Externality Valuation of Non-renewable Electricity Generation in South Africa – an ExternE Approach

by

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Declaration

I hereby declare that the work contained in this thesis, which I hereby submit for the degree Philosophiae Doctor in Engineering Management at the University of Pretoria, is my own work and has not been previously in its entirety or in part, submitted for a degree at another university.

George Alex Thopil   Date

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Abstract

The quality of electricity infrastructure and supply to a nation is seen as vital for the development of the local and regional economy. In recent times, electricity generation industries worldwide have undergone significant changes pertaining to the kind of technologies used. These changes were made in order to address concerns related to energy security and sustainability. South Africa has been identified as a carbon-intensive economy, with the electricity sector being at the high end of the carbon intensity spectrum.

The need to analyse the socio-environmental impacts of existing electricity generation techniques becomes vital when taking into account the transitions in the South Africa electricity industry. Socio-environmental impacts are categorised into public, environmental and occupational impacts, based on the point of impact. The methodology used to quantify these impacts is based on the Impact Pathway Approach used in the Externalities of Energy study. The Externalities of Energy study was devised in Europe and has gained prominence particularly in developing countries because of its ability to adapt to local conditions. Since South Africa is a developing country, the methodology is suitable for the quantification of externalities when analysing scenarios that have a dearth of local data.

South Africa historically focused on non-renewable electricity generation mechanisms. This was done primarily because of the abundant supplies of coal and secondly because of the need to provide electricity at affordable prices to the masses. The focus of the analysis is set on impacts caused by coal and nuclear electricity in South Africa, since these two technologies together contribute to more the 95% of the electricity generated.

The impacts in each category are identified, prioritised, analysed and quantified. Once impacts are quantified, monetary costs are attributed to the impacts. The aggregation of the costs caused by the impacts results in determining the damages associated with the quantified impacts. Monetary damages individually are not of much use, and therefore the significance of such damages are underlined once calculated. Determined monetary damages are interpreted in average and total terms relative to the total electricity generated with the intention of highlighting the significance of the costs. The average damage costs are compared to existing electricity prices, which enables policy- and decision-makers to segregate the damages relative to electricity prices.

The results of this analysis should enable policy-makers to prudently make decisions about the significance of the social and environmental impacts associated with the dominant non-renewable electricity generation technologies in the country while prioritising the sustainability of the society and environment.

Keywords:

externalities, electricity, emissions, pollutants, greenhouse gases, nuclear

Opsomming

Die kwaliteit van die elektrisiteitsinfrastruur en -voorsiening van 'n nasie word as noodsaaklik beskou vir die ontwikkeling van die plaaslike en streeksekonomie. Elektrisiteitsopwekkingsbedrywe wêreldwyd het onlangs aansienlike veranderings ondergaan ten opsigte van die soort tegnologie wat gebruik word. Hierdie veranderings is gemaak ten einde die kommer oor energiesekuriteit en -volhoubaarheid die hoof te bied. Suid-Afrika is as 'n koolstofintensiewe ekonomie geïdentifiseer, en die elektrisiteitsektor is aan die bopunt van die koolstofintensiewe spektrum.

Die behoefte om die sosiaal-ekonomiese impakte van bestaande elektrisiteitsopwekkingstegnieke te ontleed, word noodsaaklik as die oorgange in die Suid-Afrikaanse elektrisiteitsbedryf in ag geneem word. Sosiaal-ekonomiese impakte word volgens openbare, omgewings- en beroepsimpakte, gebaseer op die trefpunt, gekategoriseer. Die metodologie wat gebruik word om hierdie impakte te kwantifiseer, is gebaseer op die Impact Pathway Approach wat in die Externalities of Energy-studie gebruik is. Die Externalities of Energy-studie is in Europa opgestel en het veral in ontwikkelende lande gewild geword omdat dit die vermoë het om aanpassings volgens die plaaslike omstandighede te maak. Aangesien Suid-Afrika 'n ontwikkelende land is, is die metodologie geskik vir die kwantifisering van eksternaliteite vir die ontleding van scenarios wat 'n gebrek aan plaaslike data het.

Suid-Afrika het histories op nie-hernubare elektrisiteitsopwekkingsmeganismes gefokus. Dit is eerstens gedoen omdat die land 'n oorvloedige koolvoorraad gehad het, en tweedens weens die behoefte om elektrisiteit teen bekostigbare pryse aan die massa te verskaf. Die fokus van die ontleding is op die impakte wat deur elektrisiteit opgewek deur kool- en kernontbranding in Suid-Afrika veroorsaak word, aangesien dié twee tegnologieë saam bydra tot 95% van die elektrisiteit wat opgewek word.

Die impakte in elke kategorie word geïdentifiseer, geprioritiseer, ontleed en gekwantifiseer. Sodra impakte gekwantifiseer is, word monetêre kostes aan hulle toegeken. Die aggregasie van die kostes wat deur die impakte veroorsaak word, word gebruik om die skades te bepaal wat met die gekwantifiseerde impakte geassosieer word. Monetêre skades op sigself is nie baie nuttig nie, en dus word die gewig van sulke skades beklemtoon as hulle bereken is. Monetêre skades wat bepaal is, word volgens gemiddelde en totale geïnterpreteer relatief tot die totale hoeveelheid elektrisiteit wat opgewek is, met die doel om die gewig van die kostes te beklemtoon. Die gemiddelde kostes van skades word met die bestaande elektrisiteitspryse vergelyk. Dit stel beleidsmakers en besluitnemers in staat om die skades relatief tot die elektrisiteitspryse te isoleer.

Die resultate van hierdie ontleding behoort beleidsmakers in staat te stel om versigtig besluite te neem oor die gewig van die maatskaplike en omgewingsimpakte wat met die dominerende nie-hernubare elektrisiteitsopwekkingstegnologieë in die land geassosieer word, terwyl hulle die volhoubaarheid van die samelewing en die omgewing prioritiseer.

Sleutelwoorde:

eksternaliteite, elektrisiteit, vrystellings, besoedelende stowwe, kweekhuise, kernkrag

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List of acronyms

ACM	Abatement cost method
AEB	Atomic Energy Board
AEC	Atomic Energy Council
ALARA	As low as reasonably achievable
AMF	After mining factor
APHEA	Air Pollution and Health: A European Approach
CAPCO	Chief Air Pollution Control Officer
CB	Chronic bronchitis
CCGT	Combined cycle gas turbine
CCOD	Compensation Commissioner of Occupational Diseases
CDP	Carbon Disclosure Project
CFC	Chlorofluorocarbon
CNSC	Canadian National Nuclear Safety
COIDA	Compensation for Occupational Injuries and Diseases
COP	Conference of Parties
COPD	Chronic obstructive pulmonary disease
CVM	Contingent valuation method
DCM	Damage cost method
DEA	Department of Environmental Affairs
DEAT	Department of Environmental Affairs and Tourism
DME	Department of Minerals and Energy
DMR	Department of Mineral Resources
DoE	Department of Energy
DRG	Diagnosis related groups
DWA	Department of Water Affairs
EC	European Commission
EEDSM	Energy-efficiency and Demand-side Management

ERF	Exposure response functions
EU	European Union
ExternE	Externalities of energy
FGD	Flue gas desulphurification
GDP	Gross Domestic Product
GWh	gigawatt-hour
GWC	Growth without constraints
GWP	Global warming potential
GHG	Greenhouse gas
HFC	Hydroflurocarbon
HPM	Hedonic pricing method
IAEA	International Atomic Energy Agency
ICD 9	International Statistical Classification of Diseases and Health Related Problems: Version 9
ICD 10	International Statistical Classification of Diseases and Health Related Problems: Version 10
ICRP	International Council on Radiological Protection
IEA	International Energy Agency
IEP	Integrated Energy Plan
INEP	Integrated National Electrification Programme
IPA	Impact Pathway Analysis
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
IRR	Increased Risk Ratio
ISOE	Information System on Occupational Exposure
kWh	kilowatt-hour
kt	kilotonne
KNPS	Koeberg Nuclear Power Station

LCA	Life Cycle Analysis
LEAP	Long-range energy and alternative planning
LEU	Low enriched uranium
LTMS	Long-term Mitigation Scenario
LTM	Long-term mortality
Mm/yr	Millimetre per year
Mt	megatonne
mSv	millisievert
MWh	megawatt-hour
MBOD	Medical Bureau of Occupational Diseases
MEC	Marginal external cost
MEF	Methane emission factor
MEV	Market externality valuation
MHSI	Mine Health and Safety Inspectorate
MPC	Marginal private cost
MR	Marginal revenue
MSC	Marginal social cost
MYPD	Multi-year Price Determination
Necsa	South African Nuclear Energy Corporation
NERSA	National Energy Regulator of South Africa
NIOH	National Institute of Occupational Health
NNR	National Nuclear Regulator
N_2O	nitrous oxide
NWRS	National Water Resource Strategy
OCGT	Open cycle gas turbine
ODMWA	Occupational Diseases in the Mines and Works Act
OECD	Organisation for Economic Cooperation and Development
OEM	Open-cast Emission Model

OHS	Occupational health and safety
ORNL	Oak Ridge National Laboratory
person-Sv	person-Sievert
person-mSv	person-milliSievert
PBMR	Pebble Bed Modular Reactor
PPP	Purchasing Power Parity
PPPGNP	Purchasing Power Parity Gross National Product
PWR	pressurised water reactor
Q	Quantity
RAD	Restricted activity day
RAR	Reasonably Assured Resources
RBS	Revised Balance Scenario
RBS	Request by Science
RDP	Reconstruction and Development Programme
REBID	Renewable Energy Bidding
REFIT	Renewable Energy Feed-In Tariff
REIPPPP	Renewable Energy Independent Power Producer Procurement Programme
REIP4	Renewable Energy Independent Power Producer Procurement Programme
RfF	Resources for the Future
RHA	Respiratory Hospital Admissions
RMA	Rand Mutual Assurance
RTS	Return to service
RUWM	Robust Uniform World Model
SABS	South African Bureau of Standards
STM	Short-term mortality
TCM	Travel cost method

toe	Tonne of oil equivalent
TWh	Terawatt-hour
U_3O_8	triuranium octoxide
UCOR	Uranium Enrichment Corporation
UNFCCC	United Nations Framework Convention on Climate Change
VOSL	Value of statistical life
WAC	Willingness to accept compensation
WHO	World Health Organisation
WMA	Water management area
WTP	Willingness to pay
YOLL	Years of Life Lost
ZAR	South African Rand

Chapter 1: Introduction

1.1 Background

The state of energy policy and focus in South Africa has seen constant paradigm shifts to align itself with the changing political landscape. The pre-democratic era energy policy focused on the industrialisation of the nation along with energy and national security. From a social perspective these policies over looked the necessities of the majority of the population. The result of such a policy-making resulted in large scale investments that were industry and security focused. Examples of such investments were the developments of Sasol and the nuclear industry in South Africa. Heavy investments were made in the power (electricity) sector, which resulted in the construction of a fleet of coal power plants, predominantly from the mid 1970s to mid 1990s. Other investments were made in the fuel sector, which resulted in the creation of the largest synthetic fuel production market in the world. As a result of these investments Sasol became the largest producer of liquid fuels converted from coal and Mossgas (PetroSA) one of the significant gas to liquid fuel producers. These investments were made more from an industrial, than from a social and environmental perspective. The development of a robust nuclear industry as a result of large scale government investment during the 1960s to 1980s, which had to be downgraded as a result of political pressure and security fears, is another example of social interests not being at the forefront of decision-making. The prioritisation to provide heavy industries with an environment suitable for their operations has seen historically low industrial electricity prices, as discussed in latter parts.

The start of the democratic era saw a major paradigm shift in policy, especially within the electricity sector with large heavy investments being put on hold with delivering electricity to the masses being the immediate priority.

The result of a reassessment of the electricity policy was the Integrated National Electrification Programme (INEP)[1] and a change in the policy focus from a non-socialist setting to a pro-socialist goal. However, a socialist-focused approach that halted major additional investments in electricity generating infrastructure eventually caused an imbalance in the load supply and demand, which caused a load shedding crisis in 2008. This scenario led to a revisit of the electricity and energy policy of the nation.

One could without difficulty deduce from the discussion that while short-term issues are of paramount importance, a long-term strategy is vital when taking into account the nation's energy security and social sustainability. Based on the national government's major energy and electricity policy documents (which are discussed in Chapter 3) over the past decade and a half, such as the White Paper on Energy Policy (1998), the White Paper on Renewable Energy (2003), the Integrated Energy Plan (2003), the Long-Term Mitigation Scenario (2007), the Integrated Resources Plan (2010) and the White Paper on National Climate Change Response (2011), the collective precedence is given to the following:

- Social access - providing access to all population groups of society irrespective of geographical location and affordability
- Energy efficiency – providing a diverse mix of energy options to avoid fallibility caused by over reliance on a limited number of fuel sources
- Environmental sustainability – providing the energy requirements of the population in an approach that is socially and environmentally sustainable by addressing negative impacts associated with energy generation

As vital as each objective is, they are significantly correlated in the overall context of the nation.

[1] The INEP is discussed in further detail in Chapter 3 of the thesis.

While the poorer sections of the public may not be disconcerted about the energy efficiency and sustainability of the society, the effects of the two tend to have a profound effect on their way of life. The effects are usually more profound on the lower income groups of society, as opposed to the middle and higher rungs. Therefore it becomes the responsibility of the decision-making bodies in the nation to maintain a fine balancing act between prioritising these objectives. Ever since the government has been providing access to energy to lower income groups consistently through the INEP, the focus has shifted to laying a roadmap to socio-environmental sustainability.

Since the early 1990s there has been an increased global focus on socio-environmental sustainability. This resulted in the inception of the United Nations Framework Convention on Climate Change (UNFCCC) that led to individual governments being responsible for the regional and global impact of their national emissions. South Africa, as a developing country and a prominent regional and international participant, has taken the initiative to play an active part by hosting the 17th Conference of Parties (COP) in Durban. The formulation of the Long-term Mitigation Scenario (LTMS),[2] which analyses the nation's optional pathways to achieve variable goals, provides direction to a socio-environmental stable future.

1.2 Research objective

Within the multiple energy sectors of a nation, the electricity sector takes precedence. This sector forms the backbone of the country's economy and functioning on both the domestic and industrial scale. Owing to the electricity load-shedding crisis of 2008, the national electricity utility Eskom[3] decided to increase generational capacity by building additional coal-fired power plants.

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[2] The long-term mitigation scenarios are discussed in detail in Chapter 3.
[3] Eskom is the sole electricity producing utility in South Africa. The utility is described in detail in Chapter 3.

Construction of additional capacity required the utility to increase electricity prices across all sectors of society since 2008, and these are bound to keep increasing for the next few years[4]. The Integrated Resources Plan (2010) policy paper, roadmap to South Africa's electricity future, has identified the quantification of socio-environmental impacts as a gap in policy-making. This gap in policy forms the motivation and basis of this thesis which gets discussed in detail in Chapter 3 (sections 3.2 and 3.6 in particular). The cavity in policy has been addressed with the intention of providing policy makers sufficient scientific backing on socio-economic impacts.

The thesis identifies and analyses three key objectives, which are:

- to quantify socio-environmental impacts associated with electricity generation in South Africa
- to demonstrate the significance of the monetary values of the socio-environmental impacts relative to the local electricity prices
- to analyse the effect of inclusion of these values to the local electricity prices

The socio-environmental impacts or effects of electricity generation can be categorised into the following kinds of impacts centred on the point of impact:

- 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.

[4] A case study of South African electricity prices is presented in Chapter 7

Though each of these impacts is significant on its own and requires detailed quantification separately, this thesis attempts to achieve a trade-off in depth and breadth among the aforementioned impacts.

As multiple impacts are investigated in this thesis, the focus tends to gravitate towards breadth, while providing adequate amount of focus on depth. The availability of local data while quantifying the economic impact is significant in making informed valuations and poses the most important challenge. The socio-environmental impacts are from here on termed as externalities.

The theory of externalities and the techniques used to evaluate externalities are discussed in detail in Chapter 2. The externalities in focus in this study are those that occur during the generation of non-renewable electricity.

1.3 Methodology

The methodology employed to evaluate externalities in this thesis is based on the Impact Pathway Approach (IPA) used in the Externalities of Energy (ExternE) study performed in the European Union. The ExternE study is discussed in detail in Chapter 2 (in particular sections 2.2 and section 2.3 which mention why the ExternE technique has been preferred). For the time being the focus returns to the IPA methodology, which 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. Here 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 to allow for eventual monetary quantification.

- **Identification of impacts**

The first stage is the identification of impacts. In this stage the multiple burdens associated during the generational stage of the fuel cycle. It is essential to identify as many prevalent impacts as possible, as better identification helps to improve analysis.

- **Prioritisation of impacts**

Once the impacts are identified, the next stage involves prioritising them according to the ability to quantify the impact based on informed decisions and assumptions. The prioritised impacts might have, varied effects or burdens on diverse groups, thus prioritisation is a vital step in the LCA.

- **Description of priority impact pathway**

The pathway of the impact associated helps in analysing the route followed by an impact within the environment or society. An example would be the pathway followed by atmospheric pollutants emitted during the generation of electricity from a coal power plant, or the waste discharges associated from a nuclear power plant.

- **Quantification of burdens**

This stage involves determining the burden associated with an impact. Burdens are diverse and important in attaining informed results. Examples of burdens would comprise determining quantities of atmospheric pollutants released into the atmosphere. Other burdens would include occupational accidents during electricity generational activities.

- **Description of receiving environment**

The burdens that are quantified tend to affect the environment or society in multiple ways. Identifying and describing how a burden affects the society is important to realise the scale of the impact. Atmospheric pollutants tend to disperse into the atmosphere, and coupled with wind patterns the environment affected could be both local and regional.

- **Quantification of impacts**

Based on the kind of environment affected by the burden, impacts can be quantified numerically. Such cases would include the number of health effects associated with atmospheric pollution or radiation dosage during nuclear waste disposal. Impacts are quantified using different techniques based on the kind of associated impact.

- **Economic valuation**

Economic valuation is performed once the impacts are quantified. During this part of the process a cost is ascertained to an impact. The type of cost ascertained is very much impact dependent and varies across the impact spectrum. Costs vary from the valuation of human health related impacts, to radiological based costs from nuclear plant operation and occupational costs.

- **Assessment of uncertainty**

Determining the uncertainty based on decisions made during the IPA is important to facilitate revised assessments in the future. Uncertainties occur from data assumptions made during stages, such as pathway description, burden quantification, receiving environment valuation, impact quantification and economic valuation. The IPA methodology therefore always caters for an improvement based on existing uncertainties.

The IPA approach used in the ExternE analysis is better described using Figure 1.1 and is self-descriptive.

The concept used to valuate externalities can be interpreted in terms of a damage function obtained from quantification of impacts and economic valuation as,

$$\text{Damage} = \text{Impact x Cost} \qquad (1)$$

where,

Damage = Total monetary external cost

Impact = Total number of cases per externality (impact)

Cost = Monetary value per case of externality (valuation)

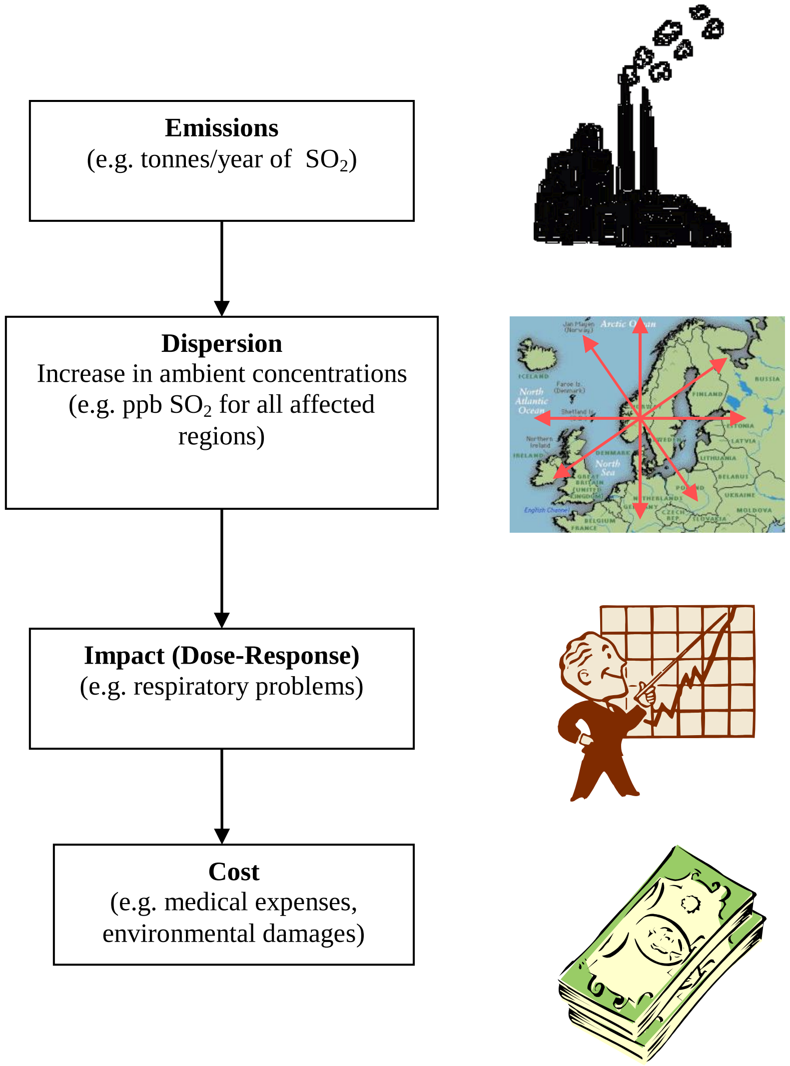


Figure 1.1: Impact pathway

The externality analysis performed in this thesis is based on certain criteria chosen to achieve consistency of results and needs to be noted. The externality analysis and evaluations are based on data sets for the year 2008 to achieve uniformity in time for all valuations being performed. In cases where local data was not available – particularly during monetary valuation – conversion to local data is made using purchasing power parity rates, which will be discussed in due course. Externality valuations are made for power plants that provide base load power. Peak load power stations are excluded from the analysis since they generate power intermittently.

1.4 Description of thesis

The aim of the thesis is to identify and evaluate important externalities occurring within the non-renewable electricity generation sector along the lines of the ExternE methodology and to analyse the costs in line with local electricity prices and other international valuations.

A chapter-wise introduction of the thesis follows:

Chapter 2 provides an analysis of the theory of externalities, followed by a literature review of international and local electricity externality studies.

Chapter 3 introduces the energy and electricity industry in South Africa while focusing on the necessity of an externality evaluation. The chapter concludes by identifying the important externalities in the non-renewable electricity generation sector.

Chapters 4, 5 and 6 investigate and evaluate the externalities associated with public health and environmental and occupational impacts respectively. Based on the availability of information on the primary externalities, quantification is performed within these chapters. Monetary evaluation is performed to obtain damage costs for prioritised externalities.

Chapter 7 concludes by aggregating the damage costs and analysing the costs to determine the objectives set out within the thesis. The chapter compares the local external costs with other international studies where after a case study of local electricity pricing is conducted.

Chapter 2: Literature review

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 a prominent role in providing decision-making entities the ability to provide judgement on future policy choices. South Africa has reached a stage where diversification of electricity generation schemes has become a priority, as to be discussed in the Chapter 3. Such a scenario requires externality valuations to be made on current electricity generation mechanisms. While there have been significant efforts to account the constantly increasing externalities in developed countries; it has not been the case in the developing world.

This chapter begins by reviewing the theory of externalities and various valuation techniques, followed by a review of international studies. The chapter then follows course to observe the trend of externalities research in South Africa's power generation sector and to analyse the gaps by putting it in context with other studies performed internationally. A statistical analysis adjusted for currency conversions provides perspective to the range of externalities. The course of the chapter provides motivation for a revised externality analysis along international lines.

2.1 Introduction

In a purely economic context an externality is a cost or benefit resulting from an economic transaction that is borne or received by parties not directly involved in the transaction. It refers to 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 (Pearce and Turner, 1990).

This effect can be either positive or negative and often goes unaccounted for. 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.

2.1.1 Theory of externalities

Externalities are an auxiliary in every instance when the economics of the environment is analysed. 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 (1930). 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).

Externalities can be classified depending on the type of effect they have. Private and public externalities are one such classification (Van Horen, 1996). There are few players involved in a private externality and the external effects are shared between the few concerns. Public externalities can be defined as externalities that affect various sections of the public and society. In most cases public externalities require intervention to counter the negative effects, whereas in private externalities, most situations resolve themselves. The resolution in the case of public externalities is usually performed by the government or any public entity, whereas in the case of private externalities the resolution is performed by the few concerned entities. Most cases of pollution tend to be public externalities.

Another category of classification is based on when an externality occurs within the life cycle of a product or commodity (Lin, 1976). These externalities are classified as production and consumption externalities. Production externalities are those that occur during the production of a product and consumption externalities are those that occur during the consumption of a product. Coal-based electricity is one such commodity that incurs production externalities caused by emissions. Gasoline is a type of commodity that has both production and consumption externalities.

Externalities can be further classified on the basis of resource allocation. These types are called pecuniary and technological externalities. The concept of pecuniary externalities states that one individual's activity in turn affects the financial status of the other, but does not necessarily create a negative impact on allocation of resources (Baumol and Oates, 1975). Technological externalities are mostly those that occur when the production or consumption of a particular agent causes an effect on the other, resulting in a misallocation of resources if there is no intervention. If a specific product increases in demand, under normal conditions the price of the commodity used to make that product will increase. This condition tends to affect the financial status of the consumer. This can be held true in most cases. However, as is the case with luxury items even a shift in pricing does not always tend to affect the consumer market.

Network externalities are those that occur when the benefit of using a product or commodity for a person or entity depends on the number of other people or entities using the product, rather than the amount of that particular. An example would be the adoption of a particular technology or networking tool.

Externalities can be illustrated in multiple forms. One such interpretation is the relation between private and social costs (Pigou, 1920).

These costs are defined in terms of who experiences the costs mentioned. In other words, private costs are those endured by the manufacturer of a product, whereas the social costs are those involved during the production and consumption of the product, which are endured by the producer as well as other groups in the society (both local and international) – depending on the extent of the effect (both positive and negative). The marginal difference between the manufacturers' costs and the social costs are called external costs, which are endured mostly by the society.

These external costs are not represented in the pricing of a product as it is a social cost, and are excluded in the methodology of the pricing mechanism of a product unless a trend has been set where a product has a history of causing social costs. These principles are explained graphically in Figure 2.1, which depicts linear functions representing cost and revenue slopes for a commodity produced by the producer. The marginal private cost (MPC) function represents the private cost associated while producing a commodity. The marginal external cost (MEC) function is the external cost incurred while producing the same commodity. The sum of the MPC and MEC comprises the marginal social cost (MSC). The marginal revenue (MR) function is the revenue generated from each unit of the commodity. As can be observed from the figure below, the quantity of commodity produced (Q) for equivalent marginal revenue and private cost occurs at point A'. However, when social costs are considered the quantity of commodity produced needs to decreased from Q to Q* for equivalent marginal revenue and social cost, at which point (B) the revenue of the producer decreases. However, from a social perspective the quantity (Q*) is the optimum quantity.

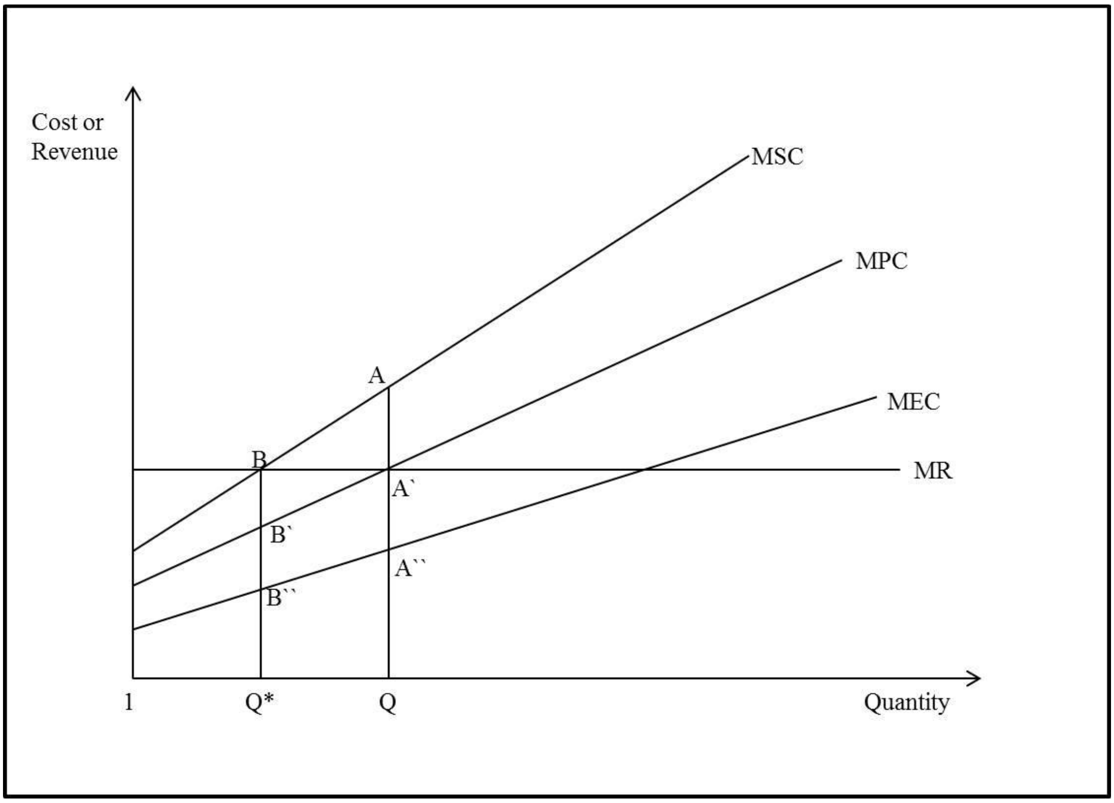


Figure 2.1: Graphic representation of marginal costs

Electricity generation is often accompanied by emission of harmful pollutants (such as sulphur dioxide, nitrogen oxide and particulates) and greenhouse gases (carbon dioxide, methane) when the technology involved uses fossil fuels. These emissions cause damage to humans as well as material assets, for example in the form of respiratory problems or structural degradation respectively. These issues, when overlooked and neglected, affect the general population. Monetary accounting of these effects on the other hand increases the cost of electricity generation schemes with political and policy consequences.

Electricity externalities started getting attention in the early 1980s, which led to a succession of evaluations in the developed countries. The idea behind performing externality evaluations was to provide policymakers with a guideline on electricity pricing, regulations and taxes.

The initial attempts (Hohmeyer, 1988; Ottinger et al., 1991; Pearce et al., 1992) showed large variations among the external costs and, compared to studies that were performed later, produced an ambiguous picture for policy-makers (Stirling, 1998).

2.2 Externality evaluation techniques

There are two categories of techniques used to evaluate externalities depending on how they affect the environment, namely ‘non-market externality valuation’ and ‘market externality valuation’ techniques (Cooper, 1981).

2.2.1 Non-market valuation techniques

As the name suggests, non-market valuations are used when there are limited or non-existent markets for socially valued items, such as clean air, for which there is no market price and assigning a cost is usually subject to controversy. These techniques are prone to a certain amount of ambiguity as there are few references that can be fixed to the market. Three popular methods, among others, are used to evaluate these scenarios: the contingent valuation method, the travel cost method and the hedonic pricing method.

2.2.1.1 Contingent valuation methods

Contingent valuation methods (CVMs) involve directly asking people, usually in a survey, how they interpret the damage that has occurred or might occur to the environment. CVMs are based on people’s willingness to pay (WTP) for an improved situation, or willingness to accept compensation (WAC) for a worse situation (Van Horen, 1996). CVMs fall under ‘stated preference’ methods, because they require people to state their values, rather than approximate values from actual choices. The valuations are performed with an assumption that the public involved in the methodology have a fair idea about market dynamics. However, this method is controversial as the monetisation of willingness in either context is subject to the individual’s perception and ability.

