damage	Impacts	Local cost / unit[1] (central estimate)	Causes	Uncertainty factors
Public health (coal)	Restricted activity days Long term mortalities Short term mortalities Chronic bronchitis Respiratory hospital admissions	180/case 157129/case 270706/case 276608/case 7066/case	SO_2, NOx, PM10	Exposure response functions
Environmental (GHG)	Regional warming	113/tonne CO_2e	CO_2, Methane	GHG estimates, Damage cost of GHGs
Environmental (water)	Scarcity of water	3.00/m^3 of water	Non-market related water pricing	Economic value of water
Occupational (coal)	Occupational injuries, mortalities and diseases	Damage costs were determined from official total costs	Occupational accidents and negligence	Accurate reporting of cases
Public and Occupational (nuclear)	Marginal preventive measures	5780/person-mSv	As low as reasonably achievable radiation	Accuracy of damage cost

[1]All values in SA Rand

a) Public health impacts from coal

The external costs for the mentioned impact are quantified using the ExternE (Externalities of Energy) methodology. All 10 base load power stations are evaluated using the Riskpoll[1]

[1] Riskpoll is the open source software used to evaluate damages from air pollutants from power plants.

software of ExternE. The pollutants considered in the analysis are sulphur dioxide (SO_2), oxides of nitrogen (NO and NO_2) and particulates (PM_{10}). The emission inventories and characteristics (such as chimney height, physical location, etc.) for the power plants were obtained from Eskom[2] (Ross, 2012). Local meteorological data was collected from Eskom's weather centre and the South African National Weather Service station.

The health impacts considered in this study included restricted activity days, long-term mortality, short-term mortality, chronic bronchitis and respiratory hospital admission. The critical choice of exposure-response functions for the mentioned health impacts, were used from the ExternE suit of studies (Rabl, 2001; Pope et. al., 1995; Ponce de Leon, 1996, Sunyer et. al., 1997). These data sets were combined with population data (obtained from Statistics, South Africa) within a radius of 500km of the individual power plants.

The atmospheric dispersion model within Riskpoll constitutes a robust uniform world model which is based on assumptions such as constant emission rate and depletion velocity of pollutants, uniform regional population, linear with zero threshold exposure response, uniform wind rose distribution and mean local meteorological conditions. The model in conjunction with local meteorological, population, power plant data and exposure-response functions is used to calculate the number of externalities or impacts.

The economic cost (or monetary valuation) per case of externality is adapted from Riskpoll using a Purchasing Power Parity (PPP) index for South Africa to avoid under-estimations when using real exchange rates, as recommended in the ExternE study (Spadaro, 2003).

b) Environmental impacts from greenhouse gases (GHG)

Environmental impacts from GHG includs the emissions of CO_2 & N_2O associated with electricity generation and methane from coal mining, respectively. South Africa is the 12th

[2] Eskom is South Africa's sole national electricity utility.

largest emitter of CO_2 (486.49 million tonnes) globally and has a per capita intensity of almost of 10 tonnes/person (EIA, 2012). 223.6 million tonnes of CO_2 and 2801 tonnes of N_2O were emitted directly from the process of electricity generation for the national grid (Eskom, 2011). It was identified that the emission intensity (kg/kWh) for the base load power plants ranged from 1.11 to 0.84 (the average being 1.00) with older power plants being less efficient as expected (Thopil, 2013).

There are no official estimates of methane emissions associated with coal mining in South Africa. South Africa, the fifth largest producer of coal in 2008 produced approximately 250 million tonnes of coal of which 125.3 million tonnes were used for electricity generation (South Africa, 2012). Methane emissions associated from opencast and underground mining of coal used for electricity generation was estimated to be 29 524 tonnes (Thopil, 2013). These estimations were based on IPCC best practices (IPCC, 2006).

The aggregation of GHGs was performed by converting the emissions of each GHG to CO_2 equivalent using the Global Warming Potential (GWP) of GHGs. A GWP (based from the IPCC, 2007) of 1, 298 and 25 was used for CO_2, N_2O and methane respectively. Using this methodology the total GHG CO_2 equivalent associated with electricity generation was estimated to be 225.172 million tonnes CO_2e.

The damage cost for a tonne of CO_2e with lower, middle and upper bounds are chosen as €9, €19 and €50 respectively (EC, 2005). These values are converted to local values using a PPP exchange rate for 2008, from Euro values to South African Rand as shown in Appendix A. Conversion of prices from countries with stronger currencies (in this case the Euro), if made using normal exchange rates, give a distorted impression of actual prices (in this case the SA Rand) within the local economy. Therefore, the price of one tonne in SA Rand with lower, middle and upper estimates is Rand 50, Rand 113 and Rand 296, respectively.

c) Environmental impacts from water usage

Water is considered a scarce resource in South Africa. With the country being located in a semi-arid region it is amongst one of the 30 driest countries in the world. South Africa could face a situation of extensive water scarcity unless current reserves and usage patterns are monitored carefully (De Wet, 2010).

