THE DECISION TO INSTALL FLUE GAS DESULPHURISATION ON MEDUPI POWER STATION: IDENTIFICATION OF ENVIRONMENTAL CRITERIA CONTRIBUTING TO THE DECISION MAKING PROCESS

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A research report submitted to the Faculty of Engineering and the Built Environment , University of the Witwatersrand, in partial fulfilment of the requirements for the degree of Master of Science in Engineering

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DECLARATION

I declare that this research report is my own unaided work. It is being submitted to the Degree of Master of Science in Engineering to the University of the Witwatersrand, Johannesburg. It has not been submitted before for any degree or examination at any other University

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____________Day of ____________year 2010

ABSTRACT

Survival of society has always been dependent on ensuring that a balance is continually maintained between the variables of social needs, resources and the environment. The difficulty is that these three elements are more often than not in conflict with each other. Arguably without such conflicts environmental decision making would be far simpler in the knowledge that the potential solution, although not pleasing everyone would be capable of responding to a range of ecological and economic concerns. Environmental decision making requires a structured holistic approach that allows for the evaluation of alternative solutions against an array of often conflicting objectives, although no specific decision making structure is advocated multi criteria objective decision making provides a means to achieve such ends. The methodology provides for the identification of all objectives which are then used to evaluate alternative scenarios or solutions against.

The following research report seeks to identify the environmental criteria that would need to be considered as part of a multi-criteria decision making structure. The report highlights the complexities and often conflicting elements that exist even within the narrow scope of environmental objectives. All discussions are made with specific reference to Eskom's requirement to comply to future air quality legislation and the potential requirement to install flue gas desulphurisation technologies on its Medupi Power Station. Legislative, technological, water and air quality issues are identified and explored as to how they should be evaluated as part of the overall environmental decision making criteria. Through the identification of the environmental criteria it is hinted that Eskoms narrow mandate of electricity production at the lowest cost could potentially prevent the organisation of fully engaging in a holistic decision making process.

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PREFACE

South Africa currently has a regulated national electricity distribution grid, mainly coal based electricity generation portfolio, as a result of the abundance of coal. In addition to coal the country also has small amounts of nuclear (5%), pumped storage and hydro (2%) generating capacity (Heinrich et al, 2007a). South Africa's base load coal fired power stations are all of the pulverised fuel (PF) type and utilise either electrostatic precipitators or pulse jet fabric filters to remove particulate matter from the flue gases. To date no South African power station makes use of any gaseous emission pollution control (Eskom, 2009).

The South African economy is currently experiencing greater than expected economic growth, resulting in a rapidly declining surplus of power. In South Africa, demand for power is expected to grow at around the same pace as gross domestic product, with long-term forecasts putting electricity demand on a growth path of 4%. This forcast is based on the 6% GDP growth included in the Goverments ASGISA commitments. Despite the economic crises in 2008/09 and the subsequent decrease in electricity demand current levels of electricity demand for the 2010/11 financial year have indicated an approximate increase of 8% from 2008 levles. In 2003, there was an installed capacity of approximately 40 000 MW, but South Africa's excess capacity, built up over the last 15 years, is close to being exhausted, requiring new capacity to be built. (Engineering News, July 2005)

As a result of the increased demand, Eskom is currently engaged in an extensive build programme. Medupi will be the first of the large base load power stations to be constructed as part of Eskom's new build programme. Medupi Power Station will be the first coal fired power station to be constructed by Eksom since the completion of Majuba in the 1990's.

An environmental authorisation was issued to Eskom, in 2006, allowing for the commencement of construction, subject to several conditions including the compliance to current and future air quality legislation.

Medupi Power Station will include pulse jet fabric filters as well as low NOx burners, therefore the abatement of particulate matter and nitrogen dioxide was not considered to be a significant concern. Sulphur dioxide emissions were however identified as a potential cause for concern

SO_x both the organic sulphur and pyrite sulphur contained in the coal are oxidised to sulphur dioxide (SO_2). Depending on the combustion conditions, a small amount of sulphur trioxide (SO_3) may also be formed. Sulphates represent a small fraction of the total chemical composition of coal and have no significant role in the combustion process itself or in contributing to emissions. The amount of sulphur emitted from coal combustion is a complicated function of the relative amounts of pyrite and organic sulphur in the coal and the combustion conditions (Alphen, 2008). Generally, 5–10% of the sulphur may be retained in the fly ash, the remainder and indeed the vast majority, in the absence of flue gas desulphurisation is released into the atmosphere as SO_2 (Gerricke, 2007)

Internationally, the significant amount of SO_2 produced by the combustion of coal in PF power stations is scrubbed out of the flue gases by various flue gas desulphurisation technologies. The implementation of flue gas desulphurisation (FGD) at international power stations has largely been the result of stricter environmental and air quality legislation (Nalbandian, 2000).

Typically, South Africa, has lagged behind international legislation with environmental trends often been driven by a series of socio-political and economic factors resulting in what has been considered as less stringent environmental requirements. However, since 1998 and the promulgation of the National Environmental Management Act, 1998 (Act No 107 of 1998) South African environmental legislation has been systematically tightened and in many cases aligned with international trends.

Several Flue Gas Desulpurisation (FGD) technologies exist, all of which are considered to be associated with significant capital and operating costs to the electricity industry. The most common technology for reducing sulphur dioxide (SO2) emission is by scrubbing with water containing an alkaline substance known as sorbent such as limestone or any other alternative calcium carbonate substance, for example dolomite (Soud, 2000).

It is the aim of this research report to identify and where applicable model the potential impacts of Medupi, with and without FGD, via dispersion modelling, impact identification and the requirements of water relative to the availability of the resource for the installation of wet FGD. As such it is an evaluation of certain technical environmental information which will be required for a comprehensive Multi Criteria Decision Assessment

This research report is divided into five chapters. In **Chapter 1** the background of this study is introduced. A general literature review briefly discusses sustainability and how the various elements which make up sustainability contribute to decision making. The narrow mandate of Eskom is questioned within this context as illustrated by discussing the potential requirement to install flue gas desulphurisation on Medupi power Station. In addition the chapter will provide an overview of the air quality legislation including emission and ambient air quality standards as a means for countries to ensure that air pollution is brought under control and that the detrimental effects on human health are minimised. The introduction of legislative and technonological issues will provide a contextual backdrop for all modelling and technical discussions in the forthcoming chapters. Multi Criteria objective decision making is identified as a potential tool for sustainable decision making. The chapter is a precursor to the forthcoming chapters which seek to identify the technical environmental criteria which will be the input into a decision making matrix. **Chapter 2** identifies the origin of the data used and the methods used to identify the environmental criteria is discussed. **Chapter 3** critically reviews the water requirements of wet FGD technology within the context of water availability within the Limpopo province. All ambient air quality modelling and associated discussions are undertaken in **Chapter 4** The chapter critically assesses the need for FGD in the context of ambient air quality concentrations and population agglomerations. Finally **Chapter 5** concludes by summarising all the environmental criteria that would need to be fed into a multi criteria decision making matrix.

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Chapter 1

1. LITERATURE REVIEW: SUSTAINABILITY AND THE NEED TO IDENTIFY ENVIRONMENTAL INFORMATION FOR MULTI CRITERIA DECISION MAKING

The passing decades have seen environmental politics and decision making becoming a more prominent feature on the socio-political and economic agendas. In fact it is impossible for any decision to be taken without some thought being given to the environment. Issues of pollution, climate change, species extinction, ecosystem protection, human health protection and so on, all affect the moral, aesthetic and ultimately business decisions taken by large corporations.

The following chapter introduces the concept of sustainability. The concept is used to contextualise Eskom's potential requirement to include flue gas desulphurisation (FGD) as part of the engineering requirements of Medupi. The narrow mandate of Eskom is questioned within this context. Air quality legislative influences and technological considerations will be introduced as influencing factors on the decision making process.

Multi Criteria decision making is identified as a potential tool for sustainable decision making. The chapter is a precursor to the forthcoming chapters which seek to generate the environmental information which will be used in a decision making matrix.

1.1. The Concept of sustainability

Decision making across governments and organisations has developed to a point where it is impossible to separate economic development issues from environmental issues. Dryzek and Scholsberg (1998) argue that development by its very nature erodes the environmental resources upon which it depends and likewise the environmental degradation erodes economic development. Decision makers are therefore faced with a complex situation whereby they are required to map out a path for economic growth on an ever diminishing resources. It is this understanding that gives way to a host of environmental discourses.

It is not the purpose of this research report to comprehensively detail all environmental discourses; that a myriad of approaches exist ranging from the 'paler shade of green' to the darker shades of green radicalism (Dryzek, 1997). For the purposes of forthcoming discussions and in an attempt to highlight the complexities of environmental decision making it is useful to review one of the descriptions provided by the Brundtland report, (1987) which could arguably be seen as a middle position in the environmental debate.

"Sustainable development is a process of change in which the exploitation of resources, the direction of investments, the orientation of technological development, and institutional change are in harmony and enhance both current and future potential to meet human needs and aspirations" (Brundtland report, 46, 1987)

Sustainable development as described by the Brundtland report puts forward the view that organisations, the economy, the world can have it all: economic growth, environmental conservation, and social justice. At first glance such a view looks ideal however on closer inspection the ideal is fraught with paradoxical complexities. If economic growth, environmental conservation and social justice were plotted as the three corners of a equilateral triangle, with the ideal sustainable situation being the centre it becomes evident that as one moves around the interior of the triangle various trade-offs need to be made (Figure 1-1).

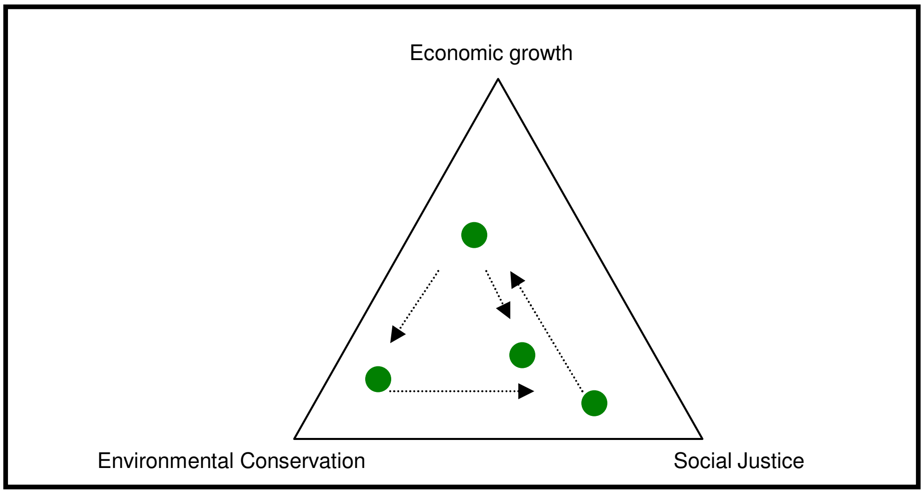


Figure 1-1 Conceptual representation of the sustainability dynamic (view expressed in figure shared by Mebratu, 1998)

1.1.1 Limits to Growth

Costanza et al (1997) argues that the focus of analysis needs to be shifted from one of marketed resources within an economic system towards a more biophysical basis of interdependent ecological and economic systems. The interdependence of ecological and economic systems is further explored by Daly (1995), who's work on "Steady State Economics" details the earth limited resources as a constraining factor on economic growth. It is therefore argued that for economies to continue to grow a focus on the increased efficiency of resource use as apposed to the current quantitative growth focus characterising current economic and subsequent industrial processes.

The concept of limited growth as a result scarce and limited resources is further explored by Goodland's (1992) argument that society has moved from an 'empty world' the economic subsystem as relatively small in comparison to its surrounding biosphere to a situation where the current economic subsystem is large in comparison to the global ecosystem, resulting in the biospheres capacity as a source for resources and a sink for waste products is severely stressed.

Ideas propagating that the scarcity of limited resources and the planets limited sink capabilities are limits to economic growth have historically been criticised. Beckermen (1974) in Adams (1990) summarises such criticism by arguing that the failure to maintain economic growth will result in certain poverty, deprivation disease and squalor. Perhaps though on a less emotive level Blowers (1993) criticises the concept on two issues; the first being that there is little emphirical or scientific evidene that the natural resources are becoming scarce, rather evidence exists that the natural resource base has expanded as a result of economic growth, new discoveries, substitutes and increased efficiency. Secondly, Blowers argues that the entire assumption of limited growth is based on the hypothesis that future trends will behave the same as they did historically. The idea is therefore based on the stoic notion of a predefined future.

Therefore despite sustainable development being viewed as a broader biological concept with respect to the regenerative capacity of natural systems as well as a physical-biological-social concept, where the notion of ongoing sustainability attaches to the relationship between nature, human welfare and the greater economy, this sustainability is only achieved by an understanding of the trade-offs required (Lafferty, 1998).

Applying the above arguments regarding sustainability and subsequently using them to evaluate the long term sustainability of coal fired power stations one needs to rationally impose all three spheres of the sustainability discourse to coal fired technology. The World Coal Institute (2009) defends the appropriateness of the utilisation of coal by arguing that despite the pressures on the technology, the world has a responsibility to provide affordable, reliable and clean energy. The institute acknowledges the environmental pressures on coal however highlights that improvements in energy efficiency, carbon sequestration, technology transfer and water utilisation highlight the technologies commitment to improving its sustainability. Vernon (2004) expands on such sentiments by arguing that coal fired power stations in fact actively meet specific aspects of the sustainability discourse (Table 1-1)

Table 1-2 Summary of positive and negative arguments relating to the sustainability of coal fired power stations (Vernon, 2004)

	Economic	Social	Environmental
Positive impacts	• Source of cheap and reliable fuel for electricity generation • Provides input to major industries • Driver for economic development, • employment and poverty reduction • Contributes to long-term continuity and security of supply	• Provides a relatively low-cost fuel for direct use where no electricity • is available • Electricity contributes to improved community and public health services • Provides opportunities for labour-saving devices, recreation and communication	• Electricity provides energy for environmental services (such as water and sewage treatment
Negative impacts		• Workforce fatalities and injuries • Adverse health impacts from direct domestic use of coal • Public health impacts from coal • combustion emissions	• Greenhouse gas emissions • Air pollution (SO2, NOx, particulates, metals) • Waste generation (ash, residues from emissions control) • Water pollution (cooling, washing, runoff from waste storage)

Although it is possible to argue that Jacob's summary is incomplete as it does not, for example, fully explore economic issues such as the impact that coal has on limiting the development of cleaner renewable technologies, it does highlight that within the sustainability discourse the continued pursuance of coal technologies will require significant trade-offs on the environmental and social criteria. Moreover, as long as coal fired power stations continually fail to address the resource and sink issue as associated with the 'limits to growth' debate the long term sustainability of the technology will always be rightly criticised.

In reality decisions made with sustainability in mind are seldom made in lieu of the equal weighting of the concepts behind the three dimensions of sustainable development.

Decision makers are required to have a holistic picture of the impacts that the trade-offs arising from the final solution may have on the overall 'triangle', this includes a detailed understanding as to how the emphasis on specific aspects will influence the final outcome. It is at this point where the decision making processes followed by institutions encounters a significant constraint. Dryzak (1998) argues that the necessity of integrating a series of potentially conflicting requirements places significant challenges on institutions as they tend to be to fragmented with departments operating independently, pursuing relatively narrow mandates with closed decision making processes. Often those persons responsible for environmental decisions within an organisation are also separated from other decision makers who may be responsible for economic or financial issues.

In particular Eskom – the South African electricity parastatal, which in terms of the current market position has a monopoly on the supply of electricity in South Africa – has an organisational structure which, it could be argued, does not always encourage holistic decision making. In addition to ensuring the sustainability of the business the company continually stives to be a low cost energy producer in order to maximise opportunities for economic growth in South Africa.

1.2. Electricity Demand in South Africa

South Africa has not increased its capacity to supply base load electricity since the Majuba coal-fired power station was brought into operation in the late 1990s. But the demand for electricity has, on average, been increasing over the past decade. Eskom has experienced an average increase in the peak demand for electricity over the past two years in excess of four percent. Consequently, the reserve margin – the difference between the peak demand and the generating capacity – has been decreasing, and has fallen below the internationally accepted norm of 15% (Eskom, 2008)

The growth in the demand for electricity is expected to continue into the future. The South African Government is targeting a six percent per annum economic growth, which relates to an average increase of four percent per annum in electricity demand. Although the government and Eskom have initiated energy efficiency and electricity conservation programmes, these programmes can only reduce the rate at which the demand for electricity grows, implying that it is necessary to build new electricity generating capacity in South Africa. In South Africa, there is a requirement for more than 40 000 Megawatts (MW) of new electricity generating capacity over the next 20 years (Eskom 2008).

Eskom currently (March-2009) has a total net generating capacity of approximately 42 244 MW (Eskom, 2009). Pending government policy and directive, Eskom is currently planning to provide all additional power requirements

1.2.1. Additional Generating Capacity

The additional generating capacity could potentially be obtained from a variety of energy sources, for example coal, liquid fuels, gas turbines, natural gas, uranium (nuclear), hydro and pumped storage schemes and wind and solar energy. The challenge is to correctly match the supply and demand, so that the sustainability of South Africa's electricity supply network will not be hampered. There are a number of factors that must be considered whilst evaluating options for electricity generation, including costs, lead time for construction, environmental impacts, and operating characteristics relative to base and peaking load power generation.

The selection of electricity generation technology by Eskom is conducted within the context of the South African energy policy framework, the legal and regulatory framework, and taking into account the required mix of generating technologies to optimally meet the daily, weekly and seasonal variation in demand for electricity. In South Africa, Eskom currently uses a number of different technologies to convert primary energy sources into electrical energy (electricity), including both renewable technologies and non-renewable technologies. It is therefore necessary to highlight that it is not the contention of this research report to evaluate the different generating alternatives. Rather it is accepted, for the purposes of this discussion that the current preferred option for base load power is coal fired power stations, while acknowledging that the choice of generation technology is multi-faceted and complex and is conducted within the context of the framework of a diversity of South African policies, the merits of which will not be evaluated here. It is also noted that any technology that relies on coal as a feed is unsustainable. The continued use of a natural resource that cannot be regenerated in the lifetime of the operation, ensures the unavailability of the resource for future generations.

Medupi Power Station, in the Limpopo Province is one of two coal fired power stations (the other, Kusile is being constructed in the Mpumalanga region) which is currently being constructed for the purposes of meeting the increasing demand in electricity.

1.2.2. The Medupi Power Station

As a result of the increased demand, as discussed above, that has accompanied economic growth in South Africa, and the consequent estimated 40 000 MW of additional capacity required by 2025 Eskom is currently engaged in an extensive build programme. Medupi will be the first of the large base load power stations to be constructed as part of Eskom's new build programme, the other station being Kusile in the Mpumalanga province. The power station forms part of a suite of build projects that include the return to service of three older power stations that had been mothballed in the days of excess and peaking plants such as open cycle gas turbines and pumped storage schemes.

Construction on Medupi Power Station began in May 2007. It is located in the Waterberg region in Limpopo Province as a result of the significant coal reserves located in the region (Medupi EIA, 2004).

The power station will be located a short distance outside of the town of Lephalale (formerly Ellisras) in the Limpopo Province, approximately 14 km west of the commercial centre of Lephalale and 8 km west-north-west of Onverwacht, a residential suburb. Marapong, another township, smaller than Onverwacht is located north east of the station. The power station will comprise of 6 x 800MW(e) super critical pulverised fuel boilers and will be operated as a base load station (table 2-1) (Eskom, 2006).

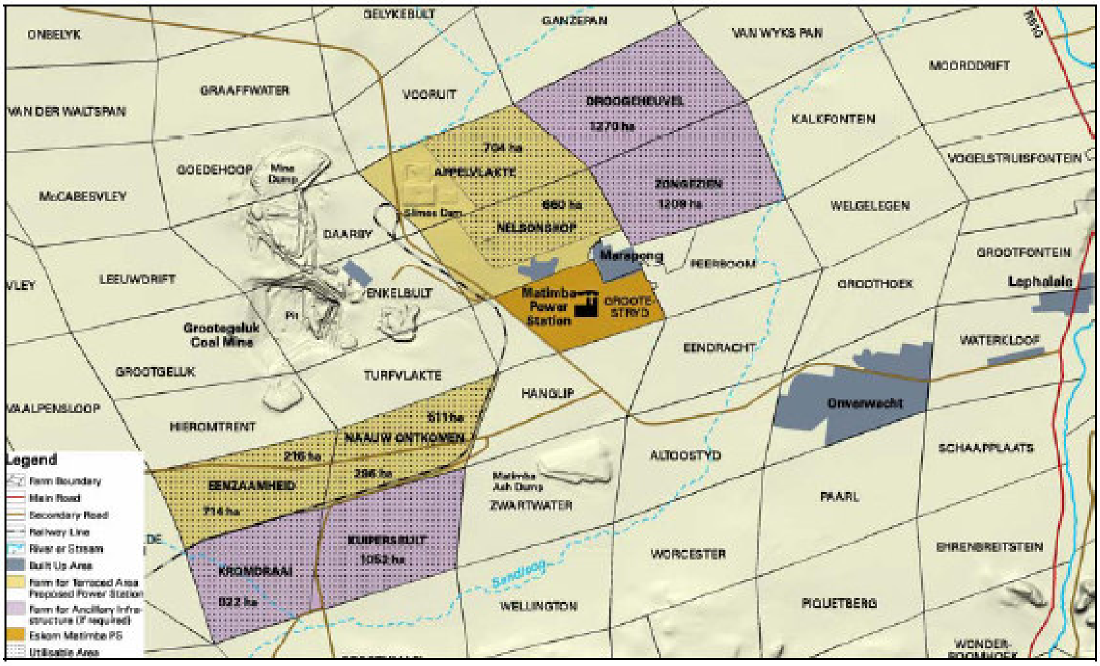


Figure 1-3The location of populated areas (indicated in grey) in relation to Matimba and Medupi power stations. Medupi is to be constructed on the farm Naauwontkomen (Medupi EIA)

Table 1-2 Basic specifications for the Medupi Coal Fired Power station

MEDUPI SPECIFICATIONS		UNITS
Coal		
CV	Approx 20.5	**MJ/kg**
Sulphur content	Approx 1.2	**%**
Ash content of coal	35	**%**
Power Station		
Boiler size	800	**MW**
Number of boilers	6	**#**
Efficiency	37	**%**
Load factor	Approx 90	**%**
Annual MWh sent out	34058	**GWh Sent Out**

Specifications contained in table 2-1 above will form the basis for calculations to be undertaken throughout this research report.

As indicated above construction on Medupi commenced in 2007 after Eskom received the necessary environmental authorisation. In addition to numerous conditions, of relevance to this research report the authorisation required the station to comply with any current and future air quality legislative standards (Medupi Record of Decision, 2006):

"Eskom shall install, commission and operate any required SO_2 abatement Measures that may be necessary to ensure compliance with any applicable emission or ambient air quality standards published in terms of the National Environmental Management Air Quality Act, 2004(Act N o.39 of 2004)."