An example of such a scenario would be a situation where inhabitants of a municipality are asked to decide on how much they would be willing to pay to conserve a fishing habitat. The valuation could for instance be influenced by an individual's preference for fishing. The willingness to pay and to accept compensation will be different among developed and developing economies based on nominal GDP (Gross Domestic Product) and PPP (Purchasing Power Parity) (Cooper, 1981). This difference can be explained by a comparison between a rich and a poor person who has to pay the same amount for an improved environmental situation. The poor person will be more reluctant to part with the valuation than the richer person. This comparison can also be extended to countries with different economic capabilities.

2.2.1.2 Travel cost method

The travel cost method (TCM) is used mainly to evaluate values of recreational areas and places of leisure (Gaterell and McEvoy, 2005), and is usually done by calculating expenses incurred while undertaking an activity of leisure. The method bases the valuation of a recreational area on how much people spend to get to the site. TCM is classified as a 'revealed preference' method, because the costs are inferred from travel and choice patterns rather than from people stating how much they would pay. The TCM can, for example, be used to restructure the entrance fee to a zoo, depending on the maintenance required. The results of the TCM are fairly easy to interpret. The ambiguity occurs as the evaluation of a person's leisure time and expenditure has no fixed limitation and is subject to preference. In other words, a person who enjoys visiting a zoo might travel very often, thereby overestimating the value.

2.2.1.3 Hedonic pricing method

The Hedonic pricing method (HPM) uses the environmental valuation based on the market-related services and property. The idea behind the method is that the price of a market good is related to its characteristics or the services it provides.

This methodology is often used to value environmental amenities that affect prices of residential properties. Thus, prices will reflect the value of a set of characteristics, including environmental characteristics that the public considers important when purchasing a piece of land (Opaluch, et al., 1999). For example, this method can be used when all characteristics of houses and neighbourhoods in an area are the same, except for the level of air pollution. If the population living in the area valued better air quality, the housing prices would vary accordingly. HPM has the advantage of relating the evaluation to the market, but falls short when extracting the environmental costs from the real market prices. In other words, the environmental benefits that can be estimated are limited to those benefits that are related to housing prices.

2.2.2 Market externality valuation

Market externality valuation (MEV) is prone to less ambiguity than non-market externality valuation when reference can be made directly to costs involved in the market, for example damage caused by acidic deposition on a building can be calculated by the cost incurred to refurbish it. Two methods used to evaluate market costs are the abatement (control) cost method and the damage (opportunity) cost method.

2.2.2.1 Abatement (control) cost method

The abatement (control) cost method (ACM) uses estimates of expenses to control or avoid a particular environmental externality. The criticism that the ACM faces is that it assumes policy-makers have accurate values for the damage or avoidance costs (Pearce et al., 1992). Also, the ACM assumes a damage to have occurred before it actually has, which could distort the reality. However, the ACM was the initial methodology used for evaluating electricity externalities (Schuman and Cavanagh, 1982).

2.2.2.2 Damage (opportunity) cost method

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). The top-down approach uses total atmospheric pollutant data of various gases and is divided further to estimate specific pollutant damage contribution, which in turn is allocated to power plants. These damages are then converted to monetised damage costs. The drawback of such an approach is that neither site specificity, nor the fuel cycle stages are considered (Clarke, 1996). Examples of this approach can be found in Hohmeyer (1988; 1992), Ottinger et al. (1991), Ott (1997) and Faaij et al. (1998) who also performed a bottom-up analysis for comparative purposes.

The bottom-up approach is probably the most reliable method to date. It takes into account site specificity and the fuel cycle. The approach follows the impact caused along the pathway of a particular pollutant and is also called the impact pathway approach. The criticism of the bottom-up approach is that is lacks validity in cases where data is not readily available and a pathway cannot be established (Clarke, 1996). Moreover, the approach is highly data intensive.

However, this approach gets chosen ahead of others as it is more suited for electricity externalities (Sundqvist, 2004) and is the preferred choice in extensive studies (European Commission, 1999; European Commission, 2005).

Other studies which have used the bottom up approach are Oak Ridge National Laboratory (1994–1998), Van Horen (1996), Bhattacharyya (1997), and Maddison (1999). Current studies on externality evaluations include simulating and predicting the trends of externalities and how they affect the electricity generation makeup over the next few decades (Rafaj et al., 2007; Klaassen et al., 2007). Klaassen and Riahi (2007) inferred that there would be a decrease in the global GDP if stringent measures were to be taken to reduce the role of coal and gas-generated electricity in favour of renewable technologies (e.g. wind, biomass and solar). Table 2.1 shows a comparison of the external costs of different coal-fired electricity externality studies performed using different market valuation methods. The table below shows the authors of the study, the method used, the country in which it was applied and the estimate of the external cost.

Table 2.1: 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	0.07–54.64
Hohmeyer (1988)	Top-down damage cost	Germany	12.42–28.33[b]
Ottinger et al. (1991)	Top-down damage cost	US	4.04–10.99
Pearce et al. (1992)	Top-down damage cost	UK	3.31–17.89
Faaij et al. (1998)	Top-down damage cost	The Netherlands	4.93
Oak Ridge National	Bottom-up damage cost	US	0.14–0.6

Study	**Method**	**Country**	**External cost** (US cents/kWh)
Laboratory and Resources for the Future (1994–1998)			
European Commission (1995)	Bottom-up damage cost	UK/Germany	1.21–2.96
Rowe et al. (1995)	Bottom-up damage cost	US	0.38
Bhattacharya (1997)	Bottom-up damage cost	India	1.68
Faaij et al. (1998)	Bottom-up damage cost	The Netherlands	4.76
European Commission (1999)	Bottom-up damage cost	EU	1.04–89.8
Maddison (1999)	Bottom-up damage cost	UK/Germany	0.38–0.88
Rafaj and Kypreos, (2007)	Bottom-up damage cost	Global average	9.08[c]
Klaassen and Riahi, (2007)	Bottom -up and top-down combination	Global average	4.84[c,d]

[a]Adapted from Van Horen (1996) and Sundqvist (2004). Values used in Sundqvist have been adjusted for 2006 from 1998 using a US Consumer Price Index of 1.24 US$ (Samuel, 2007).
[b] Values given in Van Horen were converted back to 1994 US$ using a conversion rate $0.273/R1 and adjusted for an annual inflation of 10% for the year 2006.
[c] Predicted results for the year 2010 have been adjusted backwards for the year 2006 with an annual inflation rate of 10%.
[d] Conversion factor US$ 1.3 = €1 (1995 rates).

As can be seen from Table 2.1, the result of the ACM 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 differences of the studies are mentioned in the next section. 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 2.2, which shows the entire range of externality values used in Table 2.1, helps in understanding the values better. The valuations range from a low of US$ 0,07c/kWh to a high of US$ 89,8c/kWh with a median of US$ 4,04c/kWh. The middle 50% (inter-quartile range) of the values range from US$ 1,13c/kWh to US$ 11,7c/kWh.

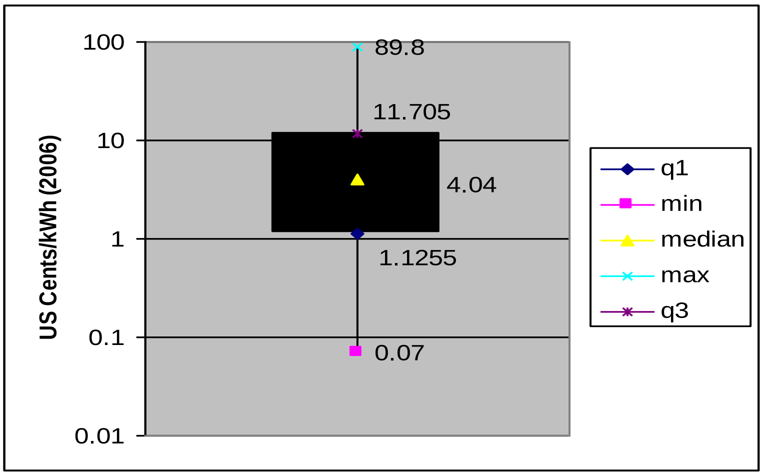


Figure 2.2: Statistical range of coal external costs

The majority of the extensive externality evaluations have been performed in industrialised economies (Hohmeyer, 1988; Pearce et.al, 1992; European Commission, 1999), with a few being from developing economies (Van Horen, 1996; Bhattacharyya, 1997; Carnevali and Suarez, 1993).

However, as the pace of industrialisation is faster than before in developing countries such as China, India, Brazil and South Africa, these countries are or are becoming major contributors to harmful emissions (International Energy Agency, 2007). Therefore, there is an increased need to monitor externalities in these countries. The Stern Review (2006) gives an international perspective into the near future on what could happen economically and socially if fossil fuel emissions are left unchecked. The review provides realistic and pragmatic solutions that are viable for national regulatory bodies to follow and calls for increased cooperation at an international level. This study was complemented by the long-term mitigation study performed locally in South Africa (Energy Research Centre, 2007). The long-term mitigation study considers two scenarios, one where emissions are left unchecked as per current economic growth patterns, and the other where emissions are checked as a means to ensure a sustainable emissions target for the future. The study attempts to arrive at solutions to bridge the gap between the two scenarios using realistic scientific and economic tools.

Informed externality valuation depends greatly on the ability to quantify local scenarios and account local site specifications. Where local data is unavailable, data from other scenarios are used to fill in. Based on the numerous externality studies that have been performed, the ExternE methodology caters best for transferability between sites and valuations within the IPA (discussed in Chapter 1), which is used in ExternE.

2.3 The ExternE Project: A brief history

It can be observed from Table 2.1 that there is a fair amount of methodological disparity in the results between the studies conducted in Europe and North America during the surge in externality valuation studies. This disparity led to a joint effort between the European Commission and United States (US) Department of Energy in 1991, called the 'European Commission (EC)/US Fuel Cycles Study', which had the aim of creating an accounting framework within which externalities could be referenced (Van Horen, 1996).

The project consisted of a multi-disciplinary approach from both sides of the Atlantic and involved energy technologists, environmental scientists, health specialists, atmospheric chemists, ecologists, and economists. The initial phase was completed in 1993. The project involved five European teams during the inception of the project, and by the time the US contribution was stopped there were at least 50 teams from 15 different countries in Europe.

The second phase of the project, from 1994 to1995, involved independent work in both the European Union and the United States and extended the externality analysis from coal and nuclear cycles to lignite, oil and gas, and wind and hydro cycles. The next phase (from 1996 to 1997) saw independent research being performed in the EU, which led to broadening of the geographical range to include almost all member states except Luxembourg. This stage also included global warming damages and used updated methodologies to perform the studies (European Commission, 1999). Another major contribution was the valuation of externalities associated with the use of energy in transport. One major difference in the evaluation of the two phases is that while the phase two study used a Value of Statistical Life (VOSL) approach to value chronic mortalities, the latter used a Years of Life Lost (YOLL) approach. The VOSL approach is based on the willingness to pay for the risk of reduced life expectancy rather than for the risk of death (Krewitt, 2002). The YOLL approach estimates an economic value for the number of working years a person loses in the event of premature death. The YOLL approach helped to reduce the external costs of chronic mortalities by half, compared to the VOSL approach (Sundqvist, 2004).

Since then, there have been major advances in methodologies for assessment of the impact on soil and water in the impact pathway approach. These included the addition of improved dose-response functions in the Riskpoll software (which is a collection of impact assessment models designed to estimate health and environmental risks of classical pollutants such as SO_x, NO_x, CO, and toxic metals such as As, Ni, Pb). The methodologies used during the earlier valuations were also updated (European Commission, 2005). CVMs were used to value changes in life expectancy. Numerous projects, based on the ExternE methodology, have been completed and are in the process in the European Union and globally, a list of which is available on the ExternE webpage under projects.

2.4 South African externality studies

A few studies have been performed in South Africa to evaluate the issue of externalities. A brief discussion of these follows.

2.4.1 Dutkiewitz and De Villiers study

Externalities were first discussed in South Africa by Pouris and Dutkiewitz (1987). A year later, the first externality evaluation study was started by Dutkiewitz and De Villiers (1993) on four electricity generation cycles, namely; coal, nuclear, wind and solar. The study aimed at revaluating the generation cost table of different fuel cycles after internalisation of the external costs. This study was performed for the Energy branch of the Department of Minerals and Energy (DME) and was carried out between March 1990 and September 1991. The methodology used was similar to Hohmeyer (1992) and Ottinger et al. (1991) and followed a ‘top-down’ damage cost approach. This approach was favoured over the control cost and willingness to pay approaches, because of the lack of prior quantifications and difference in perceptions respectively. This study considered the entire lifecycle cost of the electricity generation systems based on other studies performed in developed countries (Inhabert, 1978; Ferguson, 1981). The results of the study show that externalities locally were at the lower end of the spectrum of international studies (Van Horen, 1996). The results are shown in Table 2.2. The project cited that possible improvements in the analysis could be made by evaluating the aesthetic effects (such as reduced visibility and noise pollution) of the externalities.

2.4.2 Van Horen study

This study was performed by Clive van Horen in 1996 with an emphasis on the coal and nuclear fuel cycle to facilitate policy advice for the then newly elected government and trade unions. It formed part of the second phase of the Industrial Strategy Project funded by Friedrich Ebert Stiftung of Germany, the Hummanistisch Instituut Voor Ontwikkelingsamewerking of The Netherlands, the International Development Research Centre of Canada, and the Olaf Palme International Centre of Sweden. Van Horen used a bottom-up damage cost approach, which was possible due to the availability of site specific data. This method is favoured in cases where a study tries to cover multiple sites and estimate externalities from aggregated data. The externality modelling tool EXMOD – developed for the RCG-Tellus study in New York State (Rowe, 1995) – was used to evaluate air pollution impacts. The study brought to attention that the nuclear industry was highly subsidised and played a major role in driving up the externalities (in Table 2.2). The fiscal externalities considered were based on analysing the cumulative subsidy received by the nuclear industry from 1971 to 1995. The health hazards, though possibly significant, were not taken into account because of the high safety measures in place. The largest contributor to the coal externality was greenhouse gases and, to a lesser extent, health impacts from air pollution.

Van Horen had cited a few areas that required further investigation where possible, particularly the chronic and acute illnesses faced by coal miners, the impact of air pollution from ash dumps, the use of dose-response functions better suited for South African populations, and improved evaluation of results of greenhouse gases emissions.

2.4.3 Spalding-Fecher and Matibe study

This study, performed in 2003, expanded on the findings of Van Horen and included updated power generation infrastructure data. One significant contribution of the study was the positive effects of electrification, e.g. the cost of prevented accidents due to household fuels like kerosene being avoided.

The same methodology as for the Van Horen study was used. The central coal externality estimate of 4.4c/kWh (actual externality) was 40% and 20% of the industrial and residential tariffs respectively (1999 Eskom tariffs). From the discussion provided there was a marked decrease in the subsidy to the nuclear industry (Spalding-Fecher and Matibe, 2003). However, the nuclear external costs were not listed.

The recommendations of the study shared Van Horen's concerns, as well as mention the need to expand externality valuations to other technologies such as gas-fired and renewable power generation. The authors also recommend a macroeconomic analysis of the pros and cons of Eskom's decision to use low quality coal for local electricity production.

2.4.4 Comparative analysis

Table 2.2 shows that the results of the first study are at the lower end of the three. This could possibly have been because the study had its methodology based mainly on international valuations done during the late 1970s and early 1980s (Dutkiewicz and De Villiers, 1993), during which certain factors could have been ignored due to data unavailability. The high disparity in the nuclear sector was because of Van Horen's accounting of the subsidy to the nuclear industry. Spalding-Fecher and Matibe's had a lower externality valuation compared to that of Van Horen because of the inclusion of the positive effects of electrification, and, despite not accounting the nuclear externality, mentions a decrease in the subsidy provided to the nuclear industry.

Table 2.2: Summary of South African external studies adjusted for inflation

Study	Actual externality (Year of valuation ZAc/kWh)		Inflation adjusted externality (2006 ZAc/kWh)[a]	
	Coal	Nuclear	Coal	Nuclear
1. Dutkiewitz and De Villiers[b]	0.64	0.179 – 0.547	3.23	0.90 – 2.76
2. Van Horen [c]	2.23 – 12.45	3.32 – 11.28	6.99 – 39.07	10.41 – 35.40
3. Spalding-Fecher and Matibe [d]	1.4 – 9.3	–	2.73 – 18.12	–

[a] Adjustments performed with an annual inflation rate of 10% from the year of actual valuation.

[b] Actual valuations done in 1989.

[c] Actual valuations done in 1994.

[d] Actual valuations done in 1999.

It has to be noted that while performing conversions from international studies to the local currency or vice versa, the nominal exchange rate can often distort the true monetary value. An example of this situation can be observed in the paper by Sundqvist (2004), where he uses a 1996 exchange rate of ZAR2.47/US$1 to convert Van Horen's externality values, while Van Horen (1996) uses a 1994 exchange rate of ZAR3.66/US$1 in his study. These different values lead to a fair degree of uncertainty among policy-makers. An alternative method of conversion that could possibly be used is the PPP exchange rate, which will decrease the variation in the exchange rates as they provide a better reflection of a currency's buying power. The PPP rate usage has its detractors, as it is calculated from the value to purchase a set of basic food items and does not really cover a whole spectrum of goods, thereby not properly portraying the actual economic strength of the economy.

Other South African externality studies have been conducted, but none have necessarily focused on the externalities of electricity generation. Blignaut and De Wit (2004) provide a multi-sector analysis of the social costs of coal combustion in the form of CO_2 in the South African industry. They however did not include the effects of SO_x, NO_x and particulate matter. Scorgie et al. (2004) conducted an extensive study to quantify the health effects of air pollution caused by combustion of fossil fuels, both domestic and industrial. The study covers the main demographical centres (cities and municipalities) of South Africa. However, monetary valuation of health effects was beyond the scope of their study and hence the comparison with results in Table 2.2 is not possible.

2.5 Discussion

The number of studies investigating externalities performed in South Africa has been limited and few. The most extensive effort has been probably performed by Van Horen (1996), while Spalding-Fecher and Matibe (2003) presented new insight into the positive externalities. There were no differences in the methodologies used for evaluating negative externalities, except for the addition of new data. Van Horen's analysis had included dose-response functions used by Rowe et al. (1995), which are backdated to the early 1990s. One area that could not be properly quantified was the impact of ash dumps on human health, mainly on that of the mine workers, and the environmental impact on air, water and soil. The smoke dispersion model used within EXMOD uses a Gaussian plume model based on European conditions that differs from South African conditions (Van Horen, 1996). Revaluating the costs of various electricity generation technologies would require a thorough evaluation of renewable schemes such as solar and wind power generation. The externality analysis performed by Dutkiewitz and De Villiers (1993) on the solar and wind technologies relied on international data for assumed local infrastructure. A realistic analysis can only be performed once South Africa has solar and wind-powered electricity supplied on the national grid.

Recently, doubts have been cast over South Africa's coal reserves, originally estimated at 55 billion tons. The Department of Minerals and Energy is conducting an investigation to estimate the actual reserves, meanwhile using a temporary estimate of 38 billion tons (Winkler, 2006). If the latter estimate is true, there was a 45% overestimation. If the current consumption rates are to be followed the reserves would last for the next 200 years. However, it is predicted that with growth rates of 3% to 5%, the reserves would only last for another 40 to 50 years (Platts, 2006). This observation calls for an increased effort to diversify the nation's electricity generation schemes. Although the country does not have solar or wind power generated electricity on the national electricity grid currently, there are cases in which these technologies have been used (Eskom, 2011). The challenge will be to phase out environmentally degrading generation schemes in favour of renewables, while retaining the industrial and competitive edge provided by cheap electricity. The long-range energy and alternative planning (LEAP) model was used for South Africa (Scorgie et al., 2004) to analyse the short- to long-term effects on the environment, keeping in mind the national socioeconomic framework. The long-term mitigation study also shows the need to diversify towards renewable methods of electricity generation to account for a sustainable national future (Energy Research Centre, 2007).

Ideally, future South African analysis should include the latest possible functions and methodologies along with prominent international evaluations. This calls for an analysis preferably along the lines of the ExternE project. Also, since the methodology and parts of data sets are more than a decade old, an update of the entire analysis would be beneficial. A major motivational factor for an externality analysis from a policy point of view has been the South African government's need to diversify the electricity sector in order to allow renewable energy sources to play a bigger role in the electricity sector (South Africa, 1998; 2003). However, it is worth mentioning that in spite of being a developing country, South Africa has made reasonable attempts to evaluate electricity externalities considering the influence of coal in the local electricity sector.

2.6 References

Baumol, WJ, Oates, WE. 1975. *The theory of environmental policy*. Prentice Hall, Englewood Cliffs, New Jersey.

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

Blignaut, JN, De Wit, MP. 2004. *Sustainable options: Economic development lessons from applied environmental resource economics in South Africa*. Cape Town: University of Cape Town Press.

Carnevali, D, Suarez, C. 1993. Electricity and the environment: Air pollutant emissions in Argentina. *Energy Policy* 21(1):68–72.

Clarke, LB. 1996. *Externalities and coal-fired power generation* (IEAPER/29). IEA Coal Research: London.

Cooper, C. 1981. *Economic evaluation and the environment: a methodological discussion with particular reference to developing countries*. Hodder and Stoughton: London.

Dutkiewicz RK, De Villiers, MG. 1993. Social cost of electricity production, *Engineering Research*. National Energy Council: Pretoria.

Energy Research Centre (ERC). 2007. Long-term mitigation scenarios: Technical summary . [Online] Available at: www.erc.uct.ac.za/Research/LTMS/LTMS-intro.htm. Accessed on 15 April 2010.

Eskom. 2011. *Annual Report 2011*. Eskom: Sandton.

European Commission (EC). 1995. *ExternE: Externalities of Energy* Vol. 1–6. Office for Official Publications of the European Communities: Luxembourg.

European Commission (EC). 1999. *ExternE: Externalities of Energy* Vol. 1–6. Office for Official Publications of the European Communities: Luxembourg.

European Commission (EC). 2005. *ExternE: Externalities of Energy*, *Methodology 2005 Update*. Institut für Energiewirtschaft und Rationelle Energieanwendung – IER Universität Stuttgart, Germany.

Faaij, A, Meuleman, B, Turkenburg, W, Van Wijk, A, Bauen, A, Rosillo-Calle, F, Hall, D. 1998. Externalities of biomass based electricity production compared with power generation from coal in The Netherlands. *Biomass and Energy* 14:125–147.

Ferguson, RAD. 1981. *Comparative risks of electricity generating fuel systems in the UK*. Peter Peregrinus Ltd: London.

Gaterell, MR, McEvoy, ME. 2005. The impact of energy externalities on the cost effectiveness of energy efficiency measures applied to dwellings. *Energy and Buildings* Vol.35:815 –827.

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

Hohmeyer, O. 1992. The social costs of electricity-renewables versus fossil and nuclear energy. *International Journal of Solar Energy* 11:231–250.

International Energy Agency (IEA). 2004. [Online] Available at: www.iea.org/Textbase/stats/index.asp.

IEA. 2007. *Key World Energy Statistics*. IEA: Paris.

Inhabert, I. 1978. *Risk of energy production*. Atomic Energy Control Board: Canada.

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

Krewitt, W. 2002. External costs of energy – do the answers match the questions? Looking back at 10 years of ExternE. *Energy Policy* 30:839 –848.

Lin, AYS. 1976. *Theory and measurement of economic externalities*. Academic Press: New York.

Maddison, D. 1999. The plausibility of the ExternE estimates of the external effects of electricity production. Center for Social and Economic Research into the Global Environment (CSERGE) Working Paper GEC 99-04. University College London and University of East Anglia.

Mishan, EJ. 1965, Reflections on recent developments in the concept of external effects. *Canadian Journal of Economics and Political Science* 31:1–34.

Oak Ridge National Laboratory (ORNL), Resources for the Future (RfF). 1994–1998. *External costs and benefits of fuel cycles* Reports 2–8. McGraw-Hill Utility Data Institute: Washington.

Opaluch, JJ, Grigalunas, T, Diamantides, J, Mazzotta, M, Johnston, R. 1999. *Recreational and resource economic values for the Peconic Estuary System.* Economic Analysis, Inc: New York.

Ott, W. 1997. External costs and external price addings in the Swiss energy sector. In: Hohmeyer, O, Ottinger, RL, Rennings, K. (eds.). *Social costs and sustainability: valuation and implementation in the energy and transport sector (conference proceedings)*. Springer: Berlin.

Ottinger, RL, Wooley, DR, Robinson, NA, Hodas, DR, Babb, S. 1991. *Environmental costs of electricity*. Oceana Publications Inc: New York.

Pearce, D, Turner, RK. 1990. *Economics of natural resources and the environment*. Harvester Wheatsheaf, Hemel Hempstead: UK.

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

Pigou, AC. 1920. *The Economics of Welfare*, 4th ed. London: Macmillan and Co.

Platts,2006. South Africa’s coal future looks bright. [Online] Available at: www.platts.com/Coal/highlights/2006/ coalp _ee_091106.xml. Accessed on 23 October 2007.

Pouris, A, Dutkiewicz, RK. 1987. The social costs of energy in South Africa. *South African Journal of Sociology* 18(4): 129–132.

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

Rowe, RD, Bernow, SS, Bird, LA, Callaway, JM, Chestnut, LG, Eldridge, MM, Lang, C, Latimer, DA, Murdoch, JC, Ostro, BD, Patterson, AK, Rae, DA, White, DE. 1995. *New York state environmental externalities cost study, Report 2: methodology*. RCG/Hagler, Bailly, Inc. Empire State Electric Energy Research Cooperation: Albany.

Samuel HW. 2007. Six ways to compute the relative value of a US dollar amount, 1790–2006. [Online]: Available at www.measuringworth.com. Accessed on 12 November 2009.

Scorgie Y, Paterson G, Burger LW, Annegran, HJ, Kneen, M. 2004. Study to examine the potential socio-economic impact of measures to reduce air pollution from combustion. *Task 4a supplementary report: Quantification of health risks and associated costs due to fuel burning source groups*. National Economic Development and Labour Council: South Africa.

Schuman M, Cavanagh, R. 1982. *A model conservation and electric power plan for the Pacific Northwest*. Northwest Conservation Act Coalition (NCAC): Seattle.

South Africa. 1998. *White paper on the Energy Policy for South Africa*. Department of Minerals and Energy (DME): Pretoria.

South Africa. 2003. *White paper on Renewable Energy*. DME: Pretoria.

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

Stern N. 2006. Stern Review: The economics of climate change. Executive summary. [Online]: Available at www.hm-treasury.gov.uk/sternreview_summary.htm. 2006. Accessed on 15 April 2010.

Stirling, A. 1998. Valuing the environmental impacts of electricity production: A critical review of some first-generation studies. *Energy Sources* 20:267–300.

Sundqvist, T. 2004. What causes the disparity of electricity externality estimates? *Energy Policy* 32:1753 –1766.

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

Winkler, H. 2006. *Energy policies for sustainable development in South Africa*. Energy Research Centre: Cape Town.

Chapter 3: Energy and electricity policy in South Africa: An overview

South Africa's energy policy has seen continual change in order to accommodate the social, economic, political and environmental changes. The policy modifications brought about and being brought about are with the intention of providing the country with a sustainable socio-economic future. South Africa is often seen as an economic paradox with high unemployment and poverty rates, while boasting first world transportation infrastructural facilities (World Bank, 2011). The government of the country has borne the impact of this paradox, with the responsibility of catering for the needs of a large population that is unable to bear the expenses of the country's energy intensive industries. This situation has seen the government often trying to maintain a very delicate balancing act, requiring constant review in energy policies while bearing sustainability in foresight.

3.1 Energy industry in South Africa

South Africa is categorised as a high energy intensity country, (in other terms less efficient), with 0.27 tonnes of oil equivalent (toe) required to generate 1000 dollars (calculated according to rates for the year 2000) of the GDP in purchasing power parity in 2005, while the average Organisation for Economic Cooperation and Development (OECD) energy intensity is 0.16 toe (International Energy Agency, 2011).

Table 3.1: Comparison of energy intensity parameters of South Africa with a few other selected countries and regions for the year 2009

	TPES/GDP (PPP) toe/1000 in 2000 USD	TPES/GDP toe/1000 in 2000 USD	TPES/pop toe/capita	Elec. Consu/pop (kWh/capita)
South Africa	0.27	0.79	2.92	4532
China	0.16	0.18	1.70	2648
Turkey	0.12	0.27	1.36	2296
Malaysia	0.22	0.49	2.43	3677
India	0.15	0.77	0.58	597
Germany	0.14	0.16	3.89	6781
United Kingdom	0.11	0.12	3.18	5693
USA	0.19	0.19	7.03	12884
Africa	0.26	0.75	0.67	561
OECD	0.16	0.18	4.28	8012
World	0.19	0.31	1.80	2730

TPES = Total Primary Energy Supply

GDP = Gross Domestic Product

PPP = Purchasing Power Parity

Source: IEA, 2011.

It can be observed from Table 3.1 that South Africa's PPP adjusted and nominal energy intensity is the highest of the countries mentioned, except for the region of Africa. This can be attributed to large energy intensive industries that focus on low grade processing, and basic extraction forming a large section of industries. Low electricity prices provide encouragement for heavy industries to remain energy intensive.

The factor of low prices also encourages developed countries with higher electricity prices to outsource processing operations, thereby driving up energy intensity further.

Figure 3.1 shows South Africa's TPES mix for the year 2011. The largest energy carrier locally available is coal, while crude oil that is imported for liquid fuels is the second largest energy carrier.

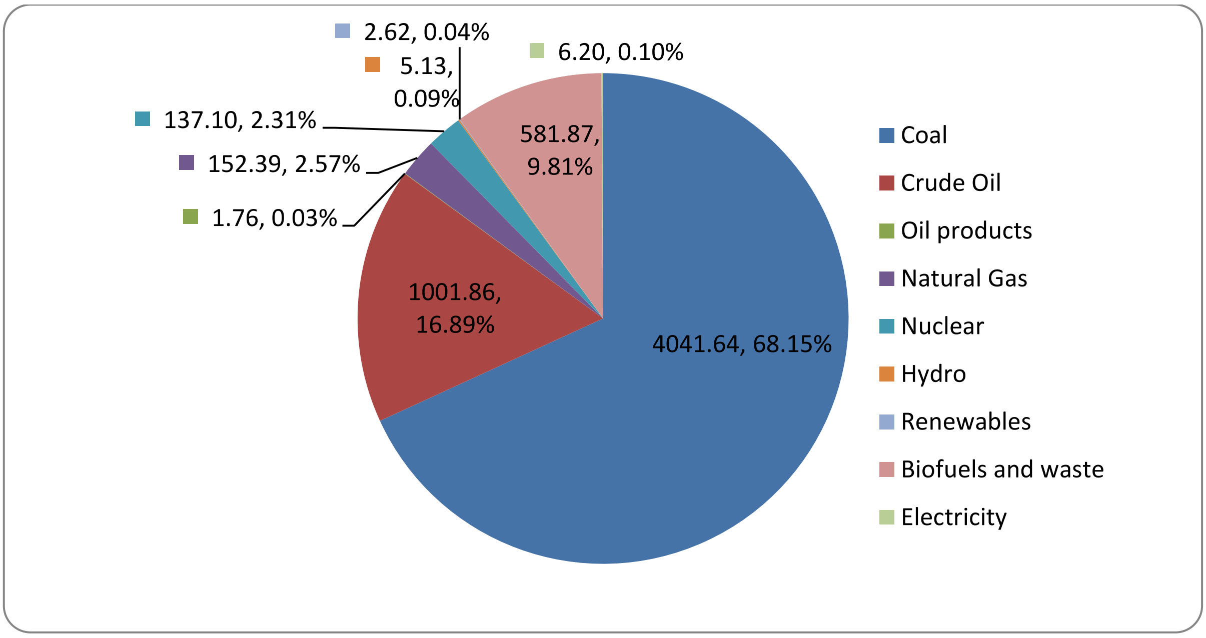


Figure 3.1: Total primary energy supply South Africa in PicoJoules

Source: IEA, 2009.