Eskom's water pricing mechanism is based on long-term purchase agreements with the Department of Water Affairs, which might be understating the actual price of water. This incongruity in pricing can be considered an externality and thus requires investigation. The economic value of water for industrial prices in the Tshwane metropolitan area, based on a willingness to pay approach was determined to be Rand 3/m^3 (Det Wit and Blignaut, 2004). Van Horen (1996) uses a window 60 cents to determine the low and high estimates of water prices. Combining the economic value with the window value gives a low and high value of water to be Rand 2.40 and Rand 3.60 per m^3. The actual water prices used in Eskom's base-load power stations are provided in Table 3.

Table 3. Water pricing in Eskom coal fired power stations

Power plant	Average price (Rand/m^3)	Power plant	Average price (Rand/m^3)
Arnot	1.26	Lethabo	1.45
Duvha	1.14	Majuba	0.32
Hendrina	1.52	Matimba	1.55
Kendal	3.03	Matla	0.88
Kriel	1.16	Tutuka	0.57

It can be noticed that there is significant variation in pricing between the various power stations to add to the variation with the economic value of industrial prices. This variation in pricing between the real price and perceived price is an externality. The variation in price is coupled with the water usage in each power plant to determine the external cost.

d) Occupational health impacts: Coal

The main body responsible for Occupational Health and Safety (OHS) in South Africa is the office of the Chief Directorate at the Department of Labour. This office is responsible for the administration of the OHS Act 1993, which covers all workers employed in the formal sector and covers all public health and safety workers without a specialist inspectorate. Compensation for workers is regulated and decided upon by two separate authorities (or offices). The first is the Compensation Commissioner's office, part of the Department of Labour, which oversees the Compensation for Occupational Injuries and Diseases Act, No: 130 of 1993 (COIDA). The second office, the Compensation Commissioner for Occupational Diseases (CCOD) in the Department of Health, administers the Occupational Diseases in the Mines and Works Act, 78 of 1973 (ODMWA) and provides compensation for mineworkers having occupational health diseases. The Medical Bureau of Occupational Diseases (MBOD) within the Department of Health provides medical examination for personnel claiming occupational disease compensation.

Occupational health externalities can be categorised into two separate sections depending on the type of office responsible for dealing with a particular health hazard. The first section contains hazards categorised under occupational injuries (both mortal and morbid), which falls under the COIDA. Data of such hazards was collected via personal interviews and archival records from the offices of Rand Mutual Assurance, which covers statutory work insurance in the mining sector in the event of injury or death, for the employee and dependents in terms of the COIDA (Kritzinger, 2013). Compensation under the occupational injury category caters for acute care, pensioner care and non-pensioner care.

The second section comprises hazards categorised under occupational diseases, which falls under the ODMWA. Accounting of such externalities is carried out by the CCOD and

MBOD in terms of the ODMWA. Data for these hazards were obtained from the annual report of the compensation commissioner's office (CCOD, 2008). Payouts are classified as first degree (10 to 40 % impairment) and second degree (more than 40%) compensations based on the damage of respiratory organs.

e) Public and occupational health impacts: Nuclear

The concept of nuclear externalities is both sensitive and critical. South Africa operates one nuclear power plant by the name Koeberg which operates two 900MW reactors in the south western part of the country. Though uranium is mined in South Africa, enrichment and fabrication does not occur locally. The fuel used in the nuclear power plant reactors are enriched, fabricated and imported for use in Koeberg. The radiation occurring from electricity generation and fuel disposal are the primary impacts. It is critical to mention that the dosages are within the ALARA (As Low As Reasonably Achievable) levels, which vary from 0.6 person-Sv to 1.0 person-Sv (Canadian National Nuclear Safety, 2004; Julien et al., 2010). Data from the operation of the power plant and fuel disposal was found to be well within the individual limit of 50 mSv set by the South African national nuclear regulator. Total dosage (person-mSv) is calculated by multiplying average dosage (mSv) with the number of personnel (person).

The economic impact of dosage is performed using an alpha value of US dollar per person mSv. The OECD Nuclear Energy Agency and the International Atomic Energy Agency together maintains a database called the Information System of Occupational Exposure (ISOE). The ISOE provides alpha values for most nuclear power plants around the world. The alpha value associated with Koeberg was determined to be 1300 US dollar/person-mSv which was calculated to 5780 SA Rand/person-mSv using 2008 purchasing power parity exchange rates.

4. Results

External costs from the impacts quantified in the previous section were analysed on aggregated and average levels. External costs are also classified and analysed based on the point of impact of the damages and is categorised into health costs (comprising public and occupational costs) and environmental costs.

4.1 *Aggregated External Costs*

The total costs associated with the quantified impacts are summarised as shown in Table 4.

Table 4. Aggregated External Costs estimates (in Million Rands)

Impact	Low	Central	High
Coal: Public health	847.10	2681	8770.40
Coal: Occupational health	Not quantified	77.66	Not quantified
Nuclear: Public & Occupational health	8.44	13.71	18.98
Coal: GHG environmental	11258.6	25444.5	66651.8
Coal: Water usage environmental	435.40	626.55	819.75
Total	12549.54	28843.42	76260.93

It can be observed that the largest single contributor of external costs is the damages associated with GHG emissions. Damages associated with public health and water usage also constitute significant segments within total damages. Larger disparity between low, central and high estimates occurs within impacts that are significant contributors which leads to the observation that, the more significant the impact, the higher the uncertainty associated while quantifying the range of the damage.