Medupi Power Station will include pulse jet fabric filters as well as low NO_x burners, therefore the abatement of particulate matter and nitrogen dioxide was not considered to be a significant concern. However, the original design of the power station did not include flue gas desulphurization (FGD) for the mitigation of sulphur dioxide.

An evaluation as to the applicability of FGD technologies, within the current South African environmental, technological and socio-economic context needs to take cognisance of the perceived net environmental benefits when compared to the associated costs of implementing and operating such technologies as well as the potential impacts that they may have on plant efficiency (which is an impact in terms of green house gas emissions).

All FGD technologies are associated with a series of positive and negative environmental impacts. FGD technologies invariably require sorbent, which will have to be mined as well as additional water resources and increased carbon dioxide (CO_2) emissions. It is therefore imperative that when selecting a technology, careful consideration needs to be given to the SO_2 reduction required, available water in the area and availability of sorbent in the area. Handling issues, additional wastes and decreased plant efficiencies ultimately contribute to increased CO_2 emissions.

Consequently any decision to install FGD at Medupi is likely to involve a complex review and evaluation of several conflicting objectives within the sustainability discourse. It is necessary to identify, organise and evaluate all criteria within a comprehensive system allowing the final decision to take account of all policy, economic, social and environmental aspects. Identifying effective solutions to such problems is invariably complicated by the fact that the various elements of the contributing systems are controlled by autonomous agents within Eskom, all of which are governed by the company's narrow mandate of electricity supply. Beck et al. (2008) argues that in such circumstances there is often little consideration that the elements are in fact linked in a dynamic system, the acknowledgement of which often leads to increased innovation, both in terms of technology development, but also in terms of agent behavior. Any decision needs to come from a structured approach that allows for the interlinking and evaluation of all competing objectives.

The difficulty arises in that Eskom as an organisation has a very narrowly defined mandate which does not necessarily allow for the development or incorporation of a range of social and environmental objectives in its planning paradigm. Rather it is left up to legislation to force the consideration of environmentally responsible solutions into Eskom's decision making. Responsible environmental decision making is therefore hampered by internal constraints.

The compliance to relevant air quality legislation is seen as a key determinant in the development of any environmental strategy within Eskom. As the organisation is compelled to comply to air quality legislation, this often becomes the minimum starting point from which environmental considerations can push against existing internal constraints.

The final choice of a preferred FGD technology will significantly influence the extent to which any set of agreed objectives are met. It is therefore considered important that, prior to discussing specific environmental criteria, a FGD technology is identified as this will inform forthcoming chapters.

1.3. South African and International Air Quality Legislation and Policy

The link between air pollution and health has been established, internationally, for well over a century. Pollution legislation including emission and ambient air quality standards are considered to be the only means for countries to ensure that air pollution is brought under control and that the detrimental effects on human health are minimised.

South Africa is part of the global economy and as such Eskom is considered a global power producer, no where is this more evident that Eskom's current reliance on international markets to raise the necessary funding for the construction of Medupi Power Station. Consequently, the engagement with international financial institutions often results in the requirement, although not legally enforceable, to comply with international air quality guidelines in addition to national air quality legislation.

Although the primary pollutants expected from Medupi power station, namely sulphur, dioxide, nitrogen dioxide and particulate matter the focus will primarily be on sulphur dioxide. Sulphur dioxide emissions being the primary motivation for the installation of flue gas desulphurisation (FGD) at Medupi, the focus of this dissertation. To a lesser extent nitrogen dioxide will be discussed, where applicable, as ambient levels of this pollutant are also affected by the introduction of FGD.

1.3.1. Legislative Background

Since 1965, the approach to air pollution control in South Africa was informed and driven by the Atmospheric Pollution Prevention Act (APPA) (Act No. 45 of 1965) (APPA) The Act did not set targets or standards that would permit the achievement of an environment that is not harmful to health or well-being and therefore is not considered to be in line with the Bill of Rights in the Constitution of the Republic of South Africa (Act No. 108 of 1996) which specifically requires that all persons have the right

a) *to an environment that ;is not harmful to their health or well-being; and*

b) *to have the environment protected, for the benefit of present and future generations, through reasonable legislative and other measures that*

- *i)* *prevent pollution and ecological degradation*
- *ii)* *Promote conservation; and*
- *iii* *secure ecologically sustainable development and the use of natural resources while promoting justifiable economic and social development.*

Given this right to a clean environment, it was clear that the APPA could not be considered a suitable piece of legislation when viewed in the context of the Constitution and it was necessary to redefine how air quality was managed in South Africa.

The initial move towards a more holistic approach to air quality management arose as a result of the publication of the *White Paper on Integrated Pollution and Waste Management for South Africa - A Policy on Pollution Prevention, Waste Minimisation, Impact Management and Remediation (IP&WM, 2000),* requiring a shift in air quality management from a reactive command and control basis to the identification for the need for more proactive strategic planning focusing on issues of human and environmental health. Such a need has been carried over into the National Environmental management Act, 1998 (Act No 107 0f 1998) (NEMA) and the National Environmental Management Air Quality Act, 2004 (Act No 39 of 2004) (NEMAQA)

National Environmental Management Act, 1998

NEMA is widely regarded the most significant single piece of legislation dealing with environmental management in South Africa. The stated purpose of NEMA is, amongst other things, to provide for co-operative environmental governance by establishing principles for decision-making on matters affecting the environment and to provide for institutions that will promote co-operative governance and procedures for co-ordinating environmental functions exercised by organs of state. The Act provides a broad legislative framework upon which area/issue specific legislation can be build.

Key principles outlined by NEMA that have relevance to Air Quality management include (National Environmental Management Act, 1998):

- *pollution avoidance or minimisation - pollution and degradation of the environment must be avoided, or,*
- *where they cannot be all together avoided, be minimised and remedied;*
- *waste avoidance and consideration of life cycle assessment· that waste is avoided, or where it cannot be altogether avoided, it must be minimised and re-used or recycled where possible or disposed of in a responsible manner;*

National Environmental Air Quality Act, 2004

In September 2005, the NEMAQA came into force, with the exclusion of sections 21, 22, 36 to 49, 51(1)(f), 51(3), 60 and 61, most of which deal with the licensing of “listed activities” and as such, at the time of writing this research report Eskom coal fired power stations wer still complying to Atmospheric Registration Certificates in terms of the Atmospheric pollution Prevention Act, 1965 (Act No 45 of 1965) (APPA), although extensive discussions and negotiations had been undertaken to convert to Emission licenses, in terms of NEMAQA

The promulgation of the NEMAQA resulted in the alignment of another piece of national environmental legislation with the environmental right set out in section 24 of the Constitution, and the environmental principles articulated in section 2 of NEMA.

NEMAQA serves to create a broad level framework to progressively (NEMAQA, 2004):

“reform the law regulating air quality in order to protect the environment by providing reasonable measures for the prevention of pollution and ecological degradation and for securing ecologically sustainable development while promoting justifiable economic and social development”.

The management and control of air pollution is therefore currently being undertaken in terms of two pieces of legislation, namely the NEMAQA, with respect to sections currently been affected, focusing on strategic and policy level issues and the APPA which still deals with the mechanisms with respect to point source emission management (emission licenses). Ultimately Chapter 5 of NEMAQA which provides for the licensing of listed activities will eventually replace the existing registration certificate process regulated under the provisions of the APPA, however a timeframe for this is not yet known with certainty..

Pollution is defined as “*any change in the composition of the air caused by smoke, soot, dust (including fly ash), cinders, solid particles of any kind, gases, fumes, aerosols and odorous substances*” (National Environmental Management Air Quality Act, 2004). Consequently, the NEMAQA sets the current level of atmospheric pollution as the baseline against which changes in the composition of the ambient air must be assessed (Smith, 2008). Therefore any further emissions to the ambient air would be classified as pollution.

This standardisation of a baseline against which air quality must be compared in order to determine whether emissions change the composition of the air, allows the Minister to:

- declare priority areas in which certain ambient air quality standards must be met and which require specific air quality management;
- list activities “which result in atmospheric emissions and which the Minister or the MEC reasonably believes have or may have a significant detrimental effect on the environment, including health, social conditions, economic conditions, ecological conditions or cultural heritage”;
- declare any activity or appliance as a “controlled emitter” which the Minister or MEC reasonably believes to have a detrimental effect on health and/or the environment as a result of atmospheric emissions; and
- declare a substance or mixture of substances used as fuel and which result in atmospheric emissions which are detrimental to the environment, to be controlled fuels.

The NEMAQA, 2004 represents a distinct shift from exclusively source-based air pollution control. The Act, provides the means to develop and implement the necessary mechanisms that are seen to be promoting a holistic and inter-related impact based air quality management program. It focuses on the adverse impacts of air pollution on the ambient environment and provides for the setting of the necessary standards to control ambient air quality levels as well as setting emission standards to minimise the amount of pollution that enters the environment.

Setting of air quality standards

The NEMAQA provides for the creation of national norms and standards for the monitoring, management and control of air emissions. In accordance to this the act identifies a total of seven (although allowance is made in the legislation for the future declaration of additional pollutants) ‘*criteria pollutants’* namely, sulphur dioxide, nitrogen dioxide, carbon monoxide, particulate matter, ozone, lead and benzene. Subsequently as part of two separate standard setting processes the

Minister has published, for public comments a set of ambient air quality standards and emission limits.

Implementation of NEMAQA

Of particular relevance to Eskom's current operations and capital expansion program, is that key aspects of the NEMAQA have been enacted or proposed.

Permitting of Power Stations

Under the APPA, 1965 air pollution control was administered at a national level by the Department of Environmental Affairs and Tourism. The Act regulated the control of noxious and offensive gases emitted by industrial processes, the control of smoke and wind borne dust pollution, and emissions from diesel vehicles. The implementation of the act is charged to the Chief Air Pollution Control Officer (CAPCO). This individual, in terms of the Act has almost absolute authority to set emission limits and subsequently regulate any emission registration certificate that a polluter needs to comply to.

All power stations are listed under Process 29 in the second schedule of the APPA, 1965 and are controlled by CAPCO through Best Practicable Means (BPM) using registration certificates. Scheduled processes represent processes listed in the Second Schedule of the Act that have the potential to release potentially significant quantities of pollutants. BPM represents an attempt to restrict emissions while having regard to local conditions, the prevailing extent of technical knowledge, the available control options, and the cost of abatement. To date Eskom's registration certificates have focused on the control of particulate matter only.

In the future, under the NEMAQA 2004, the permitting of "Scheduled Processes" by CAPCO (DEAT) will be replaced by the licensing of "Listed Activities" by local government, district municipalities and metropolitan municipalities.

During the transitional phase a provisional registration certificate will continue to be valid for a period of two years. A registration certificate will remain valid for a period of four years, with the registration certificate holder being required to lodge a renewal application with the licensing authority within the first three years of the four-year period (NEMAQA, 2004).

As a result of the additional legislative requirements of the NEMAQA, 2004, with respect to emission licenses, DEAT has initiated a process whereby all existing emission registration certificates will be systematically aligned with the requirements of the NEMAQA 2004, including their renegotiation and the inclusion of additional requirements (gaseous emissions). This process is commonly known as the APPA Registration Certificate Review Project ("APPA Review"). As part of the APPA Review, DEAT has identified several industrial sectors, including coal fired electricity generation, with which the process will be initiated.

Eskom is therefore currently in the process of negotiating new emission licenses, that although they will be issued under APPA, until such time that the relevant sections of NEMAQA are enacted they will however conform to the requirements of the NEMAQA, 2004 and subsequently will include both particulates and gaseous emissions. These new licenses will be applicable to Medupi Power Station.

1.3.2. Emission Limits

Emission limits are simple fixed limit values for a source or source type. The practical advantage of applying emission limits is that they can guarantee the reduction of emissions at a clearly defined source.

To this end the emission limits proposed by the Department of Environmental Affairs and Tourism (DEAT) are currently being reviewed by the respective South African National Standards (SANS) technical working groups and will be published for public comment in the first quarter of 2009 (table 3-1).

Table 1-3 Proposed emission limits for point source emissions arising from combustion installations (NEMAQA, 2004- draft emission limits – 2008).

Substance or mixture of substances		**mg/Nm^3 under standard conditions of 6% O_2, 273 Kelvin and 101.3 kPa.**	
Common Name	**Chemical Symbol**	**New plant**	**Existing plant**
Particulate matter (PM)	Not applicable	20	75

Substance or mixture of substances		mg/Nm^3 under standard conditions of 6% O_2, 273 Kelvin and 101.3 kPa.	
Common Name	**Chemical Symbol**	**New plant**	**Existing plant**
Carbon monoxide	CO	100(coal-fired) 250(biomass-fired)	100 (coal-fired) 250(biomass-fired)
Sulphur dioxide	SO_2	400	4000
Oxides of nitrogen	NOx	500	800

In light of the required environmental authorization for the Medupi Power Station, issued in 2005, it is currently proposed by Eskom that the station be considered as an existing plant as all design and planning was undertaken prior to the launching of the emission limits. DEAT has to date not commented on such a suggestion, and it should be noted that the Record of Decision contains specific conditions requiring that the power station comply with all emission and ambient air quality standards. It does not however specify which standards will be applicable.

1.3.3. Proposed Ambient Air Quality Standards

In addition to the proposed emission limits the South African Government is also proposing a set of ambient air quality standards (NEMAQA, 2004).

Air quality guidelines and standards are fundamental to effective air quality management, providing the link between the source of atmospheric emissions and the user of that air at the downstream receptor site. The ambient air quality standards proposed by DEAT, are intended to indicate safe daily exposure levels for the majority of the population, including the very young and the elderly, throughout an individual's lifetime. Standards are typically provided for one or more specific averaging periods, in South Africa the proposed ambient air quality standards include the following averaging periods 10 minutes, 1-hour average, 24-hour average, and an annual average (NEMAQA, 2004).

Suspended Particulate Matter

The impact of particles on human health is largely depended on (i) particle characteristics, particularly particle size and chemical composition, and (ii) the duration, frequency and magnitude of exposure. The potential of particles to be inhaled and deposited in the lung is a function of the aerodynamic characteristics of particles in flow streams. The aerodynamic properties of particles are related to their size, shape and density. The deposition of particles in different regions of the respiratory system depends on their size. The nasal openings permit very large dust particles to enter the nasal region, along with much finer airborne particulates. Larger particles are deposited in the nasal region by impaction on the hairs of the nose or at the bends of the nasal passages. Smaller particles (PM10) pass through the nasal region and are deposited in the tracheobronchial and pulmonary regions. It is these particles (particulates with an aerodynamic diameter of less than 10 µm) that are the cause of many health related impacts (Scorgie, 2006).

Internationally, air quality guidelines for particulates are given for various particle size fractions, including total suspended particulates (TSP), inhalable particulates or PM10 (i.e.), and respirable particulates of PM2.5. Locally South Africa only has proposed standards for PM10

Table 1-4 Proposed PM10 ambient air quality standards and period of phasing in periods

Averaging Period	Concentration	Frequency of Exceedence	Compliance Date
24 hour	120 µg/m^3	4	Immediate – 31 December 2014
24 hour	75 µg/m^3	4	1 January 2015
1 year	50 µg/m^3	0	Immediate – 31 December 2014
1 year	40 µg/m^3	0	1 January 2015

Sulphur Dioxide

SO_2 is an irritating gas that is absorbed in the nose and aqueous surfaces of the upper respiratory tract, and is associated with reduced lung function and increased risk of mortality and morbidity. Adverse health effects of SO_2 include coughing, phlegm, chest discomfort and bronchitis (Scorgie, 2006)

Proposed ambient air quality standards for South Africa are provided in table 3-3

Table 1-5 Proposed SO_2 ambient air quality standards and timeframe for implementation

Averaging Period	Concentration	Frequency of Exceedence	Compliance Date
Interim level 1 at 99%			
10 minute (calculated on running averages)	500 µg/m^3	526	Immediate
1 hour	350 µg/m^3	88	Immediate
24 hours	125 µg/m^3	4	Immediate
1 year	50 µg/m^3	0	Immediate

Oxides of Nitrogen

NO_x, primarily in the form of NO, is one of the primary pollutants emitted during combustion. NO_2 is formed through oxidation of these oxides once they are released into the air. NO_2 is an irritating gas that is absorbed into the mucous membrane of the respiratory tract. The most adverse health effect occurs at the junction of the conducting airway and the gas exchange region of the lungs. The upper airways are less affected because NO_2 is not very soluble in aqueous surfaces. Exposure to NO_2 is linked to increased susceptibility to respiratory infection, increased airway resistance in asthmatics and decreased pulmonary function (Scorgie, 2006).

Table 1-6 Proposed NO_x ambient air quality standards and timeframe for implementation

Averaging Period	Concentration	Frequency of Exceedence	Compliance Date
1 hour	200 µg/m^3	0	Immediate
1 year	40 µg/m^3	0	Immediate

It is noted that each ambient air quality standard is associated with a number a permissible frequencies of exceedance as well as a time period within which the standard becomes increasingly more stringent either by lowering the limit value or decreasing the amount of permissible exceedance frequencies. Current negotiations within the respective technical committees of SANS are of the view that the time frames are considered to be impractical. All large industries are of the view that the periodic tightening if the standards is not inline with the manner in which the required capital expenditure would be required. For example the implementation of FGD at any existing or proposed power station would be undertaken in a single construction.

It is therefore the current view that the 99 percentile will be valid for the entire time period.

1.3.4. An International Perspective on Air quality

World Health Organisation Guideline Values

The majority of ambient air quality standards are based on limits defined by expert bodies such as the World Health Organisation (WHO) (Sloss, 2003). The WHO Air quality guidelines (AQG) are designed to offer guidance in reducing the health impacts of air pollution based on what the organisation argues as the most current scientific evidence (WHO, 2005). The guidelines are generic in nature and are not intended to be prescriptive. The WHO (2005) itself acknowledges that the limits and standards proposed are intended to support actions aiming for air quality at the optimal achievable level of public health protection in various economic, social and environmental contexts. The standards set in each country should vary according to country-specific approaches toward balancing risks to health, technological feasibility, economic considerations, and other political and social factors. This variability will depend on the country's level of development and capability in air quality management.

Particulate Matter

PM10 guideline values, currently advocated by the WHO, are provided as a set of interim targets aimed at assisting countries in developing a more considered phased approach to PM standards. There is no recommended timeframe for the shifting from one interim target to the next.

Table 1-7Ambient Particulate WHO guideline values for annual means

	PM10 (ug/m3)	PM10 (ug/m3)
WHO interim target 1	70	35
WHO interim target - 2	50	25
WHO interim target	30	15
WHO Guideline value	20	10

Table 1-8 Ambient Particulate WHO guideline values for daily means

	PM10 (ug/m3)	PM10 (ug/m3)
WHO interim target 1	150	75
WHO interim target - 2	100	50
WHO interim target	75	37.5
WHO Guideline value	50	25

Sulphur Dioxide

Historically WHO has progressively advised more stringent ambient air quality standards with respect to sulphur dioxide. In the organisations recent amendments to guideline values the WHO argues that as a result of the uncertainty of relevant epidemiological studies as to the actual impact that SO_2 has on human health over varying averaging periods and different population groupings, a more precautionary approach has been adopted (WHO, 2005). Subsequently the WHO (2005) took the decision to base ambient air quality guideline values on studies that suggest the possibility of the occurrence of health risks at lower concentrations. This has in general resulted in significantly more stringent values compared to those previously proposed.

Table 1-9 Ambient Sulphur Dioxide WHO guideline values (WHO, 2006)

	24-hour Average Sulphur Dioxide(ug/m3)	10 minute Average Sulphur Dioxide(ug/m3)
WHO interim target 1	125	
WHO interim target - 2	50	
WHO Guideline value	20	500

The 24-hour SO_2 WHO guideline is significantly more stringent than the proposed South African standard. The proposed South African standard is in-line with European Commission (EC) and United Kingdom (UK) standards. A *'prudent precautionary approach'* (WHO, 19, 2005) has been adopted in the 2005 WHO Air Quality Guidelines in reducing the 24-hour SO_2 guideline from 125 ug/m^3 to 20 ug/m^3. The effect of SO_2 on human health is inferred from associations between hospital admissions and mortality, and SO_2 concentrations. In the WHO Guidelines, it is acknowledged that, *'there is still considerable uncertainty as to whether SO_2 is the pollutant responsible for the observed adverse effects or whether it is a surrogate for ultrafine particles or some other correlated substance'* (WHO, 18, 2005).

Nitrogen Dioxide

The WHO acknowledges the potential detrimental health impacts that may be associated with the exposure to NO2. However the 2005 guideline states that there is no new scientific evidence that requires the tightening of existing guideline values.

Table 1-10 Ambient Nitrogen Dioxide WHO guideline values (WHO, 2006)

	1 hour Average Nitrogen Dioxide (ug/m3)	Annual Average Nitrogen Dioxide(ug/m3)
WHO Guideline value	40	200

It is imperative that the WHO guidelines be considered only as, what they are meant, to be which is guideline values. They cannot be considered as standards as are considered to be grossly incomplete. The values do not include frequencies of exceedance to allow for meteorological upsets and industrial process upsets nor do they specify any monitoring protocol, such as at what point should compliance to the limit values be measured or how they should be monitored. These are but a few points which highlight the incompleteness of the guidelines when compared to actual ambient air quality standards.

World Bank environmental guidelines

The World Bank funds many environmental projects in a range of developing countries and has subsequently developed a comprehensive set of environmental guidelines which it applies to such projects. The guidelines aim is to provide a flexible benchmark upon which environmental performance can be measured, as the World Bank is careful not to allow such guidelines to restrict development in developing countries or economies that are in transition (Sloss, 2003).

In addition to the generalised limits that the Bank recommends for power station in non degraded airsheds (Table 3-9), the World Bank also identifies a series of guidelines depending on the *'grading'* of the airshed within which the activity will occur.

A *moderately* degraded air shed is categorised as complying to either of the following conditions

Condition 1(World Bank, 1998)

a) the annual mean PM10 >50 mg/m^3 (80 mg/m3 for total suspended particulates);

b) the annual mean of SO_2 >50 mg/m^3; or

c) the annual mean of NO_x >100 mg/m^3.

Condition 2 (World Bank, 1998)

The 98th percentile of 24-hour mean values of PM10, SO_2 or NO_x over 1 year exceeds 150 mg/m^3 (230 mg/m^3 for total suspended particulates).

An airshed is described as having *poor* air quality if either of the following two conditions apply:

Condition 1(World Bank, 1998)

a) the annual mean PM10 >100 mg/m^3 (160 mg/m3 for total suspended particulates);

b) the annual mean of SO_2 >100 mg/m^3; or

c) the annual mean of NO_x >200 mg/m^3

Condition 2

The 95th percentile of 24-hour mean values of PM10, SO_2 or NO_x over 1 year exceeds 150 mg/m^3 (230 mg/m^3 for total suspended particulates).