Primary energy supplied is transformed into a consumable form for the general needs of the population and industry. Transformation occurs mainly with crude oil being converted into fuels such as petrol, kerosene and such, while coal gets converted primarily for use as electricity and liquid fuels.

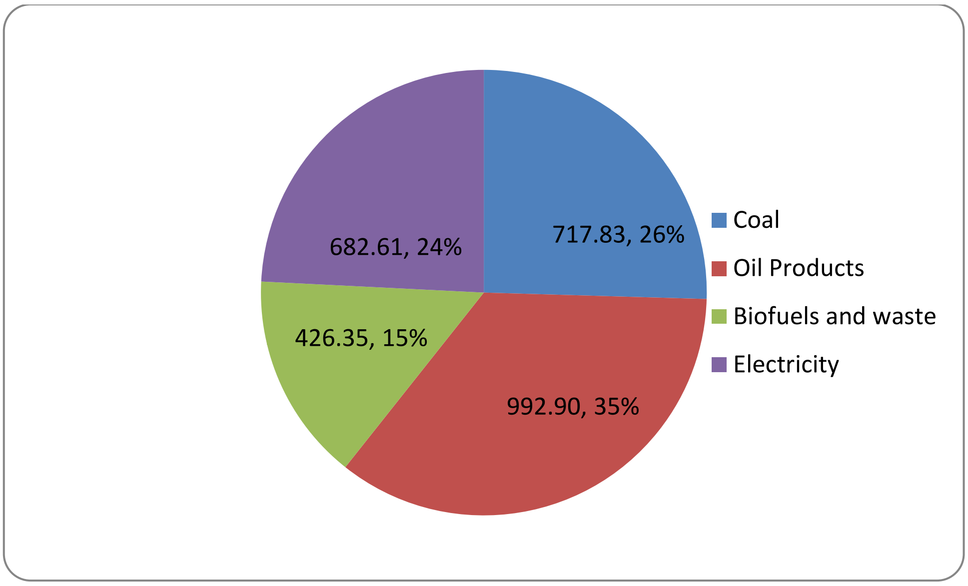


Figure 3.2: Total final South African consumption in PicoJoules

Source: IEA, 2009.

Since the focus is on the role of electricity within the economy, Figure 3.3 depicts distribution of electricity among the different sectors.

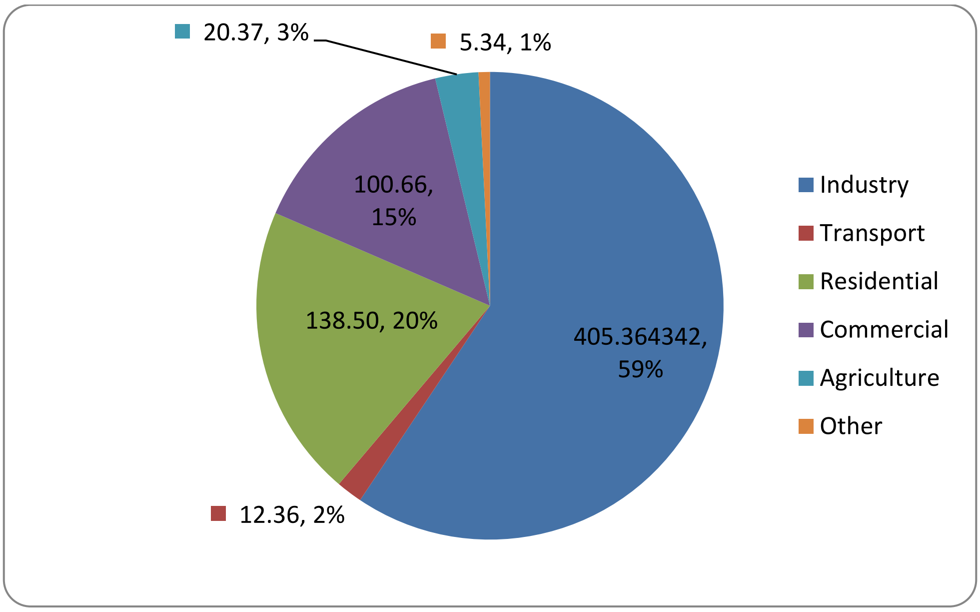


Figure 3.3: Sectoral electricity usage in PicoJoules

Source: IEA, 2009.

It can be seen that almost two-thirds of electricity is consumed by the industrial sector, while only one-fifth is used by the residential sector, which is another indication that the economy is highly industry-oriented. An area of concern is that only 3% of electricity is used by the agricultural sector, in spite of 5% of the workforce employed in the same sector.

3.2 Electricity policy in South Africa: A timeline

South Africa's energy policies post-democracy has seen major shifts and changes. The primary priority of the government has been to provide electricity to the rural and poorer populations of the country. To this end the Integrated National Electrification Programme (INEP) was initiated in 1994 (Tinto and Banda, 2005). This programme saw a major shift in energy policy with social equity and environmental sustainability being priorities over energy security and industrialisation. Still on-going, the INEP has seen tremendous success over the last decade. The electricity industry was monopolistically managed by Eskom[5] prior to 1994. The introduction of the National Energy Regulator of South Africa (NERSA) commenced the process of regulation. Eskom was mandated by NERSA to undertake the electrification programme (IEA, 2010).

In 2001 the Department of Energy[6] (DoE) took over the implementation and management of the electrification programme, while liaising with Eskom. The DoE is the governmental body which oversees the energy industry in South Africa. Post 2001 the DME employed local municipalities as well as Eskom to implement the roll out of electricity connections to private users and small businesses (South Africa, 2009a).

[5] Eskom is the national public utility which generates, transmits and distributes electricity to majority of the users and municipalities in South Africa.
[6] The Department of Energy (DoE) was known as the Department of Minerals and Energy (DME) prior to April 2009 and the two departmental names will be used intervariably based on timeframe. The name changes occurred as part of the government restructuring.

The funding for the local municipalities is provided by National Treasury and is managed by the DoE. The deadline for the INEP completion has been set for 2014 (IEA, 2010).

The White Paper on Energy Policy was meanwhile published in 1998 (South Africa, 1998). National electrification was a major priority, with enhancements being made in the White Paper for the implementation of the electrification process. The primary objectives of the White Paper were as follows:

- Increase access to affordable energy services
- Improve energy governance
- Stimulate economic development
- Manage energy-related environmental and health impacts
- Secure supply through diversity

These objectives were formed within the national context keeping in mind social and economic policies such as the Reconstruction and Development Programme (RDP). The RDP had two primary aims; the need to achieve more rapid economic growth and the need to eliminate poverty through sustained development. The energy sector was seen as a primary player towards achieving these national goals. Within the international context the aforementioned objectives were critical to South Africa's commitment to the UNFCCC, along with policy commitments within the African continent.

The next major policy investigation was the Integrated Energy Plan (IEP), formulated to investigate energy scenarios that South Africa could follow (South Africa, 2003). The IEP was developed bearing in hindsight the objectives of the White Paper on Energy. The energy plan was devised for the period 2001 to 2020 by the erstwhile DME, Eskom and the Energy Research Centre of the University of Cape Town. Long-term scenario modelling was based on the LEAP and MARKAL modelling tools.

The IEP investigated four separate scenarios:

- **Baseline simulated**: "Business as usual" scenario, continuing existing trends based on coal.
- **Baseline optimised**: Optimises scenario 1 based on least cost, taking into account energy efficiency and fuel switching.
- **Siyaphambil**i[7] simulated: Scenario promotes fuel diversification away from coal, introducing other energy technologies at specific periods.
- **Siyaphambili optimised**: Optimises scenario 3 based on least cost, using energy efficiency and fuel switching.

The highlights of each scenario are described below in Table 3.2, with the energy plan for the electricity sector being emphasised particularly:

Table 3.2: Integrated Energy Plan scenario options

Baseline simulated	**Baseline optimised**	**Siyaphambili simulated**	**Siyaphambili optimised**
General objectives			
Business as usual	Technologies selected to reduce costs	Diversify supply and improve the environment	Technologies selected to reduce costs
External costs excluded	External costs excluded	External costs excluded	External costs excluded
No regional cooperation	Regional cooperation if economic	More regional cooperation	More regional cooperation if economic

7 'Siyaphambili' means "we are moving forward".

Baseline simulated	**Baseline optimised**	**Siyaphambili simulated**	**Siyaphambili optimised**
Electricity			
Coal is dominant Mothballed power stations are re-operated New coal power stations without flue gas desulphur-ification (FGD)	New technologies are cost-oriented Conventional coal without FGD Combined gas cycle Renewable technologies Municipal waste	Technologies are prioritised above coal Combined gas cycle Renewable technologies Fluidised bed coal Peaking gas turbines FGD coal fired station is considered as a final option	New technologies are cost-oriented Conventional coal with FGD Combined gas cycle Renewable technologies Municipal waste

Adapted from Department of Minerals and Energy, 2003.

It has to be noted that external costs are excluded from all scenarios, which will be vital considering the objective of the thesis in due course. The IEP mentions that the Department of Environmental Affairs and Tourism (DEAT) was investigating the financial internalisation of externalities at the time of the publication of the energy scenarios. However, no such results of such an investigation had been published until the next major electricity policy plan was devised.

A Long-term Mitigation Scenario (LTMS) study was performed in 2007 to analyse various scenarios emerging from constraints set on carbon emissions for South Africa (South Africa, 2007). The various scenarios that are investigated in the study are for the time frame 2003 until 2050. The different scenarios and their findings are summarised below:
Scenario 1 – Growth without constraints (GWC) looks at how local carbon emissions would trend if economic growth is left unaltered the way it is currently with the economy being largely energy intensive.

Scenario 2 – Required by Science (RBS) considers options on how South Africa can contribute to the global challenge of reducing carbon emissions on a level that will be beneficial nationally and internationally, and will meet international set recommendations as those mentioned by the International Panel for Climate Change (IPCC). Different options were considered to bridge the gap between the GWC and RBS scenarios:

Option 1 – 'Start Now' considers techniques based on economic development and sustainability, with the aspect of climate change being independent. Energy supply observes a drift away from coal-fired electricity, with renewable, nuclear and clean coal technologies as alternatives.

Option 2 – 'Scale Up' is an extension of the start now option with a carbon tax of R39/tonne of CO_2 being considered and renewable electricity generation techniques expanded by 50%. The gap between GWC and RBS gets reduced to two thirds.

Option 3 – 'Use the Market' is an extension of the scale up option with a carbon tax of R100/tonne of CO_2. The high tax is set to reduce emissions drastically with a very high tax of R750/tonne introduced over the period 2040 to 2050. Building of coal electricity power plants is stopped and capacity is increased with the focus on nuclear and renewable energy. This option helps reduce the gap between the two scenarios by 75%.

Option 4 – 'Reaching the Goal' consists of strategic options that have not been modelled yet. The scale up option enables closing the gap between the GWC and RBS by 64% around 2050, while use the market achieves the same target by 2035. However, a gap still persists between achievable targets and RBS. In order to reach the goal of reducing current CO_2 levels, a revisit of strategies by 2030 would be required to achieve targets. Revisiting strategies would include focusing on key areas of investigating new technologies, identifying low carbon resources, social prioritisation and transitioning to a low carbon economy.

The LTMS is a holistic, scenario-based energy planning study that laid the foundation for the next major electricity policy plan, the Integrated Resource Plan (IRP). The IRP was formulated with the intention of expanding generation capacity from 2010 to 2030, taking into account multiple possibilities to meet electricity demand (South Africa, 2010). The major difference is that while the IEP focuses on streamlining the nation's holistic energy demand with different possible scenarios, the IRP focuses on best viable practices for South Africa's electricity future.

The IRP has been iterated a number of times and it is possible that a few more iterations will be performed in due course. The process of formulating the IRP was initiated by the DoE with the initial draft being completed in January 2010. The first round of public participation was conducted in June 2010. The Revised Balanced Scenario (RBS) was developed as a result of this consultation in October 2010. The second round of public participation was undertaken in December 2010, which led to a policy-revised formulation of the RBS where focus was on the disaggregation of renewable technologies and security of supply. The policy-adjusted IRP was endorsed for implementation by the Cabinet. The DoE however recommends a revision of the IRP every two years to account for real time scenario developments (South Africa, 2011). Table 3.3 describes the policy modifications brought about in the policy-adjusted IRP.

Table 3.3: Changes between RBS and policy-adjusted versions of the IRP

IRP (RBS)	Second round of consultation	IRP (Policy adjusted)
Nuclear power was stated as optional when considering supply security	Construction of one or two nuclear units in 2022–2024 based on cost evaluation and risk	Commitment made to a nuclear fleet of 9600 MW ensuring security of supply
Emission constraints set for coal-fired generation	Timing of emission constraint revised	Timing to impose emission constraints was revised from 2026, to 2019–2025 in order to achieve emission outcomes by 2030
Import options stated from neighbouring countries	Import options extended	Coal import options extended to Botswana while hydro options remained consistent
Eskom's demand side management was accepted as guideline for Energy-efficiency and Demand-side Management (EEDSM)	Extending EEDSM options were considered	Decision to stick to policy stated in RBS was taken with risk to security supply, negates benefits of revised EEDSM options

From a social policy perspective no mention of externalities has been made in either the RBS of the IRP or the policy-adjusted IRP, while possibilities of investigation have been mentioned. This policy gap will form the foundation of this thesis henceforth. Since the emphasis of externalities is based on electricity generation, the focus in this thesis will now shift to the electricity generation utility Eskom.

3.3 Eskom in a national and international context

South Africa's recent and past history has seen continuous innovations and shifts in the energy industry. South Africa was the first country in the southern hemisphere and Africa to introduce street lighting, in the town of Kimberly in 1882 (Eskom, 2009).

One of Eskom's innovations has been the Airborne Laser Solutions technology that conducts high speed and accurate linear surveys of thousands of kilometres' transmission lines over difficult terrain. Eskom's pioneering dry tower cooling power technique is employed in three out of ten base load coal power plants. Two new base load coal power plants that are currently under construction, Kusile and Medupi, are employing the latest desulphurification techniques. When operational Medupi will be the world's fourth largest coal power plant and the largest power plant employing dry cooling techniques. Table 3.4 describes different phases of Eskom's operations.

Eskom has over the past century grown to become one of the top 10 electricity supplying utilities in the world. Eskom was incepted in 1923 with the establishment of the Electricity Supply Commission (Escom) by the government. The period from 1930 to 1950 saw Escom trying to lay solid foundations by erecting governance structures and establishing basic electrification infrastructure to facilitate national supply. The Klip power station was built to cater for the increasing demand for electricity from the mining industry. World War II adversely affected Escom's functioning, but the challenges were overcome once the war ended, with Escom being able to acquire and expand existing regional power stations, such as the Port Shepstone power station and municipal undertakings in the present day region of the Eastern Cape. Several extensions to existing levels of infrastructure were made to supply increasing demand.

The period from 1950 onwards saw tremendous growth, with Escom's generation capability more than doubling and the construction of new power plants featuring increased generational capacity.

This trend continued through the 1960s with industrial electricity demand fuelled by the rapid growth of the mining industry, resulting in the construction of the next generation of coal power plants, some of which are even still operational. Establishment of the national power network was undertaken to connect the Cape Province with the Upper Transvaal. The 1970s witnessed the introduction and commissioning of hydro power plants to stabilise and moderate peak supply demands.

The construction of the Koeberg nuclear plant was also a major milestone in the utility's history from the viewpoint of diversifying generation techniques. The 1980s saw more coal power plants being built. Towards the end of the 1980s and the start of 1990s there was a period of political transition. The utility had to put capacity expansion on hold and restructure policies with expansion of electrification the priority. These changes saw a restructuring along with Escom being renamed Eskom by a government appointed commission.

Table 3.4: South African electricity production phases

Period	**Description**	**Occurrences**
1930–1989	Eskom establishment and growth	This period saw the roots of one the largest electricity entities in the world. Eskom would go on to build multiple coal power plants and one nuclear plant and generate more than 95% of the electricity produced in the country. Electricity supply was largely oriented

Period	**Description**	**Occurrences**
		to the population that had political rights and with a heavy emphasis on industrialisation. Heavy industries received heavily subsidised electricity to promote industrial production
1990–1999	African Renaissance – post democratic elections	National Energy Regulator was formed to ensure the regulated generation, transmission and supply of electricity in the country. Emphasis was on supplying electricity to rural and previously disadvantaged populations. Eskom Enterprises was formed with Eskom playing a larger role in Africa and all being involved in projects in the developing world
2000–2010	Recent past	National electrification programme was introduced by supplying monthly 50 kWh of free electricity to poor households. Formation of the first and second Integrated Energy Plans

Source: Thopil and Pouris, 2011.

Eskom has thirteen operational coal power plants, of which ten are base load and one a nuclear power plant, which facilitates base load supply. Hydroelectric, pumped storage and open cycle gas turbine plants supplement the grid during peak load demands.

The Klipheuwel wind farm is the only renewable technology-based power plant supplying the national grid.

Figure 3.4: South Africa's electricity grid map

Source: Eskom, 2012.

Eskom is one of the top 20 utilities in the world in terms of generation capacity. This is in sharp contrast to the mid-1990s, during which Eskom ranked among the top five in terms of generation and sales (Van Horen, 1996). The decline can be attributed to Eskom's priority shifting from expanding generational capacity to expanding electrification to the masses. Eskom generates almost 95% of the electricity in the country, with the remainder being generated by municipalities and private entities. Some of these private entities sell the remainder of their electricity to Eskom to be redistributed on the national grid (Eskom, 2011b). Table 3.5 shows the generation mix of Eskom's power plants from diverse technologies.

Table 3.5: Generation technology mix for the year 2011

Technology	**Electricity generated (GWh)**	**Percentage contribution**	**Number of plants**
Coal-fired	220 219	92.75	13
Hydroelectric	1 960	0.82	2
Pumped storage	2 953	1.24	2
Gas turbine	197	0.08	4
Nuclear	12 099	5.09	1
Wind energy	2	Negligible	1
Total production	**237 430**	**100**	**23**

Source: Eskom, 2011b.

The dominance of coal-fired electricity is quite evident from the table above. This domination is detrimental from an environmental and sustainability perspective. The technology mix is skewed even within the international context. Table 3.6 portrays the generational mix from an international perspective.

Table 3.6: Electricity breakdown comparison between utilities in percentage for year 2011

Technology	**Eskom**	**Utilities in Europe**	**Utilities in USA**	**Utilities in China**	**Utilities in South America**
Total electricity produced (TWh)	237	225	187	161	185
Coal-fired	92.8	56.0	57.0	81.0	0.4
Renewables	0.8	4.0	4.0	0.2	92.4
Pumped storage	1.2	1.0	1.0	1.2	0.3
Gas	0.1	19.0	15.3	17.6	0.0
Nuclear	5.1	20.0	11.9	0.0	6.4

Source: Eskom Annual Report, 2011.

However, since the emphasis is on the local electricity generation sector the focus is on the electricity generation schemes within South Africa.

3.4 Types of electricity generation in South Africa

Almost 97% of the electricity generated use non-renewable technologies namely coal and nuclear. This section looks at the various types of technologies that are employed for generation and the potential of technologies that can be used, but are not currently.

3.4.1 Coal-powered electricity

The abundance of coal makes South Africa the fifth largest producer of coal in the world (IEA, 2011). The geographical concentration of coal around the provinces of Mpumalanga, Limpopo and Free State, has seen coal power plants being built in the same region historically and currently.

Coal mined in South Africa is generally of bituminous grade, with 0.8% anthracite and 1% sulphur. The energy value ranges from about 27 MJ/kg for export coal, to between 22 and 15 MJ/kg for steam coal (Winkler, 2006). In 2009, 248 million tonnes of bituminous coal and 1.6 tonnes of coke coal were produced, of which 52 million tonnes of bituminous coal were exported (South Africa, 2009b). From a total of 190 million tonnes used domestically, 152 million tonnes were transformed and 33 million tonnes used for liquefaction. The amount of coal used to produce electricity in the national power plants was accounted to be 115 million tonnes, which is approximately 61% of the total coal supplied locally. Table 3.7 provides a better description of coal distribution with the country.

Table 3.7: Coal supply and distribution (2009)

Description	**Hard coal (in million tonnes)**
Production	249.5
Import	0.17
Export	-51.97
Stock changes	-7.32
Domestic supply	190.36
Transformation sector	152.13
Industry sector	23.65
Other sectors	11.68
Statistical differences	2.82

Source: South Africa, 2009b.

As discussed, the primary sector associated with coal consumption is electricity generation. Different techniques exist to generate electricity from conventional coal power plants.

Of Eskom's thirteen coal power plants, only ten are operational to supply base load requirements. The remaining three were mothballed during the late 1980s and early 1990s, but are being returned to service to supply peak demands after the load shedding crisis during 2008. A list of the existing power stations is shown in Table 3.8, all of which are pulverised fuel power stations without flue gas desulphurisation. Two new power stations, Kusile and Medupi, are being built. Kusile will be using flue gas desulphurisation (Eskom, 2012b). The Medupi power plant will feature a super critical plant able to operate at higher temperatures and pressures along with higher efficiencies (Eskom, 2012c).

Table 3.8: Coal-fired power plants

	Maximum capacity (MW)	**Cooling technique**	**Operating status**
Arnot	2 232	Wet	Operating
Camden	1 430	Wet	7 out of 8 units RTS
Duvha	3 450	Wet	Operating
Grootvlei	950	Wet	In process of RTS
Hendrina	1 865	Wet	Operating
Kendal	3 840	Dry	Operating
Komati	284	Wet	In process of RTS
Kriel	2 850	Wet	Operating
Lethabo	3 558	Wet	Operating
Matimba	3 690	Wet	Operating
Majuba	4 843	Wet/dry	Operating
Matla	3 450	Wet	Operating
Tutuka	3 510	Wet	Operating
Total	**34 952**		

RTS = Return to Service

Source: Adapted from Winkler, 2006 and Eskom, 2012.

3.4.2 Nuclear-powered electricity

Nuclear electricity in South Africa is generated from the Koeberg power plant near Cape Town, which began operation in 1984. Koeberg comprises two pressurised water reactor units with a capacity of 930 MW each and cooled with sea water. It supplies electricity to large sections of the national grid within the Cape region (Eskom, 2011a). Due to a lack of local facilities to convert the fuel used by the plant, it is imported.

Eskom, in collaboration with other stakeholders, had been developing a demonstration type Pebble Bed Modular Reactor (PBMR) that uses pellets of uranium as fuel, helium as coolant and graphite as the moderator. The uranium pellets are implanted in graphite balls. However, government funding for the project was withdrawn and the project was shelved.

The nuclear facility at Pelindaba, SAFARI-1, is a 20 MW unit used solely for research purposes and is managed by the Nuclear Energy Council of South Africa (Necsa). However, no electricity is produced to supply the national grid.

3.4.3 Gas-powered electricity

All of Eskom's gas fired electricity is produced by open cycle gas turbines (OCGT) plants. The OCGT plants use gas/fuel that mixes with highly compressed air, which then combusts and expands to rotate the blades of the rotor. Eskom has four OCGT plants (Table 3.9), which are used to supply electricity during peak or emergency demand.

Table 3.9: Open cycle gas turbine plants

	Maximum capacity (MW)
Acacia	171
Ankerlig	1 327
Gourikwa	740
Port Rex	171
Total	**2 409**

Source: Eskom, 2011b.

Both Ankerlig and Gourikwa are newly built plants that were first opened in 2007 and have had their capacity of expanded in 2009. Eskom is at risk of increasing crude oil prices when operating OCGTs because it uses diesel as the mixing fuel to generate electricity. This is sufficient reason to investigate options of a combined cycle gas turbine (CCGT).

The feasibility and viability of incorporating CCGT plants into the national electricity capacity is investigated in both the IRP and LTMS investigations. Eskom is also investigating options to convert the Ankerlig plant into a CCGT plant. Natural gas, which will be used in the CCGT plants, has to be imported from neighbouring countries such as Mozambique or Namibia. Operating costs of gas turbine plants has been the deterrent for expanding such technology. Gas-fired electricity costs almost ZAR1.60/kWh compared to average electricity prices of ZAR0.17/kWh (Engineering News, 2007).

3.4.4 Hydro and pumped storage-powered electricity

Eskom operates six hydro and two pumped storage power stations. Only two of the hydro power stations have capacities above 50 MW; the remainder are used to stabilise distribution in the Eastern Cape (Figure 3.4) and are not connected to the national grid.

Pumped storage plants are net users of electricity, taking into account the amount of electricity used to pump water to higher elevations. However, pumping (or storing) is performed during periods when demand is minimal (usually around noon). Table 3.10 shows capacities of hydro and pumped storage power plants connected to the national grid.

Table 3.10: Hydro and pumped storage plants

Technology	Maximum capacity (MW)
Hydro power	
Gariep	360
Vanderkloof	240
Pumped storage	
Drakensburg	1000
Palmiet	400
Total	**600 + 1400 = 2000**

Source: Eskom, 2011b.

As part of Eskom's capacity expansion programme, a new pumped storage power plant named Ingula is under construction in Ladysmith in KwaZulu-Natal and expected to be completed by 2014.

Generation of electricity using hydro power is categorised under renewable technologies, whereas pumped storage generation is considered separately, even though the resource used (in this case water) is renewable and harmful emissions are minimal. It is categorised separately because the pumped storage generation technique is a net consumer of electricity.

3.4.5 Wind-powered electricity

South Africa has a rich supply of wind energy along its eastern and western coasts. The wind potential for South Africa has been noted to be in the range of 500 MW to 56 000 MW (Szewczuk, 2010). Olesner (2007) mentions the potential of wind energy to be more than 70 000 MW. South Africa has three on-going wind farm projects in various stages of development and operation that are described and summarised in Table 3.11.

The Klipheuwel wind farm near Cape Town is a three-unit station with a total maximum capacity of 3 MW. The first unit of the farm was commissioned during August 2002 and all units were operational by February 2003. Electricity generated from this facility is fed directly into the regional grid.

The Darling wind farm is a demonstration wind farm project being managed by the Darling IPP and funded by the Danish government, the Development Bank of Southern Africa and the Central Energy Fund (CEF, 2008). The plant has four 1.3 MW units with a total annual power production capability of 8.6 GWh and was commissioned during May 2008. Power from the wind farm is purchased by the City of Cape Town Municipality. A third wind farm, Sere, managed by Eskom, with an estimated total output of 100 MW is under construction near Koekenaap in the Western Cape. The project is being funded by various banks, such as the World Bank, the African Development Bank, French Development Agency and the Clean Technology Fund. Construction of the farm is expected to begin by mid-2013.

Table 3.11: Wind farm (> 1 MW) status in South Africa

	Status	**Capacity**	**Grid status**
Klipheuwel	Operational	3 MW	Regional
Darling	Operational	5.2 MW	Municipal
Sere	Construction	100 MW	Regional

3.5 Summary

The topic of electricity externalities is important for South Africa when considering the environmental and physiological damages that were being overlooked in order for Eskom to provide low cost electricity to its consumers. However, the luxury of cheap electricity started to wane when generational capacity had to be increased when demand started to exceed supply capabilities. Eskom's short-term solution was to increase generational capability by building additional coal power plants and recommissioning mothballed generational capabilities. The capital to build new generation capacity had to be raised by inevitably increasing prices. The short-term strategy to increase generational capacity is driven by building additional coal-fired power plants, Kusile and Medupi, so that generation can start as early as 2013. However, these plans still do not cater for environmental sustainability and physiological damages occurring from non-renewable fossil fuel generation. The RBS and policy-adjusted versions of the IRP have made ambitious policy projections into diversifying the electricity generation capabilities with supply security and sustainability as pivotal priorities. Both versions do though mention cost investigations of externalities as an area that needs further attention.

The purpose of investigating externalities is to add motivation to the intent of diversifying the national electricity generation mix towards renewable schemes as mentioned in the IRP and IEP policy directives. Both directives mention externalities as an area that requires investigation and research. Van Horen (1996) has done pioneering externality analysis in South Africa, which was extended by Spalding-Fetcher and Matibe (2003) using the same methodology. The electricity generation and economic landscape has since changed and revised evaluation based on current scenarios could prove useful for policy-making.

Electricity generation from non-renewable fuels comprises a range of externalities when considering the total fuel cycle. This study concentrates only on the generational aspect of the fuel cycles. The externalities that occur during the generation of electricity using coal are as follows:

- Impact on human health due to atmospheric pollution constitutes the health issues caused due to emission of harmful pollutants into the atmosphere
- Impact on occupational health that occurs during the process of mining of coal for the purpose of electricity generation
- Impact on atmosphere and water bodies in the vicinity of an ash dump
- Impact on crops and building caused due to emission of harmful pollutants into the atmosphere
- Water costs associated with generation using coal
- Impact of GHG emissions

Externalities that occur from the generation of electricity using nuclear fuel are as follows:

- Occupational health during mining of fuel
- Occupational health impacts during the generation of nuclear electricity
- Public health impacts during the generation of electricity
- Occupational health during waste disposal

The variation between externalities related to coal and nuclear electricity generation is the rate of occurrence. While externalities associated with coal-based generation are a daily occurrence, nuclear-based externalities occur less frequently.

Externalities are further classified into priority and non-priority externalities. Priority externalities are those that can be quantified and analysed primarily based on availability of data, while non-priority externalities are those that cannot be thoroughly quantified because of the inability to plug data gaps when such a scenario occurs.

The IPA methodology employed in this study relies on the updated ExternE methodology for certain impacts (European Commission, 2005). The rationale behind choosing the ExternE model is because of its widespread acceptance in Europe and the similarity of certain European countries' (e.g. Spain and France) industrial setup and demographic size to South Africa The ExternE methodology uses the Impact Pathway Approach (IPA), which was also the approach followed by Van Horen (1996). However, characteristics such as the dose response functions, models and tools used by Van Horen (which are discussed in the literature review) were different to the ExternE method. Figure 1.1 shows the flow chain of the IPA and is very much self-descriptive. It is worth mentioning the tools being used in ExternE methodology. For the calculation of damage costs ExternE uses the Riskpoll software package, an integrated impact assessment model that combines atmospheric models with databases for receptors (population, land use, agricultural production, buildings and materials, etc.), dose-response functions and monetary values (European Commission, 2005). There are two additional tools for simplified analysis, namely EcoSenseLE and Ecosense. Even though these versions are newer than Riskpoll, they were not used for the current study because they do not cater for geographical locations beyond North Africa and Europe.

The primary difference between the IPA approach used in the ExternE study and the current study is the sensitivity valuation performed, based on discount rates once the damage cost is achieved. Social discounting is used primarily to estimate how much present social costs would equate to in the future.

This type of analysis is useful in determining the value of large scale social investments for future generations or determining the future value of abatement costs based on current payments (Harisson, 2010). Usage of social discounting is an already debated topic, an example of which has occurred in studies such as the Stern Review (2006) and the Nordhaus (2008) evaluation during choice of carbon tax for future generations. Social discounting is also used to evaluate the damage associated with nuclear-based costs in the long-term. In order to avoid ambiguity this study has steered clear of such an analysis for the time being and treaded along an investigation for the current timeframe.

3.6 References

Central Energy Fund. 2008. [Online] Available at: www.cef.org.za/index.php?view= article&id=41%3Aminister-switches-on-the-darling-wind-farm&option= com_content&Itemid=17. Accessed on 15 March 2012.

Engineering News. 2007. [Online] Available at: www.engineeringnews.co.za/article/ocgt-stations-fuel-eskomrsquos-winter-fire-2007-05-18. Accessed on 17 March, 2012.

Eskom. 2009. [Online] Available at: heritage.eskom.co.za/heritage/ electricity_in_south_africa.htm. Accessed on 17 March 2011.

Eskom. 2011a. [Online] Available at: financialresults.co.za/2011/eskom_ar2011/ profile_key_facts02.php. Accessed on 17 March 2011.

Eskom. 2011b. *Annual Report 2011*. Sandton: Eskom.

Eskom. 2012. [Online] Available at: www.eskom.co.za/content/2008EskomPoster.jpg. Accessed on 18 March 2012.