Aggregated costs can also be classified based on the point of impact of the damages. This distinction is achieved by distinguishing health impacts (both public and occupational) and environmental impacts. The first three rows in Table 4 constitute health impacts with the next two rows comprising environmental impacts which is summarised in Figure 2.

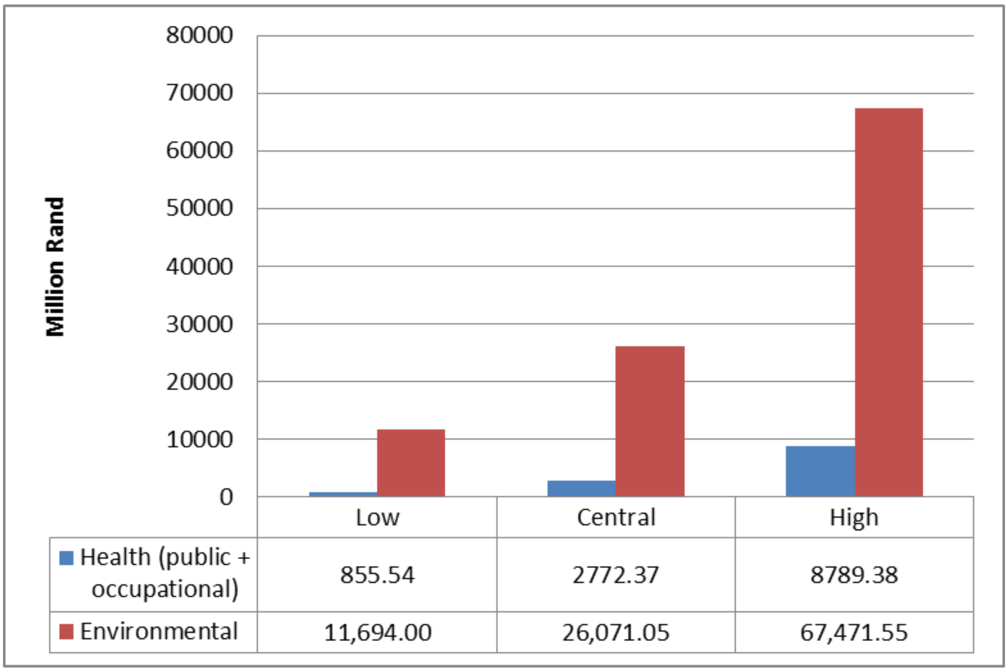


Figure 2. Estimates of aggregated health and environmental impacts

It can noticed from the figure and associated data that quantified environmental damages outweigh health damages which leads to the deduction that health impacts are better controlled as opposed to environmental impacts. It can also be observed that disparity between range estimates of health damages is higher than environmental damages which indicate higher prioritisation and range uncertainty.

4.2 *Average External Costs*

While aggregate costs help in determining impacts in terms of total damages caused, average costs are used to compare damages with respect to a common denominator, in this case the amount of non-renewable electricity generated. Average costs have been estimated for quantified damages in prior chapters and are summarised below in Table 5.

Table 5. Average External Cost Estimates (in mills/kWh)

Impact	Low	Central	High
Coal: Public health	3.90	12.37	40.50
Coal: Occupational health	Not quantified	0.36	Not quantified
Nuclear: Public & Occupational health	0.75	1.21	1.68
Coal: GHG environmental	51.96	117.44	307.64

Coal: Water usage environmental	2.00	2.89	3.78
Total	58.61	134.27	353.6

The denominator of estimating average damage cost is equivalent for all impacts except nuclear health impacts because of the different amounts of electricity generated from either technology. The variable quantifying denominator for impacts associated with coal and nuclear generation is the amount of electricity generated using each technology (216664 GWh and 11317 GWh, respectively). The largest average damage is related with GHG emission followed by public health impacts caused by pollutants.

Classification of average costs differentiated by health impacts and environmental impacts is shown in Figure 3.