In addition to the applicable emission guideline limits for each of the respective airshed the World Bank requires that Power stations located in moderately degraded airsheds ensure that there is no more than a total 5 mg/m^3 increase in the annual mean level of particulates from all plants in the area within a 10-year period. Power plants located in an air shed with poor air quality are required to ensure that emissions do not increase and that measures should be taken to reduce emissions.

Emission limits for plants in both moderate and poor air sheds are shown in Table 3-10 (World Bank, 1998).

The Waterberg airshed, within which the Medupi Power Station will be constructed would be considered as a moderately degraded airshed.

Table 1-11 Guideline emission limits for new coal fired power station (World Bank, 1998)

		Emission Limit		
Plant Type	**Plant Size**	**Particulates (PM10)mg/Sm³**	**SO_2 mg/Sm³**	**NO_x mg/Sm³**
Coal Fired	<50MWe	100	2000 (0.2 t/d total)	750
	<500MWe	50	2000 (0.2 t/d total)	750
	>500MWe	50	2000 (0.1 t/d total)	750
Coal <10% volatile matter	All			1300

Table 1-12 Guideline World Bank emission limits for plants in areas with degraded or poor air quality (World bank, 1998)

Emission	Plant size	Limit
Particulate	All	50 mg/m³
SO_2	<500 MWe	<0.2 t/d/MWe of capacity
	>500 MWe	0.2 t/d/MWe of capacity plus 0.1 t/d for each additional MWe of capacity over 500 MWe to a maximum of 500 t/d. The total concentration should not exceed 2000 mg/m³
NO_x	All	750 mg/m³ or 260 ng/J or 365 ppm
coal with <10% volatile matter	All	1500 mg/m³

Equator principles

The equator principles do not specifically deal with air quality, but rather refer to a series of high level environmental principles that the majority of international financial institutions have signed. Consequently, the importance of these guiding principles is that the raising of capital on the open international financial markets often results in the various financial institutions requiring statements of compliance to the equator principles from the borrowing organisation.

The principles aim to ensure that social and environmental risks are adequately assessed and managed in project financing. The principles are as follows Equator principles, 1998):

1. *Review and Categorisation* of project risk
2. *Social and Environmental Assessments* to be conducted
3. **Compliance with *Applicable Social and Environmental Standards* – the International Finance Corporation (IFC) Performance Standards and Industry Specific Environmental, Health and Safety (EHS) Guidelines**
4. Compilation of an *Action Plan and Management System*
5. *Consultation* with and *Disclosure* to affected communities
6. Establishment of a *Grievance Mechanism*
7. *Independent Review* of assessment, action plan and consultation process
8. *Covenants* to comply with host country legislation and action plan, to provide reports, and to decommission according to a plan
9. *Independent Monitoring and Reporting*
10. *Equator Principles Financial Institutions (EPFI) Reporting*

Projects are categorised under the Equator Principles according to their environmental and social risk:

Category A – Projects with potential significant adverse social or environmental impacts that are diverse, irreversible or unprecedented (New large scale power stations are typically placed in this category);

Category B – Projects with potential limited adverse social or environmental impacts
that are few in number, generally site-specific, largely reversible and readily addressed through mitigation measures;

Category C – Projects with minimal or no social or environmental impacts.

International Finance Corporation (IFC) Performance Standards

The following IFC Performance Standards are applicable:

- Performance Standard 1: Social and Environmental Assessment and Management System
- Performance Standard 2: Labour and Working Conditions
- **Performance Standard 3: Pollution Prevention and Abatement**
- Performance Standard 4: Community Health, Safety and Security
- Performance Standard 5: Land Acquisition and Involuntary Resettlement
- Performance Standard 6: Biodiversity Conservation and Sustainable Natural Resource Management
- Performance Standard 7: Indigenous Peoples
- Performance Standard 8: Cultural Heritage

With respect to Performance Standard 3: Pollution Prevention and Abatement, the caveat is given that:

> *'If less stringent levels or measures are appropriate in view of specific project circumstances, the client will provide full and detailed justification for any proposed alternatives. This justification will demonstrate that the choice for any alternate performance levels is consistent with the overall requirements of this Performance Standard.*'

Experience has however shown that it remains the decision of the financial institution, to which the motivation is supplied, as to whether or not to accept any motivation request more lenient standards to those prescribed to by the Principles. Typically any motivation needs to be provided by an independent consultant.

Medupi is a Category A (high risk) project. Medupi Power Station is the largest power station to be constructed in South Africa to date

IFC Industry Specific Environmental Health Standards (EHS) Guidelines

With respect to air quality issues, pertaining to large scale power generation projects, the Equator Principles Industry Specific Guidelines refer to the World Bank's *Thermal Power: Guidelines for New Plants* (1998), which contains the emission limits for power plants and any subsequent updates that may follow, including the proposed draft *Environmental, Health and Safety Guidelines for Thermal Power Plants* (11 March 2008).

Ambient air quality is dealt with in the Environmental, Health and Safety General Guideline, in that the guidelines state that projects should prevent or minimise the impact of atmospheric emissions by ensuring that *'emissions do not result in pollutant concentrations that reach or exceed relevant ambient air quality guidelines and standards by applying national legislated standards, or in their absence, the current WHO Air Quality Guidelines or other internationally recognised sources'* (EHS, 4, 1998).

1.3.5. Proposed South African versus World Bank/EHS Guidelines emission and ambient air quality standards

As indicated, the South African ambient air quality and minimum emission standards have been issued for public comment, and will only be finalised once the South African National Standards (SANS) process has been completed and public and stakeholder comments have been considered.

With regards to the proposed South African minimum emission standards, the emission limits in the 1998 World Bank Guidelines are considerably more stringent than proposed South African emission limits for an existing plant, but less stringent than the standards for new plant. The emission standards in the *EHS Thermal Plant Guidelines* are similar to the South African proposed standards for new plant, but the particulate matter standards in the EHS Guidelines are more lenient than the proposed South African standards for new plant (table 3-11).

A comparison of the SO_2 and NO_2 standards highlight that in general the WHO and EHS guideline values are more stringent, although limits proposed for new power stations are considered to be in line with each other, with the SA standards perhaps being slightly less lenient.

Table 1-13: Comparison between proposed South African, World Bank and EHS emission standards/guidelines

	Proposed South African standards (mg/Nm^3 under standard conditions of 6% O_2, 273 K and 101.3 kPa)		**World Bank Thermal Plant Guidelines (1998)** (mg/Nm^3 dry 6% O_2)	**EHS Thermal Plant Guidelines (2008 draft)** (mg/Nm^3 dry 6% O_2)*
	Existing plant	**New plant**		
Particulate matter (PM)	75	20	50	50
Sulphur dioxide (SO_2)	4000	400	2000	200-850
Oxides of nitrogen (NOx)	800	500	750	510 (PC Boiler)
Carbon monoxide (CO)	100	100		

* For a solid fuels plant ≥ 600 MW in a non-degraded airshed.

With respect to ambient air quality the World Health Organisation (WHO) Air Quality Guidelines are generally stricter than the target proposed South African standards (Table 3-12). According to the *EHS General Guidelines*, WHO air quality guidelines are to be used only in the absence of local air quality standards, however such an interpretation is not always complied with by international financiers who more often than not refer back to them as apposed to the relevant local standards

Table 1-14 Summary of proposed South African ambient air quality standards and WHO air quality guidelines

Pollutant	Averaging period	Current proposed South African standards (ug/m^3)	Target proposed South African standards (ug/m^3)	WHO Guidelines (ug/m^3)	World Bank Standards (1998) (ug/m^3)
Sulphur dioxide (SO_2)	1-year	50	50		80
	24-hour	125 (4 allowed exceedances)	125 (1 allowed exceedance)	20	150
	1-hour	350 (88 allowed exceedances)	350 (9 allowed exceedances)		
	10-minute	500 (526 allowed exceedances)	500 (50 allowed exceedances	500	
Nitrogen dioxide (NO_2)	1-year	40		40	100
	1-hour	200 (88 allowed exceedances		200	
Particulate matter PM10	1-year	50 (4 allowed exceedances)	40 (4 allowed exceedances)	20	50
	24-hour	120 (4 allowed exceedances)	75 (4 allowed exceedances)	50 (3 allowed exceedances)	150
Particulate matter PM2.5	1-year	N/A	N/A	10	
	24-hour	N/A	N/A	25 (3 allowed exceedances)	
Ozone (O_3)	8-hour	235	120	100	
	1-hour	490	200		

Both international and South African air quality legislation and associated standards are aimed at giving effect to each citizen's right to an environment sustaining their health and well-being and determining what concentration of a substance is likely to negatively impact upon the environment to the extent that the environment is significantly degraded.

The transition from the old APPA, 1965 to the wholesale commencement and operation of NEMAQA, 2004 is still in the process of been phased in. Despite this, it seems NEMAQA, 2004 has provided the necessary framework in which to give effect to sustainable development and the other principles in NEMA, 1998, as well as the environmental right contained in the Bill of Rights. The Act, although not fully aligned to international guidelines provides for a dramatic shift in the manner in which Eskom will need to approach to air quality issues. Considerable uncertainty remains as to how government will interpret the relationship between ambient and emission standards, as it is theoretically possible to comply to the one while not complying to the other.

Additional complexities are further encountered with respect to international guidelines, in many cases international financial institutions are signatory to the equator principles. Although all international guidelines acknowledge that air quality standards should reflect a country's legislative, social, environmental and economic context, the interpretation and implementation of such standards by international institutions does not always reflect such an understanding resulting in them requiring Eskom to comply to international guidelines, which are not always aligned to national standards

1.4. Flue Gas Desulphurisation Technology

As indicated South Africa is currently in the process of drafting new regulations and air quality standards to control gaseous emissions in the country. The emissions of SO_2 are directly related to the sulphur content of the coal. Eskom power stations currently utilise coal with an average sulphur content of 0.83% (0.87% in 2008) (Eskom 2009), although it is expected that for Medupi the average sulphur content will increase to approximately 1.2%.

The objective of this section is to provide an overarching review of commercially proven Flue Gas Desulphurisation (FGD) technologies, with a specific focus on wet FGD systems. Discussions of alternative technologies are included as a means of providing a comparative framework upon which wet FGD systems can be discussed

The information provided is intended to provide the reader with high-level financial and technical evaluations of wet FGD against the backdrop of competing technologies available to reduce gaseous pollutant levels of SO_2 from pulverised coal fired power stations.

The following criteria were evaluated for each of the FGD technology variants available in order to conduct a comparison between the technologies: water consumption, sorbent consumption and associated sulphur removal efficiencies, power consumption, capital and maintenance costs.

The following preclusions have been made from forthcoming discussions:

- Seawater FGD, due to the distance of seawater from the Waterberg area
- The ammonia wet scrubber (Walther process), due to Eskom's historic avoidance of ammonia based technologies as well as the technology being considered to fall outside the scope of work of this study.
- FGD technologies which have not achieved sufficient scale-up to contend with a 800MW$_e$ PC unit.
- Non-commercial technologies

The FGD technologies that will be discussed include:

- Spray dry scrubbers
- Sorbent injection processes
- Dry scrubbing technology
- Wet scrubbing technology

1.4.1. Principal Components of an FGD System

Prior to entering into any discussion regarding the various technologies associated with FGD it will be useful to briefly describe the principle components of a FGD system. Such components typically include (Nalbandian, 2006):

Scrubber vessel: The vessel into which the sorbent is injected to react with the SO_2 in the flue gas.

Booster fans and gas/gas heat exchangers: Flue gas handling is common to all FGD systems. It is necessary to boost or increase the flue gas pressure and reduce its temperature prior to entry into the scrubber. This drop in temperature often prompts the installation of a gas/gas reheater once the flue gas has exited the scrubber to ensure that the gas is of a suitable temperature to ensure sufficient plume buoyancy. It is important to note that not all FGD systems include a gas/gas reheater.

Slurry and liquor pumps: These are required for limestone/gypsum slurry recycle in wet FGD scrubbers.

Limestone milling equipment: In wet FGD scrubbers the limestone sorbent material is typically milled on site. Hydroclones are used to size and grade the limestone product from the milling equipment with large particles being returned for grinding.

Solids separation and primary dewatering equipment: Hydroclones are also used for primary product dewatering and solids separation. Primary hydroclones in the gypsum extraction system thicken the gypsum slurry from about 15% to 30% solids before final dewatering. These devices also preferentially separate fly ash and limestone particles from the gypsum. The overflow from the primary hydroclones is then passed through secondary hydroclones, to remove the remaining solids, including limestone and residual gypsum but not the fly ash, and return it with the underflow to the absorber.

Final dewatering of gypsum: the final dewatering of gypsum from wet limestone scrubbers is normally achieved by using either basket centrifuges or vacuum belt filters. Where a <10% moisture product is required, basket centrifuges are used. If >10% moisture product is acceptable, the preference is to use vacuum belt filters, as basket centrifuges are generally considered to be more maintenance intensive.

Sump agitators: multiple agitators operate continuously to prevent settling of solids and enhance mixing of the oxidising air and the slurry in the absorber.

Recirculation pumps recirculate the slurry from the lower portion of the absorber to the spray level.

Air compressors/oxidation air blowers: FGD units require large compressed air and oxidation air blowing systems.

Electrical motors: heavy duty electrical motors are required to power large booster fans, recycle pumps and numerous other smaller pumps and machines.

Materials: an FGD plant represents an extremely hostile environment so there is a requirement for corrosion resistant linings and coatings.

Wastewater treatment plant: design of the sludge dewatering system and the selection of suitable materials of construction are critical in FGD wastewater installations. Functions of a wastewater treatment plant include lime neutralisation/desaturation, heavy metal removal, clarification, filtrations, biological treatment as well as sludge thickening and dewatering.

Flue gas desulphurisation is considered as an end of pipe pollution abatement technology, typically located at the end of the pulverised fuel combustion process either directly before or after the particulate abatement technology, which will either be some type of pulse jet fabric filter (PJFF) or electrostatic precipitator (ESP)

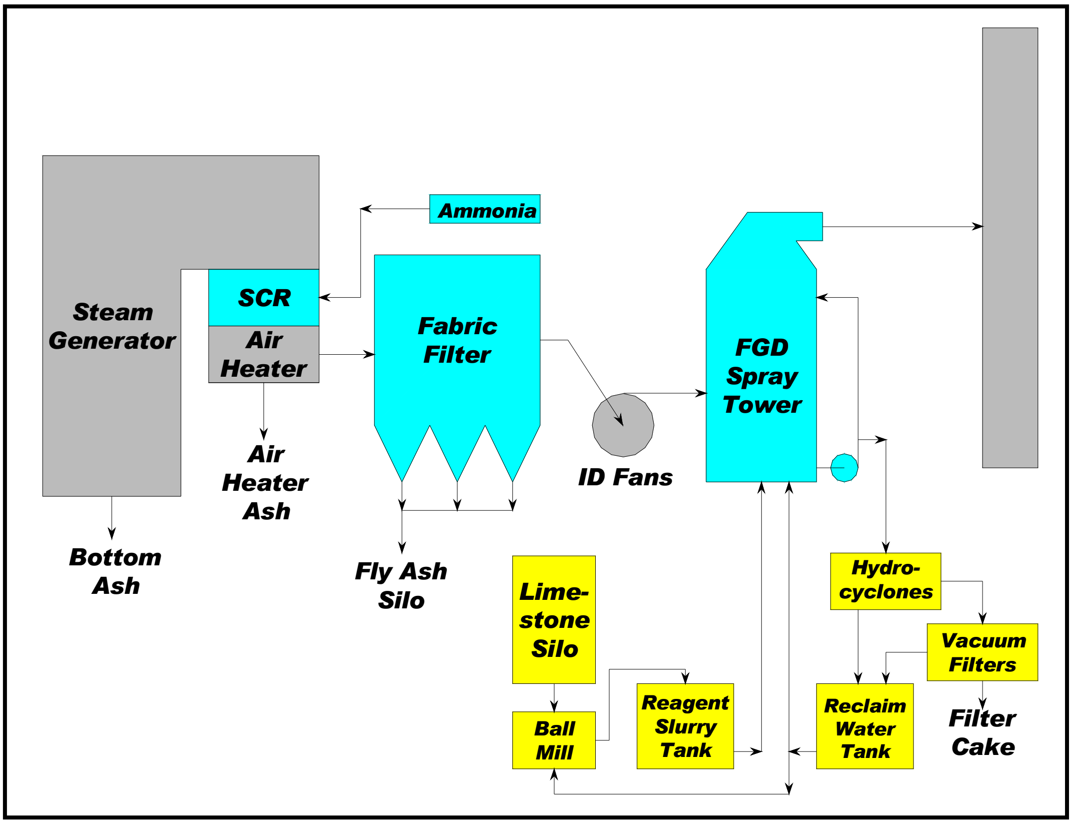


Figure 1-4 Illustration of a typical Wet FGD system (Marsulex, 2007)

Note: Layout and components may vary depending on engineering provider

1.4.2. Flue Gas Desulphurisation Technologies

Spray dry scrubbers

Spray-dry scrubbers (semi-dry scrubbers) are the second most utilised FGD technology following wet scrubbers (see section 4.2.4) and account for approximately 20% of the market share (Soud, 2003). Spray dry scrubbers require the use of an efficient particulate control device such as an electrostatic precipitator (ESP) or fabric filter plant (FFP) downstream of the scrubber, as well as a suitable recycling facility which would greatly improve sorbent utilisation, despite, internationally, the disposal of the by-product being considered the norm (Goddard, 2000).

Typically, spray dry scrubbers involve the spraying of a lime slurry to remove SO_2 from the flue gas. Spray-dry scrubbers are generally characterised by lower capital cost requirements ($26/kW), but higher operating costs than wet scrubbers due to the use of a more expensive sorbent (lime) and a slightly lower calcium utilisation. The higher sorbent costs are associated with the calcining of limestone to produce lime. The by-product from the process is normally a mixture of calcium sulphite, calcium sulphate and fly ash (as removed from the ESP or FFP), which is less valuable commercially than gypsum (Hairpersad, 2006).

The absorber construction material is usually carbon steel making the process less capital intensive compared with wet scrubbers. However, as indicated the lower capital costs are offset by the necessary use of lime in the process which increases its operational costs (Wu, 2000).

It is important to note that the size of these scrubbers is typically limited by the flue gas volume and are therefore only capable of handling, the maximum volumes being equivalent to approximately that produced by a 200 MW_e plants (IEA CCC, 2004). Larger plant require the use of several modules to deal with the total flue gas flow, making the technology slightly more complex and potentially maintenance intensive should it be applied to large scale Eskom type boilers (Hairpersad, 2006).

Spray-dry scrubbers in commercial use have achieved removal efficiencies in excess of 90% with some suppliers quoting >95% SO_2 removal efficiency as achievable (Soud, 2000).

Process Description

As indicated above, the sorbent for SO_2 absorption is typically lime (CaO). Lime is mixed with an excess of water, or is slaked to produce lime slurry also known as lime milk. The lime slurry is atomised to a cloud of fine droplets in the spray dry scrubber to facilitate the removal of SO_2 from the flue gas (Soud, 2000). Excess water produced during the sulphation reaction is evaporated by the heat in the flue gas. The fine hydrated lime particles react with SO_2\SO_3 and HCl to form calcium sulphite, sulphate and calcium chloride. A distinct advantage of this system is the fact that wastewater treatment is not required in this process as all the process water is completely evaporated in the spray-dry scrubber (Goddard, 2000).

The water consumption typically associated with the spray-dry scrubber is approximately 0.14ℓ/kWh, due primarily to the use of the water required for the preparation of hydrated lime (Hairpersad, 2006).

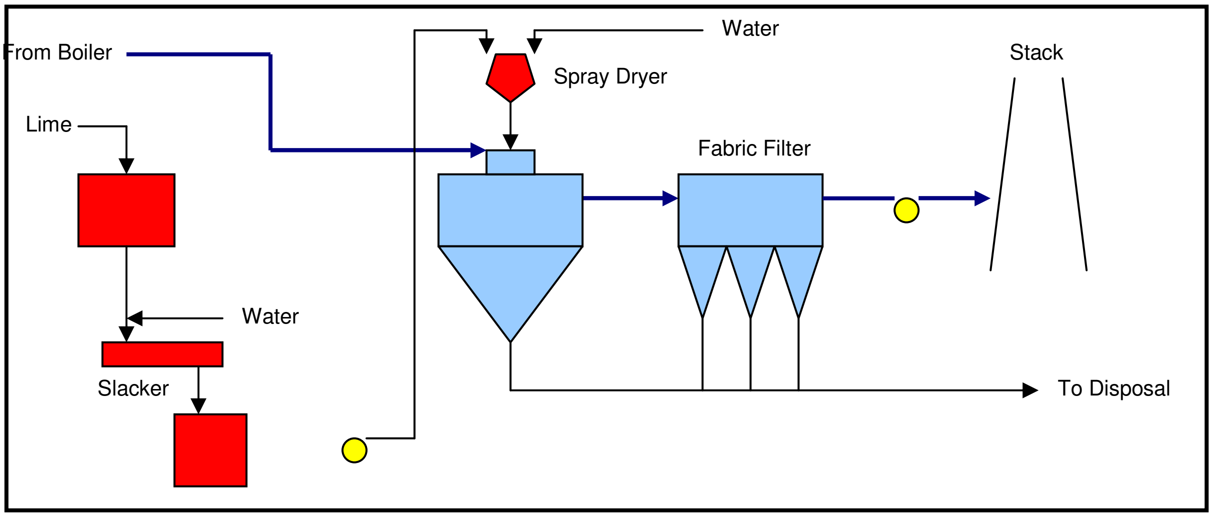


Figure 1-5: Typical Spray-Dry Scrubber (Alstom, 2006)

The process chemistry associated with SO_2 removal from the flue gas is a simple acid/base absorption reaction between SO_2 and hydrated lime. The equations describing the reactions are illustrated bellow (Hairpersad, 2006):

$Ca(OH)_2 + SO_2 \rightarrow CaSO_3 + H_2O$

$CaSO_3 + \frac{1}{2}O_2 + 2H_2O \rightarrow CaSO_4 \bullet 2H_2O$

The absorption chemistry is strongly affected by factors such as flue gas temperature, gas humidity, SO_2 concentration in the flue gas and atomised slurry droplet size Nalbandian, 2006).

It should be noted that SO_3 and HCl are removed more effectively at 95% efficiency in spray-dry scrubbers than in wet scrubbers which achieve a 90 – 95% removal efficiency

The by-product is a dry mixture of calcium sulphite, sulphate, fly ash, and unreacted lime. Although, the spray-dry scrubber process is sometimes called a semi-dry process because it uses lime slurry (a mixture of lime and water), the by-product is a dry powder, which is collected by either the ESP or a fabric filter. As the by-product contains some unreacted lime, part of the by-product is generally recycled and mixed with fresh lime slurry to enhance lime utilisation (Soud, 2000).