Eskom. 2012b. [Online] Available at: www.eskom.co.za/c/article/58/kusile-power-station/. Accessed on 18 March 2012.

Eskom. 2012c. [Online] Available at: www.eskom.co.za/c/article/57/medupi-power-station/. Accessed on 25 March 2012.

European Commission (EC). 2005. *ExternE: Externalities of Energy, Methodology 2005 Update*. Institut für Energiewirtschaft und Rationelle Energieanwendung – IER Universität Stuttgart, Germany.

Harrison, M. 2010. Valuing the future: The social discount rate in cost-benefit analysis. Visiting researcher paper for the Productivity Commission of the Australian Government.

International Energy Agency (IEA). 2009. IEA Energy Statistics. Energy Balances for South Africa. [Online] Available at: www.iea.org/stats/balancetable.asp?COUNTRY_CODE=ZA. Accessed on 25 March 2012.

IEA, 2010. Comparative study on Rural Electrification Policies in Emerging Economies. International Energy Agency: Paris.

IEA. 2011. *Key World Energy Statistics*. International Energy Agency: Paris.

Nordhaus, WD. 2008. *A question of balance: Weighing the options on global warming policies*. Yale University Press: New Haven and London.

Oelsner, H. 2007. Wind energy development: current status and future challenges. South African NEET Workshop. Sandton Convention Centre, 19-26 February, 2007.

South Africa. 1998. *White Paper on the Energy Policy of the Republic of South Africa*. Department of Minerals and Energy: Pretoria.

South Africa. 2003. *Integrated Energy Plan for the Republic of South Africa*. Department of Minerals and Energy: Pretoria.

South Africa. 2007. *Long Term Mitigation Scenarios: Strategic Options for South Africa.* Department of Environmental Affairs and Tourism: Pretoria.

South Africa. 2009a. *Socio-economic impact of electrification: Household perspective, 2009*. Department of Energy: Pretoria.

South Africa. 2009b. [Online] Available at: www.energy.gov.za/files/media/ media_energy_balances.html. Department of Energy: Pretoria.

South Africa. 2011. *Integrated Resource Plan for Electricity. 2010–2030*. Department of Energy: Pretoria.

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

Stern, N. 2006. Stern review: The economics of climate change. Executive Summary: 2006. [Online] Available at: webarchive.nationalarchives.gov.uk/ +/http:/www.hm-treasury.gov.uk/sternreview_index.htm. Accessed on 13 December, 2012.

Szewczuk, S, Prinsloo, E. 2010. Wind atlas for South Africa: Project overview and current status. Proceedings of the Science Real and Relevant Conference 2010, Pretoria.

Thopil, GA, Pouris, A. 2011. Externality valuation in South Africa's coal based electricity generation sector. *Proceedings of Picmet, 2011*. Portland, Oregon: USA.

Tinto, EM, Banda, KG. 2005. The Integrated National Electrification Programme and political democracy. *Journal of Energy in Southern Africa* 16(4).

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

Winkler, H. 2006. *Energy Policies for Sustainable Development in South Africa.* Energy Research Centre: Cape Town.

World Bank, 2011. [Online] Available at: devdata.worldbank.org/AAG/zaf_aag.pdf http://go.worldbank.org/79Z3TW8V90. The World Bank Group.

Chapter 4: Public health impacts

Emissions from power plants can be classified into two categories: air pollutants and greenhouses gases. Though both air pollutants and greenhouse gases are emitted from the same source the effects of either are distinct. Air pollutants are substances that are toxic when present in substantial concentration in the atmosphere, causing a negative impact on human health, soil, vegetation, buildings, water bodies, etc. The effects of air pollutants are on a regional or local scale depending on the size of the source of emission. Greenhouse gases in contrast cause an increase in the temperature of the atmosphere by trapping heat. The effects of such emissions are more global than regional and are discussed in Chapter 5. Examples of air pollutants are sulphur dioxide (SO_2), oxides of nitrogen (NO and NO_2) and particulates (smoke, dust and ash), whereas greenhouse gases are carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), chlorofluorocarbons (CFCs), etc.

This chapter provides an analysis of the major effects on human health in South Africa as a result of the air pollutant emissions caused by the generation of electricity using coal. The analysis performed is based on the ExternE methodology and has taken into account local scenarios and conditions, such as population, meteorological data and pollution inventory. To start off with, the trend in emissions within the country is discussed and put into context. The analysis considers five major health effects (discussed later in the chapter), including mortality and morbidity rates. As mortality effects are a sensitive issue, refined data transfer assumptions could be considered in future valuations. The analysis breaks down the total monetary damage due to individual health effects and evaluates the contribution of each coal-based power plant has on human health.

4.1 Introduction

Eskom has achieved and is consistently trying to achieve reductions in emissions through the use of technologies that enhance the efficiency of electrostatic precipitators. The use of bag filters is one such method. Sulphur dioxide flue gas conditioning, skew flow technology and modern control systems and retrofitting of pulse jet fabric filters are some of the other techniques employed to reduce emissions (Eskom, 2008). Table 4.1 gives an indication of the various technologies used in the various coal power plants.

Table 4.1: Abatement technology in Eskom's coal power plants

Power station	**Abatement technology**
Arnot	Fabric filter plants
Camden	Fabric filter plants
Duvha	Fabric filter plants, electrostatic precipitators and flue gas conditioning
Hendrina	Fabric filter plants
Kendal	Fabric filter plants, electrostatic precipitators and flue gas conditioning
Kriel	Fabric filter plants, electrostatic precipitators and flue gas conditioning
Lethabo	Fabric filter plants, electrostatic precipitators and flue gas conditioning
Majuba	Fabric filter plants
Matimba	Fabric filter plants, electrostatic precipitators and flue gas conditioning
Matla	Fabric filter plants, electrostatic precipitators and flue gas conditioning
Tutuka	Electrostatic precipitators

Eskom's power station emissions are regulated by the Chief Air Pollution Control Officer (CAPCO), who issues registration certificates to regulate maximum allowable limits (Eskom, 2008). The CAPCO falls under the Department of Environmental Affairs (DEA), which was formed from the erstwhile Department of Environmental Affairs and Tourism (DEAT).

Most of Eskom's power plants are located in the Mpumalanga Highveld. The presence of a strong inversion layer tends to have a trapping effect on low level and ground level emissions. The majority of Eskom's power stations - except for the older stations - have chimney heights which surpass the inversion layer (Appendix A). The higher the point where pollutants are emitted from into the atmosphere, the further the possibility of health impacts being concentrated.

The presence of an inversion layer in the Highveld is cause for concern and hence warrants a discussion on the concentration of the primary pollutants discussed above. Eskom has a network of monitoring sites across the country -, with more of these sites in the Highveld region - that conducts ambient quality monitoring and modelling and assesses the levels against DEA's proposed limits and standards.

Initial national air quality standards were described in Schedule 2 of the National Environmental Management: Air Quality Act, 39 of 2004. The erstwhile DEAT went through the process of reviewing and revising the national air quality standards and collaborated with the South African Bureau of Standards (SABS) to facilitate the development of health-based ambient air quality standards. Two separate standards were formulated during this process (SABS, 2011):

- SANS 69 – South African National Standard framework for setting and implementing national ambient air quality standards.

- SANS 1969 – South African National Standard framework ambient air quality and the limits for common pollutants.

Maximum emission limits classified on an annual, daily and hourly basis are set within the national standards. Concentrations of each of the major pollutants are described further. For SO_2, the annual average guideline of 50 µg/m^3 was not exceeded at any of the stations (South Africa, 2009). The maximum average daily guideline of 125 µg/m^3 was exceeded at Kendal monitoring station on two occasions (Eskom, 2008 website), while the hourly maximum average guideline of 350 µg/m^3 was exceeded multiple times.

Pollution levels for oxides of nitrogen were significantly within permissible guideline levels. The average annual level of emission was determined to be approximately 7 µg/m^3, while the permitted annual average guideline was 40 µg/m^3. The hourly maximum average allowance was set at 200 µg/m^3.

The annual average concentration of PM10 emissions was set at 60 µg/m^3 by the SABS and DEA. Eskom's annual mean emission concentration of PM10 was approximately 40 µg/m^3. Meanwhile, the daily mean guideline value of 180 µg/m^3 was exceeded at Camden monitoring station once. A comparison of local and international standards is shown in Appendix B. These standards are important in determining whether the level of emissions occurring is within allowable limits.

4.2 Externality valuation

4.2.1 Identification and prioritisation of impacts

Emissions from atmospheric pollutants associated with electricity generation tend to have varying impacts on multiple areas of the society and environment. Some of the primary impacts that have been identified include the following:

- Effects of atmospheric pollution on human health

- Effects of atmospheric pollution on ecosystems, crops and buildings

Though the effects of atmospheric pollution on ecosystems and buildings are important, the lack of local data causes this impact to be categorised as a non-priority impact. However, human health impact from power station emissions is one of the most emphasised externalities during the process of electricity generation and sufficient local data exists to make informed valuations. Where local data is unavailable international data is relied on to fill in data gaps. Externality valuation of human health impacts are quantified using information along various stages of the impact pathway (Figure 1.1). The various stages of the priority impact pathway are the following:

- Quantification of pollutant emissions from power stations
- Dispersion of pollutants
- Reception of the pollutants by human population
- Response of receptors to the pollutants
- Economic valuation of the receptor response

The major primary pollutants have been identified as SO_2, NO_x and particulate matter (in this case particulates smaller than 10 microns). Table 4.2 describes the type of damages caused by these pollutants.

Table 4.2: Health and environmental impact of air pollutants

Damage / **Pollutant**	**Health**	**Environmental**
SO_2	Causes upper respiratory tract irritation and aggravates existing respiratory diseases	Contributes to acid rain, which causes acidification of water bodies, trees and crops as well as buildings and statues.

Pollutant \ Damage	Health	Environmental
NO_X	Exposure increases the risk to respiratory diseases	Major contributor to acid rain. Causes damage to trees and crops along with buildings and statues.
PM10	Hospitalisation for respiratory or cardiovascular and intensification of respiratory diseases, such as asthma	Wet and dry deposition of particulate matter may cause damage to plants, buildings, etc. and cause contamination to soil and water.

4.2.2 Quantification of burdens: Emission trends

The majority of the high quality coal in South Africa is being exported, while the domestic demand is being met by burning low quality coal. However, there has been a change in this pattern with the demand for quality coal declining, particularly from India (Eskom, 2008). The percentage of coal-fired electricity has consistently been between 91% to 93% since the early 1990s (Eskom, 2011; Van Horen, 1996).

Table 4.3 shows the breakup of electricity produced using different technologies. It can be seen that there is a steady increase in the amount of coal-fired electricity. The marked increase in coal- and gas-based power and a decrease in hydroelectric power in 2008 can be related to the energy and load shedding crisis where unexpected peak demands had to be met. A decrease in nuclear generated power occurred from 2006 until 2008. This is related to the infrastructural issues which occurred at the Koeberg power plant during 2006. However, nuclear output has increased since 2009, but has not reached pre-2006 levels (Eskom, 2011).

Table 4.3: Total electricity output produced by Eskom in GWh

Power output	**2010**	**2008**	**2006**	**2004**	**2002**
Coal-fired	215 940	222 908	206 606	202 171	181 651
Hydroelectric	1 274	751	1 141	720	2 357
Pumped Storage	2 742	2 979	2 867	2 981	1 738
Gas turbine	49	1 153	78	-	-
Nuclear	12 806	11 317	11 293	14 280	11 991
Total	**232 812**	**239 108**	**221 985**	**220 152**	**207 223**

Source: Eskom, 2011.

Eskom is committed to reduce its greenhouse and other gaseous emissions. However, because of pressures to avoid load shedding during the affected period Eskom has been temporarily unable to meet these targets. This was mainly due to an increased quantity of coal burnt and electricity being produced, reduction in average coal calorific value and an overall drop in thermal efficiency of the power stations (Eskom, 2008b).

The average energy, ash and sulphur content are shown in Table 4.4. The average calorific value which indicates the energy contained within a substance is markedly low for the coal used in the South African coal plants. Coal with such low energy content and of such a low grade cannot be used for most commercial and domestic needs and hence use in the production of electricity seems a viable option. Categorisation of coal efficiency shows that the burnt coal is mostly of the lignite or sub-bituminous type. Because the quality of burnt coal is low, emissions tend to be higher.

Table 4.4: Quality of Coal burnt in Eskom plants

Average value of coal quality attributes	**Calorific value %**	**Ash content %**	**Sulphur content %**
	18.51	29.09	0.87

Source: Eskom, 2011.

The emissions comprise of ash and particulates along with sulphurous and nitrous components. A number of emission removal technologies are available to reduce the quantities of these gases before being released into the atmosphere. Clean coal technologies, flue gas desulphurisation and flue gas de-nitrification being among some of these. Flue gas desulphurisation and de-nitrification technologies have yet to be installed in any of Eskom's power plants. However, as a novel departure, flue gas desulphurisation technology is being implemented in the new Medupi and Kusile coal power plant projects (Eskom, 2008).

Eskom's pollution inventory is shown in Table 4.5. It can be seen that there is a relative increase in emissions of SO_2, while other emissions tend to fluctuate. These fluctuations can again be attributed to peak load periods when low calorific value coal has to be burnt to meet demands.

Table 4.5: Eskom pollution statistics in kilotonnes

Pollutant[1]	**2010**	**2008**	**2006**	**2004**	**2002**
SO_2	1856	1950	1763	1779	1494
NO_2	959	984	877	797	702
PM	88.27	50.84	45.76	59.17	57.53

[1]Calculated annual figures based on coal characteristics and power station design parameters, excluding Camden and Grootvlei

Source: Adapted from Eskom, 2008.

Table 4.6 shows the emissions of sulphur dioxide, nitrogen oxide and particulates in 2008 from individual power plants. These calculations were performed for a total power production of 216.654 TWh for the power plants considered (Ross, 2009).

Table 4.6: Emission per power plant for the year 2008[1]

	SO_2 emissions		NOx emissions		Particulate emissions	
	kt	**kg/MWh**	**Kt**	**kg/MWh**	**Kt**	**kg/MWh**
Arnot	83.9	7.19	46.73	4.00	1.8	0.16
Duvha	204.84	9.40	98.53	4.42	4.1	0.19
Hendrina	102.15	8.03	52.35	4.12	1.8	0.15
Kendal	232.66	8.40	114.94	4.15	4.0	0.15
Kriel	105.39	6.04	98.0	5.62	7.3	0.42
Lethabo	244.68	9.57	123.26	4.82	5.65	0.22
Majuba	204.62	7.14	129.64	4.52	2.0	0.07
Matimba	279.3	10.83	65.93	2.56	7.57	0.29
Matla	192.45	8.67	113.46	5.11	7.79	0.35
Tutuka	196.73	8.51	90.74	3.93	10.14	0.44
Total	1846.72	8.52	933.58	4.31	52.15	0.24

[1] Excludes Camden, Grootvlei and Komati as they are operated only if additional load is required

Source: Ross, 2009.

Van Horen (1996, p45) performs a similar analysis for emissions in 1994 (which did not include Majuba as it was still under construction) and the comparisons are interesting. The total SO_2 emission increased from 1166.7 kt in 1994, to 1846.72 kt in 2008, an increase of 58.28%. This can be attributed to the fact that the coal used to generate local electricity is of low calorific value and has high sulphur content. Thus, as more electricity is generated the amount of SO_2 also increases. A better way of depicting SO_2 emissions within perspective is that 10.97 kg is emitted per MWh, while emissions in 1994 were 7.88 kg/MWh.

This represents a 39.21% increase as opposed to the 58.28% increase in total production. NOx emissions decreased from 960.9 kt to 933.58 kt, a decrease of 2.84%, which is marginal. The visible trend however is the decrease in particulate emissions from 122.42 kt in 1994 to 52.15 kt in 2008, a decrease of 57.4%. These can be observed more clearly in Table 4.7. Though the trends show mixed results there is sufficient cause for optimism while further abatement efforts needs to be incorporated to existing technologies.

Table 4.7: Emission comparisons between 1994 and 2008

Pollutant	**kt (kilotonnes)**			**kg/MWh (kilogram/Megawatt-hour)**		
	1994	**2008**	**percentage change**	**1994**	**2008**	**percentage change**
SO_2	1166.7	1846.72	52.28 up	7.88	10.97	39.21 up
NOx	960.9	933.8	2.84 down	6.49	5.45	16.02 down
Particulates	122.42	52.15	57.4 down	0.84	0.31	63.09 down

One other by-product that cannot be ignored is the pollution or emissions that originate from the ash dumps concurrent to the power stations. Approximately 36 million tonnes of ash were produced during the 12-month period, of which 7% was recycled. The recycled ash from Lethabo, Matla, Kedal and Majuba power stations were used in the production of cement (Eskom, 2008). The rest of the ash is disposed in ash dumps and dams and rehabilitated to control rising dust by covering the dumps with grass and other vegetation. Waste water is sprayed on the dumps in situations where the possibility of the ash being blown into the atmosphere occurs.

4.2.3 Quantification of impacts: Riskpoll

The tool (software) used in the analysis is called Riskpoll, a suite of impact assessment programmes designed to estimate health and environmental risks from airborne emissions of pollutants and toxic metals. The impacted receptors include human health, agricultural crops and building materials. Riskpoll gives the option of simplified and detailed analysis models collectively called Uniform World Models, also known as simplified Impact Pathway Analysis (IPA). The Uniform World Model is described in detail in Appendix B.

There are three types of world models categorised on the basis of data requirements within the Riskpoll suite that can be used to analyse human health impacts. These are the following:

- **QUERI,** which assesses the impacts to human health and their associated damage costs due to primary and secondary pollutants. The model uses a semi-empirical approach in which correlations derived from existing IPA studies are used to approximate the impacts.
- **RUWM** (Robust Uniform World Model), which approximates the physical impacts and costs to human health from exposure to primary and secondary species. In contrast to the QUERI model, RUWM uses different simplifying assumptions to the damage function equation. Within the model, local and regional population distributions are assumed to be uniformly distributed throughout the region concerned.
- **URBAN** is used to assess the impacts of human health from emissions caused by a point source near an urban setting, in other words a city or town. Local population data is specified within a 5 km x 5 km^2 spatial resolution or can be approximated using a Gaussian-shaped function.

Table 4.8 illustrates the variances in data requirements between the aforementioned models.

Table 4.8: Comparison of health impact assessment models

Data requirement	QUERI	RUWM	URBAN
Local characteristics			
• Urban or rural location	X	X	Not applicable
• Receptor density	X	X	for urban sites
• Receptor data (5 x 5 km^2)	#	#	X
Regional characteristics			
• Receptor density	X	X	X
Local weather data			
• Mean wind speed		X	X
• Mean ambient temperature		X	X
• Pasquill class distribution		X	X
• Detailed hourly data	X	X	X
Stack data			
• Height	X	X	X
• Exit diameter	X	X	X
• Exhaust gas temperature	X	X	X
• Exhaust gas velocity	X	X	X
• Pollutant emissions	X	X	X
• Pollutant depletion velocity	X	X	X
Exposure functions	X	X	X

Source: Adapted from Spadaro, 2003c.

[#] May be used if available

The model chosen to be used in this analysis was the RUWM due to the availability of improved input data sets compared to the QUERI model. The option of being able to input detailed meteorological data within the RUWM helps in achieving higher accuracy in results as opposed to the QUERI model. RUWM is based on the following assumptions:

- Constant emission rate and depletion velocity of pollutants
- Uniform regional population
- Linear with zero threshold exposure response
- Uniform wind rose distribution
- Mean local meteorological statistics

These assumptions are similar to the Simple Uniform World Model (SUWM), except for the mean meteorological statistics. However, the provision to include population data, power station parameters and weather data makes the RUWM model more accurate than SUWM.

The first step within the process of implementing the RUWM model is to collect emission data of pollutants such as SO_2, NOx and particulates (in this case PM10) for a power plant (Ross, 2009). This data is then coupled with power plant characteristics such as geographical coordinates, stack height and diameter, gas flow and temperature, etc. For this analysis all of Eskom's regular power plants, i.e. all the base load operational plants, are included. Power plants that are operated irregularly, those being Camden, Grootvlei and Komati, were excluded.

Sample hourly meteorological data over the entire 2008 was obtained from weather monitoring stations nearest to the power plants. The data was obtained from both Eskom's own weather monitoring stations and those of the South African Weather Service. Meteorological data consisted of sampled hourly wind direction, wind speed and ambient temperature of conditions located near the power plants.

The format and sample of the meteorological data used is discussed in Appendix B. This data is used to estimate directions and rates of dispersion of the pollutants. The dispersed pollutants affect populations that are both local and remote from the source of emission.

The regional geographic area for the exposed population is considered to be a 500 km radius with the power plant as the source, therefore entirely excluding the Western Cape and Northern Cape and parts of the Eastern Cape and Free State, while the adjacent regions of Mozambique, Zimbabwe, Botswana and the whole of Lesotho and Swaziland fall within the considered radius. The local geographical area being considered will be 100 km x 100 km around the point source (Figure 3.4). The RUWM offers the choice of entering 5 km x 5 km population data over local geographical area from the point source. However, this option is not being used here as the effort is to obtain an aggregated impact from all of South Africa's major coal plants rather than emphasising on one.

The affected population is subjected to the exposure response functions (ERFs), which are correlations relating to the response of a receptor (e.g. number of hospital admissions) to a change in environmental conditions such as an increase in air concentration of a particular pollutant (e.g., PM10). The ERFs, in conjunction with the population characteristics, help in determining the number of cases per health impact. A monetary damage cost is assigned for each case per health impact. Since the ERFs and monetary damage costs are adapted from European studies it is worth describing them in further detail as is done below.

4.2.3.1 Exposure response functions

There have been a limited number of studies in South Africa which have tried to associate environmental quality and health impacts, with the focus on respiratory illness. However, there have been no studies yet that have developed exposure response for exposure to pollutants.

This had led to studies performed in South Africa relying on ERFs developed in other regions of the world (Van Horen, 1996; Scorgie, et al., 2004; Naidoo et al., 2004).

The ERFs were chosen from case studies performed within the ExternE methodology, in this case a hypothetical case study performed in Tunis, Tunisia. The functions were compared to values used in a practical case study performed in Paris and found to be relatively similar. These values were based on epidemiological information followed in the EU (Rabl, 2001).

The Tunis case study seemed a more appropriate study for ERF benchmarking, considering the geographic and population characteristics. Paris on the other hand is a metropolis whose characteristics are very different from the semi-urban South African demographic and geographical make-up. Another reason why the Tunis study seemed a more appropriate choice is the similarity in the socio-economic conditions with South Africa. These socio-economic conditions include income levels, health conditions such as life expectancy, infant mortality, level of nutrition and such and tend to determine how a population (in this case receptor) tends to respond to pollutants. Hence, it seems only logical to base South Africa's case along the lines of a country with similar characteristics.

The ERF slope is obtained by multiplying the IRR (Increased Risk Ratio (% change in risk per µg/m^3)) by the incidence rate for the end point in question (annual cases per receptor at risk – adult, child, etc.) and by the fraction of population affected (% adults in the exposed population).

The following formula describes the methodology based on how the ERFs were calculated (Spadaro, 2003a).

ERFs can be depicted based on the formula:

$$ERF = IRR \times Baseline$$

where,

IRR = Increased Risk ratio in % per µg/m^3

Baseline = Incidence x fpop

where,

Incidence = cases/year.receptor

fpop = fraction of total population affected

The IRR is the % change in the rate of occurrence of a particular disease in the population at risk, relative to the baseline or the nominal rate of occurrence of the same particular disease per unit change in ambient concentration. In numerical terms, an increase of 1µg/m^3 causes a percentage risk change of 0.46 for long-term mortality in the population group above the age of 30, in Europe (Rabl, 2001). In other words an increase in 1 µg/m^3 could decrease the life expectancy of the European population above the age of 30, by 0.46%.

The baseline is the nominal rate of occurrence of a particular disease in annual number of cases per person. As an example, for mortality impacts, the baseline would be the annual mortality rate normalised per person (around 900 deaths per 100 000 persons in Europe).

Five different health impacts were considered in this study:

Respiratory hospital admissions (RHA)

RHA are classified based on the nine codes of the ICD (International Classification of Diseases) (Ji et al., 2011). These include all hospital admissions as a result of asthma and emphysema. Chronic bronchitis falls under this category, but is analysed separately.

Long-term mortality in terms of years of life lost

Long term mortality (LTM) in terms of years of life lost (YOLL) can be described as mortality caused due to a pathogen, agent or pollutant over a longer period of time. The particular timeframe which comprises *long-term* could vary from a few months to years.

Short-term mortality in terms of YOLL)

Short-term mortality (STM) in terms of YOLL can be described as mortality caused due to a pathogen, agent or pollutant over a shorter period of time. This particular time range could vary from immediate death, to loss of life which occurs in a matter of days or weeks.

Chronic bronchitis

Chronic bronchitis (CB) is a type of chronic obstructive pulmonary disease (COPD) that involves a long-term cough with associated mucus. Symptoms include cough accompanied with wheezing, chest pains, fever and fatigue.

Restricted activity days

Restricted activity days (RADs) include all those cases which include loss of productivity as a result of illness, which renders a person unable to work or carry on with normal physical activities.

These health impacts have been investigated in accordance to the primary pollutants SO_2, NO_X and PM10. Table 4.9 depicts the type of health impact that was accounted for a particular type of primary pollutant.

Table 4.9: Pollutant vs. health impact assessment

Impact / Pollutant	RHA	LTM - YOLL	STM - YOLL	CB	RAD
SO_2	X		X		
NO_X	X	X		X	X
PM10	X	X		X	X

Table 4.10 indicates the health impact, population groups, the ERFs for the respective population groups and the study from which they were derived.

Table 4.10: Summary of ERFs

Health impact	Population	Pollutant	ERF	Study
STM – YOLL	All	SO_2	1.290E-06	Sunyer et al., 1997
RHA	All	SO_2	2.840E-06	Ponce de Leon, 1996
LTM – YOLL	Above 30	PM10	9.989E-05	Pope et al., 1995
CB	Above 18	PM10	2.626E-05	Rabl, 2001
RAD	Above 18	PM10	1.715E-02	Rabl, 2001
RHA	All	PM10	2.560E-06	Rabl, 2001
LTM – YOLL	Above 30	NO_x	9.899E-05	Rabl, 2001
CB	Above 18	NO_x	2.620E-05	Rabl, 2001
RAD	Above 18	NO_x	1.715E-05	Rabl, 2001
RHA	All	NO_x	2.560E-06	Rabl, 2001

The response functions can be interpreted by considering an example from the table above. Considering the case of STM – YOLL, the response function of 2.84 x 10^{-6} depicts that one person in 2.84 million people will die due to a 1 ugm^{-3} increase in SO_2 concentration. In other words, if a population of 50 million people was exposed to a 1 ugm^{-3} increase it would lead to approximately 18 deaths.

It can be seen that most response functions have been adapted from Rabl's analysis, which is an integral part of the ExternE IPA methodology. The Air Pollution and Health: A European Approach (APHEA) project was a study performed in Europe to investigate the short-term effects of air pollution and was an initial process that formed part of the ExternE methodology (Sunyer et al., 1997). The study conducted by Ponce de Leon et al., was an investigation performed in London. The response functions within the study were incorporated into the ExternE suite of studies.

These ERFs were adapted for South Africa by considering the fraction of population exposed for each health impact. The analysis of long-term and short-term mortality is based on the YOLL valuation. This would mean that the impact of both long-term and short-term mortality would be measured in terms of YOLL because of death. The YOLL valuation tends to place a value on the number of years lost with respect to an average lifespan. In this case the valuation for short-term and long-term mortality is 0.75 and 11.2 years respectively. The YOLL approach is much more accurate in epidemiological studies where life is valued, as it prevents monetary over-estimation of a lost life (Kühn 1998, European Commission 1999).

4.2.3.2 Monetary cost units

The choice of monetary unit costs is again based on those used in Riskpoll. To transfer unit costs that are based in US dollars for the European Union (EU) and to convert it to the appropriate country this formula (Spadaro, 2003b) is used:

Unit cost in COUNTRY = Unit Cost in EU x $(PPPGNP_{COUNTRY} / PPPGNP_{EU})^{Y}$

In this case the COUNTRY being South Africa.

PPPGNP stands for Purchasing Power Parity Gross National Product, normalised per capita and *Y* is the income elasticity coefficient between the country being evaluated and the EU, typical values ranging from 0.3 to 1.0. A value less than 1 for *Y* would indicate that an individual in South Africa would be willing to spend a larger percentage of his or her personal income on treatment or health care, than a person living in the EU. This certainly would not be the case considering the average person's economic status in South Africa. Thus the value of 1 seems the most practical choice for the income elasticity coefficient in this event.

The values being used here takes into consideration PPPGDP of SA in 2008 as US$10 427 and that of the EU in 2008 as US$31 932 (World Bank, 2012). This ratio is then multiplied by the unit cost in EU to obtain the unit cost in South Africa in terms of US$, which then gets multiplied by the PPP exchange rate of 1$=4.44 Rand in 2008 terms to obtain the unit cost in ZAR (Appendix A). The monetary costs for the treatment of a single case of the health impacts investigated in this study are summarised in Table 4.11.

Table 4.11: Monetary cost of health impact

Health impact	Monetary cost (Rand)
CB	276 608
RHA	7 066
RAD	180
LTM	157 129
STM	270 706

Chronic bronchitis is shown to have the highest monetary cost. This is because of the coupling effect of treatment costs and income lost during period of inactivity (disability). This leads to the question as to why long-term and short-term mortality is valued lower. Long-term and short-term mortality value a loss in life expectancy and do not include any treatment cost.

4.2.4 Economic valuation

Riskpoll was set up for RUWM and run separately for each power plant. The power plant characteristics, along with emission data, were coupled with the meteorological data from the weather station nearest to the power plant. The ERFs and monetary cost units are the same for each power plant. Riskpoll calculates the damages per health impact for each power plant. The aggregated damage (of all ten plants) for each health impact is shown in Table 4.12 (individual damages are shown in Appendix B).

Table 4.12: Total health impacts damages occurring from power station emissions

Health aspect	Units	Impact		
		Low	**Central**	**High**
CB	Cases in person (affected people)	1 928	5 784	17 352
RHA	Cases in person (affected people)	645	1 936	5808
RAD	Cases in days (productivity lost)	1 258 867	3 776 418	11 329 980
LTM	Number of years (shortened life)	351	1 406	5 623
STM	Number of years (shortened life)	104	623	3 742

The number of years lost in terms of mortality both long and short-term can be translated back into cases/year by dividing the damages by 11.2 and 0.75 years respectively, which would amount to 125 long-term, and 830 short-term mortalities. These numbers seem to be overestimated because of the ERFs transfer from the European background based on larger population concentrations and higher health standards in Europe.

Short-term mortalities are caused by SO_2 emission and are not coupled with any other pollutant. Even if short-term mortalities were reduced by a scaling factor of 0.5 to account for uncertainties through the pathway, the number of cases is still high. This provides enough reason to believe that SO_2 emissions need to be prioritised and monitored by the electricity utility, Eskom. Emissions cannot go unchecked for long and once checked need to be reduced. However, the largest uncertainty was expected to be in the estimation of mortalities and has proved to be the case.

The central estimate of damage cost is calculated by multiplying the impact with the monetary cost and is shown in Table 4.13. The central estimate in turn is used to calculate the low and high estimates. The damage function is a product function characterised by a lognormal distribution (Rabl and Spadaro, 1999). The low and central estimates can also be called confidence intervals of the central estimate. The intervals used here are based on a 68% confidence interval, where the low and high estimates are shown as:

68% confidence interval = [central estimate/ $sigma_G$, central estimate x $sigma_G$]

where, $sigma_G$ is the geometric standard deviation. The $sigma_G$ values used in the study are also summarised in table 4.13.