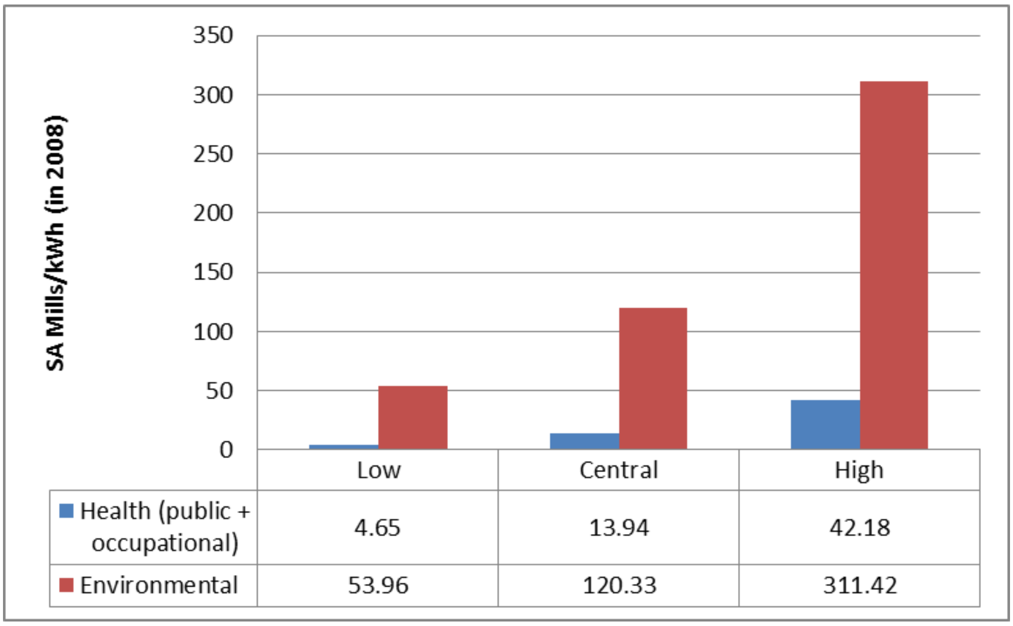


Figure 3. Estimates of average health and environmental impacts

The behaviour of the range of estimates of average costs is similar to range of estimates of total costs. Continuing the focus on average costs, it is worthwhile to differentiate costs in relation to the type of generating technology which is depicted in Table 6. A better comparison of these results are possible when average local costs are converted to US dollar cents /kWh using purchasing parity rates for the year 2008 (Appendix A).

Table 6. Average External costs in (SA cents/kWh and US cents/kWh) 2008 values

	SA cents/kWh			US cents/kWh		
Generation	Low	Central	High	Low	Central	High
Coal	5.786	13.30	35.19	1.30	2.99	7.82
Nuclear	0.075	0.121	0.168	0.016	0.027	0.037
Total average costs	5.86	13.427	35.36	1.31	3.02	7.95

The range of 5.86 – 35.36 SA c/kWh, with a central value of 13.43 SA c/kWh, falls in line with van Horen's valuation (which is most comprehensive externality valuation to date in South Africa) for the coal based externalities. However the nuclear externalities are much lower in this study compared to van Horen's analysis. The cause for such variances is because van Horen performs a fiscal externality analysis for nuclear generation as opposed to the health and environmental externality analysis performed in this study. The PPP adjusted range of 1.31 – 7.95 US c/kWh, with a central value of 3.02 US c/kWh, falls in range with the comparisons made between various international studies (Thopil & Pouris, 2010) as well as the comparisons made in table 1 and figure 1.

4.3 *Average External Costs vs Electricity Prices*

Quantification of external damages as a separate entity does not provide any added benefit to policy makers unless contextualised with electricity prices. The relative significance of external costs can be highlighted when compared with local electricity tariffs. The electricity tariffs for the year 2008, used to contextualise externalities are categorised into three sectors namely: average domestic tariff, average industrial tariff and average overall tariff, which are 44.56, 17.28 and 19.59 c/kWh, respectively (Eskom, 2009). The tariffs and percentage relativeness are summarised as shown in Table 7.

Table 7. Total average external costs relative to sectorial tariffs

Sector	Average 2008	Total Avg. External Costs relative to Tariffs		
	Tariffs (c/kWh)	Low (5.86 c/kWh)	Central (13.43 c/kWh)	High (35.36 c/kWh)
Domestic	44.56	13%	30%	80%
Industrial	17.28	34%	78%	205%
Overall	19.59	30%	69%	181%

Of the three considered sectors, only the domestic tariffs manage to encapsulate the average external estimates. This gives a fair indication of the disparity in local sectorial electricity prices.

Table 8 exhibits the percentage share of the main impacts (Table 5) with respect to average overall 2008 price of 19.59 c/kWh (or 195.9 mills/kWh), in which the individual contribution of each impact relative to the average overall tariff is distinguished.

Table 8. Individual average external costs relative to overall average tariff

Impact	Low	Central	High
Coal: Public health	1.9 %	6.3%	20.67%
Coal: Occupational health	Not quantified	0.18%	Not quantified
Nuclear: Public & Occupational health	0.4%	0.62%	0.85%
Coal: GHG environmental	26.5%	59.9%	157.04%
Coal: Water usage environmental	1.02%	1.47%	1.93%
Total	29.91%	68.54%	180.5%

By distinguishing the contribution of impacts on electricity tariffs, decision and policy makers are in a better position to analyse the role of each impact separately.

The final step of this analysis entails internalisation of total average costs into the overall average tariff of 19.59 c/kWh. For this analysis only overall tariffs are used for inclusion since external costs are shared across all sectors of the society.

Table 9. Inclusion of total average costs to average overall tariffs.

Estimate	Average External Costs c/kWh	Internalised Average tariff		% Increase on 2008 prices
		SA c/kWh	US c/kWh	
Low	5.86	25.45	5.72	30%
Central	13.43	33.02	7.43	69%
High	35.36	54.59	12.28	181%

The above analysis leads to the conclusion that inclusion of average external costs to the average 2008 electricity tariffs would cause an increase of 30 to 181% with a central increase of 69%. The current externality analysis and internalisation into prices occurs at a time when there are significant changes occurring in pricing mechanisms in the local electricity sector.