Sorbent injection process

The SO_2 emission regulations internationally have generally differentiated between existing utility boilers and new boilers. For older boilers with a relatively short remaining life, technologies with a low capital investment with slightly higher operating costs have generally been considered to be more economically feasible over the remaining life of the plant, despite them not being able to achieve the same removal efficiencies as wet and spray dry technologies. Another factor favouring the use of direct sorbent injection when considering retrofitting of an existing plant with FGD units, is limited space. Sorbent injection technology has been developing and is operating commercially, however only a few utilities are implementing this technology over wet and spray dry scrubbers (Soud, 2000)

Sorbent injection technology is a simplistic process, capable of achieving a moderate SO_2 reduction (30% - 60%) with very low capital cost compared to other FGD systems. It can be divided into four broad categories depending on where the sorbent will be injected into the PF process (Goddard, 2000):

- Furnace sorbent injection
- Economiser sorbent injection
- Duct sorbent injection
- Hybrid sorbent injection

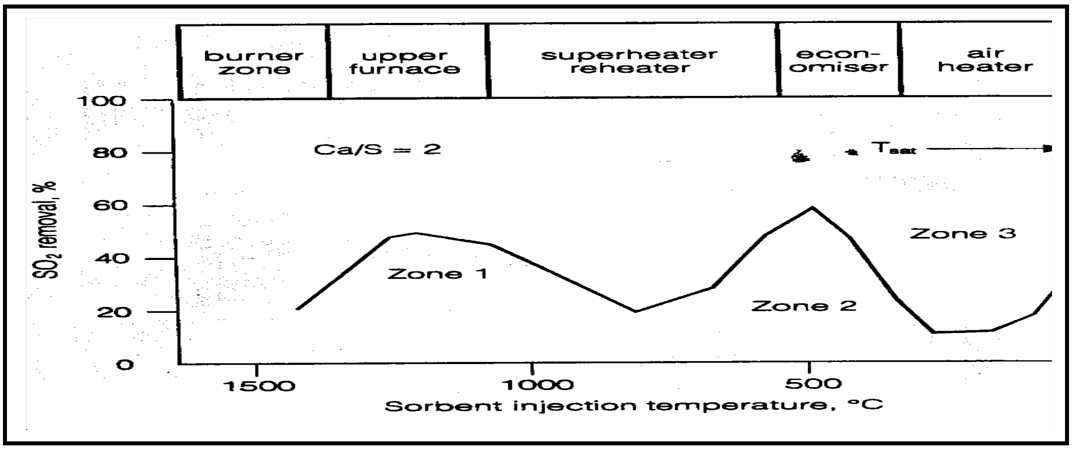


Figure 1-6 SO_2 Removal capability at different temperature windows for sorbent injection (Reproduced with permission from Hairpersad, 2006)

Figure 1-6 illustrates the relationship between the available temperature window and SO_2 removal. Zones 1 and 2 correspond to furnace sorbent injection and Zone 3 to duct sorbent injection. Furnace sorbent injection is considered commercially available since it has been in operation for several years. However, duct sorbent injection is still being investigated. Hybrid sorbent injection systems combine furnace and duct sorbent injection, with some commercial applications. Sorbent injection into the furnace is followed by either sorbent injection into the duct or humidification in a specially designed vessel (Hairpersad, 2006).

Furnace Sorbent Injection

Furnace sorbent injection is the simplest of the sorbent injection processes where a dry sorbent is injected into the upper part of the furnace to react with the SO_2 in the flue gas. The finely grained sorbent is distributed quickly and evenly over the entire cross section of the upper part of the furnace in a region where the temperature is in the range of 750-1,250°C. Commercially available limestone ($CaCO_3$) or hydrated lime ($Ca(OH)_2$) is used as the sorbent. Whilst the flue gas flows through the convective pass, where the temperature remains above 750°C, the sorbent reacts with SO_2 and O_2 to form $CaSO_4$. This is later captured in a FFP or ESP together with unused sorbent and fly ash. Temperatures over 1250°C result in sintering of the surface of the sorbent, destroying the structure of the pores and reducing the active surface area (Soud, 2000).

Removal efficiency of up to 50% can be obtained with a Ca/S molar ratio of 2 using $Ca(OH)_2$ as the sorbent. If $CaCO_3$ is used as the sorbent the removal efficiency will be considerably lower, or the Ca/S ratio will have to be higher (Bjerle et al, 1993)

Economiser Sorbent Injection

In an economiser sorbent injection process, hydrated lime is injected into the flue gas stream near the economiser zone where the temperature is in the range of 300-650℃. In contrast to the furnace sorbent injection process, where the reaction temperature is approximately 1100℃, $Ca(OH)_2$ reacts directly with SO_2 since the temperature is too low to dehydrate $Ca(OH)_2$ completely (Wang et al, 1993). In this temperature range, the main product is $CaSO_3$ instead of $CaSO_4$ and the reaction rate is comparable to or higher than that at 1100℃. The production of carbonate in the process is undesirable, since it not only consumes the sorbent but also blocks the access of SO_2 to active sorbent surfaces. Carbonation significantly increases with reaction temperature (Hairpersad, 2006).

Duct Sorbent Injection

Duct sorbent injection aims to distribute the sorbent evenly in the flue gas duct after the preheater where the temperature is about 150℃. At the same time, the flue gas is humidified with water if necessary. Reaction with the SO_2 in the flue gas occurs in the ductwork and the by-product is captured in a downstream filter. Removal efficiency is greater than with furnace sorbent injection systems, with an 80% SO_2 removal efficiency been reported in actual commercial installations (Soud, 2000).

In order to achieve good utilisation rates of the $Ca(OH)_2$, small particles with an open pore structure need to be created in the process. A dry sorbent has to be finely ground and a sorbent in suspension must be atomised into small droplets, favouring the implementation of wet grinding (Hairpersad, 2006). Such a process, however results in significant handling difficulties which would need to be carefully considered. It is further critical that the temperature of the flue gas be kept above the dew point temperature in order to avoid the formation of unwanted residues, which could result in corrosion problems (Nabandian 2006).

The major factors influencing the performance of the duct sorbent injection process include sorbent reactivity, quantity of injected sorbent, relative humidity of the flue gas, residence time of gas and solids in the duct, and quantity of recycled, unreacted sorbent from the particulate control device (Goddard, 2000).

Hybrid Sorbent Injection

The hybrid sorbent injection process is usually a combination of the furnace and duct sorbent injection processes aimed at achieving higher sorbent utilisation and greater SO_2 removal (Blythe, et al, 2002).

Dry Scrubbers

Circulating fluidised bed and moving bed technologies, which utilise a dry sorbent to capture SO_2 emissions from a flue gas stream in a dedicated reaction chamber are categorised as dry scrubbers. These technologies are often characterized as clean coal technologies and are substantially different to PF systems. Typically the reaction chamber and the boiler are a single vessel (Hendeson, 2003)

In the circulating fluidised bed (CFB) dry scrubber process, hydrated lime is injected directly in the CFB reactor. Water is also injected into the bed in order to create an operating environment close to the adiabatic saturation temperature. The process achieves SO2 removal efficiency of 93-97% with a Ca/S molar ratio of 1.2 – 1.5.

The first advanced CFB dry scrubbing process for semi-dry FGD with slaked lime slurry feed to the fluid bed, has been operated commercially with good results. It is reported that the process can achieve high SO2 removal efficiencies at a substantially reduced lime cost compared with scrubbing by conventional CFB dry scrubbers or spray dry scrubbers (Graf and others, 1995).

Although mentioned here these technologies will not be discussed as they fall outside the scope of this discourse, which is focused on technologies suitable for PF boilers.

Wet Scrubbers

Wet scrubbers, particularly the limestone-gypsum processes, are the front running FGD technologies and it is estimated that they have captured about 80% of the world market share (Goddard, 2006) The technology is actively being utilised in large utility boilers in the 400 – 800MW_e size range (Soud, 2000). The overwhelming bias towards this technology is a result of the high SO_2 removal efficiencies, process reliability, low operating costs and the ability of the process to produce a by-product (gypsum), which is highly marketable in overseas countries (Clark, 1998). Moreover, internationally limestone is the favoured sorbent, as a result of its wide availability.

The by-products are either gypsum or a mixture of calcium sulphate and calcium sulphite, depending on the oxidation mode (Soud, 2000). The production of gypsum requires an additional process step of forced oxidation (Hairpersad, 2006).

The capital costs associated with wet scrubbers are estimated at $45/kW, and operational costs are in the region of $16,075,324/kW, mainly consisting of the cost of the limestone used as the reagent for SO_2 removal.

In the simplest configuration of a wet scrubber, all chemical reactions takes place in a single integrated absorber resulting in reduced capital cost and energy consumption. The integrated single tower system requires less space thus making it easier to retrofit to existing plants (Soud, 1993). This is of particular relevance to Medupi, which as a minimum will be required to be FGD ready, meaning, that should it be recommended not to include FGD as part of the initial construction activities the station could be required at a later date to retrofit FGD.

The absorber usually requires a rubber, stainless steel or nickel alloy lining to control corrosion and abrasion. Fibreglass scrubbers are also currently in operation (Wu, 2003).

Commercial wet scrubbing systems are available in several variations and OEM proprietary designs. Systems currently in operation include:

- Lime/limestone/sludge wet scrubbers
- Lime/limestone/gypsum wet scrubbers (The Limestone Gypsum [LG] Process)
- Wet lime, fly ash scrubbers
- Other non calcium based wet scrubbers include seawater, ammonia, caustic soda, sodium carbonate, potassium and magnesium hydroxide

Wet scrubbers can achieve removal efficiencies as high as 99%. Such high removal efficiencies, coupled with the process's ability to produce a saleable by-product, make it highly likely that the technology will continue dominating the FGD market (Hairpersad, 2006). The increasing cost of land filling in and the introduction of increasingly strict regulations regarding by-product disposal within South Africa and internationally further favour the process.

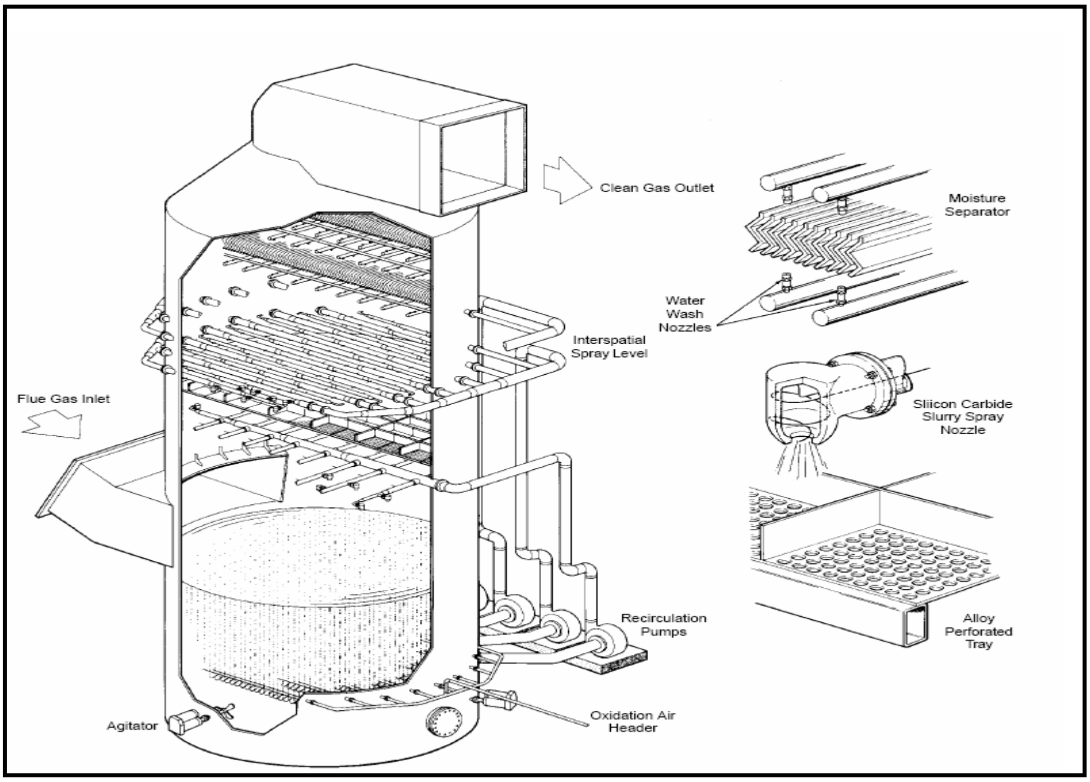


Figure 1-7: Babcock and Wilcox (B&W) Wet FGD Absorber Tower (Babcock, 2006)

Eskom has identified wet FGD technology as its preferred option for inclusion at Medupi, should it be required. This is despite the technology's increased water utilisation, compared to competing technologies. Table 1-17, provides a brief comparison of key aspects associated with the various technologies. The decision to pursue wet FGD was primarily based on lowest life-cycle costs (Eskom, 2006)

Process Description

Flue gas leaving the particulate control system passes through a heat exchanger, and enters the FGD absorber in which SO_2 is removed by direct contact with an aqueous suspension of finely ground limestone. Fresh limestone slurry is continuously charged into the absorber. Scrubbed flue gas passes through the de-mister, and is emitted to the atmosphere through a stack or a cooling tower. Reaction products are withdrawn from the absorber, and are sent for dewatering and further processing. Typical water consumption in a wet scrubber process is approximately 0.21ℓ/kWh (Patel, 2008) depending on optimisation and water conservation strategies implemented, in the case of Medupi this will equate to approximately an additional 1.7 – 2.4Mm^3/a

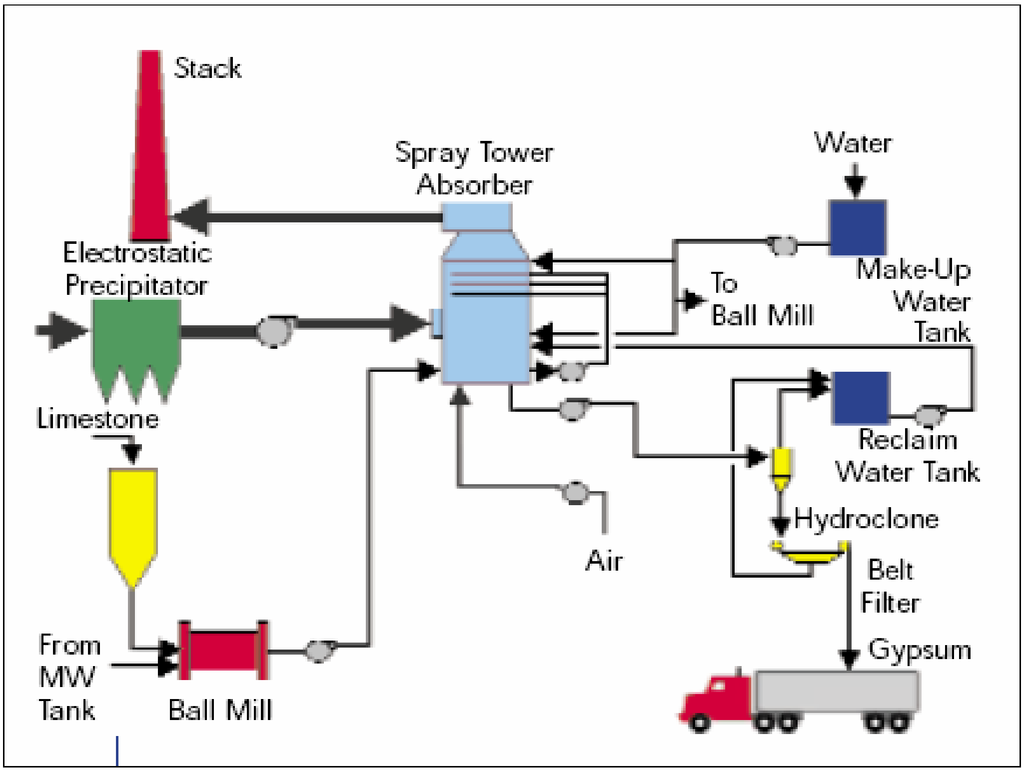


Figure 1-8 Wet Limestone/Gypsum Scrubber Process (Alstom, 2006)

The wet scrubber is generally divided into two categories according to the type of oxidation i.e. forced-oxidation and natural-oxidation mode (Soud, 2000). The mode of oxidation is determined by the chemical reactions, the pH of the reagent slurry and the by-product. In forced-oxidation mode with a pH range of 5 to 6, which is common in wet scrubbers, the chemical reactions are as follows:

$$SO_2 + H_2O \rightarrow H_2SO_3 \qquad (1)$$

$$CaCO_3 + H_2SO_3 \rightarrow CaSO_3 + CO_2 + H_2O \qquad (2)$$

$$CaSO_3 + \tfrac{1}{2}O_2 + 2H_2O \rightarrow CaSO_4 \bullet 2H_2O \qquad (3)$$

Overall

$$CaCO_3 + SO_2 + 2H_2O + \tfrac{1}{2}O_2 \rightarrow CaSO_4 \bullet 2H_2O + CO_2 \qquad (4)$$

Reactions (1) and (2) are common to all wet FGD systems. Reaction (3) shows the forced-oxidation of calcium sulphite by air and the formation (crystallisation) of calcium sulphate bihydrate or gypsum, (Haipershaad, 2006). In forced-oxidation mode, air is introduced into the bottom of the absorber to oxidise calcium sulphite to calcium sulphate, achieving over 99% oxidation (Henderson 2003).

In natural-oxidation mode, calcium sulphite is partly oxidised by the oxygen contained in the flue gas. The main product is typically about 10-20% of solids. The mixture of calcium sulphite hemihydrate and gypsum produced is a sludge:

$$CaSO_3 + ½H_2O \rightarrow CaSO_3 \bullet ½H_2O \qquad (5)$$

In the lower pH range of 4.5 to 5.5, the chemical reaction is different, after SO_2 absorption (1), the primary product of the neutralisation by limestone is not calcium sulphite, but calcium bisulphite $Ca(HSO_3)_2$:

$$CaCO_3 + 2H_2SO_3 \rightarrow Ca(HSO_3)_2 + CO_2 + H_2O \qquad (6)$$

$$Ca(HSO_3)_2 + ½O_2 + H_2O \rightarrow CaSO_4 \bullet 2H_2O + SO_2 \qquad (7)$$

Calcium bisulphite is much more soluble than calcium sulphite. The operation in the lower pH range is associated with a lower risk of scaling and plugging resulting in most process aiming to operate within this range (Soud, 2000). Calcium bisulphite is oxidised and crystallised to form gypsum or calcium sulphate bihydrate (7) (Hairpersad, 2006).

It is important to note that the longer the residence time of the sorbent in the absorber, the larger the final gypsum crystals, which if too large will result in the gypsum being unsuitable for top end markets, as these markets require very high purities. Internationally, it is these markets (including wall board) which are the major users of FGD produced gypsum. The reactivity of the sorbent is also a critical factor in this regard (Black and Veach, 2006).

In addition to the actual desulphurisation process, a key component of the wet FGD process, in its entirety is that of waste water management (Figure 1-8) and dewatering of the gypsum (Figure 1-9).

Dewatering and waste water management

As indicated a significant motivation for employing wet FGD is its ability to produce a saleable gypsum by-product. The various market constraints on this product require that a range of impurities, contributed by the flue gas are removed. Limestone as well as scrubbing products that could accumulate and interfere with the process efficiency as well as the final gypsum product all need to be removed. Such products typically include, particulates chlorides and non-recoverable losses as a result of maintenance (Hebbs and Cooper, 1991). It is therefore unavoidable that waste water is produced although it is possible, at a significant cost to create a closed loop, thereby eliminating the need to discharge the water.

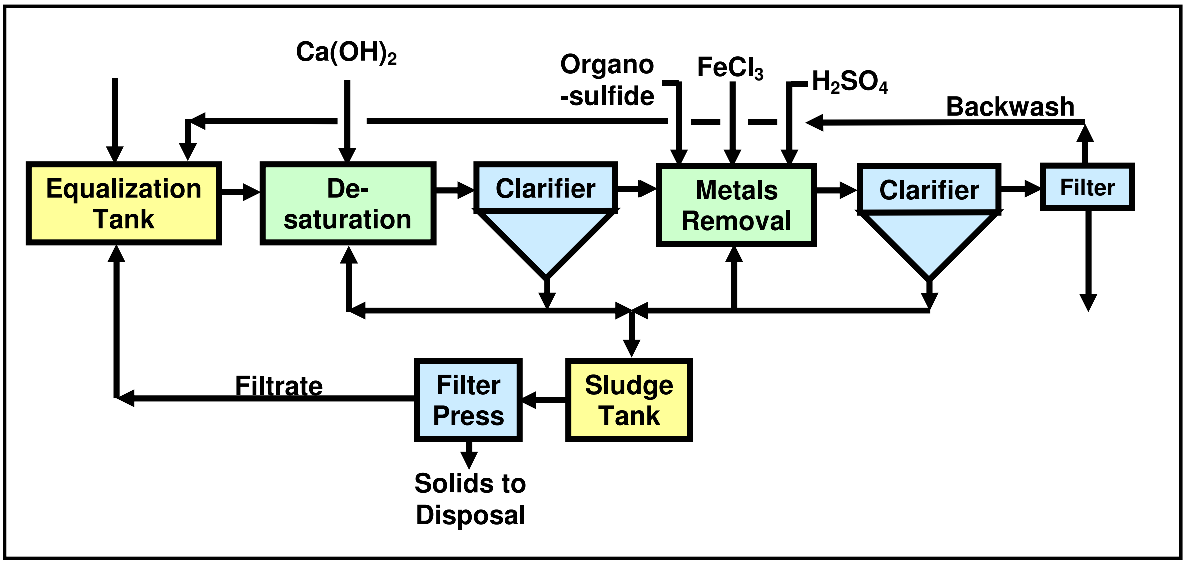


Figure 1-9 Typical waste water management system (Black and Veach, 2008)

Typically FGD waste water is a highly acidic, highly saline solution with variable amounts of suspended solids, metals, chlorides and fluorides. The potential quantity and exact composition of the water is dependent on the following (Clarke 1993):

- Type of FGD process
- Composition of lime and lime stone
- Composition of coal and the flue gas
- Efficiency of the dewatering process:

The most common method of waste water treatment is by means of physiochemical processes involving precipitation and settling (Figure 1-9). Firstly the gypsum saturation is reduced, heavy metals are precipitated by increasing the pH to result in the formation of metal hydroxides and subsequently metal sulphates.