Table 4.13: Damage cost contribution of individual health aspect

Health Aspect	**Damage Cost in Million Rand**			**$sigma_G$**
	Low estimate	**Central estimate**	**High estimate**	
CB	533.33	1 600	4741.2	3
RHA	4.56	13.68	41.04	3
RAD	226	677.8	2 033.4	3
LTM	55.24	220.9	883.6	4
STM	28.13	168.8	1013	6

It can be seen that the largest central damage cost is for long- and short-term mortality respectively. This is as expected since the impact and monetary costs combined are greatest for the mortality health impact. The larger uncertainty involved with mortality valuation further pushes up the high estimate.

The contribution of damage costs for each pollutant is shown in Table 4.14. It can be observed that the central costs are highest for NO_X and least for SO_2. This can be attributed to the fact that the number of health aspects investigated for SO_2 is fewer than NO_X (Table 4.9).

Table 4.14: Total damage cost contribution of pollutant

Pollutant	Total damage cost in million Rand		
	Low estimate	**Central estimate**	**High estimate**
SO_2	31.36	178.5	1 042
NO_X	713	2 140	6 349
PM10	104	364.9	1 321

Damage costs are also interpreted per unit of pollutant as shown in Table 4.15. The damage has been seen to be least associated with $SO_{2,}$ while the most damage per unit pollutant has been observed for PM10, though the total emission of PM10 is lowest (from Table 4.6). Though total damages associated are highest for $NO_{X,}$ the damage per unit pollutant is considerably lesser than PM10. This leads to the observation that PM10 causes most damage per unit, while NO_X does so in absolute terms.

Table 4.15: Damage cost contribution per unit pollutant

Pollutant	Damage cost per kilogram in Rand		
	Low estimate	Central estimate	High estimate
SO_2	0.0017	0.096	0.564
NO_X	0.763	0.23	6.8
PM10	1.98	6.96	25.2

Table 4.16 shows the breakdown of total damage costs for all health effects in terms of individual power plants.

Table 4.16: Damage cost contribution of individual power plant

	Low estimate		Central estimate		High estimate	
	R millions	[1]Mills/kWh	R millions	Mills/kWh	R millions	Mills/kWh
Arnot	41.05	3.52	129.2	11.07	419.9	35.96
Duvha	86.87	3.98	274.2	12.58	896	41.10
Hendrina	45.72	3.59	144.2	11.34	471.1	47.04
Kendal	99.57	3.59	313.5	11.32	1021	46.86
Kriel	91.33	5.23	286.8	16.43	920	52.77
Lethabo	109.9	4.29	347.6	13.59	1 137	44.45
Majuba	106.2	3.70	329.9	11.51	1 053	36.75
Matimba	69.1	2.67	227	8.8	784	30.40
Matla	105.2	4.74	332.7	14.99	1 083	48.97
Tutuka	93.08	3.99	295.9	12.81	990.4	42.86
Total/production	847.1	3.90	2681	12.37	8 770.4	40.5

[1]1Mill = 0,1 cent = 0,001Rand

4.3 Discussion and uncertainty

It can be seen that the Lethabo power plant causes the largest damage cost in total terms, while Kriel has the most impact in mills per kWh (see footnote of Table 4.16). The damages in mills per kWh are calculated by dividing the damages of each power plant by the amount of electricity produced by each plant. The least total damages are from the Arnot power plant, whereas the cleanest electricity (lowest mills per kWh) is produced by the Matimba power station. It is worth noting that the low and high estimates are aggregates of all the health impacts for each power plant, and not a direct factor of $sigma_G$.

The impact on human health associated with electricity generation is among the prioritised impacts in the ExternE study. The estimation of health impacts for electricity generation in South Africa is based mainly on the availability of data from the local electricity utility. The uncertainty associated with quantification occurs during transfer of European ERFs and monetary values. However, conversion of European monetary values to local values is performed using PPP rates, which are also subject to uncertainty.

4.4 References

Eskom. 2008. *Annual Report 2008*. Eskom: Sandton.

Eskom. 2008b. *Annual Abridged Report 2008*. Eskom: Sandton.

Eskom. 2011. *Annual Report 2011*. Eskom: Sandton.

European Commission (EC). 1999. *ExternE: Externalities of Energy*, Vol. 1–6. Office for Official Publications of the European Communities: Luxembourg.

Ji M, Cohan, DS, Bell, ML. 2011. Meta-analysis of the association between short-term exposure to ambient ozone and respiratory hospital admissions. *Environmental Research Letters, 2011* 6(2).

Kühn, I. 1998. The potential role of external costs on liberalised energy markets. Paper Presented at the Fourth IAEE/GEE Conference in Berlin, September 9, 1998.

Naidoo, RN, Robins, TG, Solomon, A, White, N, Franzblau, A. 2004. Radiographic outcomes among South African coal miners. *International Archive of Occupational Environmental Health* 77:471–481.

Ponce de Leon, A, Anderson, HR, Bland, JM, Strachan, DP, Bower, J. 1996. Effects of air pollution on daily hospital admissions for respiratory disease in London between 1987-88 and 1999-92. *Journal of Epidemiology Community Health* 50 Suppl 1: 63–70.

Pope, CA, III, Thun, MJ, Namboodiri, MM, Dockery, DW, Evans, JS, Speizer, FE, 1995. Particulate air pollution as a predictor of mortality in a prospective study of US adults. *American Journal of Respiratory Critical Care Medicine*151:669–674.

Rabl, A, Spadaro, JV. 1999. Environmental damages and costs: An analysis of uncertainties. *Environmental International* 25(1):29–46.

Rabl, A, Leksell, L. 2001. Air pollution and mortality: Quantification and valuation of years of life lost. *Risk Analysis* 21(5):843–857.

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

Ross, K., 2009. Personal communication. Eskom Megawatt Park, Sandton.

SABS, 2011. South African Bureau of Standards: *South African National Standard – Ambient Air Quality – Limits for common Pollutants.* SABS, Pretoria.

Scorgie, Y, Paterson, G, Burger, LW, Annegran, HJ, Kneen, M. 2004. Study to examine the potential socio-economic impact of measures to reduce air pollution from combustion. Task 4a supplementary report: Quantification of health risks and associated costs due to fuel burning source groups. Report compiled on behalf of NEDLAC.

South Africa, 2009. National Ambient Air Quality Standards. Government Gazette for the Department of Environment Affairs. Pretoria.

Spadaro, JV. 2003a. Exposure response functions – Riskpoll (version 1.04).

Spadaro, JV. 2003b. Monetary values – Riskpoll (version 1.04).

Spadaro, JV. 2003c. Input data requirements – Riskpoll (version 1.04)

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

Sunyer, J, Spix, C, Quénel, P, Ponce-de-León, A, Pönka, A, Barumandzadeh, T, Touloumi, G, Bacharova, L, Wojtyniak, B, Vonk, J, Bisanti, L, Schwartz, J, Katsouyann, K. 1997. Urban air pollution and emergency admissions for asthma in four European cities: The APHEA project. *Journal of Thorax* 72:760–765.

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

World Bank. 2012. International Comparison Programme Database. [Online] Available at: data.worldbank.org/indicator/NY.GDP.PCAP.PP.CD. Accessed in January 2012.

Chapter 5: Environmental impacts

Having covered the vital externality of public health impacts, other important externalities that are quantified and evaluated are addressed in this chapter. The chapter is divided into two parts. The much debated topic of greenhouse gas emission is discussed and evaluated within the initial part. The second part discusses the topic of water usage within electricity generation. Though water usage is not considered an associated externality in most other international studies, it is in this case, because water is a scarce resource in South Africa. The scarcity of water on a local and regional level causes consideration of water usage to be analysed.

5.1 Greenhouse gas emissions

5.1.1 Introduction

Carbon dioxide emissions have been a major point of discussion over the past couple of decades at every major climate change forum, particularly the United Nations climate change conferences and meetings. Emissions of carbon dioxide from electricity production are categorised into greenhouse gas (GHG) emissions because of their impact on global warming. Some of the primary sources of GHGs are water vapour, carbon dioxide, methane and ozone, with other important contributors being chlorofluorocarbons (CFCs) and hydroflurocarbons (HFCs) (IPCC, 2007a). The global warming potential (GWP) or impact of GHGs is also stated as an equivalent of CO_2 and denoted as CO_2e. Alternatively, the impact of methane and other GHGs on global warming can be denoted as an equivalent of CO_2, thereby enabling the representation of emissions in CO_2e. As an example, a unit of CO_2 has a GWP potential of 1, whereas a unit of methane has a GWP potential of 25, which means that one tonne of methane emissions is equivalent to 25 CO_2e (EPA, 2012).

All major GHGs are produced naturally as well as artificially. When animals exhale, CO_2 is generated.

Animals exhaling tend to be a natural phenomenon, whereas burning fossil fuels, which produce CO_2, is an unnatural occurrence or man-made phenomenon. Though all GHGs are significant, emissions of CO_2 are prioritised higher because of the larger amount of relative emission compared to other GHG gases.

South Africa is the 12th largest emitter of CO_2 globally and has a per capita intensity of almost 10 tonnes/person (EIA, 2012).

Table 5.1: Country comparison of CO_2 emissions for 2008

Country	**CO_2 emissions (million metric tonnes)**	**Global impact (percentage)**	**Continental impact (percentage)**	**Per capita impact (tonne/person)**
USA	5 835.37	19.24	84.69	19.18
Canada	600.04	1.97	8.7	18.06
North America	6 889.69	22.72	-	15.39
China	6 721.43	22.16	54.87	5.10
India	1 474.19	4.86	12.03	1.29
Australia	412.87	1.36	3.37	19.66
Asia/Oceania	12 247.76	40.39	-	3.28
South Africa	**486.49**	**1.6**	**42.01**	**9.97**
Egypt	183.05	0.6	15.80	2.36
Africa	1 158.04	3.81	-	1.18
Germany	823.06	2.71	12.09	10.02
UK	563.86	1.85	8.29	9.14
Russia	1 630.98	5.38	23.97	11.45

Country	CO_2 emissions (million metric tonnes)	Global impact (percentage)	Continental impact (percentage)	Per capita impact (tonne/person)
Europe and Eurasia	6 803.37	22.44	-	7.65
World	30 318.09	-	-	4.57

Source: EIA, 2012.

Table 5.1 shows that South Africa's global emissions are 1.6% of the total share although on the continental scale, emissions are 42.01%. These percentages tend to distort the actual impact of CO_2 emissions from the country because of the dissimilarity in industrial development between South Africa and the rest of Africa. A different perspective is provided by the CO_2 intensity or emission per person. It can be seen that South Africa's emission intensity is in the same range as countries such as Germany, UK and Russia. As can be expected sectorial breakdown of CO_2 emissions within the energy sector shows that the majority of emissions is caused by burning coal.

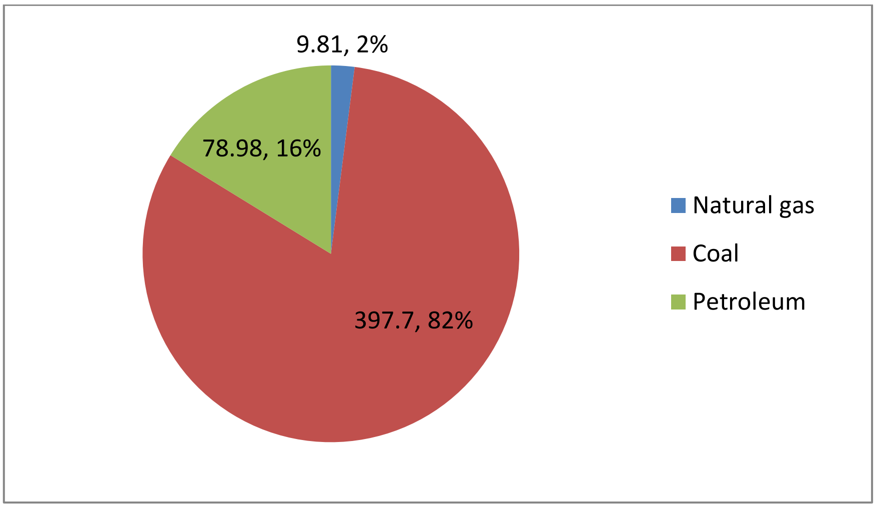


Figure 5.1: Sectorial CO_2 emissions in the energy sector in million metric tonnes (2008 data)

Source: EIA, 2012.

The power sector relies heavily on coal and the bulk of coal is burned in this sector. Metal production is also coal-intensive, because of the furnaces that use coal as their primary fuel (Deverajan, et al., 2009). Industries and sectors that are heavily carbon-intensive need to be monitored and directed towards less carbon-centric alternatives. The Carbon Disclosure Project (CDP), which requires companies to disclose their carbon emissions, was extended to South Africa in 2007 to include the top 40 companies listed on the Johannesburg Stock Exchange (CDP, 2007). The CDP has the following primary objectives (CDP, 2008):

- To identify strategic risks and opportunities and their implication
- To determine actual absolute GHG emissions
- To determine performance against targets and plans to reduce GHG emissions
- To determine responsibility and management approach to climate change
- To estimate scope 1 and scope 2 emissions based on business

Eskom has voluntarily agreed to participate in the CPD project even though the organisation is not listed on the stock exchange. This is a vital step considering Eskom's significance in the energy sector and its contribution to the GHG emissions in the country. Some of the major contributors of both scope 1 and scope 2 emissions for 2009 are listed in Table 5.2, with an updated table for 2012 presented in Appendix C. Detailed scope 1 and scope 2 disclosures of emissions were not available in 2008, therefore 2009 data is presented.

Table 5.2: Disclosed CO2e emission estimates for 2009, based on CDP Report, 2009

Company	**Scope 1* tCO_2e**	**Scope 2** tCO_2e**
Eskom	221 700 000	0
Sasol	62 966 000	9 714 000
BHP Billiton	23 093 870	28 798 955

Company	Scope 1* tCO_2e	Scope 2** tCO_2e
Arcelor Mittal	12 420 730	3 756 528
Anglo American	9 620 000	10, 177 000
Portland Pretoria Cement	5 453 949	558 110
Sappi	5 198 854	1 755 190
Mondi	4 435 000	1 568 000
SAB Miller	1 513 037	830 147
AngloGold Ashanti	1 414 817	4 527 119
Gold Fields	1 143 188	3 464 083
Anglo Platinum	493 312	4 993 136
Harmony Gold Mining Company	83 584	4 143 503

*Source 1 emissions are GHG emissions occurring directly from sources owned by the company or organisation. Examples: CO_2, SF_4
**Source 2 emissions are indirect GHG emissions associated with the generation of purchased electricity consumed by the company or organisation. Scope 2 emissions physically occur at the facility where the electricity is generated. Examples: CH_4, N_2O

From an aggregated total of 434 million tonnes of CO_2e, Eskom contributes more than 50% and Sasol approximately 14% of the total industrial, as well as national emissions.

5.1.2 Externality valuation

5.1.2.1 Identification and prioritisation of impacts

As per the Stern Review (2006), the current level of concentration of GHG emissions is around 430 ppm (of CO_2e) compared to pre-industrial levels of 280 ppm. Stern states that if the rate of emission was to hold steady, concentration levels could reach 550 ppm, double the pre-industrial levels, by 2050. However, because emission rates are increasing, these levels could be reached as early as 2035 causing average temperatures to increase by 2^{o} C. The impacts of such events could cause significant damage on a local and regional scale (National Treasury, 2010):

- South Africa and similar developing countries could be susceptible to the effects based on its reliance on sectors such as agriculture, fishing and mining.
- An increase in temperature of 3 to 4^{o} C could lead to a 15% decline in African crop yields, causing severe food shortage in an already volatile sub-Sahara Africa.
- A rise in temperatures could cause prevalence of contagious diseases such as malaria to increase.
- Extreme weather patterns could cause large scale weather phenomenon causing population displacement.

Emissions from electricity generation in South Africa almost entirely originate from Eskom's power plants, thus the focus from here on will be on its GHG emissions. As per Eskom's 2009 Annual Report, GHG emissions for 2008 were 223.57 Mt of CO_2 and 957 kt of N_2O. Eskom does not disclose methane emissions occurring during coal mining from open cast and underground mines. Methane emissions will be estimated in the following section, along with an analysis of CO_2 power plant emission.

5.1.2.2 Quantification of impacts: Eskom's GHG emissions

CO_2 emissions

During 2008, Eskom generated a total of 222 908 GWh from its coal-fired power stations resulting in an emission of 223,6 Mt of CO_2 (Eskom, 2009). Of the total generated electricity for 2008, emission profile is considered only for the base load power plants with the only peak load plant, Camden, being excluded. The emission profile for ten of Eskom's peak load power plants is shown in the figure below.

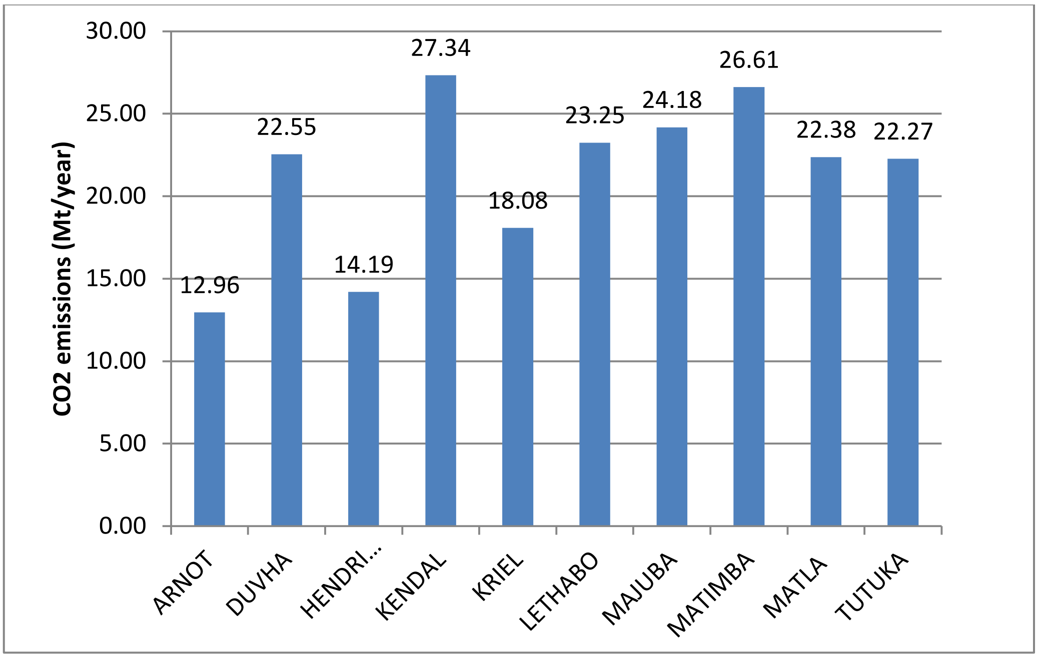


Figure 5.2: CO_2 emission profile of Eskom's peak load plants

Source: Kristy, 2011.

The efficiency of a power plant is better depicted using the emission intensity (emission per unit of electricity generated). Figure 5.3 shows the intensity by dividing the total emission from each power plant by the amount of electricity generated for each power plant which is presented in Appendix A.

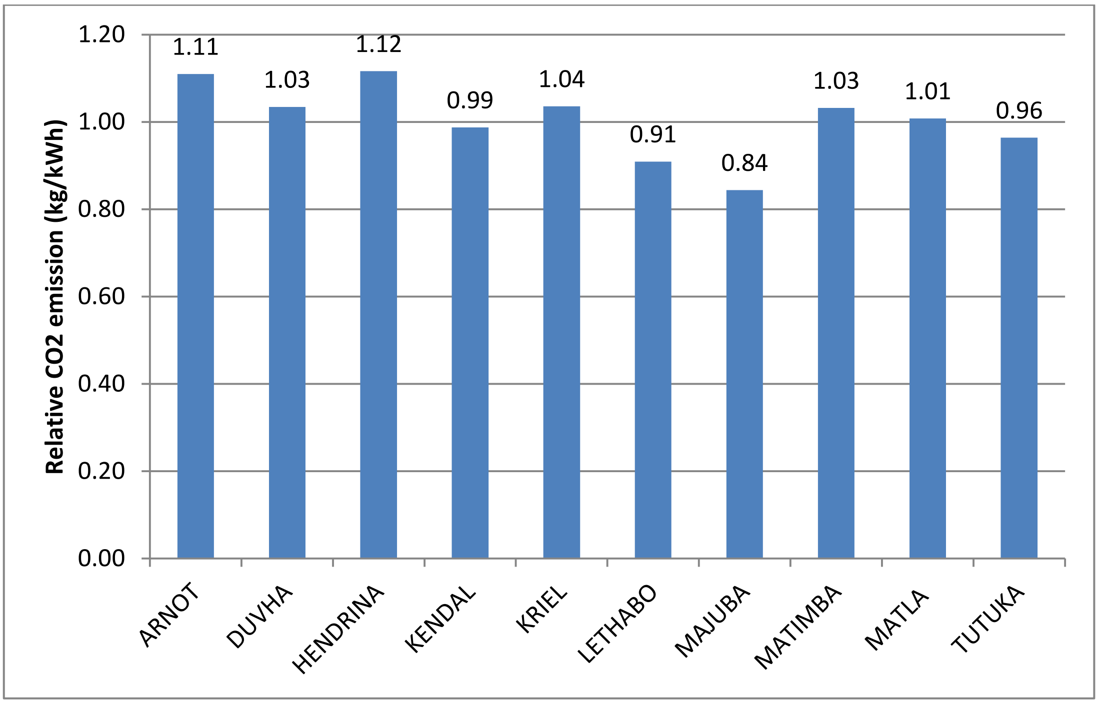


Figure 5.3: CO_2 emission intensity of Eskom's peak load plants

It can be seen that while Eskom's older power plants (Arnot, Hendrina, Kriel, built during the 1970s) have higher emission intensities, the more recent power plants (Kendal, Lethabo, Tutuka, commissioned during the early 1990s) have lower emission intensities. Majuba, the newest power plant, has the least emission intensity.

Eskom's other GHG emissions are mainly N_2O and methane, of which N_2O is accounted for in the annual report. A total of 2 872 tonnes of N_2O was emitted during 2008 (Eskom, 2009). There are no official reports of methane emission from the mining of coal used to generate electricity, therefore an effort to achieve a theoretical estimate is performed.

Methane emissions

There are no official estimates of methane emissions from Eskom's power plants or resultant operations. Emissions of methane during the process of electricity generation occur when coal is mined for the production of electricity. South Africa, the fifth largest producer of coal, produces approximately 250 Mt of coal of which approximately 50% is used for electricity generation (Eskom, 2009). During 2008, 125.3 Mt of coal was burnt in Eskom's power plants. Coal is mined from two types of mines, namely underground and opencast mines. About 51% (63.9 Mt) of the coal mining is performed underground and the remainder (61.4 Mt) from open cast methods (Department of Energy, 2012).

A number of studies have been performed to estimate emission factors for methane from coal mining. Zhou, et. al. (2009) attempts to develop country specific emission factors for South Africa based on IPCC best practices (IPCC, 2006), but falls back on the observational sample study performed by Cook and Lloyd (2005) for methane emissions. Cook's (2005) study provides models which can be used to estimates methane emissions if the quantity of mined coal is known. Cook presents simplified models (with detailed models shown in Appendix C) based on IPCC's Tier 2 approach for both underground and open cast methane emissions, which are described as follows:

Underground methane emissions (m^3) = (1.11 ± 0.26) * sgc * tonnes

Opencast methane emissions (m^3) = ± 0.012 * sgc * tonnes

where,

tonnes = quantity of coal mined

sgc = seam gas content, volume of methane contained in a tonne of coal

The constants 0.26 and 0.012 are correction factors used to account for worst case and best case emission scenarios. In this case because prior estimates are absent these correction factors are approximated to be zero in order to provide central estimates of methane emissions which lead to the formulae:

Underground methane emission (m^3) = 1.11 * sgc * tonnes

Opencast methane emission (m^3) = sgc * tonnes

The sgc's for underground and opencast coal is 0.63 and 0.014m^3/tonne respectively (Cook, 2005). For a production of 63.9 Mt and 61.4 Mt from underground and open cast mining respectively, the methane emissions can be calculated as 28 906.7 tonnes and 617.48 tonnes, which totals to 29 524.18 tonnes. These calculations are achieved with a density of 0,718 kg/m^3 for methane (Appendix C).

Aggregated GHG emissions from non-renewable electricity generation

The major GHG emissions that occur directly from electricity generation are CO_2, N_2O and methane. Though N_2O and methane emissions are significantly lower than CO_2 emissions, the effects on global warming are diverse. GWP indices state the effect of GHGs in equivalent CO_2 terms. Table 5.3 shows the aggregated total of major GHGs produced in South Africa during electricity generation in CO_2e terms.

Table 5.3: Aggregated GHG emission from electricity generation

GHG	Emission in tonne	GWP[1]	CO_2 equivalent
CO_2	223 600 000	1	223 600 000
N_2O	2 801	298	834 698
Methane	29 524	25	738 100
Total	223 632 325		225 172 798

[1]Based on IPCC (2007a) for a 100-year period.

It can be noticed that even after taking into account GWP equivalencies of other gases, the contribution of CO_2 emissions is significant comparatively. These aggregated emissions amount to levels that require policies to be implemented to curb emissions using the method of taxes with the aim of gradually reducing emissions.

5.1.2.3 Quantification of burdens: Carbon tax

Countries such as Germany and UK are categorised as developed (Annex 1) countries under the Kyoto protocol and had ratified the protocol with pledges to reduce emissions by 8% (UN, 1998). South Africa, with the same level of CO_2 per capita emission (Table 5.1), is categorised as a developing country with no binding targets even though cutting down GHG emissions caused through human action (both industrial and domestic) has become a global priority.

However, more recently South Africa as a nation has been involved in formulating policies with the intention of reducing CO_2 emissions by hosting the 17th edition of the Conference of Parties (COP 17) in 2011. The LTMS and IRP policy mentioned in Chapter 1 cites scenarios and formulates plans to shift South Africa towards a less carbon intensive and energy efficient society within the next 40 years. In 2011 the White Paper for the National Climate Change Response was published, stating South Africa's commitment towards a sustainable and environmentally friendly future (South Africa, 2011). The primary objectives of the policy are to (ibid, 11):

- Effectively manage inevitable climate change impacts through interventions that build and sustain South Africa's social, economic and environmental resilience and emergency response capacity
- Make a fair contribution to the global effort to stabilise GHG emissions in the atmosphere at a level that minimises interference with the climate system in a manner that allows social, economic and environmental development to proceed in a sustainable manner

The basis for the White Paper was laid when National Treasury introduced a discussion on carbon tax options to reduce GHGs (National Treasury, 2010). The discussion paper states two optional policy mechanisms to reduce GHG emissions, those being carbon taxation and emission trading schemes. The mechanism of carbon taxation has been prevalent since the early 1990s and was first tested by the Scandinavian countries, with Finland leading the field in 1990 and other European countries following suit (Anderson, 1998). The emission trading mechanism has been favoured in the US primarily because the mechanism enables energy inefficient economies to buy permits from more efficient economies, thereby avoiding domestic reductions. The primary difference between carbon taxes and carbon (emission) trading is that carbon taxes increase the price of a commodity, causing a decrease in demand, whereas carbon trading keeps the quantity of the commodity constant with a variable price. Table 5.4 shows the major differences between carbon taxes and carbon trading.

Table 5.4: Differences between policy mechanisms to reduce GHGs

Carbon taxes	**Carbon trading**
Price-based policy mechanism: Increase price of fuel causing emissions to decrease based on consumption	Quantity-based policy mechanism: Emission levels are fixed causing emission levels to decrease to meet fixed limits

Carbon taxes	**Carbon trading**
Taxes are paid to the government based on consumption of fuels that are consumed within the economy	Caps or limits are divided into transferrable units called quotas, which are priced and is tradable among participators within the system
Allows for collective focus on decrease in domestic emissions among all sectors, including consumption on household level within the domestic economy	Allows for trade internationally among private cross border entities (companies and countries), creating a market for private trade
Taxes are resistant to activities by large energy corporates, which could increase or decrease general energy flow within the system	Permit pricing allows for adjustment in inflation and external price shocks, whereas taxes do not have the pricing flexibility to cater for external shocks
Taxes can be recycled back into the economy creating scope for improvement in other sectors	Permits can generate revenue only if units are auctioned and not just traded

Source: Adapted from Baumert, 2012.

The benefit or reasoning behind carbon tax being the more favoured fiscal instrument in developing countries as opposed to an emission trading scheme is primarily because of the domestic impact carbon taxes have on all sectors of the society in general, and also because carbon taxes provides more domestic regulation. Developing countries also oppose the idea of emission limitations, which are the basis of emission trading, curbing the development in many developing economies. For such reasons South Africa has chosen the path of carbon taxes as the favourable policy instrument for the future (Energy Research Centre, 2007). The Stern Review also proposes the implementation of a carbon tax in order for GHG concentration levels to stabilise by mid-century.

A review of multiple studies provides varied proposed carbon tax estimates which are tabulated below.

Table 5.5: Carbon tax estimates from multiple studies

Study	**Estimated CO_2e tax per tonne (high estimate)**	**Emission reduction path (25 to 30% globally unless stated)**
Stern (2006)	US$30	Stabilisation of CO_2e at 550 ppm by 2050
Nordhaus (2008)	US$8	Stabilisation of CO_2e at 550 ppm by 2050
IPCC (2007b)	US$80 by 2030 US$155 by 2050	Stabilisation of CO_2e at 550 ppm by 2050
	US$65 by 2030 US$130 by 2050	Stabilisation of CO_2e at 550 ppm, taking into account induced technological changes
EU (2005)	€20 in current terms	Achieving Kyoto targets set for EU states (8 % reduction by 2012)
Energy Research Centre (2007)	R100 by 2008 R250 by 2020-2040 R750 by 2040-2050	Reduction of national emissions by 30 - 40% from 2003 levels by 2050

A wide range of carbon tax values has been advocated in theory in numerous studies over the span of two decades (Tol, 2005). For the current analysis, carbon tax values used in the ExternE study are used to evaluate the marginal cost created due to emissions from electricity generation and compared with values recommended by the LTMS. During the 2008 annual budget speech, the erstwhile Minister of Finance, Mr Trevor Manuel, announced an environmental levy of 2c per kWh on electricity generated through non-renewable means for the year 2008 and onwards (South Africa, 2008). The implementation of the proposed levy was postponed and implemented during the 2009 fiscal year. The electricity levy was seen as a significant first step towards more inclusive carbon taxation policies.

5.1.2.4 Economic valuation

Since the valuation of air pollutants was based on the ExternE methodology, GHG emissions are also analysed based on the same study. The updated methodology of the ExternE study uses a valuation of €33/tonne of carbon or approximately €9/tonne of CO_2e[8] for a medium discount rate based on damage cost analysis. The recommended range for damage costs valuations to achieve Kyoto targets is based between a range of €5 to €20/tonne of CO_2e (EU, 2005, p197). The ExternE study also mentions price fluctuations in the valuations of permits during 2005, which varied from €18 to €24/tonnes of CO_2e. A value of €19/tonne of CO_2e is chosen as an appropriate central value, with €9 the lower bound. For achieving EU targets of limiting global temperatures to 2^{o}C above pre-industrial levels, or a concentration of 550 ppm of CO_2e, a cost of €95/tonne of CO_2e might be required. However, this does not seem a feasible value for society and a value of €50/tonne is recommended as the upper bound (ibid, p197).

Based on the discussion, the damage cost for a tonne of CO_2e with lower, middle and upper bounds are chosen as €9, €19 and €50 respectively. These values are converted to local values using a PPP exchange rate for 2008, between the Euro and the South African Rand (ZAR) as shown in Appendix A. The PPP exchange rate is considered for the same reasons mentioned during the valuation of human health (Chapter 3). 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 ZAR) within the local economy. Therefore, the price of one tonne in ZAR with lower, middle and upper estimates is R50, R113 and R296, respectively. It can be observed that these estimates are in line with the abatement costs recommended within the LTMS. Based on the aggregated GHG emissions from Table 5.3, the total cost of CO_2e can be estimated as shown in the table below.