4.4 *South African External costs vs International External Costs*

At this point it is important to compare the average external costs in this analysis with the average costs in other countries (primarily the EU25 countries) that have performed electricity externality analysis using the ExternE methodology. The ExternE methodology studies shown in Table 10 below are shown in milliEuros (1999 prices). South African external costs are adjusted from millsRands to milliEuros using 2008 PPP rates used in Appendix A.

Table 10. Average external costs using ExternE methodology (in millEuros/kWh)

Country	Human Health (Coal) central estimates	GHG emissions (Coal)	Human health (Nuclear) central estimates
Belgium[1]	17.2	4-128	0.4
Germany[1]	11.9	3-111	0.18
Netherlands[1]	8.1	3-126	0.11
France[1]	48.4	4-151	0.44
Sweden[1]	0.7	3-102	0.41
South Africa[2]	2.25	9.43-55.8	0.22

5. Discussion

External costs as a stand-alone entity do not provide policymakers sufficient background to make decisions that may lead to abatement of factors causing externalities. Relevant policy measures across all sectors are reconsidered and revaluated usually when externalities and tariffs are brought into context, which is performed in this discussion. In order to better understand the significance of externalities a brief case description of the recent developments in electricity pricing is essential. The first section focuses on sector based analysis of pricing, which highlights that industrial prices in South Africa are lower than average. The recent renewable energy focus occurring (which could lead to reduced externalities) within the electricity sector is also highlighted as a separate sub-section. In the final certain policy proposals that could be implemented within the local electricity industry are proposed particularly via incentive based pricing and regulation, in order to reduce high energy intensity production and thereby reducing externalities.

5.1 *Electricity pricing in South Africa*

The South African electricity industry has seen a dramatic increase in prices over the past three years. The increases are because of the need to build additional generational capacity to meet increasing demand. The government's policy to provide free basic electricity access to large segments of the population since the mid-nineties has coincided with a period when additional capacity has not been added to the grid. The financing of new power plants has caused the National Energy Regulator to increase prices to recover costs on behalf of the ailing national electricity utility. These increases have been blanketed across all sectors and are based on a number of factors such as type of sector, amount of usage, suburb in case of domestic pricing, etc. South Africa's price of electricity, particularly within the industrial sector has been one of the least expensive in the world. The case provides an analysis of the consequences of price determination mechanisms employed in recent years and the effects on local prices. A comparison of local and international prices is made in order to observe the rising trends, which is followed by a mention of recent developments in the electricity sector.

With Eskom's priority centring on providing basic electricity to the masses and electrification being the primary focus, generational capacity expansion was shelved. Incremental demand since the mid-nineties culminated in demand exceeding supply capabilities in 2008 with Eskom having to employ load shedding until demand stabilised. The formulation of the Integrated Resources Plan was made with the intention of expanding generation capacity from the period of 2010 to 2030, taking into account multiple possibilities to meet electricity demand (DOE, 2011). The process of expanding generational capacity meant increased revenues for Eskom primarily by increasing tariffs.

The regulation and determination of electricity prices is performed by the National Energy Regulator of South Africa (NERSA). The electricity pricing scheme employed by NERSA is based on the multi-year pricing determination (MYPD). The MYPD was implemented based on Eskom's cost recovery requirements, so that the utility remains functioning and be able to sustain itself economically (NERSA, 2010). The functioning and economic sustainability of Eskom is vital, considering the significance Eskom plays in the electricity sector in South Africa.

MYPD or MYPD1 was formulated for the years 2006/07 to 2008/09. However since then two more revisions of the MYPD, namely MYPD2 for the period 2010/11 to 2012/13 has been implemented and MYPD3 for the period 2013/14 to 2017/18 has been approved. A summary of the three stages are shown in the Figure 4 below.

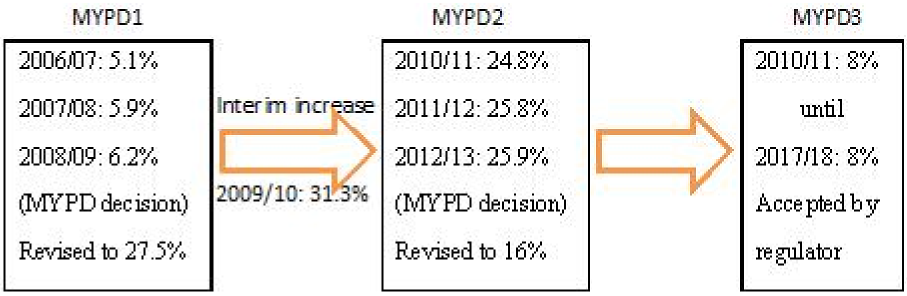


Figure 4. MYPD1, MYPD2 and MYPD3 summary

At this point an observation of local electricity sales made by Eskom is warranted. Local electricity sales from Eskom can be subdivided into the following categories: residential, commercial, industrial, mining, agricultural, traction and redistributors (municipalities). Industrial and mining (which are the two largest sectors) – contribute to 77% of the sales but generate only 67% of the revenue, with the industrial sector having the largest disparity. The largest reverse disparity (where percentage of revenue from electricity sales is greater than percentage of electricity sales) occurs in the agricultural sector, which is a vital sector of the South African socioeconomic makeup. The residential sector also shows a degree of reverse disparity. This leads to the question whether the industrial sector, in spite of being the largest sector in terms of sales, is under-priced; one of the primary reasons being standing contractual agreements between Eskom and large industrial users such as mines. These contracts are equally beneficial for both entities, since the large industrial users contribute to the largest section of revenue for the utility while being able to keep their utility costs low.