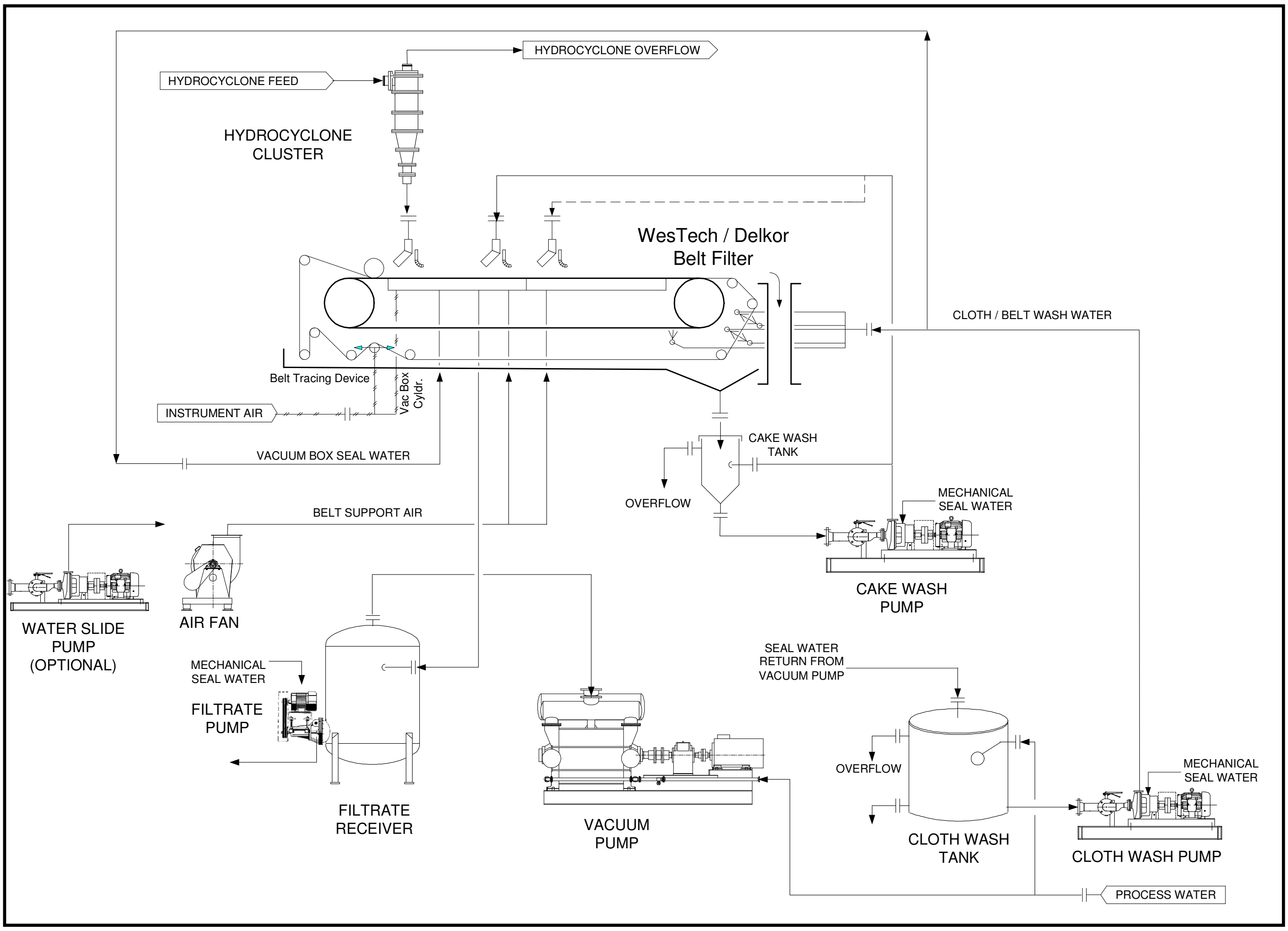


Figure 1-10 Typical gypsum dewatering process (Masulex, 2006)

In addition to managing the waster water it is necessary to dewater the final gypsum product either for storage or final disposal. Should it be required, as is the case internationally, to provide the market with a suitable gypsum product it is important to extract as much water from the gypsum as possible. This is typically achieved by means of a series of hydrcyclones, centrifuges and vacuum conveyers (figure 1-10)

1.4.3. Removal Efficiency and Sorbent Utilisation

Removal efficiencies of SO_2 are typically designed to increase as the sorbent/SO_2 ratio (Ca/S molar ratio) and inlet flue gas temperature increase and the approach-to-saturation temperature decreases (Hairpersad, 2006.

Typical Ca/S molar ratio for the various FGD technologies are provided in Table 1 below.

Table 1-15: Typical Ca/S Molar Ratio for FGD's (Hairpersad, 2006)

FGD TYPE	Ca/S RATIO
1. Wet scrubbers	1.1 – 1.6
2. Spray dry / dry scrubbers	1.01 – 1.05
3. Sorbent injection processes	2 – 3

1.4.4. Sorbent Type and effects of FGD Technology

Table 1-15 illustrates the types of calcium based sorbents suitable for use in the various FGD technologies and the resultant by-products from these processes (Soud, 2000).

Table 1-16 Sorbent Classification for FGD Technologies (Soud, 2000)

FGD Systems	Sorbent CLASSIFICATION	By-product
2. Spray Dry Scrubbers:	$Ca(OH)_2$	$CaSO_3/CaSO_4$
	$Ca(OH)_2.MgO^*$	
3. Sorbent Injection:		
➢ Furnace sorbent injection	$CaCO_3$, $Ca(OH)_2$	$CaSO_3/CaSO_4$
➢ Duct sorbent injection	$Ca(OH)_2$, CaO	$CaSO_3/CaSO_4$
➢ Hybrid sorbent injection	$CaCO_3$, $Ca(OH)_2$	$CaSO_3/CaSO_4$
1. Wet Scrubbers:		
➢ Limestone	$CaCO_3$	Gypsum
➢ Slaked Lime	$Ca(OH)_2$	$CaSO_3/ CaSO_4$
➢ Quicklime	CaO	$CaSO_3/ CaSO_4$
➢ Dolomite	$CaMg(CO_3)_2^*$	

Table 1-17 Summarised comparison of the various FGD technologies

FGD TECHNOLOGY (All technologies below are commercially proven – max. modular size demarcated in brackets)	**SO_2 REMOVAL CAPABILITY** (Based typically on 1.5% Sulphur coal, and FGD unit at MCR)	**Ca/S MOLAR RATIO** (Typical ratios to achieve the SO_2 removal efficiencies)	**WATER CONSUMPTION** (Typical)	**POWER CONSUMPTION**	**OPEX (8000hrs)**	**CAPEX**
Spray-Dry Scrubber (approx. 200MW$_e$)	70 – 90%	1.01 – 1.05	0.14ℓ/kWh (mainly associated with the hydration of lime)	0.5 – 1%	$54 Million or R 543 Million	$26/Kw (2002) or R 260/Kw (2002)
Sorbent Injection Processes (used mainly on older and/or smaller units, effectively a low capital retrofit option)	30 – 60%	2 – 4	N/A (If duct injection is considered, then the sorbent used has to be hydrated lime)	N/A	N/A	$5 – 15/kW
Dry-CFB Scrubber (approx. 200mW$_e$ – 3 modules required for a 700MW$_e$ unit)	93 – 97%	1.2 – 1.5	0.14ℓ/kWh (mainly associated with the hydration of lime)	0.5 – 2%	$54 Million or R543 Million	$26/kW or R260/kW
Wet Scrubber (up to 700MW$_e$)	90 – 99%	1.1 – 1.6	0.21ℓ/kWh	1 – 2%	$16, Million or R160 Million	$45/kW (2002) or $450/kW (2002)

Note: Costs may vary depending on O&M provider, power station requirements and country conditions. All costs are calculated assuming an exchange ratio of R10:1$. All costs are based on published costs

The wet limestone/gypsum scrubber is the most widely used FGD process worldwide, however in South Africa, limestone resources which are used in this process are not readily available in close proximity to the proposed Medupi Power Station. Alternate sorbent such as dolomite do exist in larger quantities. The wet scrubber offers the best SO_2 removal capability (90-99%), followed closely by the spray-dry and dry-Circulating Fluidised Bed scrubber (70-95%).

The sorbent injection process could be considered as an attractive alternative for older power stations requiring retrofits. However based on the high operating costs and low removal capability, it is not considered as a viable option for the Medupi Power Station

Associated capital costs for an equivalent sized unit, are higher for wet scrubbers than spray/dry scrubbers. However the operating costs for wet scrubbers are lower, owing to their lower maintenance requirements and no requirements for hydrated lime. The wet scrubber is further considered to be a more fully integrated unit which addresses the entire desulphurisation process, and is capable of being fitted to PF boilers in excess of 800MW_e. In comparison, the spray dry scrubbers will require a modular design with each module catering for approximately 200MW_e, hence to desulphurise the flue gas produced by a 800MW_e boiler, it is likely that four (4) individual scrubbers would be required.

Eskom has undertaken the decision to favour the Wet Flue Gas Desulphurisation process should it be required at Medupi Power Station. It is acknowledged however that such a decision did not fully consider the various environmental considerations, particularly water usage, and was based primarily on life cycle costing, engineering applicability and greater sorbent all of which are in line with Eskom’s narrow mandate for low cost energy production. Despite any reservations that may exist regarding the FGD technology choice it is not this purpose of this research report to interrogate the rationale rather the decision to utilise wet FGD provides a technological base upon which environmental evaluation criteria can be identified for the purpose of decision making.

1.5. FGD in the Context of Medupi Power Station

Discussions thus far have provided a generic view of flue gas desulphurization technologies. Wet flue gas desulphurization has been identified as a preferred technology, primarily as a result of lower life cycle costs, higher SO_2 removal efficiencies and greater sorbent flexibility. Considerable uncertainty exists as to whether or not to install FGD at Medupi Power Station. This decision is dependent on the implementation and interpretation of national and international air quality legislation and guidelines by both government and international investing agencies, existing and future ambient air quality conditions in the region and the availability of water within the Waterberg region.

However before any detailed assessment and discussion of such risks can be determined it is necessary to develop an understanding of the impacts that a power station at varying stages of FGD readiness will have on the design of the power station. This could range from the immediate installation of FGD on some or all of the units or alternatively the inclusion of FGD at some point in the future. The following chapter will therefore strive to achieve two key objectives. Firstly, although it is acknowledged that air quality and water considerations are fundamental to any decision as whether or not to install FGD there exist several environmental impacts that are directly related to the technology.

Although it is not necessary to discuss the detail design of the Medupi power station, what is required, in the context of this dissertation, is an understanding of the key factors that influence the design of the power station as such factors ultimately impact on the maintenance regimes, operation and resources of the power station. Therefore the second objective of this chapter is to develop an understanding of the technical considerations of installing FGD and how such considerations impact on including FGD now or at some later date. Discussion or at the very least acknowledgement of such issues will considerably contribute to ensuring a greater understanding of the complexities as to whether or not FGD at the Medupi power station is a viable and necessary option. This is explored in later chapters, as well as providing a sufficient framework to determine the manner in which the term ‘FGD ready’ can be applied to the Medupi Power Station.

1.5.1. Environmental Considerations Associated with Wet FGD

Despite the significant increases in capital and operating costs associated with the installation of a wet FGD technology, the pursuit of cleaner air does not only revolve around the economics and engineering characteristics of flue gas desulphurisation abatement technologies. The installation of FGD potentially results in a series of additional environmental impacts as well as the simple transference of ‘pollution’ from one medium to another.

Despite the potential for significant reductions in SO_2 emissions the installation of FGD at Medupi is likely to be associated with an array of additional environmental impacts (figure 1-10). Such impacts can be summarised as follows

- Increased carbon dioxide emissions (as a result of both decrease in plant efficiency and the FGD chemistry)
- increased water use;
- increased effluent discharge;
- increased resource use (sorbent);
- increased solid waste;
- visual impacts (wet plume due to FGD);
- traffic and transport impacts; and
- increased land-use

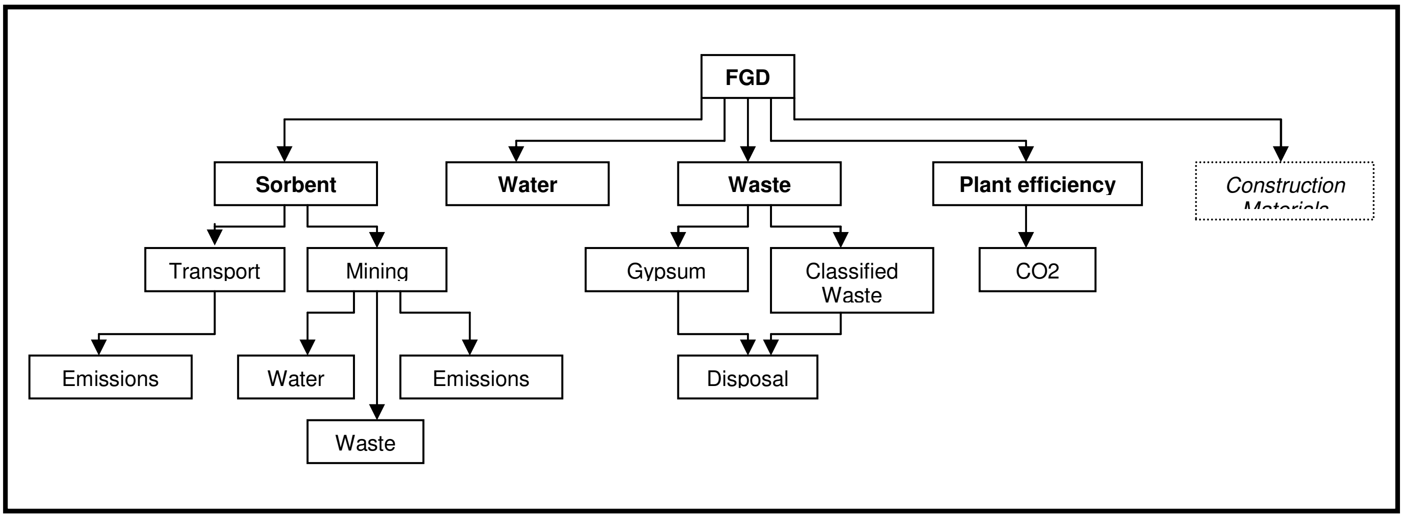


Figure 1-10: Simplified Life Cycle schematic diagram indicating the various environmental impacts associated with the operational aspect of a wet FGD

The schematic diagram presented is not meant to be exhaustive; indeed a full life cycle assessment, if undertaken would extend far beyond the boundaries represented in Figure 1-10 Rather the diagram serves to illustrate the various secondary and tertiary impacts associated with FGD technologies, in which emission reductions are achieved at the expense of a series of associated environmental costs. The focus of forthcoming discussions will be on those impacts directly associated with FGD. Impacts directly associated with FGD at Medupi can be categorised into consumables, which includes plant efficiency, sorbent and water utilisation and additional waste generation. Lower order impacts will only be discussed in a qualitative manner in cases where it is felt that they will aid in the understanding of the primary impacts.

Consumables

FGD if installed at the Medupi power station would require additional water, sorbent and power (Table 1-18), all of which is associated with additional financial and environmental costs.

Table 1-18 Additional consumables required by a wet FGD process at Medupi (Hairpersad et al., 2008)

Item	Consumable	Description	Amount required	Units
1	Sorbent (reagent)	Limestone	700 062	t/annum
2	Water	Water (raw and softened water)	6.5-7.2	Mm^3/a.
3	Power	FGD Equipment (Pumps, motors, fans)	1.5-2	% per unit

Sorbent availability

Despite its highly variable ore grade, sedimentary carbonates are South Africa's major resource of limestone and dolomite *(Figure 1-10).* Deposits of economically viable deposits are typically hosted in five sedimentary units (Hairpersad, 2006):

- The Campbell Rand Subgroup and the Malmani Subgroup – the former in the Northern Cape Province, and the latter in the Gauteng, Limpopo, Mpumalanga and North West provinces,
- The Mapumulo Group – outcropping at Marble Delta in southern KwaZulu-Natal,
- The Nama Group – in the Vanrhynsdorp area of the Western Cape,
- The Malmesbury Group – in the Western and Eastern Cape and,
- The Tertiary and Quaternary coastal limestones – along the Cape coast.

Calcrete and dolocrete deposits are located in the arid regions of the country and provide important resources of low-grade material for both the cement manufacturing and agriculture industries. Travertine deposits are generally small, the exception being the deposit at Ulco in the Northern Cape Province (Eskom, 2007).

The largest limestone resources in South Africa occur in a relatively narrow 150-km long belt along the Northern Cape boundary. Along this belt, most quarries are proximally located to the Kimberley-Postmasburg railway line. Large resources of high-grade limestone and dolomite occur in the Richtersveld (Northern Cape), but have not been exploited because of their remote location. Figure 1-11 provides an overview of limestone recources within South Africa

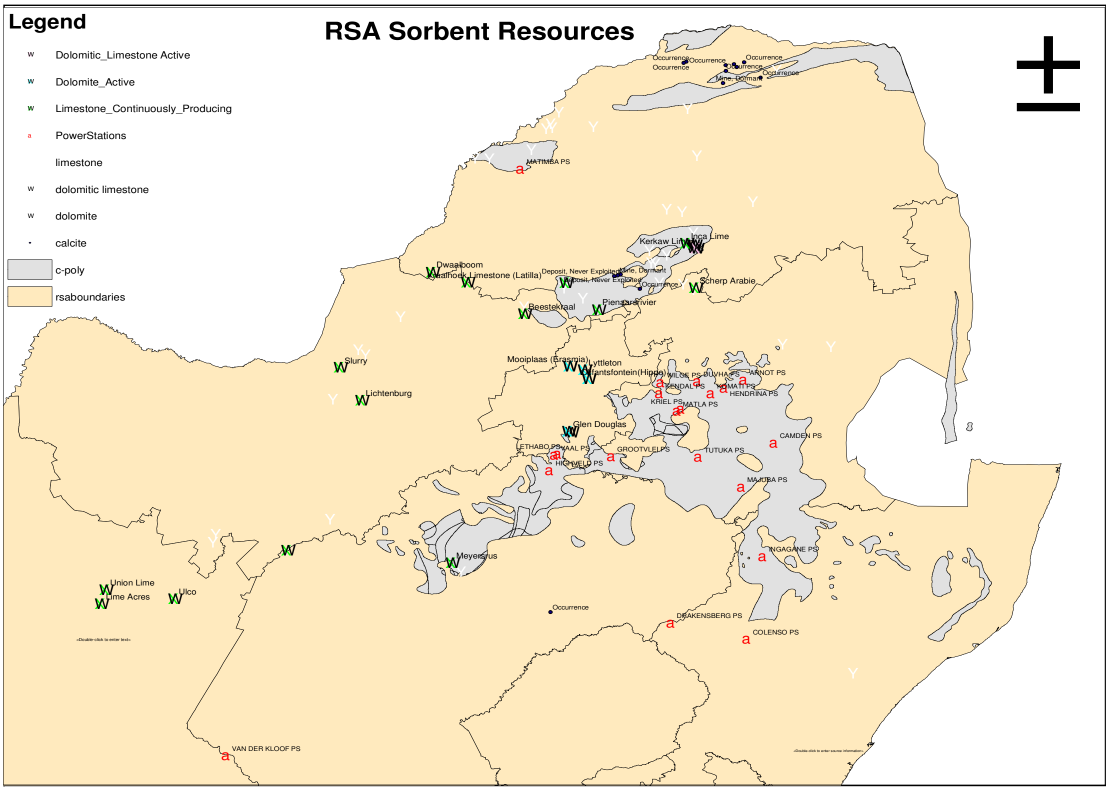


Figure 1-11 Potential sources of Sorbent in South Africa (Eskom, 2007)

South Africa has more abundant dolomite ($Ca.MgCO_3$) resources than limestone ($CaCO_3$), making more readily available for FGD. Tests by Eskom Research and Innovation Division have shown that the magnesium constituent in dolomite does not adversely affect the desulphurisation characteristics within a fluidised bed combustion process. Tests are still underway to confirm the performance for flue gas desulphurisation (FGD), which is the process commonly, associated with scrubbing SO_x emissions from PF stations (Rajoo, 2008).

Initial studies undertaken by Eskom have highlighted that potential commercial sorbent options for the Medupi station, may include (Eskom, 2008):

- Limpopo – Dwaalboom, Lattilla.
- Mpumalanga – Scherp Arabie/Marble Hall, Mooiplaas, Lyttleton, Olifantsfontein.
- Free State – Beestekraal, Glen Douglas.

Despite the potential availability of sorbent, there remains considerable uncertainty as to the quality and quantity of sorbent available. Moreover, initial discussions with the various producers have indicated that in order to meet the requirements for Medupi they would need to significantly scale up their existing operations.

The commercialisation of any new sorbent resource will result in a series of impacts for the area where the mining activity may take place, as any mining activity will result in additional water requirements, waste generation and emissions (both point source and fugitive). The increase in operations of any existing mine or the opening of a new mine will also need to be viewed within the context of the requirements of the Mineral Petroleum Resources Development Act, 2004 (Act No 39 of 2004).

The amount of sorbent likely to be required, at Medupi, will be dependent on the quality of the sorbent available, however it is currently estimated that approximately 700 000 tons/annum of sorbent (limestone) will be required. The requirement for additional sorbent will result in additional traffic and transportation impacts. The sorbent for FGD will probably be transported between 150 and 440 km to Medupi by rail.

Water requirements

Medupi power station will utilise dry cooling technology. Latest estimates indicate that Medupi's long-term steady state water demand will be in the region of 4.38 million cubic metres per annum (Mm^3/a) without any units of FGD being installed. Estimates of the water requirements for the installation of FGD on all six (6) units with 90% removal efficiency and no gas-to-gas re-heater, will increase the stations water requirements by between 6.5 to 7.2 Mm^3/a .

Power

The size of the FGD plant and its subsequent additional power requirements potentially result in an approximately 1.5 to 2% efficiency loss for the power station, resulting in both a loss of financial income for the power station as well as an increase in carbon dioxide (CO_2) produced.

The reduction of CO_2 is considered to be important as the introduction of an FGD system at Medupi would automatically result in additional CO_2 being produced per unit sent out and it is almost certain that South Africa will be required to mitigate CO_2 to prevent global warming in the post 2012 period. Despite the fact that Medupi's net overall thermal efficiency (after deducting auxiliary power used by the power station complex) will be better than 37.5% (Eskom, 2007) in comparison to Matimba Power Station (which is similar in design and size and is also dry cooled) which operates at an overall thermal efficiency of 33.3% (2000 figures), Medupi will remain a significant source of CO_2, emitting approximately 26 000 000 on a annual basis or 808 tons/MWh produced. The decrease in efficiency associated with the chemistry of the FGD plant will result in approximately 1 200 000 tons/year of additional CO_2 being produced with FGD on all six units (5-6% increase).

It should however be noted that any likely increases in CO_2 as a result of efficiency losses can be offset by an increased efficiency in electricity utilisation by the end consumer as a result of increases in electricity prices.

Waste generation

It has previously been indicated that by means of forced oxidation the wet FGD process will produce a saleable by-product, namely gypsum. Internationally gypsum is considered to have an economic value and is therefore a marketable resource. South Africa currently uses gypsum in the construction and agricultural sectors depending on the quality of the final product. Currently the total amount of gypsum utilised across all sectors is estimated at 960 kt/a (Thomson, 2009 and Kruger, 2009). Gypsum is available from natural deposits or as a synthetic by-product such as phosphogypsum, and to a limited degree, FGD processes operating at various industries. The use of gypsum within the South African market is well established with no viable alternatives existing within the construction industry and few available in the agricultural sector.

Naturally, occurring gypsum, in South Africa, typically occurs close to the surface making mining relatively inexpensive and the consequent cost of the final product more dependent on the transportation of gypsum to the market.