[8] Since the molecular weight ratio of CO_2 to carbon is 44/12 (3.66), the abatement cost of a tonne of carbon is 3,67 times the cost of a tonne of CO_2

Table 5.6: Estimated damage cost of aggregated GHGs in million ZAR

	Low estimate	Central estimate	High estimate
Total value (Rm)	11 258.6	25 444.5	66 651.8
Per unit (mills/kWh)	51.96	117.44	307.64

The per unit damage cost is achieved from dividing total damage costs by total production from coal plants. The central estimate of 11c/kWh is significant with respect to current electricity prices. A breakdown of damage costs associated with each power plant is shown in Table 5.7.

Table 5.7: Damage cost estimate per individual power plant[1]

	Low estimate		Central estimate		High estimate	
	R millions	Mills/kWh	R millions	Mills/kWh	R millions	Mills/kWh
Arnot	697.7	59.77	1 576.9	135.07	4 130.79	353.82
Duvha	1 177.3	54.01	2 660.8	122.07	6 969.88	319.75
Hendrina	759.6	59.73	1 716.8	134.99	4 497.09	353.6
Kendal	1 416.7	51.16	3 201.9	115.63	8 387.82	302.89
Kriel	953.8	54.65	2 155.6	123.51	5 646.42	323.54
Lethabo	1 212.6	47.42	2 740.4	107.16	7 178.37	280.71
Majuba	1 259.1	43.94	2 845.6	99.31	7 454.11	260.13
Matimba	1 380.6	53.52	3 120.2	120.95	8 173.33	316.82
Matla	1 168.7	52.65	2 641.4	118.99	6 919.16	311.69
Tutuka	1 163.4	50.35	2 629.3	113.8	6 887.27	298.09
Total/ production	11 189.2	51.65	25 289	116.72	6 6243.77	305.75

[1]Does not include N_2O and methane costs

5.1.3 Discussion and uncertainty

The total damages are marginally less than the total aggregated damages (in Table 5.6), since only CO_2 costs can be broken down for each power plant. The range of average costs for each power plant confirms the emission intensity in Figure 5.3 with Majuba and Lethabo showing the lowest average damages while Arnot and Hendrina are in the higher range.

The estimation of the damage costs of GHGs is vital considering the global attributes to such emissions. However, extensive public consensus exists over the appropriate damage cost associated with GHGs. The valuation GHGs emanating from electricity have been quantified, based on the damage costs recommended within the ExternE methodology. The conversion of European damage costs to South African values using PPP conversions was in line with the damage costs recommended in the LTMS study performed for South Africa. Though damage costs are in line, improved studies are required to apportion the damage costs with lesser variability.

5.2 Water usage

5.2.1 Introduction

Electricity generation from coal consumes significant amounts of water, which is required to produce the steam used to drive the turbines, as well as to cool down the high temperature steam within the cooling towers. Water scarcity in South Africa is a highly prioritised topic with national decision-making bodies. Eskom's pricing mechanism is based on long-term purchase agreements with the Department of Water Affairs (DWA), which might be understating the actual price of water. The possible discrepancy is considered an externality which requires investigation.

In terms of legislation the National Water Policy of 1997 was the first policy paper passed to encourage socio-economic development with the usage of water within perspective. The National Water Act of 1998 stated integrated management of water resources as one of its primary agendas. Foresight and sustainability while managing water resources, as well as making water available across all spectrums of population and industry, were mentioned as primary priorities. The National Water Resource Strategy (NWRS) of 2004 states how the water resources of the nation will be protected, used, developed, conserved, managed and controlled. The primary objective of the strategy is to ensure that water is used to support equitable and sustainable, social and economic transformation and development. The NWRS mentions that there are sufficient resources (at the rate of current precipitation and run-off) for the next 25 years if managed wisely.

Along with management comes improved investment across the nation's water cycles. The nation's minister for Water and Environmental Affairs, Edna Molewa, mentioned during a briefing in Cape Town in 2012 that South Africa needs more than R570 billion of investment across the various spectrums, including water resource infrastructure, water services, water conservation and demand management across the central government, municipalities and water boards (Mail & Guardian, 2012). The funding strategy in the plan depicted a shortfall of 56% according to the Chief Operations Officer, Trevor Blazer. The implication of such a shortfall alternatively leads to the alternative of increasing water tariffs. A similar situation has arisen in the electricity capacity sector where Eskom's expansion of capacity could only be funded by increasing tariffs.

5.2.2 Externality valuation

5.2.2.1 Identification of impacts: Water scarcity

South Africa is located in a semi-arid region and considered among 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 managed properly (De Wet, 2010). These assessments are given further weightage when considering the fact that South Africa's mean annual precipitation is 497 mm/yr, which is well below the global average of 860 mm/annum (Turton, 2008). Putting things further into perspective, Botswana and Namibia have an annual rainfall of 400 mm/yr and 254 mm/yr respectively, but have populations of only 2,00 and 2,28 million, while South Africa has a population of 50 million people (World Bank, 2010). To add to this, South Africa's relatively low rainfall and large population place a skewed level of stress on the limited water resources causing sporadic social discontent with concerns to service delivery. South Africa has no extensive or navigable rivers, with the Zambezi River being the closest. The rivers in South Africa, namely the Limpopo, Inkomati, Pongola and Orange, have a combined annual flow of 49 000 cubic metres per year (m^3/a), which is less than half of the Zambezi's (NWRS, 2004). The hard rock nature of the country's geology allows only about 20% of the groundwater resources' major aquifer systems to be available for utilisation on a large scale.

The majority of the water resources (62%) in South Africa is used for agriculture and irrigation, while domestic and urban use accounts for 27% and large industries and power generation accounts for 8% (CSIR, 2010).

As a result of the presence of minerals and resources urban populations in regions (such as Gauteng and Mpumalanga Highveld) that are devoid of major water sources, have increased and led to a skewed supply demand scenario. To facilitate water management the country has been divided into 19 catchment-based water management areas (WMA). The inter-linking of these areas plays a major role in catering to avoid disparity of water supply. Of the 19 WMAs, water requirements exceeded availability in 11 catchment areas (NWRS, 2004). The province of Gauteng in particular is expected to suffer shortages as early as 2013.

However, cooperation with the Lesotho government through the Lesotho Highlands Project is expected to ease shortages (South African Water Research Commission, 2009).

A similar situation of natural misallocation of water resources has also been observed in China, with the north of the country facing severe shortages compared to the south. China's economy is similar to South Africa's from the perspective of the agricultural sector's water usage to GDP contribution. China's agricultural sector uses 65% of water resources, while contributing to less than 15% of the GDP (Wong, 2009). South Africa, on the other hand, utilises 62% of the water resources to generate 12% of the GDP (South Africa, 2012). One recommended option to reduce the mismatch between water usage and the agricultural sector is to have a more services-oriented economy rather than a shift towards manufacturing or heavy industry as these industries have high water intensity.

Another major cause of scarcity of water is climate change. From a sub-Saharan and South African perspective, the projections portray a negative picture, with rainfall expected to decrease by 50% (De Wit and Stankiewicz, 2006).

5.2.2.2 Quantification of burden/impact: Water consumption

Of the 10 existing base load coal power plants, eight use wet recirculating cooling techniques while two (Kendal and Majuba) use dry cooling techniques. The dry cooling technique uses air instead of water in the heat exchange mechanism to cool down high temperature steam. Table 5.8 shows a summary of the cooling techniques being used in Eskom's current and future coal-fired plants.

Table 5.8: Cooling techniques in Eskom coal power stations (current and future)

		Cooling technique	Location
Base load	Arnot	Wet recirculating	Mpumalanga
	Duvha	Wet recirculating	Mpumalanga
	Hendrina	Wet recirculating	Mpumalanga
	Kendal	Indirect dry	Mpumalanga
	Kriel	Wet recirculating	Mpumalanga
	Lethabo	Wet recirculating	Limpopo
	Majuba	Wet recirculating and dry	Mpumalanga
	Matimba	Direct dry	Mpumalanga
	Matla	Wet recirculating	Mpumalanga
	Tutuka	Wet recirculating	Mpumalanga
Return-to-service	Camden	Wet recirculating	Mpumalanga
	Grootvlei	Wet recirculating and dry	Mpumalanga
	Komati	Wet recirculating	Mpumalanga
New build	Medupi	Direct dry	Limpopo
	Kusile	Direct dry	Mpumalanga

Source: Adapted from Wassung, 2010.

Dry cooling systems are more expensive than conventional wet cooling techniques when considering the infrastructural investments required (EPR1, 2008). Eskom employs three different types of cooling techniques. The first and most basic, the wet recirculating cooling technique, uses cooling water through condenser tubes with steam on the outside. The temperature variation between the water and steam causes condensation. The warm water in the condenser is collected in the cooling tower where an upward draft of air removes the heat. The cooled water is then recirculated to the condenser. A major drawback of this technique is that water is lost through evaporation when the warm cooling water comes in contact directly with air (Eskom, 2010a).

Indirect dry cooling uses bundles of cooling elements arranged in concentric rings inside the cooling tower. Heat is conducted from the warm water by these cooling elements, which have cool water flowing through them. Cooling water that flows through the elements is then cooled down by cold air passing over and then returned to the condenser. This system is referred to as a closed system since there is no loss of water due to evaporation. Dry cooling techniques differ in the respect that heat exchange occurs between hot steam leaving the turbine blades and a heat exchanger. Air passing through the exchanger is supplied by multiple electrical fans. The heat forms steam that is removed by the air within the exchanger thereby condensing the steam back into water.

Eskom's net water consumption was reported to be 316 202 million litres with an average usage of 1.34 litres/kWh for all base load and Camden (Eskom, 2010b). The national utility does acknowledge the situation of water being a scarce resource and has initiated relevant projects. The Mokolo, Crocodile and Komati water augmentation projects are intended to supply water to the new power stations and the return to service plants. The water for the base load power stations is supplied from different catchment areas, rivers and dams from sources near the stations (DWA, 2009). Eskom purchases water from the DWA and prices are based on prior agreements related to historical costing. In other words, stations that receive water from sources that are relatively older tend to have prices that are lower based on the low infrastructural costs required to build the source of water supply. This situation runs a risk of underestimating the actual price to the social price of water (see Table 5.9).

Table 5.9: Water consumption and pricing in Eskom coal power stations (2008 data)

	Water consumption		**Average price**
	Total (million m^3)	Per unit (l/kWh)	R/m^3
Arnot	20.98	2.169	1.26
Duvha	48.49	2.127	1.14
Hendrina	25.89	2.21	1.52

	Water consumption		Average price
	Total (million m^3)	Per unit (l/kWh)	R/m^3
Kendal	32.59	0.132	3.03
Kriel	42.47	2.434	1.16
Lethabo	41	1.901	1.45
Majuba	5.93	1.148	0.32
Matimba	2.99	0.126	1.55
Matla	51.45	2.042	0.88
Tutuka	17.90	1.998	0.57
Total/average	289.69	1.628	

Source: DWA, 2009.

The difference between the actual price of water being paid by a consumer and the economic cost of water is an economic impact and can be classified as an externality.

5.2.2.3 Economic valuation

Attributing an economic cost to water is a sensitive process and involves consideration of multiple factors, such as benefits to users and from returned flows, and indirect benefits whereas actual prices are usually set based on financial pricing strategies or environmental pricing strategies. Economic pricing tends to reflect and capture the opportunity cost of providing water, with emphasis on long-term investment planning and long-term water demands. Financial pricing tends to focus on maintenance, servicing and capital investment costs whereas environmental pricing recognises costs associated with water use that in turn impact potential for resource use by other users (De Wit and Blignaut, 2004). Environmental pricing meanwhile reflects environmental costs related to water usage that in turn impact the usage of water as a resource for other users. To make matters more intrinsic, the true economic value of water also needs to take into account values of non-consumptive factors such as maintenance of life, ecosystem sustainability and aesthetic facilities.

The economic value for water for the study has been chosen to be the value used by King (2002 in Det Wit and Blignaut, 2004). King used a value of R3/m^3 for the industrial user in the Tshwane metropolitan area based on a willingness to pay approach. Van Horen (1996) used a value of R1.50/m^3 based on discussions with personnel at the DWA. Van Horen then uses low and high estimates with a 60c window from the central estimate. Using a similar approach the low, central and high values for this study was chosen to be R2.40, R3.00 and R3.60 per m^3respectively.

Table 5.10: Water prices and externality valuation in Eskom coal power stations (2008 prices)

	Low estimate		**Central estimate**		**High estimate**	
	R/m^3	**R million**	**R/m^3**	**R million**	**R/m^3**	**R million**
Arnot	1.14	28.86	1.74	44.06	2.34	49.09
Duvha	1.26	58.42	1.86	86.24	2.46	51.61
Hendrina	0.88	24.73	1.48	41.59	2.08	100.85
Kendal	0	0	0	0	0.57	18.57
Kriel	1.24	52.66	1.84	78.16	2.44	103.62
Lethabo	0.95	46.18	1.55	75.35	2.15	104.51
Majuba	2.08	68.42	2.68	88.16	3.28	19.46
Matimba	0.85	2.76	1.45	4.71	2.05	6.61
Matla	1.52	68.90	2.12	96.1	2.72	123.29
Tutuka	1.83	84.47	2.43	112.17	3.03	139.94
Total		**435.44**		**626.55**		**819.75**
Average mills/kWh		2.00		2.89		3.78

The analysis shows that the externality caused by under-pricing the water supplied for electricity generation accumulates to 0,29 c/kWh.

5.2.3 Discussion and uncertainty

The externality of water costs is not included in the ExternE methodology. However, the issue of water scarcity in South Africa makes usage of water in electricity generation an important impact worth quantifying and making the externality vital from a South African context. The variation in the range of estimates is linear as opposed to other impacts investigated within the study. The uncertainty is caused by the uncertainty associated with the estimate of the economic cost of water and the value attributed to a scarce resource.

5.3 References

Anderson, MS. 2008. Environmental and economic implications of taxing and trading carbon: Some European experiences. In: J E Milne (ed). *The reality of carbon taxes in the 21st century*: 61–87. Environmental Tax Policy Institute: Vermont.

Baumert, K. 2012. Carbon taxes vs. emission trading. [Online] Available at: www.globalpolicy.org/component/content/article/216/45883.html. Accessed on 12 December 2013.

Carbon Disclosure Project. 2007. *South Africa JSE 100*. London: United Kingdom.

Carbon Disclosure Project. 2008. Questionnaire. [Online] Available at: https://www.cdproject.net/CDP%20Questionaire%20Documents/184_594_196_sclc08_questionnaire.pdf. Accessed on 5 December 2013.

CSIR, 2010. *A CSIR perspective on water in South Africa*. CSIR: Pretoria.

Cook, A. 2005. *Greenhouse methane emissions for South African coal mining: Models for predicting methane gas release from coal seams*. COALTECH, 2020. Marshalltown: South Africa.

Cook, A, Lloyd, P. 2005. Methane release from South African coal mines. *Journal of South African Institutes of Mining and Metallurgy* 105:483–490.

Deverajan, S, Go, DS, Robinson, S, Theirfelder, K. 2009. *Tax Policy to Reduce Carbon Emissions in South Africa*. World Bank, Africa Region.

De Wet, H. 2010.*The Environmental Handbook: a guide to green business in South Africa*. 2nd ed. Trialogue: Cape Town.

De Wit, M, Blignaut, J. 2004. *Sustainable options – Development lessons from applied environmental economics*. UTC Press, Cape Town.

De Wit, M, Stankiewicz, J. 2006. Changes in surface water supply across Africa with predicted climate change. *Science* 311(5769):1917–1921.

DWA. 2009. *Domestic and industrial – raw water tariffs*. Department of Water Affairs. Pretoria.

Energy Information Administration. 2012. [Online] Available at: www.eia.gov/countries/data.cfm#undefined. Accessed on 21 January 2013.

Environmental Protection Agency. 2012. United States Environmental Protection Agency. [Online] Available at: www.epa.gov/climatechange/glossary.html#C. Accessed on 18 December 2012.

Energy Research Centre (ERC). 2007. Long-term mitigation scenarios: Technical summary . [Online] Available at: www.erc.uct.ac.za/Research/LTMS/LTMS-intro.htm. Accessed on 15 April 2010.

EPRI. 2008. *Water use for electric power generation*. Report number 1014026.

Eskom. 2009. *Annual Report 2009*. Eskom: Sandton.

Eskom. 2010a. *Water management – COP17 fact sheet*.

Eskom, 2010b. *Annual report 2010*. Eskom: Sandton.

European Commission (EC), 2005. *ExternE: Externalities of Energy, Methodology 2005 Update*. Institut für Energiewirtschaft und Rationelle Energieanwendung (IER). Universität Stuttgart: Germany.

Intergovernmental Panel on Climate Change (IPCC). 2006. *Guidelines for National Greenhouse Gas Inventories Volume 2*. Intergovernmental Panel on Climate Change: Geneva.

IPCC. 2007a. Climate Change 2007: The Physical Science Basis. Contribution of the Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. University Press: Cambridge.

IPCC, 2007b. Climate Change 2007: Issues related to mitigation in the long term context. Climate change 2007: Mitigation Contribution of the Working Group I to the Fourth

Assessment Report of the Intergovernmental Panel on Climate Change. University Press: Cambridge.

Mail & Guardian, 2012. South Africa’s water crisis just got expensive. [Online] Available at: mg.co.za/article/2012-04-16-sas-water-crisis-just-got-expensive. Accessed on 18 October 2012.

National Treasury. 2010. *Discussion Paper for Public Comment. Reducing greenhouse gas emissions: The carbon tax option*. Pretoria: South Africa.

Nordhaus, WD. 2008. *A question of balance: Weighing the options on global warming policies*. Yale University Press: New Haven and London.

NWRS. 2004. *National Water Resource Strategy*. Department of Water Affairs: Pretoria.

Ross, K. 2011. Personal communication. Eskom: Sandton.

South Africa. 2008. Annual Budget Speech. National Treasury, Pretoria. [Online] Available at: www.info.gov.za/speeches/budget/budget2008.pdf. Accessed on 14 December 2012.

South Africa. 2011. *White Paper on National Climate Change Response for South Africa*. Department of Environmental Affairs. Pretoria.

South Africa. 2012. [Online] Available at: www.energy.gov.za/files/coal_frame.html. Department of Energy. Pretoria. Accessed on 30 June 2012.

South Africa. 2012. South African Government Information. [Online] Available at: www.info.gov.za/aboutsa/agriculture.htm. Accessed on 25 January 2013.

South African Water Research Commission. 2009. The state of water in South Africa – Are we heading for a crisis? *The Water Wheel*. September/October:31–33. South African Water Research Commission: Pretoria.

Stern, N. 2006. Stern Review: The economics of climate change. Executive Summary. [Online] Available at: webarchive.nationalarchives.gov.uk/+/http:/www.hm-treasury.gov.uk/sternreview_index.htm. Accessed on 13 December 2012.

Tol, RSJ. 2005. The marginal damage cost of carbon dioxide emissions: an assessment of the uncertainties. *Energy Policy* 33:2064–2074.

Turton, A, 2008. Three strategic water quality challenges that decision-makers need to know about and how the CSIR should respond. Keynote address: A Clean South Africa. Presented at the CSIR Conference, Science Real and Relevant: 18 November 2008. Pretoria.

United Nations, 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change.

Wassung N, 2010. Water scarcity and electricity generation in South Africa. Masters dissertation, University of Stellenbosch.

Wong, J. 2009. The Green Leap Forward. [Online] Available at: greenleapforward.com/2009/02/17/chinas-new-water-efficiency-targets-and-implications-for-food-and-energy/. Accessed on 25 October 2012.

World Bank, 2010. [Online] Available at: data.worldbank.org/country/south-africa. Accessed on 27 October 2012.

Zhou, PP, Yamba, FD, Lloyd, P, Nyahuma, L, Mzezewa, C, Kipondya, F, Keir, J, Asamoah, J, Simonsen, H. 2009. Determination of regional emission factors for the power sector in Southern Africa. *Journal of Energy in Southern Africa* 20(4): 11–18.

Chapter 6: Occupational health impacts

This chapter quantifies the occupational impacts that occur during both coal- and nuclear-fired electricity generation. The occupational impact related to coal-based electricity being evaluated here are the occupational injuries, fatalities and diseases occurring during coal mining. The nuclear occupational impact covers mining of the fuel, as well as operation of the power plant. Since quantifiable public impacts of nuclear plant operation based on available data are minimal, this impact is quantified and evaluated, along with other nuclear externalities.

6.1 Occupational health in coal mining

The coal mining industry in South Africa employs the third largest number of workers after platinum and gold (South Africa, 2010). Table D1 in Appendix D shows the labour statistics in the coal mining industry from 1986 to 2007.

Employee numbers have dropped drastically over the 20-year period, with relative stabilisation during recent years. The substantial decrease in employee numbers can be attributed to the improved mechanisation in the mines, coupled with reduced reporting of labour statistics. The change in the country's political landscape, along with the mining policies during the late 1980s until the early 2000s, is another factor responsible for the decrease. However, the recent upward trend in worker statistics can be linked to better reporting of labour statistics from the mines rather than an influx of labour. The increases in wages are steady since 1993 and can be related to the role played by the trade unions in negotiating better wages for the workers (South Africa, 2010). Improved data collection and methodology have also contributed to the increase in official wage statistics.

Improved wages do not however relate to improved occupational structures in the uneventful case of accidents or injuries at work. South Africa has a relatively complex compensation framework for accidents at the workplace when compared to countries such as the United Kingdom and Australia, which can be attributed to the involvement of a number of organisations involved in the process.

6.1.1 Introduction

In South Africa no single institution is solely responsible for the development and implementation of the Occupational Health and Safety (OHS) policy. The main body responsible for OHS is the office of the Chief Directorate at the Department of Labour. This office is responsible for the administration of the Occupational Health and Safety Act 1993, which covers all workers employed in the formal sector and covers all public health and safety workers without a specialist inspectorate. The Mine Health and Safety Inspectorate (MHSI) in the Department of Mineral Resources (DMR) administers the Mine Health and Safety Act 1996, which is the largest specialist OHS inspectorate. Various regulators exist that monitor and regulate OHS within their own industry and report to the Department of Labour. For example, the National Nuclear Regulator (NNR) is responsible for OHS within the nuclear industry.

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) in the Department of Health provides medical examination for personnel claiming occupational disease compensation.

The Department of Health has various agencies that conduct research and provide medical care with respect to occupational health. The National Institute of Occupational Health (NIOH) is one such body that conducts research for the benefit of occupational health in the country. Naidoo et al. (2004) is one case where the NIOH conducted a study recording the prevalence of pneumoconiosis among coal miners and provides pioneering physiological work into the medical health of coal workers in South Africa.

Van Horen (1996) attempts to quantify the monetary effect of occupational health among South African coal miners. However, the analysis was limited to fatalities and injuries, which economic valuation was based on methodologies used in North America. EC (1995) provides case studies and methodologies for specific coal power plants to aid the monetisation of occupational health effects, which is very subjective to availability of data in the vicinity of the power plant analysed.

6.1.2 Externality valuation

6.1.2.1 Identification and prioritisation of impacts

Since 90% of the electricity industry depends on coal as the primary fuel source, the condition of coal workers who extract coal from the mines cannot be passed over. These miners are subject to potentially risky physical scenarios in their daily occupational routine.

Occupational hazards can be classified into the following categories based on the kind of effect (Donoghue, 2004):

a) Physical

This is the largest and most frequent type of injury sustained by mine workers. These injuries may cause morbidity or mortality based on the severity of the condition. Rock falls, fires, explosions, transport and handling accidents are some of the causes which lead to physical damages.

b) Biological

Hazards of these types include the risk of diseases such as malaria and dengue fever because of the presence of stagnant water in warm temperatures, which is favourable for mosquito larvae. Improved fumigation and sanitation have helped control these factors considerably (Jorgensen, 1972).

c) Chemical

These hazards comprise of risks associated with the inhalation of chemical particles, such as crystalline silica and coal dust, which causes silicosis and coal workers pneumoconiosis, respectively. Means available to control these effects are dust suppression, ventilation and respiratory protection (Kizil and Donoghue, 2002). Prolonged exposure to chemical particulates can cause cancer and tuberculosis, which deteriorates in the case of HIV patients.

d) Psychosocial

Since most mining operations are situated away from communities prolonged separation can have a negative impact on the psyche of an employee, which could lead to substance and alcohol abuse. However, most mining operations have measures in place to supervise breath and blood alcohol levels. Working in aesthetically unsuitable conditions for prolonged periods could also affect normal behaviour.

e) Ergonomic

Risks associated with coordination between the human body and the disability to perform a function properly as a result of occupation-related fatigue, fall under the ergonomic hazard category. Sleep deprivation and repetitive strain injuries cause risks of the ergonomic type.

This chapter intends to investigate the risks involved in the physical and chemical categories based on the availability of data. The other categories (biological, psychosocial and ergonomic) were deemed unquantifiable because of the lack of available data. Monetisation of occupational health effects involves identifying the different type of occupational accidents and then attributing the average cost of each accident type to the corresponding accident. The individual costs are aggregated to calculate the total occupational health external cost associated with electricity generation.

6.1.2.2 Quantification of burdens and impacts

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. The accounting of such externalities is carried out by the Rand Mutual Assurance (RMA) in terms of the COIDA. The second section comprises hazards categorised under occupational diseases, which falls under the ODMWA. The accounting of such externalities is carried out by the CCOD and MBOD in terms of the ODMWA. Table 6.1 provides a better indication of the framework in which occupational health externalities are accounted for and dealt with.

Table 6.1: Occupational health accounting framework

	Type of occupational externality	
	Occupational injury	Occupational disease
Office concerned	RMA	MBOD/CCOD
Act concerned	COIDA	ODMWA

Occupational injuries

Occupational injuries involve both mortal and morbid cases. RMA, which was established in 1894, is a mutual association licensed to administer and provide comprehensive worker benefits and compensations. RMA – also called Rand Mutual – primarily covers statutory worker insurance in the event of accidental death or injury at the workplace, for the employee and their dependents. RMA also covers for injuries or deaths that occur while travelling to and from work. However, this aspect is not included in the study. The benefits provided by RMA are summarised as follows (Kritzinger, 2009):

- Payment of reasonable medical cost
- Total temporary disablement or loss of earnings
- Permanent disability
- Emergency transport
- Monthly pension to dependents in case of fatal injury
- Funeral expenses

The claims process of the RMA comprises four primary steps (Kritzinger, 2009):

- Timely reporting of claims along with submission of supportive documents (containing details of the injury) by the employer.

- Medical treatment of injured or disabled employees by medical service provider supported with concurrent medical reports (containing details of treatment, scale of recovery, etc.). If treatment comprises three consecutive days off work then the employee is compensated under loss of earnings.
- Award of compensation for functional loss in accordance with the instructions of COIDA and based on final medical report from the doctor. Compensation rewarded is in the form of a lump sum payment or monthly pension depending on functional loss expressed as percentage of permanent disability.
- Support for on-going medical treatment and disease-related conditions.

Timely reporting of cases has been stated as the most challenging aspect within the claims process, as delays could cause claims being rigorously verified thereby delaying all other steps within the claims process.

Claims are ICD 10 (International Classification of Diseases) coded as per type of claim and medical reports. The classification of diseases has been devised by the World Health Organisation (WHO) based on diseases, symptoms, complaints and external cause of disease and injury (World Health Organisation, 2012). The ICD 10-coded claims are further classified into DRG (Diagnosis Related Groups) to cater for reporting and statistical objectives. DRGs are used to classify hospital cases into groups, based on the service rendered by the hospital for each case or claim.

Table 6.2: DRG classification of claims for 2008

DRG	Description	Number of claims
DRG 00	Fatal	9
DRG 01	Spinal cord injuries	0
DRG 02	Lower limb amputees	1
DRG 03	Upper limb amputees	0

DRG	**Description**	**Number of claims**
DRG 04	Partial or total blindness	4
DRG 05	Noise induces hearing loss	61
DRG 06	Injuries to the head	116
DRG 07	Injuries to the neck	15
DRG 08	Injuries to the thorax	34
DRG 09	Back injuries	54
DRG 10	Injuries to the abdomen and pelvis	4
DRG 11	Injuries to shoulder and upper arm	42
DRG 12	Injuries to elbow and fore arm	31
DRG 13	Injuries to the wrist and hand	225
DRG 14	Injuries to the hip and thigh	27
DRG 15	Injuries to the knee and lower leg	114
DRG 16	Injuries to the ankle and foot	98
DRG 17	Injuries involving multiple body regions	43
DRG 18	Foreign body in eye, ear and lung	21
DRG 19	Burns and corrosion	2
DRG 20	Toxic effects – solvents, metal, gases	0
DRG 21	Effects of radiation, heat, pressure	0
DRG 22	Mental and behavioural disorders	0
DRG 23	Diseases of the respiratory system	2
DRG 24	Skin disease (dermatitis/eczema)	1
DRG 25	Other conditions – miscellaneous	6
Null	Null	48
Total		976

It can be observed from the above table that injuries to limbs constitute the majority of the claims, with injuries to the head being surprisingly high as well.

This section of occupational health can be further classified into three subsections based on the type of care (compensation) provided:

- Acute care
- Non-pensioner care
- Pensioner care

The aggregate costs for all three categories based on benefits are shown in Table 6.3.

Table 6.3: Total cost of care for reported cases for 2008

(Compensation Commissioner of Occupational Diseases, 2008)

Benefit	**Cost (Rand)**	**Cost %**
Days off	545 260.9	2.56 %
Fatal	4 258 198.96	20 %
Medical	9 928 562.42	46.65 %
Not classified	167 743.42	0.78 %
Permanent disability	6 842 684.55	32.15 %
Recoveries	-694 290	-3.26 %
Sundry	234 212.46	1.1 %
Total	21 282 373	100

As is to be expected, medical costs constitute the majority of the costs, with permanent disability and fatal costs also comprising a large share. Recoveries consist of amounts wrongly paid out and claimed back by the insurer.

Occupational disease

Occupational disease pay-outs are classified into two sections, namely one-sum benefits and pensions. The type of compensations can be further classified as follows:

- First degree compensation – Degree of impairment of lungs/respiratory organs of between 10 to 40%.
- Second degree compensation – Degree of impairment of lungs/respiratory organs of 40% or more.

Another separate category includes tuberculosis (TB) damages paid as form of compensation for loss of earnings during treatment. However, this category has the condition that only 75% of lost earnings are compensated for. One-sum benefits include any disease that could cause limited lung function. Table 6.4 shows the breakdown of compensations paid.

Table 6.4: One-sum benefits with varying degree of impairment for 2008

Type of impairment	**Cost (Rand)**
Diseases in first degree	36 927 975
Diseases in second degree	93 861 157
Tuberculosis – first degree	1 969 022
Tuberculosis 75%	780 563
Tuberculosis – second degree	20 805 693
Dependents	103 072
Miscellaneous	37 800
Total	154 485 282

Source: CCOD, 2008.

Pensions are paid for cases of coal workers' pneumoconiosis and TB with a range of variance. Table 6.5 gives a breakdown of pensions paid out for pneumoconiosis of varying degrees.

Table 6.5: Pensions for pneumoconiosis with varying levels of cardio-respiratory impairment

Type of impairment	Cost (Rand)
Cases more than 20%, but less than 50%	291 097
Cases more than 50%, but less than 75%	18 159
Cases more than 75%	32 448
Pneumoconiosis with TB	212 214
TB	90 935
Dependants	2 899 337
Total	3 544 190

Source: CCOD, 2008.

The above tables (6.4 and 6.5) give an aggregated compensation and pension pay-out for all kinds of mined commodities and not exclusively coal. The Compensation Commissioner of Occupational Diseases (CCOD) Annual Report for 2008 gives a breakdown of the number of controlled mines that compensations are tailored for. Out of a total of 199 controlled mines, 71 are coal mines, which indicate approximately a 35% share. Table D2 in Appendix D gives a more detailed breakdown of the controlled mines in South Africa.

In order to avoid a baseless overestimation or underestimation an approximation of pay-outs for the commodity of coal is done based on the percentage of coal mines within the total number of mines. Since coal mines constitute approximately 36% of the total mine number the compensation pay-outs for coal-based occupational hazards are also approximated to be 36% of the total pay-outs in Table 6.4 and Table 6.5. This approximation can be more clearly illustrated using the table below.