In order to confirm the argument that the industrial sector is under-priced in South Africa, the electricity supply prices in South Africa and a number of other countries is compared. Table 11 shows a comparison of industrial and household prices of a few OECD (Organisation for Economic and Development) countries and South Africa. A close inspection of the data shows that the ratio of domestic to industrial prices is a factor between 1 and 2 for all countries except for Mexico where industrial prices are higher than domestic prices. In the case of South Africa the domestic to industrial price factor is between 2 and 3. In other words the disparity between domestic and industrial prices is largest in South Africa compared to all other countries.

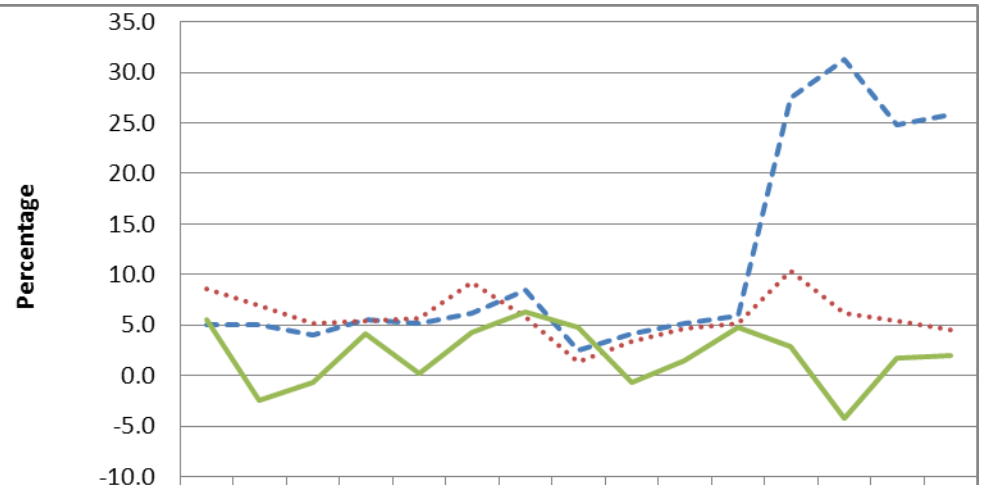
Table 11. Electricity prices in US dollar cents/kWh adjusted for Purchasing Power Parity (PPP)[c]

Country[a]	**2007**		**2008**		**2009**		**2010**	
	Domestic	**Industrial**	**Domestic**	**Industrial**	**Domestic**	**Industrial**	**Domestic**	**Industrial**
Belgium	14.51	9.62	18.53	9.83	16.05	11.39	16.85	10.87
Denmark	12.65	9.42	16.95	11.34	14.89	10.52	15.54	11.24
France	10.35	5.82	10.25	6.33	10.34	6.73	11.29	7.11
Finland	9.23	5.98	10.38	7.03	10.63	7.20	11.18	7.16
Greece	12.53	10.98	15.05	13.12	13.25	12.00	13.27	12.12
Ireland	17.64	12.89	18.85	14.93	18.10	12.95	18.83	12.99
Mexico[b]	13.06	14.45	13.39	15.82	10.68	11.78	Na	Na
Netherlands	15.05	10.03	15.61	10.52	16.34	10.92	15.01	10.12
Norway	13.17	7.73	15.85	9.58	14.91	8.87	17.99	10.38
Spain	15.82	12.52	17.75	14.12	19.40	15.59	20.75	14.46
South Africa	9.95	3.81	9.97	3.86	11.25	4.56	12.81	5.41
South Korea[b]	11.49	8.44	14.09	9.93	9.67	7.43	Na	Na
Sweden	12.48	8.02	14.57	9.84	14.05	9.07	16.59	10.83
Switzerland	9.66	5.93	10.34	6.32	9.82	5.87	Na	Na
Taiwan[b]	11.93	9.23	12.48	9.49	12.82	11.73	Na	Na
UK	17.38	12.72	19.61	13.45	17.78	12.91	17.89	12.42
USA[b]	10.06	6.17	10.34	6.44	11.05	6.87	Na	Na

[a]All prices were obtained from the Eurostat portal, except where mentioned. (Eurostat, 2011)
[b]Prices obtained from “Energy prices and taxes” online database.
[c]PPP adjustments were performed using the online OECD database. (OECD, 2011)

Table 11 also shows that South Africa’s industrial electricity prices are among the cheapest in the world. These prices have been kept low historically, and the adverse effects of this are being seen now. Closer inspection of the prices shows that most countries have either avoided hiking electricity prices or marginally decreased or increased them during the period of 2008–2009, which coincides with the economic downturn. Meanwhile, South Africa’s electricity utility has been forced to increase prices significantly to recoup monetary resources to invest in the ever increasing demand for electricity. These increases have taken place across the board for all sectors and are out of sync with the increases seen internationally.