It is estimated that FGD at the Medupi Power Station would produce in the order of 1.2 million tons per annum of gypsum which following initial discussions with various potential buyers would be in excess of South Africa's current requirements (La Farge and Saint Gorbain, 2008). The situation needs to be further contextualised by the fact that Kusile, Eskom's second coal fired power station under construction in the Mpumalanga Highveld area, will have FGD and is likely to produce a similar tonnage per annum of gypsum. Kusile is far closer to potential customers making it far more competitive than any gypsum produced at Medupi. However, the proximity to the market is not the only reason for the installation of FGD at Kusile, rather the power station is located in a stressed airshed, which has been declared an air quality priority area by the national government. Moreover air quality modelling exercises undertaken as part of the EIA indicated that the station could potentially result in significant human health impacts should FGD be excluded (Kusile EIA, 2006)

In the event of Medupi Power Station operating with FGD, it is considered unlikely that suitable markets will be identified for gypsum produced without significant effort been expended by national government and Eskom to open additional market opportunities. Such opportunities do exist if a comparison of per capita usage is made between South Africa which has a current usage of 0.66, and that of the United States with a usage of 9.18 (Berland, 2003).

In the likely event of not finding suitable markets for the Medupi FGD gypsum the power station will be required to dispose of the material, a task that could be problematic in terms of current and proposed South African legislation. The gypsum produced will be considered as a waste product, because it is generated from a flue gas cleaning process, and, therefore, must be classified and the environmental risks assessed using the Minimum Requirements. Initial leaching tests with reference to the FGD gypsum to be produced at Kusile, indicated the potential to leach fluoride, which is considered to have a moderate hazardous rating (Munro and Baldwin, 2008).

Conversely leaching tests undertaken at Eskom power stations indicate that ash is likely to be classified as a general waste. The co-disposal of ash/gypsum is considered to result in the potential leaching of lead and magnesium, both of which have a high hazardous rating in terms of the minimum requirements (Munro and Baldwin, 2008).

The cost and land requirements therefore become an issue of concern as, should the gypsum and ash be co disposed, the entire ash dam would need to be appropriately lined to comply with a H:H rating, alternatively the 1.2 mill tons[1] pa (approximate) of gypsum could be disposed of at a separate H:h landfill site.

In addition to the disposal of the gypsum it will be required to dispose of approximately 523,700 m^3/annum of waste water depending on the extent of associated dewatering processes and the number of recycles before it is necessary to dispose of the process water. In this regard the higher the number of cycles the greater the concentration of the chlorides. Typically waste water has a chloride level of approximately 12 000ppm. In an effort to cut down on water utilisation the intervals between the blowing down of the absorbent can be increased which will result in a chloride concentration of approximately 30 000ppm before final disposal to the various maturation dams (Eon, 2008)

Additional environmental considerations

Air quality

In addition to the FGD being resource intensive, the technology also has impacts on plume visibility and dispersion. The FGD configuration at Medupi will likely be one of a wet stack i.e no gas/gas heater. This will result in the flue gas exit temperature being approximately 50℃. The consequent reduction in plume buoyancy will likely impact on ground level NO_x concentrations, as a result of decreased dispersion, as well as the deposition of water droplets within close

[1] Ratio 1.73 tons of Gypsum per ton sorbent utilised – per Babcock Wilcox calcs (Kusile)

proximity to the stack. These water droplets will be associated with a high level of corrosivity owing to their low pH.

The decision not to include a gas to gas heater at Medupi can be summarised as follows:

- reduced cost (capital and operational);
- removal of a maintenance intensive piece of equipment for improved availability;
- simplification of design including removal of additional duct-work;
- higher absorber efficiency due to the removal of heater seal leakage;
- reduction in CO_2 emissions as a result of less electrical power demand due to no reheating of the flue gas.

NO_x dispersion, with and without a gas to gas reheater has been modelled and will be discussed in greater detail in Chapter 6. However, for the purposes of current discussions any configuration which excludes a gas to gas reheater will generally result in an increase of approximately 10% in the annual ambient average NO_x concentrations. In addition, the water vapour emitted from the chimney will result in a white condensation plume. The extent of the visibility of the plume will be determined by ambient temperatures, with higher temperatures being associated with a less visible plume.

International studies regarding such a plume have indicated that the water droplets emitted from the 'wet stack' would not be detectable beyond a distance of 500m from the stack.

1.5.2. Technical and Design Considerations

The extent to which Medupi needs to be FGD ready depends on likelihood that the station will be required to be legally to current and proposed air quality standards as well as the potential current and future impact that the power station may have on the surrounding air quality and communities. Simply, and for the purposes of this discussion, such risks are considered to be directly associated with time, immediate non-compliance or significant risks would result in FGD being installed at construction of the power station. Conversely as time progresses through the operational life of the power station the risk and need to install FGD will also vary, to the extent that it is likely to diminish. It is unlikely that any FGD retrofit would occur beyond the station 25 year half life refurbishment due to the fact that it would be financially more beneficial to defer any FGD investment to newer developments in the region

It is agreed that the relationship is not linear or one dimensional and in fact is dependent on an array of uncertainties including the development of other industries in the region. However as a result of the varying extent of time that Medupi would be required to be off line to retrofit any FGD system in the future, taking into account the current constrained nature of the South African electricity system, which does not have the spare capacity to allow for unscheduled outages, the readiness of the power station is inextricably linked to the amount of engineering that can be completed during the power station's normal operational outages. Outages of significance, in this regard include a station GO (28 day outage) or alternatively a station half life refurbishment which occurs after 25 years of operation.

Although a detailed list of all design and engineering considerations for installing FGD at Medupi are included in Appendix 5-1, this list derived from a workshop of all engineering disciplines, is only relevant if FGD was to be installed immediately at the time of construction. Internal Eskom discussions as well as international consultants (Eon, 2008 and PB Power, 2008) have concluded that the FGD readiness of Medupi Power station, other than immediate inclusion, is dependent on a minimum of approximately 22 significant considerations (Table 1-19). In addition to such considerations, detailed assessments work-shopped between Eskom and external consultants have also highlighted several additional requirements (Annexure 3). It should however be noted that these issues ,although pertinent to the debate on FGD installation are not considered relevant to the FGD readiness of Medupi as their inclusion can be managed during normal outage schedules or while the station is still on load.

Table 1-19 Summary of engineering considerations that will need to be taken into account depending on the timeframe within which FGD would need to be installed

FGD Ready Requirements	FGD expected to be installed at			
	5 years	15 years	25 years (mid-life)	35 years
OVERVIEW OF CHANGES	**Design altered such that tie-in of FGD process can occur during 28 day outage period and plant is optimised for FGD operation.**	**Design altered such that tie-in of FGD process can occur during 28 day outage period and plant is optimised for FGD operation.**	**Very few changes recommended for FGD Ready design due to financial benefits of delayed capital expenditure, likely deterioration of equipment, advances in techniques/technology, etc.**	**Very few changes recommended for FGD Ready design due to financial benefits of delayed capital expenditure, likely deterioration of equipment, advances in techniques/technology, etc.**
Chimney Location	Move chimney out allowing FGD to be installed between pulse jet fabric filters (PJFF) and stacks.	Move chimney out allowing FGD to be installed between pulse jet fabric filters (PJFF) and stacks.	Keep chimney in original location leaving space to add FGD behind the stacks - tie in would take approximately 2-3 weeks.	Keep chimney in original location leaving space to add FGD behind the stacks - tie in would take approximately 2-3 weeks.
Chimney Lining (borosilicate)	Line stacks to cater for wet flue gas conditions.	Line stacks to cater for wet flue gas conditions.	Don't line stacks at present - material may deteriorate + techniques may improve in 25 years (may take 2-3 months).	Don't line stacks at present - material may deteriorate + techniques may improve in 25 years (may take 2-3 months).
Chimney Flue Connection	Design for flue duct connection at approx. 45m level of chimney.	Design for flue duct connection at approx. 45m level of chimney.	Design for flue duct connection at approx. 45m level of chimney.	Design for flue duct connection at approx. 45m level of chimney.
Induced draft (ID) Fan	Install uprated debladed ID fans on all units that are sized for FGD operation.	Install uprated debladed ID fans on all units that are sized for FGD operation.	Install uprated debladed ID fans on all units that are sized for FGD operation. / Booster fans can be added as part of FGD plant constructed behind stacks.	Booster fans can be added as part of FGD plant constructed behind stacks.
Flue Ducts	Provide flue design with easy tie-in for FGD absorber and wet gas lining, consider capability to withstand additional gas pressures.	Provide flue design with easy tie-in for FGD absorber and wet gas lining, consider capability to withstand additional gas pressures.	Provide flue design with easy tie-in for FGD absorber and wet gas lining, consider capability to withstand additional gas pressures. / Original flue design.	Original flue design.
LPS - raw water	Raw water transfer line from reservoir to FGD process would be installed during FGD construction.	Raw water transfer line from reservoir to FGD process would be installed during FGD construction.	Raw water transfer line from reservoir to FGD process would be installed during FGD construction.	Raw water transfer line from reservoir to FGD process would be installed during FGD construction.
LPS - fire system	System should not require additional capacity. Blind flanges provided to allow easy connection.	Nothing required.	Nothing required.	Nothing required.
LPS - compressed air	Nothing required - system is adequately sized to cater for FGD requirements.	Nothing required - system is adequately sized to cater for FGD requirements.	Nothing required - system is adequately sized to cater for FGD requirements.	Nothing required - system is adequately sized to cater for FGD requirements.
LPS - CCCW	Nothing required.	Nothing required.	Nothing required.	Nothing required.

FGD Ready Requirements	FGD expected to be installed at			
	5 years	15 years	25 years (mid-life)	35 years
OVERVIEW OF CHANGES	Design altered such that tie-in of FGD process can occur during 28 day outage period and plant is optimised for FGD operation.		Very few changes recommended for FGD Ready design due to financial benefits of delayed capital expenditure, likely deterioration of equipment, advances in techniques/technology, etc.	
LPS - potable water	Nothing required - system is adequately sized to cater for FGD requirements.			
Waste Water Treatment	System not yet specified.			
Raw Water Reservoir	Construct reservoir for 800,000m^3 at this stage (FGD for 3 units).	Construct reservoir for 400,000m^3, however, design with option to expand to 800,000m^3 in future.		
Electrical - unit transformer	Install uprated transformers.		Uprated transformers not initially required - dedicated FGD transformer may be provided when required.	
Electrical - general design	Design for FGD including increased fault levels.		Design for system excluding FGD.	
Electrical - essential services	Nothing required.			
C&I	Only space in control room required.			
Civils - foundations	Area between PJFF and Chimney should be level - no blasting requirements for foundations.			
Civils - pits/cable trenches	Pits should be blasted. Trenches not required if able to run services on pipe racks above ground.		Nothing required.	
Ash/Gypsum Dump	Developed largely independently of FGD - concept not yet finalised.			

FGD Ready Requirements	FGD expected to be installed at			
	5 years	15 years	25 years (mid-life)	35 years
OVERVIEW OF CHANGES	**Design altered such that tie-in of FGD process can occur during 28 day outage period and plant is optimised for FGD operation.**		**Very few changes recommended for FGD Ready design due to financial benefits of delayed capital expenditure, likely deterioration of equipment, advances in techniques/technology, etc.**	
Gypsum Handling/Conveyor	Ash conveyor adequately sized for co-disposal - if separate disposal then nothing required (reserve area).			
Limestone Handling	Reserve area.			
Rail Siding	Assuming siding is provided for Fuel Oil offload then only reserved area for additional limestone offloading will be required.			

It is possible to debate at length as to the minimum requirements that a station needs to conform to in order for it to be considered FGD ready. Despite a range of differing opinions, it is generally agreed that as an absolute minimum sufficient space, with associated civil works, should be allowed for the absorber either behind the stacks or between the stacks and the PJFF plant.

Flue gas desulphurisation is not a 'clean technology'. It is resource dependent and requires the handling of significantly large waste streams in addition to the normal quantities of ash that are likely to be produced. The technology requires considerable engineering amendments to any pulverised fuel power station. The concept of FGD readiness is fluid, with its definition being directly linked to the likelihood of Medupi having to retrofit the technology at some point in the future which in turn is dependent on the associated risk at that specific point in the future.

In a country and region which is characterised by limited water and sorbent availability, coupled with the additional environmental impacts that are likely to be associated with FGD, it is essential that any perceived need, legislative or environmental, to ultimately fit FGD to Medupi cannot be viewed in isolation.

Perhaps, in light of South Africa's severe water scarcity issues the predominant concern with respect to FGD requirements is the amount of water that the technology requires. The availability of suitable water sources needs to be fully understood and evaluated within the context of the region's water scarcity and current and future developments within the region.

1.6. Multi Criteria Decision Making

Multiple objective models provide decision support to decision makers by providing a tool for rationalising the comparison among alternative solutions, thereby enabling the decision maker to grasp the inherent tradeoffs and conflicts among the distinct objectives and thereby selecting a satisfactory compromise (Antunes et al; 2001). It is further argued by Heinrich et al (2006) that multiple objective models provide a structured framework for the evaluation of various parameters that are non linear (e.g environmental and social) as well as elements of uncertainty over a period of time. Both authors highlight the applicability of such models to electricity planning. Any move towards a sustainable solution should be driven by a rational argument directly related to the problem as well as the democratic desire to change (Lafferty, 1998). Furthermore if rationality is understood as a means of increasing the reasonableness of decisions through the involvement of full knowledge of the system in question (Muller, 1992) the decision to include FGD at the time of construction or at a later date would require the generation of a series of alternative scenarios and solutions all of which will need to be evaluated against a single set of objectives.

Pirasashti (2009) argues that the evaluation of a solution derived from a multi criteria problem can only be accepted if the following conditions are met, namely: that selection criteria are aligned to corporate strategy, that qualitative (rather than just quantitative) benefits are considered; that the needs and desires of all stakeholders are reconciled and integrated and finally that multi staged and group decision making processes are used. Simply put the decision whether or not to install FGD at Medupi cannot be considered in isolation of all other decisions, it needs to be taken within the context of all contributing internal and external factors

The aim of multi criteria decision making is to allow decision makers to learn about the specific problems which they may face, to learn about personal value systems, to learn about organisational values and ultimately through the exploration of all of the above within the context of the problem to identify a satisfactory solution (Pirasashti et al, 2009). The methodology allows for the identification and ranking of alternatives on the basis of several criteria (Climaco, 1995). In multi criteria models the concept of the optimal solution or the nondominated solution is the most feasible solution for which there is no improvement in any objective function without sacrificing on at least one of the objectives (Climaco, 1995).

Several methods exist for the identification of the non dominated or preferred solution, one approach involves the analysis of trade-offs against a common objective, such as cost. By assigning cost benefits or penalties to each of the more significant non cost criteria. Alternatively it is possible to recast all except one objective functions as a set of constraints operating on the remaining objective function. Finally a third option, and in the opinion of the author, potentially a favourable option within a large parastatal environment, is the evaluation of the objectives separately through the use of weighted sums of each. Such a method allows for interactive participation with all stakeholders in the definition of the weights and the goals until a satisfactory solution is reached (Heinrich et al, 2007). Such a methodology allows for lobbying and co-operative buy in to be gained at an early stage of the process.

A key aspect of multi criteria decision making is its ability to manage uncertainty. Sinding (1998) states that the minimisation of uncertainty within an organisation is a critical objective as it affects corporate strategy and economic efficiency.

1.6.1. Managing uncertainty

With reference to FGD in the context of environmental problem solving, such as the case of including FGD on Medupi, uncertainty is derived from both internal and external sources. External uncertainty includes the ambiguity about the natural environment and the various cause and effect relationships that exist (Sinding, 1998), with specific reference to FGD and associated air quality this can also be extended to human health issues. In addition regulatory responses are also considered to contribute to external uncertainties particularly as a result of the fact that environmental regulation is continually changing moreover policy instruments used by government are also continuously been reviewed and amended (Sinding, 1998). Finally Sinding (1998) states that the third area of external uncertainty is derived from external responses relating to actions that an organisation may take as a result of some external influence.

With respect to internal sources of environmental uncertainty Sinding (1998) identifies three areas of specific impacts namely, financial; organisational values and information processing impacts.

Perhaps the most important question that arises is how does multi criteria decision making take uncertainties into account. Heinrich et al. (2007) state that the consideration of uncertainties in multi criteria decision making involves the concepts of ‘robustness’ and ‘flexibility’ of the solutions generated. In this context robustness is defined as the degree to which a solution is affected by any parameter which at the time of its development was unknown. Similarly, flexibility is defined as the degree to which a solution can be adapted at a future point.

From the above discussions it is evident that multi criteria decision making provides a means for the choosing and or ranking of alternative scenarios on the basis of the evaluation against several, often weighted, criteria or objectives. It is therefore plausible that any decision making process with respect to the sustainability of installing FGD at Medupi would require the identification of a range of environmental, social and economic criteria which could be used to evaluate the two scenarios that Eskom is faced with, namely: install FGD on all or part of the station at the outset of construction or make the necessary engineering decisions to allow for FGD to be retrofitted at a later stage, with the least amount of effort and cost

It is at this point that the focus of this research report is reached. Although acknowledging that the identification of criteria will span across a range of sectors including cost, electricity planning, technology decision making and so forth, this research report will solely focus on the identification of the environmental criteria within the sustainability debate. Inter-relationships will be identified and discussed where appropriate, but for the most part environmental concerns will be addressed with a specific focus on the external environmental factors contributing to the uncertainties of any multi criteria decision model.

Furthermore, it is acknowledged that the potential scenarios do extend beyond the two identified above and will include FGD technology choices and configurations, however for the purposes of this report the two identified scenarios will be considered with respect to wet FGD.

Finally, it should be noted that no attempt will be made to under take any multi criteria analysis rather only , within the scope identified above, the decision making criteria will be identified, with appropriate discussion, motivation a criticism, which may be utilised within a suitable decision making model.

1.7. Objectives

The purpose of this research report is to generate (via modelling) as well as collate/identify various environmental criteria and considerations required to evaluate the impacts of either installing wet FGD, at Medupi Power Station at the time of construction or alternatively install FGD at a later time period.

It is not within the scope of this research report to comprehensively explore all possible alternatives and objectives as well as to draw a final conclusion through the use of multi criteria decision making.

2. DATA AND METHODS

The data used in this research report has been drawn from a variety of published literature and Eskom internal documentation. All data used in the calculation of water demand curves as well as ambient air quality databases was obtained from Eskom databases pertaining to the planning and construction of the Medupi Power Station.

The following chapter outlines the source of all air quality data and water data utilised in this research report. Modelling methodologies are also briefly discussed.

2.1. Data Requirements

2.1.1. Emissions data

Emissions from Matimba power station are assumed to be the same as those in the 2005/06 financial year (April 2005 to March 2006). Emissions from Medupi power station were calculated using a flow rate of 675.5 Sm3/s and a 90% load factor (and 100% availability). SO_2 emissions from Medupi were calculated using the specifications of the expected coal (sulphur content of 1.2%, ash content of 35%, and calorific value of 20.5 MJ/kg) and assuming that the FGD system has an SO_2 removal efficiency of 90%. An average diurnal emission profile is assumed. NO_x emissions from Medupi will be reduced by low NO_x burners and over-firing. The expected NO_x emission rate of 500 mg/Nm^3 is considered. It is assumed that 98% of the NO_x is emitted in the form of NO, and the remainder as NO_2. The NO to NO_2 conversion is calculated by the CALPUFF modelling system.

FGD reduces the exit temperature, and thus the buoyancy, of the flue gas. It is assumed that no gas-to-gas reheater is installed.

Table 2-1 Emissions data utilised to input into the CALPUFF Model

	Matimba	Medupi/Coal3/ Coal4 without FGD	Medupi with FGD on 3 units	Medupi/Coal3/ Coal4 with FGD
SO_2	315 971	439 474	241 711	43 947*
NO_x (as NO_2)**	67 599	57 514	57 514	57 514
NO	43 206	36 759	36 759	36 759
NO_2	1 352	1 150	1 150	1 150

*219 737 tons/annum are emitted from the three units at Medupi without FGD, and 21 974 tons/annum from the three units with FGD.

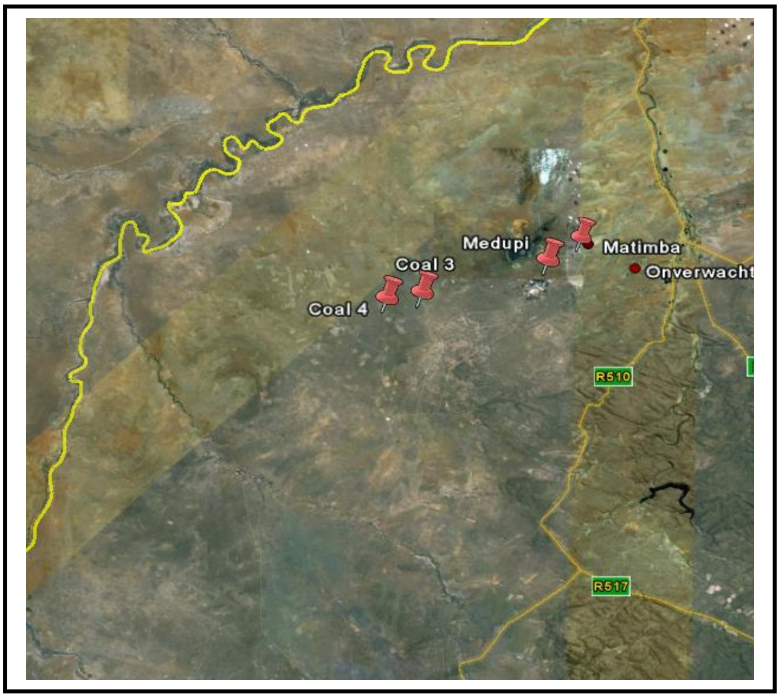


Figure 2-1 Map of modelling domain (Map not to Scale)

Stack parameters

No reheating was considered

Table 2-2 Emissions data utilised to input into the CALPUFF Model

	Matimba	Medupi/Coal3/ Coal4 without FGD	Medupi/Coal3/ Coal4 with FGD
Exit temperature (℃)	132	130	49
Exit velocity (m/s)	24.84	26.0	18.0
Effective stack diameter (m)	12.82	12.75	13.70
Stack height (m)	250	220	220

Flow rate from Hitachi data sheet for Medupi: 1106.6 m^3/s
(Calculated flow at 49℃ is 884.18 m^3/s)

2.1.2. Ambient air quality data

Ambient air quality data was obtained from previous monitoring campaigns undertaken by Eskom's Sustainability and Innovation Department. Since 1984, Eskom has undertaken several monitoring campaigns within the Lephalale region, many of which have focused on the continuous monitoring of ambient SO_2 in the vicinity of the Matimba Power Station. Monitoring was conducted at Zwartwater for the period 2001 to September 2003. In September 2003 the Zwartwater monitoring station was relocated to Grootstryd. In 2005 the monitoring station was subsequently relocated to the Marapong Township, as part of the conditions of the Medupi Environmental authorisation. At this time the station was also expanded to include a NO_x analyser. Typically the monitoring stations measured both SO_x and PM however for the purposes of these discussions only the SO_2 data will be considered

Additional historical SO_2 monitoring campaigns, relevant to this study included:

- Sampling at five sites (M1-M5) during the August 1991 to January 1992;
- Sampling at Waterberg station during the 1984 to 1989 period;

All data was obtained from the Eskom EDWEIS air quality data management system. EDWEIS is an Eskom developed ambient air quality database and analysis tool. The software allows the user to review and perform basic analysis, such as pollution roses and pollution trends for all of Eskom's, current and historical ambient air quality data. Eskom's ambient air quality monitoring network is SANAS accredited.