Table 6.6: Approximation of coal-based pay-outs

	All commodities	**Coal**
Number of mines	199	71
Compensation (Rand)	158 029 472	56 382 374

6.1.2.3 Economic valuation

The sum of the total costs in Table 6.3 (occupational injuries and deaths) and Table 6.4 (occupational diseases) gives the total occupational health costs associated with coal mining. These total costs - when interpreted in terms of the net electricity produced - give a cost per unit of electricity. Inclusion of the occupational cost per unit of electricity to the cost of unit price of electricity constitutes the process of internalisation of occupational health effects. This process is shown below.

Total occupational health cost = R77 664 747 (Sum of tables 6.3 and 6.7) (A)

Total electricity produced = 216 664 GWh (base load for 2008) (B)

Occupational health/unit = 0,36 SA mills/kWh (C)

The significance of these damages with respect to other externalities is discussed in the next chapter.

6.1.3 Discussion and uncertainty

An aggregate of the total health costs were obtained and interpreted in terms of the total electricity generated. The evaluation could be beneficial in garnering more attention to the state of the workers in coal mines. The uncertainty involved in the evaluation is associated with the estimation of occupational pay-outs related to externalities exclusive to the coal used for electricity generation. Unreported cases of accidents and incidents are another cause of uncertainty related to mining occupational health. The study can be improved by timely reporting of accidents and incidents in the coal mines.

Inclusion of other components of the coal mining life cycle can be included to provide improvements to this study.

6.2 Nuclear externalities

6.2.1 Introduction

Nuclear energy is proposed as an alternative to fossil fuels because of a lack of GHG emissions and cost-effectiveness in the long-term. Enriched uranium has electricity generating capability ratio of 14000:1 relative to conventional coal fuel generation techniques. In other words, 1 kg of enriched uranium can generate 45 000 kWh of electricity, which would otherwise require 14 000 kg of coal (ENS, 2013). The South African government has proposed a diversification of electricity generation mechanisms primarily to achieve better energy security while accomplishing the goal of environmentally responsible. The IRP policy paper has proposed an additional 9 600 MW capacity of nuclear power, which is however subject to financial risk and availability and construction capability (South Africa, 2011). Though nuclear-based electricity is highly fuel efficient and emission friendly, there are risks associated as in any other electricity generation technique. Prior to performing a risk assessment of nuclear electricity generation in South Africa, an introduction of the nuclear industry background and regulatory bodies is provided.

6.2.1.1 History of the nuclear industry in South Africa

South Africa’s nuclear history dates back to the 1920s, when uranium was found as an offshoot from gold mining in the Witwatersrand area around Johannesburg. A slow progression saw mining of uranium occur mainly for the purposes of export. This led to the establishment of a Parliamentary Act and formation of the Atomic Energy Board (AEC) in 1948 with offices in Pretoria, under the primary mandate of regulating production and trade of uranium.

During the early 1960s the Act was revised to make provision for uranium conversion, enrichment and fuel fabrication. The first reactor to be built on South African soil was Safari-1 in 1965, which was acquired from the US as part of the 'Atoms for Peace' programme. This led to the formation of the Uranium Enrichment Corporation (UCOR) and a programme of conversion, enrichment and fabrication of uranium was started during the 1970s.

By the 1980s UCOR was incorporated into the Atomic Energy Corporation (AEC, the erstwhile AEB), whose offices were moved to Pelindaba. The primary mandate of the AEC during the late 1970s and 1980s was to develop the ability to sustain an indigenous nuclear fuel cycle for the operation of nuclear power plants and to deliver material for nuclear weapons. The result was the design and fabrication of six nuclear weapons (US: DoS, 2003). On the civilian front construction of the Koeberg power plant commenced in 1976 and was commissioned in 1984. During the late 1980s the political transition triggered fears of political instability and security worries caused the government to dismantle the nuclear weapons, making South Africa the first country to voluntarily to give up its nuclear programme. South Africa signed the nuclear non-proliferation treaty in 1991, thereby making its nuclear facilities available to inspections by the International Atomic Energy Agency (IAEA). Since then South Africa has focused on using domestic nuclear resources for civilian electricity production and medical purposes.

6.2.1.2 South African nuclear industry

The South African nuclear industry comprises of a few main entities;

South African Nuclear Energy Corporation (Necsa)

The South African Nuclear Energy Corporation (Necsa) was formed from the previously known AEC and is entirely state-owned. It is responsible for activities and stimulating R&D in the field of nuclear energy and radiation sciences.

Necsa is also responsible for the operation of Safari-1, which is a 20 MW tank-in-pool type research reactor. Safari-1 produces and supplies radioisotopes used in the medical industry. The production of Molybdenum-99 (Mo99) using low enriched uranium (LEU), the radioisotope used as a raw material for technetium-99, which is an extensively used diagnostic nuclear medicine isotope, is one of Safari-1's significant contributions. Necsa operates commercial subsidiary businesses through NTP Radioisotopes (Pty) Ltd., which is responsible for a range of radiation-based products and services for health care, life sciences and industry and Pelchem (Pty) Ltd., which supplies fluorine and fluorine-based products (South African Nuclear Energy Corporation, 2011). Both subsidiaries supply products for the local and international markets.

National Nuclear Regulator

The National Nuclear Regulator (NNR) is directed with the task of granting nuclear licences for nuclear operators. The NNR's primary focus and task is to monitor and enforce regulatory safety standards in order to achieve safe operating conditions, prevention and mitigation of nuclear accidents, thereby resulting in occupational, public and environmental safety against radioactive material and ionizing radiation (National Nuclear Regulator, 2012). The regulatory frameworks devised by the NNR are consistent with the recommendations of the International Commission for Radiation Protection (ICRP) and the International Atomic Energy Agency (IAEA).

Koeberg Nuclear Power Station

The Koeberg Nuclear Power Station (KNPS) is located 30 km northwest of Cape Town along the Atlantic coast. Construction of KNPS began in 1975, with unit 1 being commissioned in 1984 and unit 2 the following year. Both units have a capacity of 900 MW. KNPS uses a pressurised water reactor (PWR) plant design and is the only nuclear power plant in South Africa and generates 5 to 6% of South Africa's total electricity requirements. The electricity requirement of the south-western part of the country is mainly met by KNPS, making it a vital part of the national electricity grid.

Vaalputs National Radioactive Waste Disposal Facility

The Vaalputs site covers an area of about 10 000 ha. Located in the Northern Cape it is used as a storage site for low and intermediate level waste originating from operations of the KNPS. Necsa is responsible for the transportation of waste to the site, and its maintenance and administration. High level waste from KNPS operations is kept in storage ponds on the KNPS site.

6.2.1.3 South African uranium profile

The Uranium 2009 Redbook (Organisation for Economic Cooperation and Development, 2010) gives a comprehensive description of the uranium and related industries, production and demand. Uranium reserve estimates are categorised into two categories based on reasonably assured resources (RAR) and inferred resources, which together comprise the identified resources. Each category is further divided into four categories based on the cost required to extract (mine) a tonne of triuranium octoxide (U_3O_8). Table 6.8 provides an estimated breakdown of the four categories for South Africa.

Table 6.7: Breakdown of South African uranium resources (in thousand tonnes)

Category	< 40kg/U	< 80kg/U	< 120kg/U	< 260 kg/U
Identified resources	153	232	295.6	295.6
RAR	76.8	142	195.2	195.2
Inferred resources	78.5	90.9	100.4	100.4

Source: OECD, 2010.

South Africa is also one of the countries which has an excessive production capability. Table 6.8 shows the top uranium producing countries in the world.

Table 6.8: Major uranium producing countries (in tonnes)

	2007	2008	Rank	%
Canada	9 476	9 000	1	20.51
Australia	8 602	8 433	2	19.21
Kazakhstan	6 633	8 512	3	19.39
Namibia	2 832	4 400	4	10.03
Russia	3 413	3 512	5	8.00
Niger	3 193	3 032	6	6.91
Uzbekistan	2 270	2 340	7	5.33
USA	1 747	1 492	8	3.4
Ukraine	800	830	9	1.89
China	710	770	10	1.75
South Africa	540	565	11	1.28
World total	41 244	43 880		

Source: OECD, 2010.

Even though South African uranium production ranks high internationally, requirements rank high proportionally. This is primarily because South Africa only operates one nuclear power plant, the KNPS, which has two units. Table 6.9 shows the requirement of major nuclear electricity producing countries along with their nuclear power plant infrastructure.

Table 6.9: Major selected nuclear power producing countries (international ranking in brackets)

	Requirement in tonnes	Reactors units	Capacity (GW)
United States	16 425 (1)	104 (1)	101 (1)
France	9 000 (2)	59 (2)	63.1 (2)

	Requirement in tonnes	**Reactors units**	**Capacity (GW)**
Japan	6 915 (3)	55 (3)	47.94 (3)
Russia	4 100 (4)	31 (4)	21.74 (4)
Ukraine	2 480 (6)	15 (10)	13.1 (7)
China	1 800 (8)	11 (11)	8.44 (11)
Canada	1 600 (9)	18 (7)	12.7 (8)
Sweden	1 575 (10)	10 (12)	9 (10)
Spain	1 515 (11)	8 (13)	7.45 (12)
UK	950 (12)	19 (6)	10.1 (9)
Brazil	450 (16)	2 (19)	1.76 (19)
South Africa	280 (20)	2 (20)	1.8 (18)

An observation of Table 6.8 and Table 6.9 shows that some of the major uranium producing countries have no uranium requirements (e.g., Australia, Kazakhstan, Niger), whereas some of the major users of uranium have no local available resources (e.g., USA, France, Japan). In the case of South Africa though local production far surpasses local requirements, there are no local facilities to convert, enrich and fabricate uranium into fuel for usage at the KNPS (South Africa, 2008). Since South Africa's conversion, enrichment and fabrication facilities have been shut down since the 1990s, enriched and fabricated fuel for usage at KNPS is imported from the international market, mainly Sweden and France (Engineering News, 2009).

6.2.2 Externality valuation

When considering the total nuclear fuel cycle, the important steps involved during the operation of a nuclear power plant are as follows (International Atomic Energy Agency, 2009):

- Mining
- Milling
- Enrichment
- Fuel fabrication
- Electricity generation
- Spent fuel storage and disposal
- Reprocessing
- Decommissioning of plant

For the purposes of this study, only the processes associated with the generation of nuclear power are taken into account because of two reasons. The first is that this study only quantifies generational externalities in the fuel cycle and the second that currently only processes involved with the generation of nuclear power exist in South Africa. The stages relevant for the South African nuclear power generation that consist of priority impacts and are applicable for the South African landscape are as follows:

- Mining
- Electricity generation
- Spent fuel storage and disposal

6.2.2.1 Identification and prioritisation of impacts

Stages such as milling, enrichment and fabrication related to electricity generation are not performed in South Africa currently and are thus not considered to have priority impacts relevant for South Africa. During the aforementioned priority stages various kinds of impacts occur that affect the environment and society by varying degrees. Nuclear impacts can be categorised into two groups, radiological and non-radiological impacts from routine and accidental operations. Radiological effects are those caused by radioactive emissions from the nuclear power plant.

While on the topic of radiological emissions, it is vitally important to mention that radioactive emissions from routine operations of a nuclear power plant is of many orders of magnitude lesser than the radioactivity received by a chronic smoker. Non-radiological effects are those that occur during routine operations that are common to any occupation and not nuclear related. An event such as a broken leg caused by a fall from a flight of stairs is categorised as non-radiological. Both these impacts affect public population, occupational workers and the surrounding environment by varying degrees. Below is a listing of priority impacts based on significance of impact and availability of quantifiable data:

- Radiological occupational health from mining
- Radiological occupational health and public health effects from routine power plant operations
- Radiological public health and occupational effects from waste disposal

One major impact that needs addressing, but has not been due to a lack of quantifiable data is the damage to public health in the event of a major nuclear accident. However, since such an accident has never occurred in South Africa, it creates a hypothetical scenario and is thus categorised as a non-priority impact.

6.2.2.2 Quantification of burdens

Radiological emission from a radioactive source can be broken down into four stages before it affects or reaches a source. These stages are described as follows:

- The radioactivity from the source of radiation - Radioactivity is measured in becquerels (Bq) or curie (Ci) and is the rate at which one nucleus decays per second. During practical measurements 1 Bq is considered a very small value.

- The energy of the source of radiation – The energy of ionizing radiation is measured in electronvolts (eV). One eV is a very small amount of energy. 1 joule is an equivalent of 6 200 billion MeV.
- Absorbed dose – When ionizing radiation interacts with a body, the tissues and cells get energised. The amount of energy absorbed per unit weight of tissue is called absorbed dose and is expressed in Gray (Gy). Different types of particles, even on emitting the same quantity of ionizing radiation, cause different levels of damage and is attributed weighing factors (Wr) shown in Appendix D.
- Equivalent dose – In order to quantify the damaging impacts from the various particles the concept of equivalent dose is used. The equivalent dose which is also called 'dose' is denoted as Sieverts (Sv) and is calculated as:
- Dose in Sieverts (Sv) = Dose in Gray (Gy) x Radiation weighing factor (Wr)

From the perspective of human health and occupational health, the most important quantifying factor is the equivalent dose. Dosage is usually expressed in Sv (or mSv or µSv depending on order) for an individual over an annum (year). Dosage can also be expressed in terms of the collective dosage expressed as 'Sv person' which is the average dosage received by the population group multiplied by the number of people in the population group.

6.2.2.3 Quantification of impacts

The South African NNR has recommended levels of maximum equivalent dosage for occupational and public dosage (National Nuclear Regulator, 2009). The NNR has set a regulatory dosage limit of 50 mSv per annum and 20 mSv averaged over five consecutive years for occupational workers. There is no stated collective dosage level stated by the national regulator. However, there are recommended levels which could be used as guidelines as per ALARA (As Low As Reasonably Achievable) recommendations, which vary from 0,6 person-Sv to 1 person-Sv (Canadian National Nuclear Safety, 2004; Julien et al., 2010).

ALARA guidelines are however very stringent as the names suggests and most national regulators have their own set standards. On the other hand, the collective public dosage constraint set by the national regulator is 0,25 mSv per annum. Quantification of all burdens is performed for 2008.

Radiological occupational impact from mining

The data of radiation doses from mine works is supplied to the NNR by licence holders of the mines. Exposure to workers is primarily through the inhalation of gases caused by radon decay in the mines. None of the license holders reported dosage levels above the 50 mSv level set by the regulator. However, the dosage data reported for mine workers in the NNR report is ambiguous and will not be used for estimation in this chapter. Instead the estimation used in the EC (1999) study for the Herault open-pit and underground mine is used as a guideline. The study states that for an average extraction of 1000 tU/year, a collective dose of 4,34 person-Sv was estimated.

None of the uranium produced locally is used for local electricity generation. However, it is going to be assumed that since South Africa produces uranium locally, the uranium required for electricity generation is sourced internally. Based on the calculation of 4,34 person-Sv for 1 000 tonnes and the local uranium requirements for electricity production of 280 tonnes (table 6.9); the dosage associated with the uranium mined for electricity generation is calculated to be 1,215 person-Sv.

Radiological occupational and public impact from operation at KNPS

The peak individual annual dosage recorded during 2008 for routine operation at KNPS was 12,6 mSv, which is lower than the prescribed regulatory limit of 50 mSv. The average individual occupational dosage recorded was 0,59 mSv. For a total occupationally exposed workforce number of 2 556, the collective annual dosage was 1508,04 person-mSv or 1,508 person-Sv (NNR, 2009).

The projected public dosage recorded from operations at Koeberg for the most hypothetically exposed group was recorded to be 0,00047 mSv-person for gaseous and 0,0038 mSv-person for liquid discharges respectively. Therefore, total dosage amounted to 0,00427 mSv-person.

Radiological occupational and public impact from operation at Vaalputs

The maximum individual annual dosage recorded during 2008 for routine operation at the Vaalputs site was 1,7 mSv. The average individual occupational dose was recorded to be 0,5 mSv for a workforce number of 18. Thus the collective annual occupational dosage was calculated to be 9 mSv-person.

The estimated public dosage recorded from operations at Vaalputs for the most hypothetically exposed group was recorded to be 0,00025 mSv-person for gaseous and 0,0011 mSv-person for liquid discharges, respectively. Consequently total dosage accrued to 0,00135 mSv-person.

Aggregation of impacts

Based on the quantified impacts associated with mining, operation of KNPS and waste disposal at Vaalputs, the collective occupational and public dosage is as shown in Table 6.10.

Table 6.10: Summary of occupational and public dosage

Impact	**Public dosage** (person- mSv)	**Occupational dosage** (person-mSv)
Mining for electricity use	Na	1215
Operation of KNPS	0,00427	1508
Waste disposal at Vaalputs	0,00135	9
Total	0,00562	2372

Na = not available

It can be observed that public dosage as expected is of a much lower order than occupational dosage even in circumstances where data is available for the same impact. Though data is not available for public dosage associated with mining currently, public dosage should be less than occupational dosage and about the same range as operation of KNPS. In totality it is important to stress that none of the collective dosage (public and occupational) calculated is of significance sufficient enough to cause any damage. The calculated impacts are well within limits set by the national regulator and international ALARA.

6.2.2.4 Economic valuation

The economic valuation of dosage impacts is categorised into two, based on occupational and public dosage. Economic valuation for dosage is quantified in monies equivalent to collective dosage or person-Sv values and is denoted as alpha value per man-sievert values. Valuation for occupational dosage is obtained from the Information System of Occupational Exposure (ISOE). The ISOE is a database maintained by the OECD Nuclear Energy Agency and IAEA to provide national regulatory bodies and nuclear power plant operators with a platform to share information. The ISOE conducts a survey among nuclear regulators and utilities to determine use of alpha values with the most recent survey being conducted in 2009. The alpha values for selected nuclear utilities in different countries are shown in Appendix D. Alpha value associated with KNPS as per the survey was revealed to be USD1 300/person-mSv (ISOE, 2012). The revealed central alpha value is equivalent to ZAR5 780 in local currency, which is obtained by using 2008 PPP conversion rates (see Appendix A).

KNPS discloses only a single alpha value unlike other nuclear plants, which provide a range of values. To account for low and high estimates of dosage a conservative range of ± USD500/person-mSv is used to account for variations in average dosage, thereby providing values of 800 and USD1 800/person-mSv as low and high occupational alpha values, respectively.

Use of a range of alpha values is used in many nuclear utilities the world over (ibid, p6). The low and high estimates in local currency are calculated using the 2008 PPP rates and are determined to be 3 557 and 8 003.

Alpha values for public dosage is not however surveyed by the ISOE. Local data for public dosage alpha values was not attainable; therefore the valuation in this study falls back on international literature. Alpha values can be determined using two techniques, the first being the willingness to pay approach, where the public – based on informed choices and critical information – decide on the value to be paid (or accepted), which is also discussed in Chapter 2. The second is the human capital approach adopted in Europe, within which the alpha value is calculated by valuing a single year of loss of life expectancy with the GDP per capita for a year (Eeckhoudt, et al., 1999).

Taking into account the average South African's knowledge of the social costs and benefits of electricity generation and the lack of public awareness programmes from the electricity utility Eskom, the willingness to pay (receive) approach is ruled out. The human capital approach seems more viable, since it requires economic indicator values to achieve a valuation. The alpha value using human capital approach is estimated as follows (ibid, p24):

- Average loss of life expectancy associated with radiation induced health effect (fatal cancer and hereditary effect): 16 years
- South Africa GDP PPP per capita (2008): USD10 427[9]
- Monetary valuation of radiation induced health effect: 10 427 x 16 = USD166 832
- Probability of occurrence of a radiation induced health effect for the public: 7.3 x 10^{-2}/Sv
- Monetary value of person-sievert:
  USD166 932 x 7.3 x 10^{-2} = USD12 178,74/person-Sv

[9] World Bank indicators for South Africa

The European study (ibid, p25) uses multiplying factors of 3, 5 and 6 based on risk aversion coefficients of 2 and 3 specified in the study for the prospect of accompanying compensation for occupational workers. In other words, the calculated alpha value for collective dosage associated with public health is USD12,18/person-mSv, which taking into account multiplying factors for variability, ranges from USD36,54 to 73,08/person-mSv with a central estimate of USD60,9/person-mSv. Upon conversion to local currency using 2008 PPP conversion rates (Appendix A), the alpha value ranges from ZAR162,5 to 325/person-mSv with a central value of ZAR271/person-mSv.

Based on the provided valuation, the alpha values for occupational and public dosage can be summarised as shown in Table 6.11.

Table 6.11: Summary of alpha value per person-mSv in South African Rand

	Low	**Central**	**High**
Occupational	3 557	5 780	8 003
Public	162.5	271	325

The summary of aggregated dosage profile for occupational and public health (from Table 6.10) coupled with the alpha values in Table 6.11, helps in ascertaining the damage costs associated with nuclear electricity generation. These costs are summarised in Table 6.12.

Table 6.12: Aggregated damage costs related to nuclear electricity generation

	Low	**Central**	**High**
Occupational (ZAR)	8 437 204	13 710 160	18 983 116
Public (ZAR)	0.91	1.52	1.83
Total (ZAR)	8 437 204.91	13 710 161.52	18 983 117.83
Total/production (mills/kWh)	0.75	1.21	1.68

6.2.3 Discussion and uncertainty

The average damage cost is obtained by normalising the damage cost to each unit of nuclear electricity produced during the time frame for which externalities are calculated. Based on the generational output of 11317 GWh for the year from KNPS (Eskom, 2011); the average central damage cost can be calculated to be 1,21 mills/kWh. The low and high damage costs are 0,75 and 1,68 mills/kWh.

Estimation of nuclear health externalities associated with electricity generation is being performed the first time in South Africa. However, uncertainties in quantification of damage costs still prevail primarily from the perspective of dosage associated with mine workers. Since uranium mined locally is not used for electricity generation, the extrapolation of local dosage associated with uranium mining has been performed using European data. The monetary evaluation of public health is also performed based on European methodology employed in ExternE valuations. Nonetheless, PPP conversions are performed to avoid overstating actual damage costs, which add to the degree of uncertainty.

6.3 References

Canadian National Nuclear Safety (CNSC). 2004. *Keeping radiation exposures and doses "as low as reasonably achievable (ALARA)".* Ottawa, Canada.

Compensation Commissioner for Occupational Diseases (CCOD). *Annual Report, 2008*. Department of Health: Johannesburg.

South Africa. 2010. Department of Mineral Resources. Statistics Table B1. *Bulletin mineral statistics tables 1998–2009.* [Online] Available at: www.dmr.gov.za/ Mineral_Information/Statistic.html. Accessed on 25 February 2011.

Donoghue AM, 2004. Occupational health hazards in mining: An overview. *Occupational Medicine* 54:283–289.

Eeckhoudt, L, Schiber, C, Schnieder, T, Godfroid, P. 1999. *Monetary value of the Man-Sievert for public exposure versus worker exposure*. Report Number 262.

Engineering News. 2009. [Online] Available at www.engineeringnews.co.za/article/ westinghouse-wins-30m-koeberg-fuel-contract-2009-11-30. Accessed on 19 January 2013.

Eskom. 2008. *Annual Report 2008*. Eskom: Sandton.

Eskom. 2011. *Annual Report 2011*. Eskom: Sandton.

European Commission (EC). 1995. *ExternE: Externalities of Energy*, Vol. 1–6. Office for Official Publications of the European Communities: Luxembourg.

European Commission (EC). 1999. *ExternE: Externalities of Energy*, Vol. 1–6. Office for Official Publications of the European Communities: Luxembourg.

European Nuclear Society. 2013. [Online] Available at: www.euronuclear.org/info/ encyclopedia/f/fuelcomparison.htm. Accessed on 17 January 2013.

Information System of Occupational Health (ISOE). 2012. *Man-Sievert monetary value survey Information Sheet No. 55*. ISOE European Technical Centre.

International Atomic Energy Agency (IAEA), 2009. *Nuclear Fuel Cycle Information System: A directory of nuclear fuel cycle facilities*.

Jorgensen H. 1972. Hygiene in mines. In: Rogan JM, ed. *Medicine in the mining industries*: 333–343. William Heinemann Medical: London.

Julien, S, Yue, B, Olayiwola, L, Hau, K. 2010. *ACR-1000 design features minimising collective occupational radiation exposure and public dose to public*. Atomic Energy of Canada Limited: Ontario, Canada.

Kizil, GV, Donoghue, AM. 2002. Coal dust exposures in the longwall mines of New South Wales, Australia: A respiratory risk assessment. *Occupational Medicine* 52: 137–149.

Kritzinger, D. 2009. Rand Mutual Assurance – The workmen's compensation carrier for the mining industry. *Occupational Health Southern Africa* 15(5):4–5.

Naidoo, RN, Robins, TG, Solomon, A, White, N, Franzblau, A. 2004. Radiographic outcomes among South African coal miners. *International Archive of Occupational Environmental Health* 77:471 –481.

National Nuclear Regulator (NNR). 2009. *Annual Report, 2009*. Centurion: Pretoria.

National Nuclear Regulator (NNR). 2012. [Online] Available at: www.nnr.co.za/what-we-do/. Accessed on 16 January 2013.

Organisation for Economic Cooperation and Development (OECD), 2010. A Joint Report by the OECD Nuclear Energy Agency and the International Atomic Energy Agency. *Uranium 2009: Resources, Production and Demand*.

South Africa. 2008. *Nuclear Energy Policy*. Department of Energy: Pretoria.

South Africa. 2011. *Integrated Resource Plan for Electricity 2010–2030*. Department of Energy: Pretoria.

South African Nuclear Energy Corporation (Necsa). 2011. *Annual Report, 2011*. Pretoria: South Africa.

US Department of State. 2003. South Africa: Nuclear Case Closed? Unclassified document.

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

World Health Organisation (WHO). 2012. International classification of diseases. [Online] Available at: www.who.int/classifications/icd/en/. Accessed on 17 December 2012.

Chapter 7: Conclusion

A number of socio-environmental impacts (called externalities) have been quantified during the course of this thesis. Summarisation of these impacts is essential to determine the relevance of the economic damages associated with the impacts on the electricity prices. External costs are analysed on an aggregated, as well as averaged level to contextualise the damage from each impact. The analysis places the average external costs in context with the local electricity prices, which are then placed in context with international studies performed using the ExternE methodology and is followed by a case study of South African electricity pricing. In conclusion, the electricity policy options for the local industrial sector are discussed to analyse policy options for the future.

7.1 Summarised external costs

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

7.1.1 Aggregated external costs

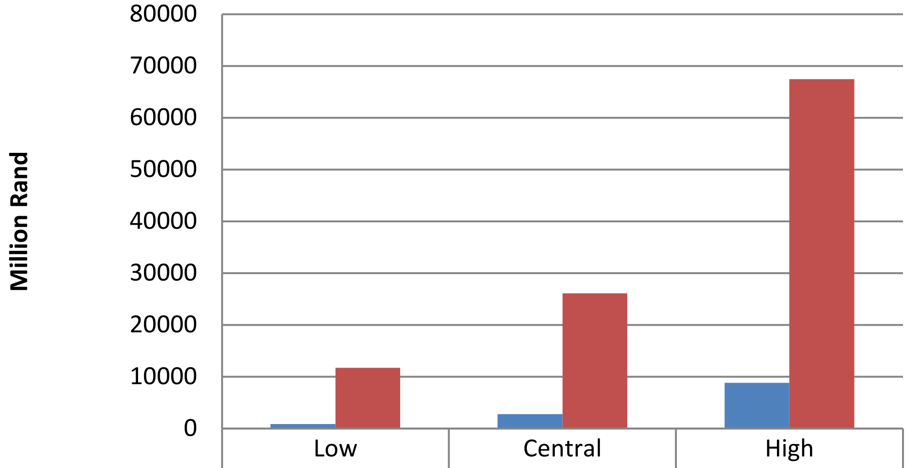
The total costs associated with the quantified impacts (in Chapters 4, 5 and 6) are summarised in Table 7.1.

Table 7.1: Aggregated external costs estimates (in Million Rand)

Impact	**Low**	**Central**	**High**
Coal: Public health	847.10	2 681	8 770.40
Coal: Occupational health	Nq	77.66	Nq
Nuclear: Public and occupational health	8.44	13.71	18.98
Coal: GHG environmental	11 258.6	25 444.5	66 651.8
Coal: Water usage environmental	435.40	626.55	819.75
Total	12 549.54	28 843.42	76 260.93

It can be observed that the largest single contributor to 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 7.1 constitute health impacts with the next two rows comprising environmental impacts, which are summarised in Figure 7.1.



	Low	Central	High
Health (public + occupational)	855.54	2772.37	8789.38
Environmental	11 694.00	26 071.05	67 471.55

Figure 7.1: Estimates of aggregated health and environmental impacts

It can be noted from the figure and associated data that quantified environmental damages outweigh health damages, which lead 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.

7.1.2 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 7.2.

Table 7.2: Average external cost estimates (in mills/kWh)

Impact	Low	Central	High
Coal: Public health	3.90	12.37	40.50
Coal: Occupational health	Nq	0.36	Nq
Nuclear: Public and 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 common 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 7.2.

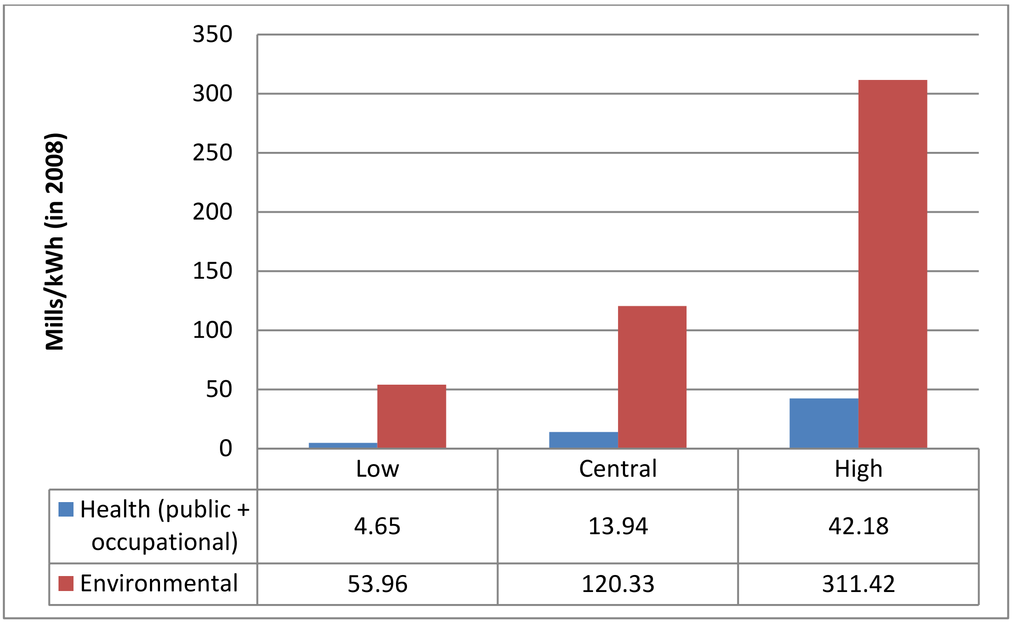


Figure 7.2: Estimates of average health and environmental impacts

The behaviour of the range of estimates of average costs is similar to the 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 7.3. These estimates help in comparing the results of this study with the review of other studies performed in Chapter 2 (Table 2.1 and 2.2). A better comparison of these results is possible when average local costs are converted to US dollar cents /kWh using purchasing parity rates for the year 2008 (Appendix A).

Table 7.3: 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	0.168	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 the 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 in Table 2.1 and Figure 2.2.

7.1.3 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 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 7.4.

Table 7.4: Total average external costs relative to sectorial tariffs

Sector	**Average 2008 Tariffs (c/kWh)**	**Total average external costs relative to tariffs**		
		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 7.5 exhibits the percentage share of the main impacts (Table 7.2) with respect to the 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 7.5: 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	Nq	0.18%	Nq
Nuclear: Public and occupational health	0.4%	0.62%	0.85%

Impact	**Low**	**Central**	**High**
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 included since external costs are shared across all sectors of the society.