A better indication of the price increases can be observed by comparing the indicators described in Figure 5 over the time period 1997-2011. It can be noticed that while percentage increases in CPI and generation capacity stay constant, electricity price increases have steeped since 2007 and have stayed at that level. However the national regulator’s decision to stick to 8% increases for the next 5 years (as per MYPD3), shows signs of increases being steady.



	97	98	99	00	01	02	03	04	05*	06	07	08	09	10	11
Price Increase	5.0	5.0	4.0	5.5	5.2	6.2	8.4	2.5	4.1	5.1	5.9	27.5	31.3	24.8	25.8
CPI increase	8.6	6.9	5.2	5.4	5.7	9.2	5.8	1.4	3.4	4.6	5.2	10.3	6.2	5.4	4.5
Generation increase	5.6	-2.5	-0.7	4.1	0.1	4.3	6.3	4.7	-0.6	1.5	4.7	2.9	-4.3	1.7	2.0

Figure 5 Indicator comparison (Source: Eskom Annual Reports)

5.2 *Renewable electricity initiatives*

The over dependence on fossil fuel power generation, rising electricity prices and the need to provide improved energy security has led to the formulation of the Renewable Energy Independent Power Producer Procurement Programme (REIPPPP or REIP4). The REIP4 programme was devised as a replacement for the Renewable Energy Feed-In-Tariff (REFIT) scheme which was abandoned mid-2011 by the regulator. The reasons for abandonment lack clarity as the national regulator only mentioned postponement of the programme (NERSA, 2011). It is speculated that the government's liability concerning long term feed-in tariffs and legal concerns regarding procurement were the reasons for abandonment of the programme (Bloomberg, 2011). The main opposition was from the National Treasury's objection concerning the pricing regime of the REFIT programme (Pegels, 2011). The REFIT programme was developed by the Department of Energy under the stewardship of the National Treasury and revised to formulate the REIP4 mechanism based on the vision of the IRP. The REIP4 is based on a process of competitive bidding by independent power producers (IPP) thereby acquiring the name REBID (Renewable Energy Biding). The REBID programme is assigned to add 3725 MW of renewable energy to the national grid between mid-2014 and 2017, with primary focus on wind and solar energy. The bidding process is based on a tariff cap set for the technologies included in the REIP4 process. The total of 3725 MW is available for bidding by interested IPPs over five separate bidding windows, two of which have already been completed (DoE, 2012). A summary of the REBID programme is mentioned in Table 12.

Table 12 REBID programme summary

Technology	**Tariff cap R/kWh (2011)**	**MW allocated (2011)**	**REIP4 Window 1 MW allocation**	**REIP4 Window 2 MW allocation**
Onshore wind	1.15	1 850	633.99	562.4
Solar PV	2.85	1 450	631.53	417.1
Concentrated Solar	2.85	200	150	50
Biomass	1.07	12.5	0	0
Biogass	0.8	12.5	0	0

Technology	Tariff cap R/kWh (2011)	MW allocated (2011)	REIP4 Window 1 MW allocation	REIP4 Window 2 MW allocation
Landfill gas	0.84	25	0	0
Small hydro	1.03	75	0	0
Small RE < 1-5 MW		100	0	0
		3 725	**1 415.52**	**1 043.8**

Source: Eskom, 2012.

The current state of renewable energy allocation based on tariff caps, MYPD implementation and capacity addition of coal fuels plants Medupi and Kusile makes the South African electricity industry an exciting place to be in. However lessons must be learnt from past incidents such as the rejection of the REFIT programme. This would require a consolidated and integrated approach by the major players within the electricity industry while keeping socio-environmental interest in foresight.

5.3 *Policy proposals*

In summary the externality cost analysis and the discussion of the local electricity pricing industry raise some key questions, those being:

a) How can external costs be accommodated or reduced by altering the price of electricity?

b) Is a sector based discriminatory pricing mechanism a favourable option as opposed blanketed price increases?

Eskom currently employs time and seasonal based differential pricing for its urban customers. Differential pricing is also used based on the voltage supplied and transmission distance. A system called inclined block tariffing is used for residential customers, which means that lesser the customer uses the lesser the tariff (Eskom, 2011b). However pricing for large industrial customers are based on long term binding contracts. Since large industrial users are major drivers of the economy, they have a larger footprint on the socio-environmental impacts of the region.

A lack of differential pricing however still exists within the local industrial sector. Lin and Liu (2011) investigated differential pricing in energy-intensive industries in the Henan province of China, where differential electricity pricing was used to curb profits of high energy intensive commodity production. However the results of such a mechanism implemented by the central government were mixed since profits of energy intensive production for all commodities under investigation did not decrease. Such a scenario was attributed to the local government subsidising electricity to compensate for the central government's price hike. If such a policy is implemented in South Africa by the national government, the likelihood of success is higher since provincial interference is unlikely.