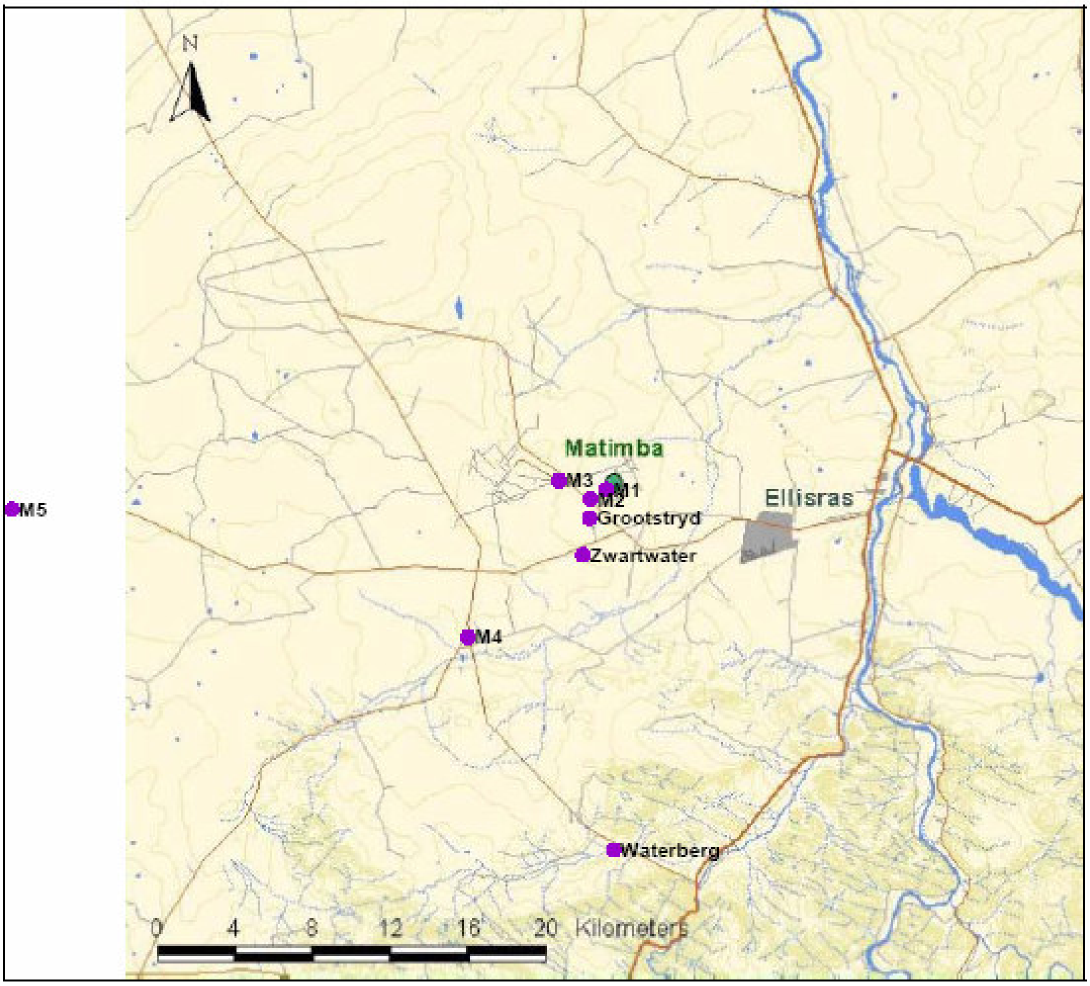


Figure 2-2 Location of all monitoring campaigns in the Lephalale region

2.1.3. Water Data

Water data for the Medupi Power Station was based on the existing Matimba power station which uses approximately 0.16 l/kW sent out which equates to approximately $5Mm^3/a$. Water used in the FGD process was obtained from literature surveys and various discussions with external engineers and Eskom engineers. The figure utilised of 0.21 l/kW sent out or $7.2Mm^3/a$ is the same figure that Eskom is currently using for all planning purposes with respect to the power station. All supporting water data for the Grootstryd mine and Lephalale town was obtained from Exarro and the local municipality. Data pertaining to the possible development of an additional coal to liquid plant in the Waterberg area were obtained through Eskom Sasol research partnerships.

2.2. Methods

All water calculations were undertaken by means of an excel model.

Dispersion modelling was undertaken for 5 scenarios including a base case of Matimba without any FGD. Alternatives modelled included the no FGD on either Matimba or Medupi, the inclusion of FGD on 3 units as well as six units of Medupi. With respect to future scenarios and Eskom's current investigations to construct 2 additional coal fired power stations in the Lephalale region two additional scenarios were run including no FGD on any of the coal fired power stations and FGD on the proposed additional two coal fired power stations (coal 3 and 4)

2.2.1. Dispersion modelling and meteorological data

The CALMET/CALPUFF suite of models was used due to the size of the baseline region to be included in the study. The dispersion modelling was conducted for a 100 by 100 km domain at a resolution of 2 km. CALMET simulates a three dimensional meteorological profile for the study area using more than one surface weather station and upper air data. The model requires hourly average meteorological data including wind speed, wind direction and temperature. Given the sparse surface meteorological data available for the region, upper air meteorological data was obtained from the Conformal Cubic Atmospheric Model (C-CAM) run at the University of Pretoria. Hourly surface meteorological data was obtained from monitoring stations in the vicinity of the power stations.

Calpuff is a regional model suitable for application in modelling domains of 50 km to 200 km. Due to its puff-based formulation the CALPUFF model is able to account for various effects, including spatial variability of meteorological conditions, dry deposition and dispersion over a variety of spatially varying land surfaces. The simulation of plume fumigation and low wind speed dispersion are also facilitated. CALPUFF allows for first order chemical transformation modelling to determine gas phase reactions for SO_x and NO_x. Chemical transformation rates were computed internally by the model.

3. MEDUPI POWER STATION: WATER DEMAND AND AVAILABILITY

Flue gas desulphurisation requires water, irrespective of technology, to the extent that the water requirements of a wet FGD system will significantly increase those of the dry cooled power station such as Medupi. It is therefore imperative that any decision to install FGD needs to be taken within the context of Integrated Water Resource Management.

The following chapter serves to highlight both the short term and long term risks associated with water supply to the Lephalale region. The ability of the region to meet the additional demands for water utilisation associated with FGD at Medupi and potential future development in the region will be discussed. The DWA National Water Resource Strategy(NWRS), is the guiding water planning policy document in South Africa, and will form the backdrop to all discussions.

The chapter will be structured such that the NWRS will be summarised with particular reference to its implications for Eskom and consequently the Medupi Power Station. Following such discussions the water supply and demand situation within the Waterberg region will be discussed highlighting the various transfer schemes that are in the process of being constructed.

Finally, all water demand and supply data are discussed, as obtained from the Eskom water supply database and, supplemented by figures provided in previous chapters will be utilised to compile a simple water demand and supply model (annexure 4) which will serve to highlight any current and future constraints that may be imposed on future developments in the Waterberg region as a result of water scarcity.

3.1. Alignment of Eskom's Water Supply Strategy to the NWRS

3.1.1. Principles of the National Water Resource Strategy Relevant to Eskom

The NWRS provides the implementation framework for the National Water Act (no. 36 of 1998) (NWA), which states that the nation's water resources must be protected, used, developed, conserved, managed and controlled in accordance with the NWRS. The NWRS was first adopted in 2004, and is scheduled for review every 5 years after mandatory consultation with stakeholders. The next iteration is scheduled for 2010, and a draft which will be available early in 2009 is currently being compiled by DWA. The ultimate objective of the NWRS is to allow strategic management of national water resources.

The NWRS is a comprehensive document, and our aim is not to repeat it. Rather, discussions will review aspects of the NWRS that are considered to be relevant to Eskom's Water Supply Strategy in the Lephalale region.

3.1.2. Protection of water resources

The NWRS highlights the fact that South Africa is a country with scarce and unevenly distributed water resources. Protection of this resource should therefore be the priority of all users. Protection of water resources in terms of the NWA refers to maintaining both water quality and quantity at desired levels through two fundamental approaches:

- *Resource-directed Measures* measure the condition of the resource itself, including in-stream and riparian habitats and the condition of aquatic biota
- *Source-directed Controls* seek to manage water use activities at the source of impact through tools such as standards and conditions included in water use authorisations.

This applies to both surface water and groundwater, which could both be impacted upon by Eskom's Medupi operations. In particular, migration of mobile species from Medupi's ash dumps (which may include disposed Gypsum) is a matter requiring consideration in this regard.

3.1.3. The "polluter pays" principle

Where the resource is polluted through accident, negligence or deliberate actions, the NWA holds the polluter responsible for clean-up and rehabilitation of the resource. This applies to both point source and diffuse source pollution, the latter being the primary mode through which Medupi could impact on water resource quality.

Risks to Medupi arise from the potential co–disposal or single disposal of gypsum and ash. DWA's stance is that pollution of water resources is to be avoided as far as possible. Where avoidance cannot be achieved, the aim is to avoid irreversible damage and to ensure that other users of the resource do not bear the costs of the pollution i.e. costs are to be internalised by the generator of the pollution.

It is therefore important that in the absence of appropriate gypsum markets, clear consideration is provided for the additional liabilities that Medupi could be required to manage.

3.1.4. Authorisation of water use

The use of water for power generation has to be authorised. Such authorisation must be current, and the conditions attached to each authorised water use must be met by the user. Water Use Authorisation gives DWA significant leverage through the conditions attached to each licence. Systems should be in place from Eskom's point of view to enable routine monitoring and measurement of compliance to licence conditions. Non-compliance is an offence in terms of the NWA.

3.1.5. Water Conservation and Water Demand Management

Due to the spatial distribution of surface water resources across South Africa, water transfers are an unavoidable reality. Dams are also a necessary part of water resource infrastructure in the country, due to the seasonality of rainfall patterns. The NWRS seeks to complement these supply-side options with demand-side initiatives, the most important of which from Eskom's perspective would be a focus on water conservation and water demand management (WC/WDM). Medupi Power station therefore cannot assume that it is the responsibility of DWA to ensure security of supply. Eskom, and indeed the Medupi Power Station, needs to carefully manage its demand for water.

3.1.6. Power generation as a strategic water use

In terms of the NWRS, operational responsibilities for water management will be devolved from DWA to Catchment Management Agencies (CMA's) which will be responsible for these matters in each of the nineteen Water Management Areas (WMA's) in South Africa. The NWRS assesses water resources in each of these WMA's against demand, and identifies development opportunities and constraints. Water demand is considered for various sectors, specifically irrigation, urban, rural, mining and bulk industrial, power generation and aforestation. Of these, power generation is officially recognised as a strategic user of national importance, subject to authorisation by the Minister of Water Affairs and Forestry rather than a CMA. This means that water transfers between WMA's (the other strategic use recognised in the NWRS) to supply Eskom's needs are supported by DWA and that there is a commitment to a secure supply for the sector. Strategic users do not however receive the highest water use priority, and are preceded by provisions for the water reserve, international obligations and agreements, and water requirements for social needs.

The fact that Eskom enjoys strategic user status imbues the organisation with unique responsibilities, not by law, but through the required sense of social responsibility expected from corporate citizens of the scale of Eskom. It would be unacceptable for the organisation to use as much water as it does (1.5% of SA's annual fresh water consumption) without considering other users, particularly given the need for social redress in South Africa. This responsibility is fundamental to the evaluation of the need for FGD in the context of water demand and supply in the Lephalale region

3.1.7. Integrated Water Resource Management (IWRM)

A fundamental principle of the NWRS is that of integrated water resource management (IWRM). The IWRM philosophy recognises that various competing objectives associated with water use have to be considered in a holistic fashion in order to achieve the best overall outcome. It recognises that water use efficiency and water quality are indivisible, and that environmental, social and economic issues are best considered as an integrated whole where water use is concerned. IWRM recognises further that surface water and groundwater are both components of the resource and have to be managed as an integrated whole.

These principles apply at the national level, but they apply equally to local environments as well. Consequently, Medupi Power station represents an integrated water management system, which receives raw water and will produce effluents which can impact on surface and groundwater resource quality. The securing of water supplies to the power station requires consideration in concert with water conservation plans for that power station, and with careful review of the network of power stations, and other water users that may be sharing the resource and infrastructure with the station concerned. Water use for the power generation should not compromise social redress, economic growth opportunities of other users, the environment or South Africa's international obligations.

3.1.8. A Summary of Implications of the NWRS for Eskom

As a water-intensive industry, Eskom has to secure water supplies to the organisation's various power stations, including Medupi.

In the long term, unresolved water management issues will ultimately be reflected in the price of water, or the cost of compliance to specific water use authorisation conditions which DWA may impose on Eskom. Water management issues run deeper than commercial considerations only, however. Water is a national asset with social value, and Eskom is in the unique position, as identified by the NWRS, of being the only organisation recognised by DWA as a strategic water user. With this comes a level of responsibility towards water use that transcends that of other users in South Africa.

3.2. The Allocation of Water to Medupi Power Station

Practically, there are two processes that are used for securing the required water supply; these are the application for a water use licence and ongoing participation by Eskom in planning conducted by the Department of Water Affairs (DWA). The licensing requirement is effected under the auspices of the National Water Act (NWA). If a water use licence is issued by the DWA, this is simply permission to use the water should it be available. Eskom has already applied for and obtained a draft water use licence for Medupi but this allocation is only sufficient for three generating units (without FGD). The water will be sourced from the Mokolo system and essentially draws on a supply that had originally been allocated to Matimba Power Station but as a result of design and operating efficiencies has never been used (pers comms, van der Merwe, 2008).

In order to ensure that the water will be available, for the entire Medupi station and potential future coal fired power stations, Eskom participates in bi-annual planning meetings with the DWA. It also submits current and future water demands to DWA annually for operational planning purposes. Eskom has communicated the total water demand for Medupi to DWA through this planning process. Currently, the projected water demand includes the provision for FGD, as a result of the uncertainties surrounding the FGD decision. Due to the issues of severe water scarcity, DWA has not been overly supportive of FGD, however, they have accepted that FGD could prove necessary and have incorporated such provision in their planning.

As part of the planning process it has been recognised by DWA that the existing water supply is insufficient to provide water for more than three generation units, even without FGD. The requirements stipulated by Eskom as well as other water users in the area resulted in the commissioning of a feasibility study on the supply of the additional water required by means of an inter-basin transfer (from the Crocodile West catchment). Although Eskom has contributed to the planning process, Eskom will still need to apply for a new water use licence for the additional three generation units and for FGD, should it be required. However at this stage the planning is in place for the supply of the required increased water allocation required for Medupi, inclusive of 6 units of FGD.

3.2.1. Water Supply to the Medupi Power Station

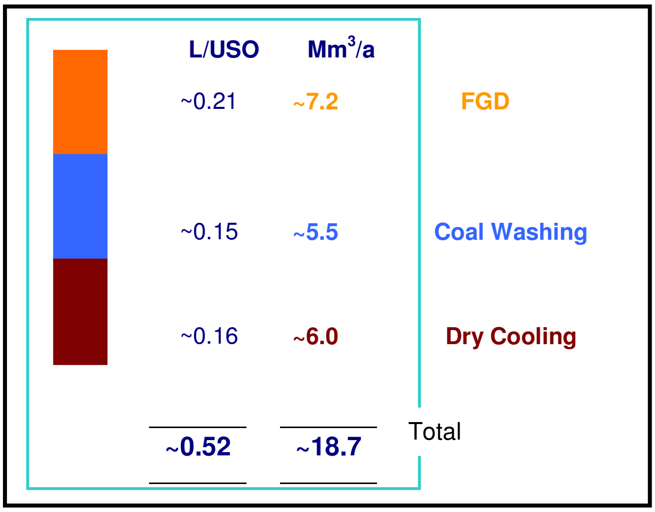


Figure 3-1 Estimated water requirements for Medupi Power Station
Note: USO – Units Sent Out (pertaining to a unit of energy or kW)

Estimates indicate that Medupi's long-term steady state water demand will be approximately 6 million cubic metres per annum (Mm^3/a) without FGD being installed (figure 6-1) Estimates of the water requirements for 6 wet FGD plants (i.e. on all 6 Medupi units) with 90% removal efficiency and no water efficiency initiatives range from 6.5 to 7.2 Mm^3/a. Estimates of the water requirement for a FGD system on 3 units range from 3.2 to 3.9 Mm^3/annum (Eskom, 2008). The addition of coal washing at the mine to supply Medupi with coal increases the total industrial demand associated with Medupi to approximately 18.7 Mm^3/a[2]. Currently, only 5 Mm^3/a of water is available and it is predicted that this allocation will be exceeded with the commissioning of Medupi's third unit in 2012.

[2] This figure is considered to be generous and could be expected to be 2-5 Mm^3/a lower with the implementation of various water conservation practices (gas-gas reheater, water recycling and dry coal destoning processes. However this high Figure has been used in this work as it is not known at this stage as which water conservation measure will be (some water conservation strategies may be associated with specific design implications, materials used and maintenance programs all of which are not always considered favourable.

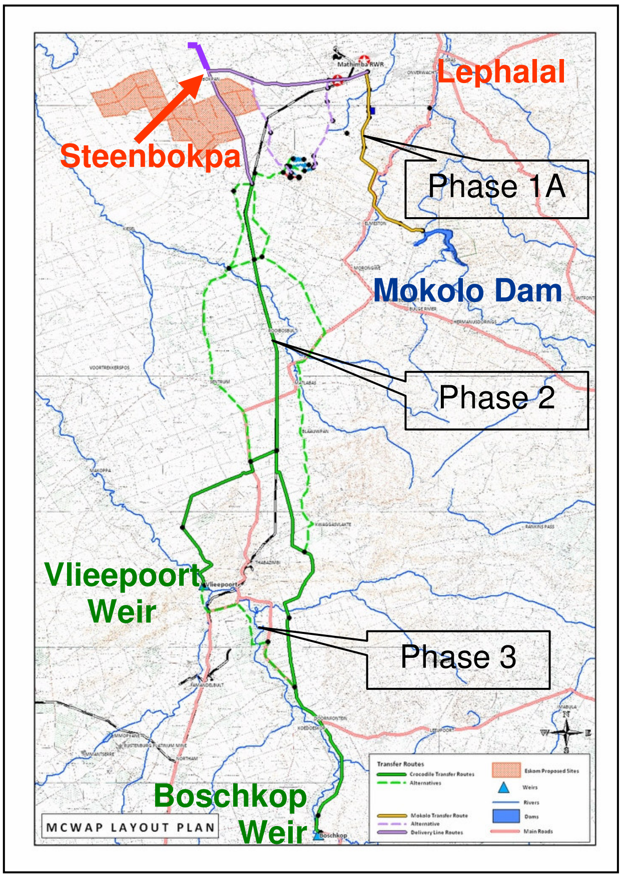


Figure 3-2 Representation of Water transfer schemes required for the Waterberg region (Eskom, 2009)

Medupi Power station will be supplied by the Mokolo Dam until mid 2014 (Phase 1A) (Figure 3-2), after which supplies will be via the second phase of the Crocodile Mokolo Water Augmentation Project (CMWAP) (Figure 3-2). The timing of the commissioning of this second phase, which transports return flows from the Crocodile River to Lephalale, is critical to Medupi's assurance of supply, since it has been determined by an independent source commissioned by DWA (DWA, 2007) that the Mokolo Dam will probably fail by mid 2014 if used as the sole supply to Medupi as planned. This would place both Medupi and Matimba Power Stations at risk. Return flows from the Crocodile River are considered by DWA to be more than adequate to meet Medupi's needs.

Further development of generation capability in the Lephalale area will be supported through return flows from downstream of the Vaal Dam which will be transferred into the Crocodile River. There is also the option of transferring water directly from the Vaal Dam to Lephalale if required (Phase 3). Various scenarios have been evaluated by DWA in cooperation with Eskom and other users such as SASOL, and this engagement appears to be robust.

In the long term, water for Medupi is to be supplied from return flows from the Crocodile River. Water will be supplied to users from terminal dams constructed at the end of the pipeline(s). A number of potential transfer routes have been assessed (Figure 3-2).

As Eskom demands increase, return flows from sewage treatment plants downstream of the Vaal Dam will be transferred into the Crocodile River after treatment to reduce phosphates, and then transferred to Lephalale. The magnitude of the return flows in question is expected to be sufficient for Matimba, Medupi, as well as additional Eskom capacity and Sasol (should Sasol decide to proceed with the Mafuta project in the region). The volume of these return flows will increase with increasing sanitation levels and population influx. Although increased levels of WC/WDM among domestic users and industries supplied by municipalities could reduce these return flows, there are additional return flows that could be accessed if necessary. A direct augmentation from the Vaal Dam is also possible if required.

3.2.2. Timing of Implementation of the Water Augmentation Scheme

The second phase of the CMWAP is scheduled to be commissioned at the end of 2014. The commissioning schedule for the Medupi PS is outlined in Table 6-1 below. Clearly, this phase of the CMWAP will not be available in time to meet the needs of Medupi when the first units are commissioned. The initial phase of the CMWAP (Phase 1A) will entail the building of an additional 50Mm^3/a pipeline from the Mokolo Dam.