Table 7.6: Inclusion of total average costs to average overall tariffs

Estimate	**Average external costs c/kWh**	**Internalised average tariff**		**Percentage 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 occur at a time when there is significant changes occurring in pricing mechanisms in the local electricity sector.

7.1.4 South African external costs vs. international external costs

At this point it is significant 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 7.7 are for those shown in millEuros (1999 prices). South African external costs are adjusted from millRands to milliEuros using 2008 PPP rates used in Appendix A.

Table 7.7: 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
The 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

Source: [1]EC1999 (ExternE, National Implementation); [2]South African prices are obtained from this study and adjusted to Euro values.

It can be observed that significant variation occurs in the human health cost because of variable factors such as the technology of the power plant, quality of coal used, site location, atmospheric conditions, population variables and such. However, GHG emissions costs show less variance as local conditions have no effect on determining damage costs. Nuclear costs on the other hand show the 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 though considering uncertainties and variations fall within the range of valuations performed in European countries using the ExternE methodology.

At this point it becomes essential to highlight the significant features of this study by summarising the contributions, uncertainties and recommendations associated with the current external analysis.

7.2 Contributions

As in any quantitative analysis the results are subject to the methodology used and data processed during analysis. The contributions of this study, enables policy- and decision-making bodies to make informed decisions. This analysis has been performed with the intention of addressing the lack of energy externality information that has been mentioned in multiple scenarios of the IRP policy document. The aim of this study was to quantify externalities along international best practices and to analyse them with respect to the local electricity prices thereby providing policy-makers an improved basis during decision making. The contributions made during this analysis are manifold and are as follows:

- The current externality analysis is based on the ExternE methodology that caters for site transfer and local scenario consideration, which can be extended on availability of improved data sets while analysing public health impacts.
- Estimation of methane emissions occurring during coal mining connected to electricity production, thereby creating a GHG inventory related to electricity generation.
- Review of water costs which is often overlooked as a vital component during electricity generation when considering the national scarcity of water.

- Segregation of occupational health impacts related to coal mining using local data which is essential in avoiding over estimation.
- Assessing public and occupational health effects associated with nuclear electricity generation and collection of local data.
- PPP valuations and conversions are performed in situations where economic data from European and North American contexts are used, which prevents overestimation of local results.
- The findings of the current analysis fall within range with other electricity externality studies performed worldwide, leading to the fact that while external costs are significant it has not reached a situation of grave concern. However the external costs need to be closely monitored and accounted in the energy roadmap of the nation.

7.3 Uncertainties

However, during analysis of each impact there are uncertainties associated at various points of the pathway analysis. Though uncertainties vary on level of magnitude and scale, the most significant issues are identified and stated.

- The primary cause of uncertainty while estimating the human health impact from pollutants is the migration of European ERFs and monetary valuation of health impacts. Nonetheless, PPP valuations are performed to mitigate overemphasis of monetary values, uncertainty over ERF migration still exists.
- The damage costs used to quantify aggregated damages of GHGs are from European background. Though PPP valuations and conversion confirm damages to be in range with the LTMS study, which is based on local scenarios, global uncertainty prevails in choice of damage costs for GHGs.
- There is varied opinion about the economic cost of water across literature and scenarios.

- Occupational disease costs associated with coal mining have been estimated from disease costs occurring across all commodities in the mining sector, which adds to the uncertainty of actual costs.
- Though PPP conversion is performed on monetary valuations of public nuclear health costs based on European methodology, uncertainty prevails when using conversion factors.

7.4 Recommendations

The uncertainties and gaps occurring within this current analysis can be used as opportunities to add on to the existing body of knowledge from either a theoretical research perspective or to aid decision making. The gaps occurring within the current analysis are based on the lack of local data required to quantify impacts that are vital within the overall externality analysis. These impacts are identified as follows:

- Impact of power plant emission on buildings and vegetation and visibility
- Impact of coal power station ash dumps on water resources and human health
- Impact of uranium mining on public health

The IPA methodology used in this thesis can be extended to other energy intensive sectors of the economy, such as the transport sector, construction sector, mining sector or even alternative electricity generation mechanisms. The ExternE using the IPA methodology has been extended to cover the transport and alternative electricity generation schemes and a similar extension can be used in South Africa.

Though the focus in this thesis is to monetarily analyse the socio-environmental impacts or externalities, there are other important factors that is worth mentioning. A multifaceted approach which takes into account energy alternatives from a social, technical, economic, environmental and political (STEEP) can be used to consider the non-monetary aspects. The technical aspect is important while making decisions on adoption of new technologies. The social dimension involves the consideration of job creation, land use, etc., environmental dimension takes into account changes in landscape in addition to pollution effects and political aspects include the political viability of alternative energy and sustainable use. The implications of such an analysis could be multipronged and could lead to additional analysis and discussion.

The costs of the above stated impacts while using a multifaceted approach could be vital from a local perspective and require attention in future evaluations. Thus, while externality evaluations can be modified and refined it is vital that a standardised methodology be used to cater for improvements in analysis and data aggregation. The modifications to energy and electricity policy when taking into effect externalities have to be made by keeping the electricity pricing policy in context. Henceforth a case study of the South African electricity prices is presented.

7.5 Case study of South African electricity prices

External costs as a stand-alone entity do not provide policy-makers sufficient relevance to make decisions that may lead to abatement of factors causing externalities. Relevant policy measures across all sectors are reconsidered and revaluated usually when prices or tariffs are brought into context which is performed in this case study. Electricity prices are of much significance in South Africa when taking into account the impact it has across multiple sectors of the economy. The recent renewable energy focus and trends happening within the electricity sector are also highlighted towards the latter part of the case study.

The South African electricity industry has seen a dramatic increase in prices over the past three years. This increase has been blanketed across all sectors and is based on a number of factors, such as sector, usage, suburb in case of domestic pricing, etc. South Africa's price of electricity, particularly to 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.

In South Africa, the concept of a regulator is relatively new: the National Electricity Regulator (NER) was established only in 1995 and undertook its price-setting responsibilities in relation to Eskom in 2000. Prior to 1994, the government had an agreement with Eskom, requiring a decrease in the real price of electricity by 15% during the period 1994 to 2000. 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-1990s 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 (South Africa, 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 able to sustain itself economically (National Energy Regulator of South Africa, 2010). The functioning and economic sustainability of Eskom is vital, considering the significance of Eskom in the electricity sector in South Africa. The reasons for the revised application by Eskom were specified as follows:

- Fuel price volatility caused by increase in fuel commodity (coal, gas) price, which will directly impact the price of electricity
- Fuel mix uncertainty as a result of varied type of power generation technologies which might to cause prices to vary across regions
- Energy demand/volume uncertainty due to changes in the economic growth that may cause excess demand, thereby creating uncertainty
- Fuel burn rate efficiency uncertainty that could be caused due to a change in the quality of the type of fuel being used to generate an equivalent amount of power

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 Figure 7.3.

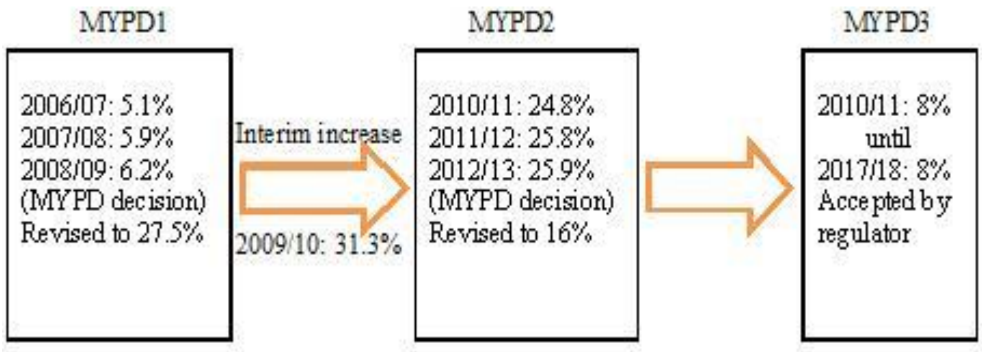


Figure 7.3 MYPD1, MYPD2 and MYPD3 summary

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).

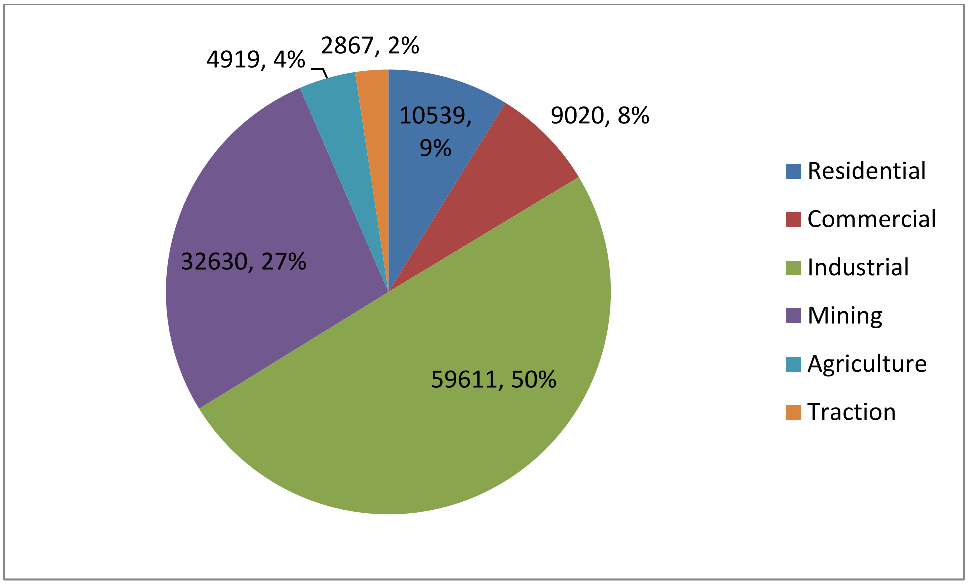


Figure 7.4: Revenue from local electricity sales by Eskom in Rand million

Source: Eskom, 2011a.

The chart above excludes sales to redistributors (municipalities) by Eskom, when taking into account the lack of sectorial breakdowns of sales and revenue figures for redistributors.

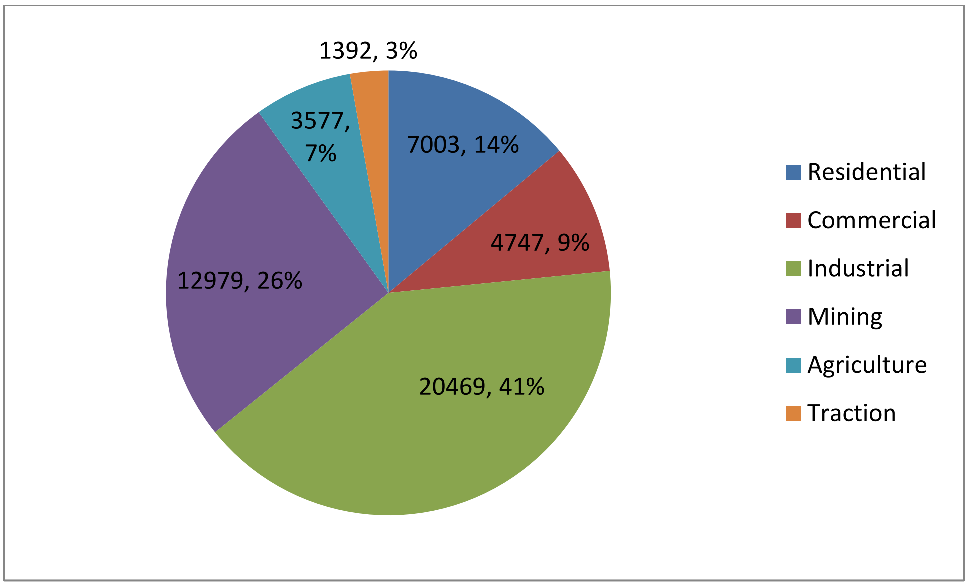


Figure 7.5: Revenue from local electricity sales by Eskom in Rand million

Eskom, 2011a.

It can be observed from Figure 7.3 that two sectors – industrial and mining (which are the largest two sectors) – contribute to 77% of the sales, but generate only 67% of the revenue, with the industrial sector having the largest disparity. This can be better observed in the revenue to sales (R/S) ratio of the percentage contribution, shown in Table 7.8.

Table 7.8: Revenue-to-sales ratio

Sector	Revenue/sales (R/S) ratio
Residential	1.56
Commercial	1.125
Industrial	0.82
Mining	0.96
Agriculture	1.75
Traction	1.5

The largest reverse disparity (where revenue is greater than sales) occurs in the agricultural sector, which is a vital sector of the South African social 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 7.9 shows a comparison of industrial and household prices of a few OECD countries and South Africa. A close inspection of the table 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 7.9: 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
The 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

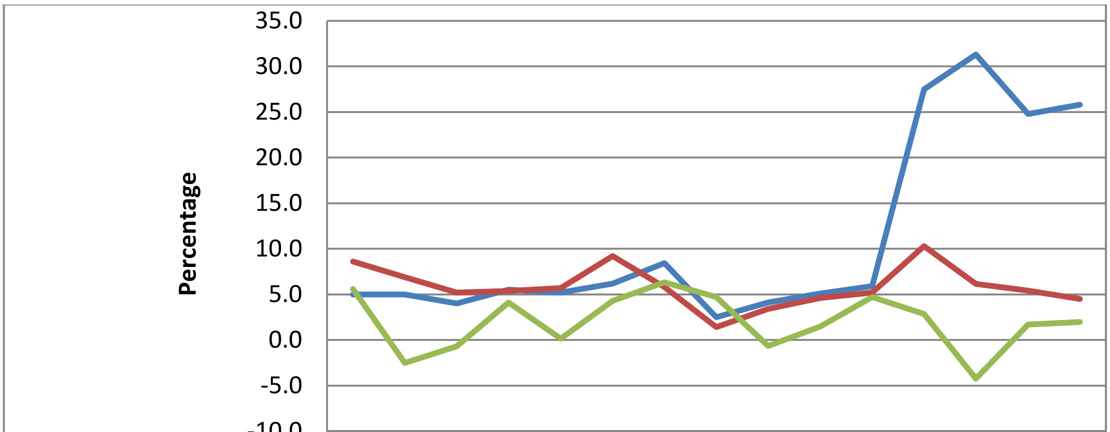
[a]All prices were obtained from the Eurostat portal, except where mentioned. (Eurostat, 2011)

[b]Prices obtained from "Energy prices and taxes" online database.

[c]PPP adjustments were performed using the online OECD database (Organisation for Economic Cooperation and Development, 2011).

Table 7.9 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 2008 to 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 7.4 over the period 1997 to 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 five 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 7.6: Indicator comparison

*The generational data for the year 2005 has been averaged for a 12-month period instead of the 15-month period in the Annual Reports.

Source: Eskom Annual Reports.

Other recent developments within the local industry include 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 (National Energy Regulator of South Africa, 2011). It is speculated that the government's liability concerning long-term feed-in tariffs and legal concerns regarding procurement as the reasons for abandonment of the programme (Bloomberg, 2011). The main opposition was from the National Treasury concerning the pricing regime of the REFIT programme (Pegels, 2011). The REFIT programme was drafted by the Department of Energy and revised to formulate the REIP4 mechanism under the stewardship of the National Treasury 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 3 725 MW of renewable energy to be in commercial operation 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 3 725 MW is available for bidding by interested IPPs over five separate bidding windows, two of which have already been completed (South Africa, 2012). A summary of the REBID programme is mentioned in Table 7.10.

Table 7.10: 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	2.85	200	150	50

Technology	**Tariff cap R/kWh (2011)**	**MW allocated (2011)**	**REIP4 Window 1 MW allocation**	**REIP4 Window 2 MW allocation**
Solar				
Biomass	1.07	12.5	0	0
Biogass	0.8	12.5	0	0
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 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.

7.6 The policy way forward

The externality cost analysis and the case study of the local electricity pricing industry raise the following key questions:

- How can external costs be accommodated or reduced by affecting the price of electricity?
- Is a sector-based discriminatory pricing mechanism a favourable option as opposed to the existing structure?

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 the less the customer uses, the lower the tariff (Eskom, 2011b). However, pricing for large industrial customers is 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, in which 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 subsiding 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 internal 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, especially considering 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 should be no different towards creating a local industry aware of its responsibilities both socially and environmentally.

In conclusion 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 the long term socio-environmental impacts. Policy prioritisation and pricing mechanisms need to be altered with a focus on curbing and minimising the cause of such impacts. An integrated and coordinated approach between government and industry is required, if such goals are to be achieved.

7.7 References

Bloomberg. 2011. Clean energy: South Africa decides to give wind and PV a tender embrace. *New Energy Finance Research Note*.

Eskom. 2009. *Annual Report 2009*. Eskom: Sandton.

Eskom. 2011a. *Annual Report 2011*. Eskom: Sandton.

Eskom. 2011b. *Tariffs and charges booklet, 2011/12*. Eskom: Sandton.

Eskom. 2012. *Renewable Energy Independent Power Procurement Programme: An Eskom perspective*. Eskom: Sandton.

European Commission. 1999. *ExternE National Implementation Vol. XX*. European Commission, Directorate-General XII. Science, Research and Development.

Eurostat. 2011. [Online] Available at:epp.eurostat.ec.europa.eu/portal/page/portal/energy/data/database. Accessed on 2 December 2011.

Jamasb, T, Pollitt, M. 2001. Benchmarking and regulation: International electricity experience. *Utilities Policy* 9: 107–130.

Lin, B, Liu, J. 2011. Principles, effects and problems of differential power pricing policy for energy intensive industries in China. *Energy* 36: 111–118.

National Energy Regulator of South Africa (NERSA). 2010. Nersa's decision on Eskom's required revenue application – MYPD 2010/11 to 2012/13. Pretoria: South Africa.

National Energy Regulator of South Africa (NERSA). 2011. Delays on timelines for the approval of REFIT Review Tariff. Pretoria: South Africa.

Organisation for Economic Cooperation and Development (OECD). 2011. OECD StatExtracts. [Online] Available at: http://stats.oecd.org/Index.aspx?datasetcode=SNA_TABLE4. Accessed on 2 December 2011.

Pegels, A. 2011. *Pitfalls of policy implementation: The case of South African feed-in-tariff*. German Development Institute.

South Africa. 2011. *Integrated Resource Plan for Electricity 2010-2030*. Department of Energy: Pretoria

South Africa, 2012. Renewable Energy Independent Power Producer Procurement Programme. [Online] Available at: www.ipprenewables.co.za/ Accessed on 7 September 2012. Department of Energy. Pretoria.

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

Appendix B: Human health impact data

B1: Air quality standards

Table B1: Comparison of South African and international standards

Pollutant	Averaging time	WHO recommendations[1]	National recommendations[2]
PM10	1 year 24 hours	20 ug/m^3 50 ug/m^3	50 ug/m^3 120 ug/m^3
NO_2	1 year 1 hour	40 ug/m^3 200 ug/m^3	40 ug/m^3 200 ug/m^3
SO_2	24 hours 10 minutes	20 ug/m^3 500 ug/m^3	125 ug/m^3 500 ug/m^3

[1]WHO air quality guidelines global update, 2005. Bonn, Germany, 18-20 October, 2005.

[2]Government Gazette, Vol.534. Pretoria, 24 December 2009. No. 32816

B2: Uniform world models

The most basic form of the Uniform World Model is the Simplified Uniform World Model (SUWM) which is based on these assumptions:

- Constant emission rate and depletion velocity
- Uniform population density
- Linear with zero threshold exposure response

The damage cost associated with the SUWM is calculated with this calculation:

$$SUWM\ damage\ cost = \frac{Emission\ \times Receptor\ \times CRF}{Depletion\ velocity} \times Unit\ cost$$

where, receptor is population density in an area with a radius between 500 and 1 000 km and centred at the emission source location.

For primary pollutants, the SUWM local damage cost for a radius of 50 km is approximated by:

$$\frac{SUWM\ Local\ Damage\ Cost}{SUWM\ Damage\ Cost} = 1 - exp\frac{-t}{\tau}$$

where t = ${}^{Ro}/_{U}$; t is the plume transit time, U is the wind speed and τ = mixing layer height / depletion velocity.

The QUERI model is an extension of the SUWM where site ID, population density and stack parameter of the site are taken into account. These extended parameters together are comprised of a scaling factor (C_f) and denoted as follows:

$$QUERI\ Damage\ Cost = SUWM\ Damage\ Cost\ x\ C_f$$

The scaling factor is the function of source site ID, local and regional populations and stack parameters. Site ID is dependent on the location of emission source from general populated areas and the population ratio which is the local to regional population density ratio. Various site IDs are described as shown in Table B2.

Table B2: Site ID description

Site ID	**Definition**	**Population ratio**
0	Rural source	2
1	Urban source (close to small city)	6
2	Urban source (close to medium city)	10
3	Urban source (close to large city)	> 10
4	Source located between 15 to 25 km from large city centre	
5	Source located between 15 to 25 km from large city centre	
6	Source located more than 40 km from a large city centre	

The RUWM is very similar to the QUERI model except for the inclusion of detailed meteorological data as described in the next section.

B3: Meteorological data format

The weather data used in the QUERI model comprises of parameters such as wind direction, wind speed and ambient temperature. The data is sampled hourly for the duration of an entire year. Data was collected from the South African Weather Service station for locations closest to the power plants and Eskom’s own weather monitoring stations and triangulated to choose the data closest to the relevant power station. The format of the input data used within the QUERI model is as shown in Table B3.

Table B3: Abridged meteorological data for Arnot power plant for the year 2008

Year of data	**Month**	**Day**	**Hour**	**Wind direction (deg from North)**	**Wind speed (m/sec)**	**Ambient temperature in Kelvin**
8	1	1	1	70.23	1.32	280.6
8	1	1	2	50.78	1.67	285.09
8	1	1	3	71.2	1.93	284.3
8	1	1	4	75.4	1.08	283.56
8	1	1	5	29.9	0.6	282.5
8	1	1	6	33.89	0.51	282.72
8	1	1	7	39.9	0.64	287.69
……	……	……	…..	……….	…….	………
……	…….	……	…..	……….	…….	………
8	12	31	19	349.2	2.42	298.21
8	12	31	20	66.78	2.62	295.78
8	12	31	21	67.52	6.4	292.33

Year of data	**Month**	**Day**	**Hour**	**Wind direction (deg from North)**	**Wind speed (m/sec)**	**Ambient temperature in Kelvin**
8	12	31	22	70.1	6.26	290.7
8	12	31	23	71.1	6.8	289.82
8	12	31	24	74.2	5.91	289.42

The input weather data also consists of anemometer height, which is usually the height at which weather data is sampled at weather stations and is usually 10 m for non-urban stations. Pasquill classes which indicate atmospheric stability are categorised into six classes to indicate atmospheric stability. Classes A, B and C indicate atmospheres that are turbulent, whereas D indicates a neutral atmosphere. Classes E and F indicate atmospheres that are stable. In meteorological terms an unstable atmosphere occurs when buoyancy forces cause the vertical motion of air across the lower atmosphere (or troposphere), usually during day time as a result of high solar activity. Since Pasquill class data was not available from the weather stations, hourly atmospheric stability was not considered in the analysis.

B4: Health impacts for individual power plants

Table B4: Health impacts estimated for Arnot (central estimates)

Health aspect	**Units**	**Impact**
Chronic bronchitis	Cases in person	285
Respiratory hospital admissions	Cases in person	93
Restricted activity days	Cases in days	185838
Long-term mortality	Number of years	52
Short-term mortality	Number of years	30

Table B5: Health Impacts estimated for Duvha (central estimates)

Health aspect	Units	Impact
Chronic bronchitis	Cases in person	600
Respiratory hospital admissions	Cases in person	209
Restricted activity days	Cases in days	392 100
Long-term mortality	Number of years	111
Short-term mortality	Number of years	69

Table B6: Health impacts estimated for Hendrina (central estimates)

Health aspect	Units	Impact
Chronic bronchitis	Cases in person	317
Respiratory hospital admissions	Cases in person	112
Restricted activity days	Cases in days	207 288
Long-term mortality	Number of years	53
Short-term mortality	Number of years	37

Table B7: Health impacts estimated for Kendal (central estimates)

Health aspect	Units	Impact
Chronic bronchitis	Cases in person	695
Respiratory hospital admissions	Cases in person	240
Restricted activity days	Cases in days	453 650
Long-term mortality	Number of years	107
Short-term mortality	Number of years	78

Table B8: Health impacts estimated for Kriel (central estimates)

Health aspect	Units	Impact
Chronic bronchitis	Cases in person	621
Respiratory hospital admissions	Cases in person	140
Restricted activity days	Cases in days	405 330
Long-term mortality	Number of years	199
Short-term mortality	Number of years	36

Table B9: Health impacts estimated for Lethabo (central estimates)

Health aspect	Units	Impact
Chronic bronchitis	Cases in person	756
Respiratory hospital admissions	Cases in person	262
Restricted activity days	Cases in days	493 600
Long-term mortality	Number of years	157
Short-term mortality	Number of years	86

Table B10: Health impacts estimated for Majuba (central estimates)

Health aspect	Units	Impact
Chronic bronchitis	Cases in person	765
Respiratory hospital admissions	Cases in person	224
Restricted activity days	Cases in days	499 962
Long-term mortality	Number of years	53
Short-term mortality	Number of years	68

Table B11: Health impacts estimated for Matimba (central estimates)

Health aspect	Units	Impact
Chronic bronchitis	Cases in person	433
Respiratory hospital admissions	Cases in person	239
Restricted activity days	Cases in days	282 880
Long-term mortality	Number of years	193
Short-term mortality	Number of years	90

Table B12: Health impacts estimated for Matla (central estimates)

Health aspect	Units	Impact
Chronic bronchitis	Cases in person	715
Respiratory hospital admissions	Cases in person	212
Restricted activity days	Cases in days	465 370
Long-term mortality	Number of years	208
Short-term mortality	Number of years	65

Table B13: Health impacts estimated for Tutuka (central estimates)

Health aspect	Units	Impact
Chronic bronchitis	Cases in person	598
Respiratory hospital admissions	Cases in person	205
Restricted activity days	Cases in days	390 400
Long-term mortality	Number of years	273
Short-term mortality	Number of years	67

Appendix C: Environmental impact data

C1: Most recent CDP disclosure of major South African firms

Table C1: Selected firm disclosed CO_2e emission estimates for 2012 based on CDP Report, 2012

Company	Scope 1* tCO_2e	Scope 2 tCO_2e
Eskom	231 900 000	0
Sasol	61 396 000	9 308 000
ArcelorMittal	10 961 907	4 487 197
Portland Pretoria Cement	4 728 271	582 841
BHP Billiton	3 187 000	13 388 000
Anglo American	3, 020, 716	7, 709, 504
Sappi	2 829 691	1 393 269
Mondi	878 910	723 262
Gold Fields	622 591	4 567 035
Anglo Platinum	534 431	5 900 537
SAB Miller	344 965	783 073
AngloGold Ashanti	73 000	3 006 000
Harmony Gold Mining Company	32 851	3 249 167

C.2: Methane emission models

C.2.1: Underground mines

Methane emission factor (MEF)

The MEF is derived from the ventilation methane concentrations, combined with the total production from test site mines.

This gives a value for the MEF of (1.11 ± 0.26) * sgc

After mining factor (AMF)

The AMF is derived from the residual gas remaining in the coal from the test site mines. This gives a value for the AMF of (0.30 ± 0.06)* sgc

The Underground Emission Model (UEM) is a combination of MEF and AMF given by:

UEM = MEF + AMF

= (1.41 ± 0.32)*sgc * tonnes

C.2.2: Open cast mines

The Open cast Emission Model (OEM) for surface mines is derived from the difference between the in situ sgc and the residual seam gas content (sgc_R);

$$OEM = sgc - sgc_R$$

$$= [(0.030 \pm 0.007) – (0.016 \pm 0.005)] * tonnes$$

$$= (0.014 \pm 0.012) * tonnes$$

C.2.3: Density of methane

The assumed density of methane for the calculations in this report is 0.718 kg/m^3 which occurs at zero degrees Celsius.

Appendix D: Occupational impact data

Table D1: Labour statistics from South African coal mines

Year	Average number of employees In Service			Earnings – R1 000		
	Total	Males	Females	Total	Males	Females
1986	120 214	116 020	4 194	1 246 132	1 202 885	43 247
1987	114 022	110 083	3 939	1 383 246	1 332 197	51 049
1988	108 988	104 945	4 043	1 544 872	1 486 724	58 148
1989	107 170	102 917	4 253	1 869 947	1 801 915	68 032
1990	103 808	99 388	4 420	2 129 635	2 045 953	83 682
1991	96 207	91 872	4 335	2 440 860	2 343 515	97 345
1992	76 049	73 194	2 855	2 081 563	2 010 420	71 143
1993	61 438	59 152	2 286	1 883 545	1 821 312	62 232
1994	60 187	57 900	2 287	2 020 594	1 948 763	71 831
1995	62 064	59 715	2 349	2 370 974	2 288 345	82 629
1996	63 397	60 940	2 457	2 781 716	2 686 884	94 832
1997	61 607	59 182	2 425	3 204 101	3 094 864	109 237
1998	60 309	57 881	2 428	3 522 812	3 399 296	123 516
1999	55 378	53 317	2 061	3 831 148	3 698 025	133 123
2000	51 346	49 375	1 971	4 287 493	4 126 651	160 842
2001	50 740	48 801	1 939	4 451 185	4 293 204	157 981
2002	47 469	45 511	1 958	4 468 143	4 288 536	179 607
2003	47 239	45 125	2 114	5 481 105	5 251 724	229 381
2004	50 327	48 106	2 221	5 863 461	5 582 370	281 091
2005	56 971	54 501	2 470	6 481 823	6 155 962	325 861
2006	57 778	54 933	2 845	7 269 836	6 854 933	414 902
2007	60 439	56 582	3 857	8 692 064	8 107 230	584 834

Adapted from Department of Mineral Resources, Labour Statistics

Table D2: Controlled mines; breakdown per commodity for 2008

Type of commodity	Number of mines
Gold	23
Chrome	13
Vanadium	2
Coal	71
Platinum	14
Phosphate	1
Asbestos	1
Quarries	45
Uranium	1
Copper	1
Mica and Felspar	4
Andalusite	2
Iron ore	5
Manganese	2
Lead	1
Diamond	10
Fluorspar	2
Mangesite	1

Source: CCOD, 2008.

Table D3: Units of radioactivity and radiation dose

Quantity	SI unit and symbol	Non-SI unit	Conversion factor
Radioactivity	becquerel, Bq	curie, Ci	1 Ci = 3.7 x 10^{10} Bq = 37 Gigabecquerels (GBq) 1 Bq = 27 picocurie (pCi)
Absorbed dose	gray, Gy	Rad	1 rad = 0.01 Gy
"Dose" (Equivalent dose)	sievert, Sv	Rem	1 rem = 0.01 Sv 1 rem = 10 mSv

Table D4: Recommended Radiation weighing factors

Type and energy range	Radiation weighting factor, WR
Gamma rays and x rays	1
Beta particles	1
Neutrons, energy	
< 10 keV	5
> 10 keV to 100 keV	10
> 100 keV to 2 MeV	20
> 2 MeV to 20 MeV	10
> 20 MeV	5
Alpha particles	20

Source: www.ccohs.ca/oshanswers/phys_agents/ionizing.html

Table D5: Alpha value of selected nuclear power plants

Country	**Nuclear power plant**	**Survey year**	**Value in Euro** (USD or local currency)
Canada	Gentilly NPP	2002	789.7 € (1000 CAD)
Finland	Olkiluoto NPP	2002	170 €
Mexico	Laguna Verde NPP	2009	404.2 € (520 USD)
Romania	Cernavoda NPP	2009	570 €
South Africa	Koeberg NPP	2009	1010.5 € (1300 USD)
Spain	Asco NPP	2002	1554.6 € (2000 USD)
Sweden	Ringhals NPP	2009	1179.76 € (10000 SEK)
USA	Multiple NPPs	2009	Average of 1865.2 € (2400 USD)