Another technique that could be used to deal with external costs and industrial pollution is the method of incentive based pricing. Jamasb and Pollitt (2001) discuss benchmarking and regulation in the OECD countries as well as the effect of the incentive based regulation. The concept of pricing based on incentivised regulation is useful in South Africa when bearing in mind the levels of carbon intensity. Such a system could create a culture of environmentally suitable manufacturing if based on the reward of an incentive in electricity prices. Incentives are often the instigator towards better performance and the same concept should be used towards creating a local industry aware of its responsibilities both socially and environmentally.

6. Conclusion and policy implications

In summary, the external costs that have been analysed and calculated in this study are in line with the studies performed internationally which brings to light the necessity to tread with caution when considering long term socio-environmental impacts. South African central external costs are roughly 70% of 2008 electricity prices. The major contributors of total central external costs (13.4 SA c/kWh) were public impacts from coal (1.23 SA c/kWh, 9.2%) and environmental impacts from coal (11.74 SA c/kWh, 87.4%). South African external costs per kWh were found to be in the range of European countries that have used the ExternE methodology.

It can be observed that significant variation occurs in the human health cost because of variable factors such as technology of power plant, quality of coal used, site location, atmospheric conditions, population variables and such. However GHG emissions costs show less variance for the reason that local conditions have no effect on determining damage costs. Nuclear costs on the other hand show least variance since technology and operating conditions are adhered to as per strict safety regulations which are standardised globally. It is worth noting that South African valuations (while considering uncertainties and variations) fall within the range of valuations performed in European countries using the ExternE methodology. The methodology employed and results arrived at can be used for benchmarking by countries within the Southern African and African region as well as other developing countries that do not have a mix of fuel sources being used for electricity generation.

The internalisation of external costs by placing an environmental tax on general users is not feasible, considering the background where prices are already being increased to raise capital to add new generation capacity. The presence of coal as a cheap and abundant resource is bound to keep South Africa reliant on coal in the near future, however technologies such as retrofitted FGD and carbon capture storage must be considered for new build projects. The presence of renewable electricity generation mechanisms is a welcome addition to decrease the impact of fossil fuels. However the variability and limited availability of solar and wind power combined with the aging national transmission grid brings added risk when pursuing renewables without caution.

Policy prioritisation and pricing mechanisms need to be altered with a focus on curbing and decreasing the cause of externality impacts. An integrated and coordinated approach between government and industry is required, if such goals are to be achieved while maintaining the competitiveness of the local industry. The advent of the renewable energy programme has unlocked a range of opportunities and challenges in the South African electricity industry. The implementation of renewable energy mechanisms will provide a new range of technologies that will require external cost analysis which can be compared with the existing technologies linked to South African grid. The introduction of renewable technologies and cleaner non-renewable technologies could drive external costs (per kWh) down on one hand but increased capacity and production could drive total externalities up on the other hand. These dynamics will have to be observed and will form the basis for future investigations.

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Appendix A: Power plant characteristics and monetary conversions

A1: Power station characteristics

Table A1: Eskom power station characteristics (location and capacity)

	Latitude (S)	Longitude (E)	Altitude (m)	Units Produced (GWh)	Nominal Capacity (MW)
Arnot	25.95	29.79	1 610	11 675	2 020
Duvha	25.89	29.54	1 590	21 798	3 450
Hendrina	26.03	29.60	1 610	12 718	1 990
Kendal	26.09	28.96	1 550	27 691	3 840
Kriel	26.25	29.18	1 550	17 452	2 850
Lethabo	26.73	27.96	1 460	25 572	3 558
Majuba	27.09	29.77	1 700	28 655	3 842
Matimba	23.66	27.61	1 100	25 798	3 690
Matla	26.28	29.14	1 610	22 200	3 450
Tutuka	26.77	29.35	1 600	23 105	3 510
Total				216 664	32 200

Table A2: Eskom power station characteristics (physical and gas flow)

	Stack height (m)	Stack diameter (m)	Exhaust gas velocity (m/s)	Exhaust gas temperature (K)
Arnot	195	11.1	20.3	410.8
Duvha	300	12.5	23.8	403.0
Hendrina	155	11.1	19.4	402.4
Kendal	275	13.5	24.1	398.5
Kriel	213	14.3	16.6	403.0

Lethabo	275	10.6	23.5	408.0
Majuba	250	12.3	29.8	403.0
Matimba	250	12.8	24.8	405.0
Matla	213 and 275	12.5	25.5	397
Tutuka	275	12.3	24.9	403.0

A:2 Estimation of Euro to ZAR PPP exchange rates

Table A3: US$ to € PPP exchange rates

PPP Rates	2007	2008	2009	2010	2011
US$ to €	0.823	0.806	0.8	0.805	0.801
€ to US$	1.215	1.240	1.25	1.242	1.248

Source: OECD StatExtracts.

Table A4: US$ to ZAR PPP exchange rates

PPP rates	2007	2008	2009	2010	2011
US$ to ZAR	4.197	4.446	4.747	5.051	5.341

Source: OECD StatExtracts.

Based on the two data sources an estimate of the PPP exchange rate between € and ZAR with the US$ as the reference point would be a direct conversion from € to US$ and then from US$ to ZAR achieved by multiplying the two rates.

Table A5: € to ZAR PPP exchange rates

PPP rates	2007	2008	2009	2010	2011
€ to ZAR	5.099	5.51	5.933	6.273	6.665