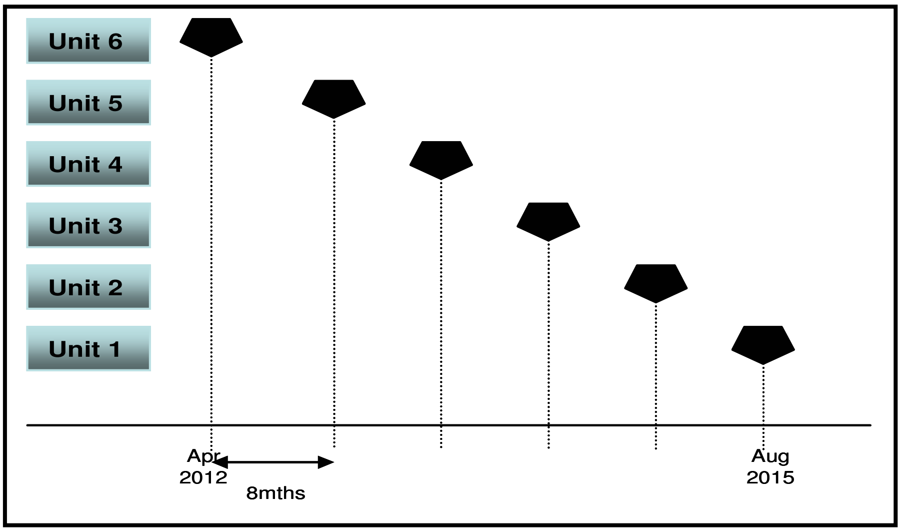


Figure 3-3: Estimated Commissioning Schedule for Medupi

3.2.3. Interim Arrangements from Mokolo Dam

The current pipeline from Mokolo Dam has a capacity of 13.5 Mm^3/annum. The pumps can deliver up to 28 Mm^3/annum (there are 3 pumps which are not all required). The demands by Matimba PS, DWA 3rd parties and Exxaro are of the order of 8.3 Mm^3/annum. This leaves a surplus capacity in the pipeline of some 5.2 Mm^3/annum, which as indicated is insufficient to meet current needs as well as those of Medupi PS, which will require some 12 Mm^3/annum, without FGD. Although it could be argued that the excess water is sufficient to provide water to Medupi until the end of 2014 (first 3 units), the extensive development of coal fields and towns in the Lephalale area will necessitate additional infrastructure to supply water from the Mokolo Dam until the second phase of the CMWAP is commissioned. Since the second phase of the CMWAP is expected to only be operational in mid 2014, an interim solution is needed to meet demands which will arise when the first unit is commissioned in April 2012.

The second Mokolo pipeline (the first phase of the CMWAP) will supply water to Eskom as well as other users, and will have a capacity of some 50 Mm^3/annum. This pipeline is expected to become operational by mid 2011. Based on the current commissioning dates for Medupi PS (table 3-1), this pipeline should be in place in time to meet demands. Water required for construction of Medupi could be supplied from the existing pipeline.

The 1:200 yield of the Mokolo Dam is estimated at 23 Mm^3/annum. This should be adequate to meet current demands as well that of Medupi PS. However, there will be a fair amount of growth and development in the Lephalale area. This could mean that demands from users other than Eskom could deplete reserves in the Mokolo Dam and place assurance of supply at risk resulting in the potential shutting down of the power station. A study commissioned by DWA has indicated the possibility of a supply failure from the dam by mid 2014. Such a failure would be catastrophic to Eskom and the country, since both Medupi and Matimba would be at risk. The current thinking from DWA is that the assurance of supply from Mokolo Dam could be adequate to meet Eskom's needs until the second phase of the CMWAP if allocations could be leased from non-Eskom users (principally irrigators) to increase assurance of supply to Eskom. Water supplied by the second phase of the CMWAP will then be used to supply users who source water from Mokolo Dam, allowing the dam level to recover. In discussions with irrigators, DWA has established that such an arrangement would be viable for one planting season only. There may also be undesirable social impacts, for example increasing unemployment among farm labourers, who may not be able to secure alternative employment. In addition, the quality of water in Mokolo Dam is good, while the return flows are nutrient-rich and prone to algal growth. Some users may not wish to use water of this quality, particularly if it has to be stored.

All of the above means that there is significant risk to Medupi's water supply until the second phase of the CMWAP is commissioned.

3.2.4. Evaluation of Water Demand Risks

The Waterberg is home to vast coal deposits. It is estimated that the coal resource accessible by open cast mining is of the order of 60 billion mineable tons *insitu* of which, if beneficiated, 40% would be of an Eskom type product which can be used in a conventional PF boiler (Medupi type power stations). This would be adequate for 24 additional power stations (assuming 50 year life and 6x 800 MW size units) (Eskom, 2009). The underground resource is estimated to be 100 billion mineable tons *insitu* which probably could also supply a number of power stations. In addition to Eskom power stations, several large industrial projects are currently planned to be constructed in the region with their respective feasibility studies at various stages. Such projects include the potential construction of additional coal to liquids plants by Sasol.

A coal fired power station typically has an operational life of 50 years excluding life extension opportunities. It is therefore foreseeable that the region will include several additional coal fired power stations as well as various other industrial complexes. Current planning, highlighted above has indicated that an additional 220Mm^3/a of water could be transferred into the area. In order to evaluate the adequacy of such demands two scenarios were investigated, in line with the scenarios modelled for the ambient air quality, in the forthcoming chapter. Both scenarios were modelled on the assumption that all future coal fired power stations would include FGD as it was necessary to test the limits of water supply (figure 3-4).

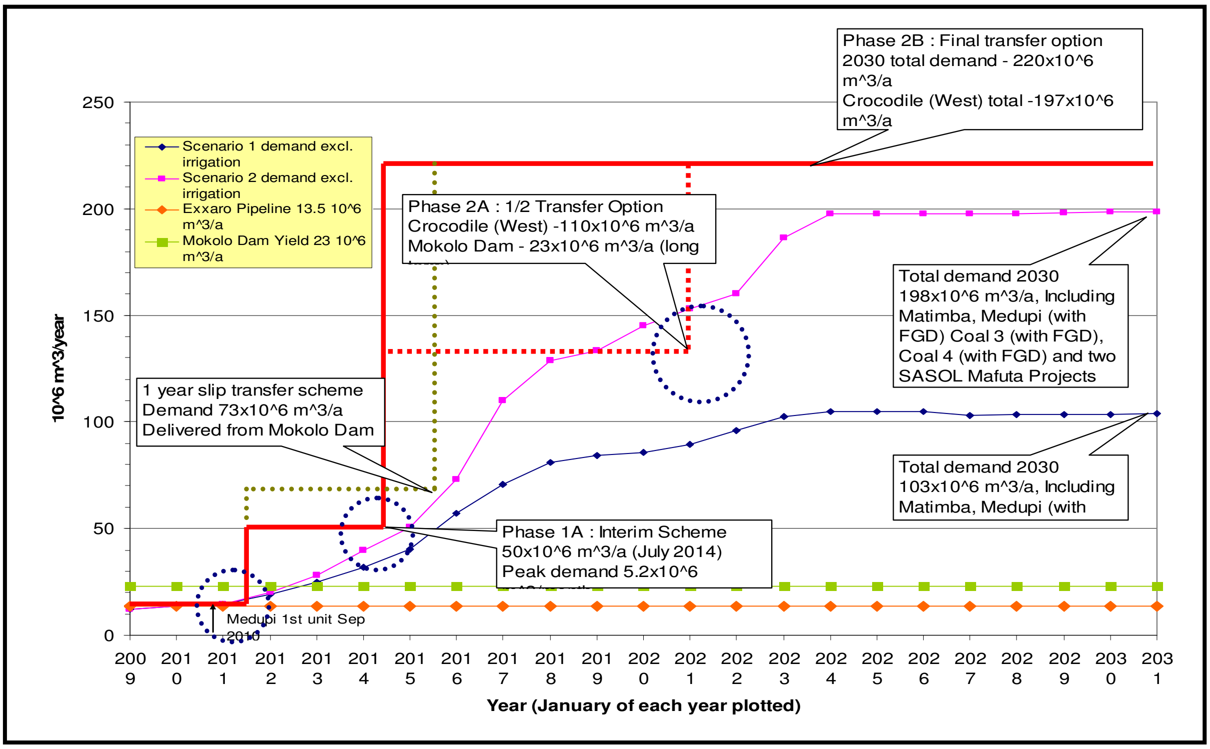


Figure 3-4 Comparison of water demand and water availaibility for all competing water users in the Lephalale region

Note: *Scenarios 1 and 2 (refer to appendix 3) differ with respect to the inclusion of the Sasol Mafuta projects. Both scenarios included the development of Medupi coal fired power stations as well as two additional dry cooled coal fired super critical power stations with FGD, associated mining activities and residential developments as associated with the expansion of the various industrial expansions. All quantities obtained for the scenario planning was obtained from Eskom's current interaction between Eskom, DWA and Sasol. Scenarios exclude the projected agricultural allocation, which is estimated to be constant at 16Mm^3/a*

The solid red line indicats the water availaibilty at different time periods with respect to the phasing of the various water augementation schemes. The line illustrates that additional water water will only become available in two phases the first been in 2011 and the second 2014. The blue circles highlight points of risk, owing to the fact that any potential slip in the water augmentation phasing could result in a water deficit for the Medupi Power station. The most critical point is the 2011 phasing of the projected water supply. Two scenarios were modeled (blue and purple line). Scenario two, which is a worst case scenarion indicates that the inclusion of two additional coal fired power stations to Medupi as well as the planned construction of the proposed Sasol Mafuta project would significantly limit the opportunity for any future industrial development in the region, despite the regions abundance of coal

It is clearly evident that, assuming the continued industrial expansion of the Waterberg region, there is only sufficient water for two to three additional power stations, with wet FGD. Current planned water supply in the region can be considered to be a severely limiting factor to future development, with planning unlikely to be capable of meeting the demands should the full extent of the coal resource be exploited. It should be noted that all moels excluded the amount of water required for irrigation purposes, making the projections even more onerous.

Furthermore it should be noted that the planning of future water transfer schemes will be required to span ever increasing distances from already water stressed regions, resulting in the increasing of the engineering and environmental scope. Time lines associated with the various aspects of implementing such transfer schemes (financial approvals, design, EIA, construction) are also likely to extend. In the past, partly due to projects being smaller and subjected to less onerous environmental scrutiny it was possible to implement projects relatively timeously. The increasing complexity of such transfer schemes further increases the likelihood of public appeals and environmental and social constraints.

Supplies to Medupi are at risk until the second phase of the CMWAP has been commissioned. Any delays in implementation of the pipeline from the Crocodile River will increase this risk even further.

Water scarcity in the Waterberg region is likely to, at some point in the future, severely limit the exploitation of the coal resources. Medupi power station, with and without FGD, is considered to be at risk as a result of the water supply issues.

Any decision to install FGD should, solely based on water scarcity issues be deferred as long as possible until such time that the inclusion of the technology can be justified in terms of environmental and air quality considerations. It is further likely that alternative FGD technologies, which are less water dependent will need to be investigated in an attempt to manage the scarce water resources.

Information presented in both this and previous chapters has highlighted that the installation of FGD requires the careful consideration of several interrelated environmental and technical issues all of which have significant impacts on both plant and the surrounding environment. It is therefore essential that any decision to install FGD needs to be motivated by a clear need.

4. MODELING THE EFFECT OF MEDUPI ON AMBIENT AIR QUALITY

Previous chapters have sought to provide the necessary background information, while highlighting some of the key impacts of FGD. A suitable understanding should have been developed highlighting the legislative constraints placed on coal fired power stations, which in turn result in the need to consider the installation of FGD. It has further been highlighted that FGD, is associated with various impacts on both the power station and the environment and that any decision to install FGD at Medupi needs to be made only after complete understanding of such implications.

In short, FGD, after all considerations have been taken into account must result in a net benefit to the region. Air quality must be weighted against other factors according to Multi Criteria Decision Making Analysis

The following chapter focuses on determining the potential impacts that the Medupi power station will have on the air quality both with and without FGD. The quality of the Lephalale airshed will be evaluated both in terms of current and possible future developments

Discussions will thus seek to establish a baseline upon which the potential impact on the following parameters can be evaluated and discussed:

- potential sensitive receptors within the Lephalale region
- Ambient Air quality
    - Compliance to current ambient air quality standards (proposed South African Standards and the EC);
    - Qualitative assessment of the potential health risk due to SO_2 emissions

The assessment of ambient air quality will take into account the potential construction of two additional coal fired power stations in the Waterberg region. All ambient air quality modeling[3] was undertaken using the CALPUFF dispersion

[3] All modelling was undertaken with the assistance of Dr Kristy Ross

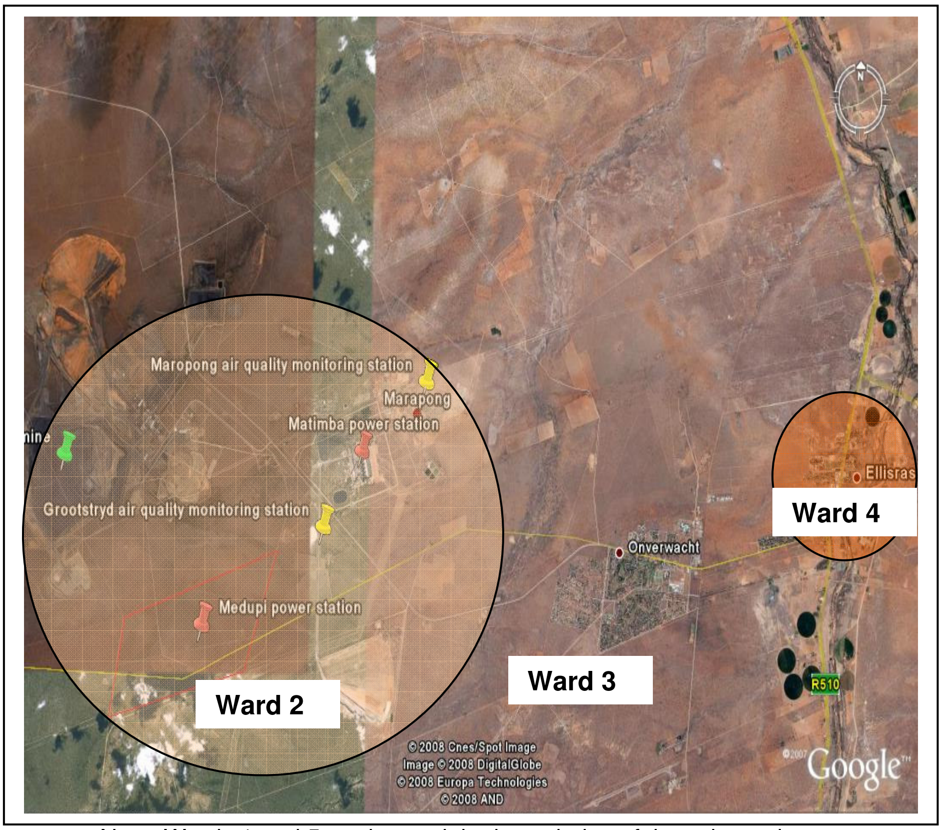
modeling suite, with comparative information provided by Eskom's monitoring network in the Lephalale region.

In addition to assessing the ambient air quality associated with the Medupi Power Station emission rates, these will be compared to international guideline values and proposed South African Standards.

4.1. Establishing the baseline

4.1.1. Sensitive receptors

The Medupi Power Station will be constructed within a region, which is associated with low level emissions (e.g. from mining and ashing operations) and elevated emissions (power station stacks). Cumulatively, and as a stand alone power station, Medupi has the potential of impacting on receptors in the near and medium surrounds. Ward numbers 2, 3 and 4 (Figure 4-1)of the Lephalale Local Municipality are the most sensitive to impacts related to atmospheric emissions as a result of their proximity to the power station and locality in relation to prevailing winds. Wards 1 and 5 may also be affected depending on the spatial extent of impacts. Residential areas in the vicinity of the proposed operations include Marapong (Ward 2) located just south of the Farm Zongezien and northeast of the existing Matimba Power Station and Onverwacht (Ward 4) and Lephalale (Ward 5) situated to the southeast and east of the existing power station respectively. Farm households are scattered through the area, with livestock farming (primarily cattle and game) representing the main agricultural land use in the area. The closest schools and clinics include: Ellisras School, Clinic and Hospital (Ward 4), the Lekhureng Primary School (Ward 1) and Weltevrede Montoma School (Ward5) (Census 2001).



Note: Wards 1 and 5 are beyond the boundaries of the schematic

Figure 4-1 Schematic map illustrating location of various towns in relation to the census wards

4.1.2. Meteorological conditions

Annual and seasonal wind roses generated based on measured data from the EDWEIS system are illustrated in Figure 4-2.

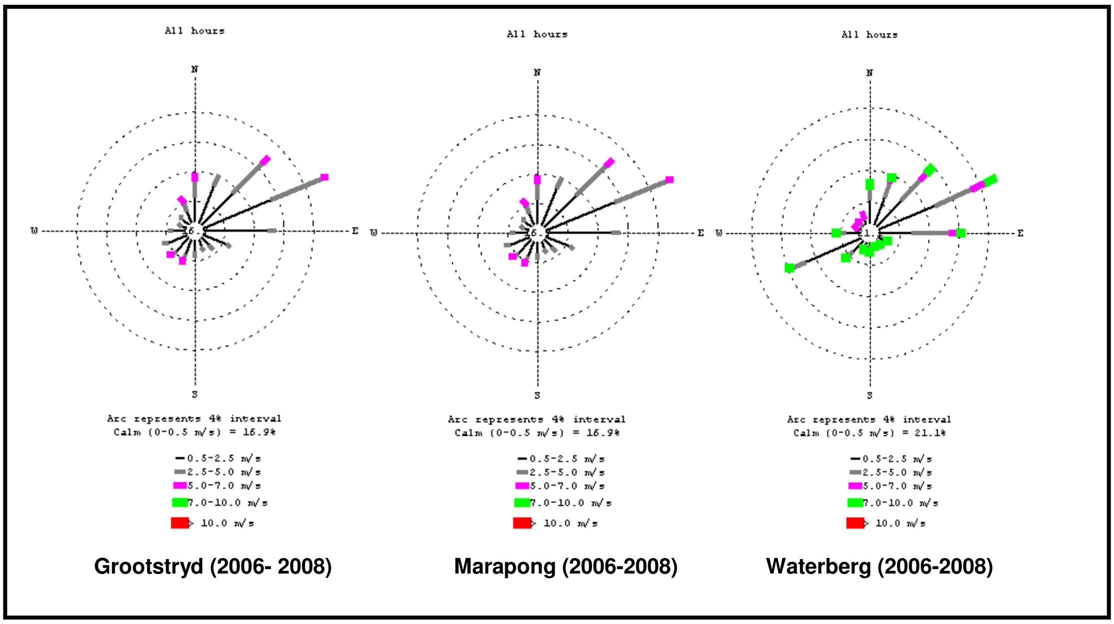


Figure 4-2 Annual average wind roses for the Waterberg region, taken at various monitoring stations (Data generated by EDWEIS, 2008)

The wind field is dominated by northeasterly winds as may be expected due to the continental high pressure, which persists over the region, in combination with the tropical easterly systems (Scorgie, 2006) which influence the flow field during much of the year. Winds are experienced infrequently from the westerly and south-easterly sector for all three periods analysed. The wind speeds are generally low throughout the period (5-7 m/s). The wind rose generated from data at the Waterberg monitoring station indicating wind speeds up to 10m/s

The wind patterns do not vary significantly seasonally from that of the annual average and between seasons, with perhaps a slight decrease in wind speed and percentage of north easterly winds being the only variation (figure 4-3)

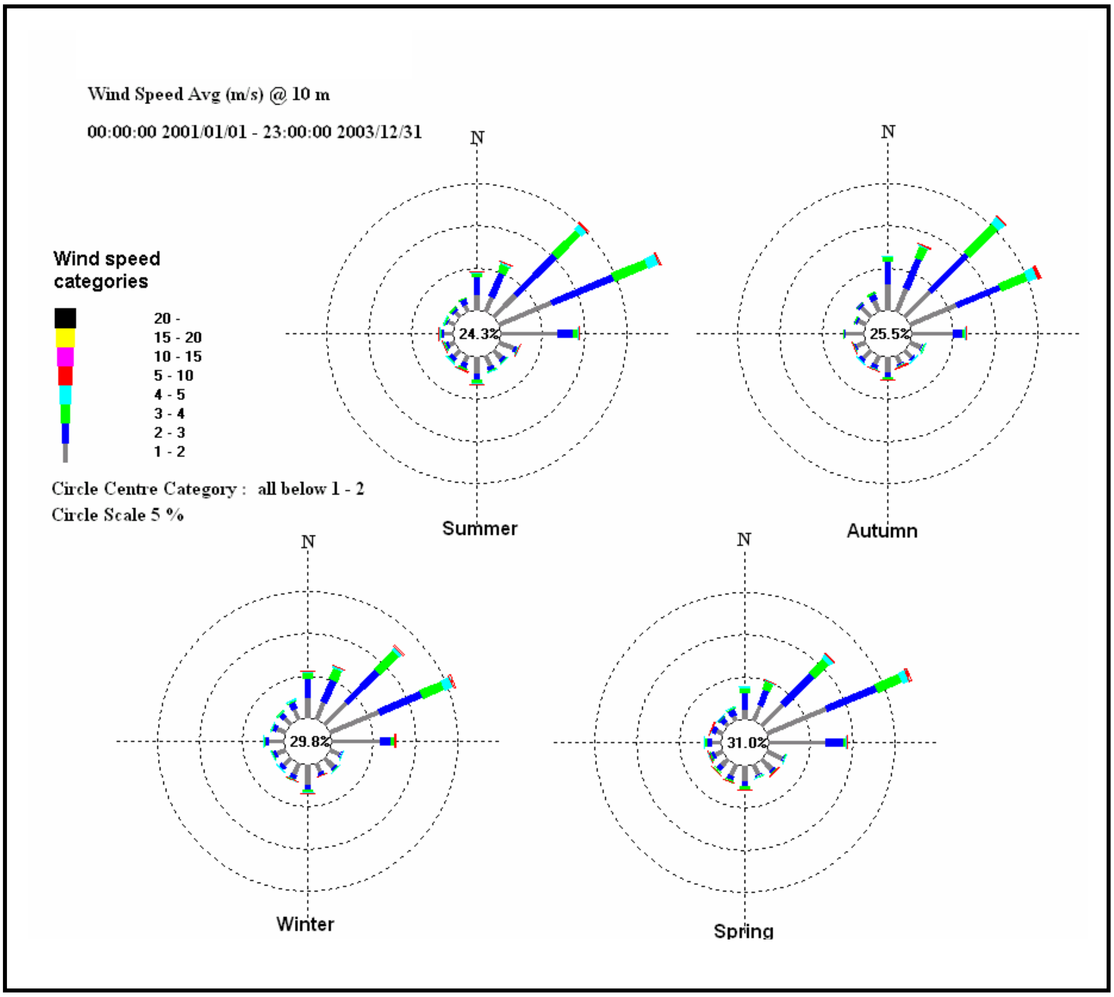


Figure 4-3 Seasonal Wind Roses for the Lephalale region for the period 2001-2003 (Data generated by EDWEIS, 2008)

4.1.3. Existing Sources of atmospheric emissions

Existing sources of atmospheric emissions which occur within the Lephalale area include (Scorgie, 2007, Ross 2008 and Viviers, 2008):

- existing Matimba Power Station and its associated ash dump,
- Grootgeluk coal mining operations (situated west of Matimba power station)
- brickworks operating at Hangklip
- household fuel combustion
- potential veld fires (infrequent)
- wind blown dust from open areas and agricultural activities

Although all of the above sources would be considered pertinent to any air quality modelling exercise, this study is however focused on sulphur dioxide emissions, therefore, for the purposes of these discussions only those sources which are considered to significantly contribute to ambient sulphur dioxide concentrations are discussed. Such sources include:

- Existing Matimba Power Station
- Brickworks operating at Hangklip, and
- Household fuel combustion
- vehicle exhaust releases and road dust entrainment along paved and unpaved roads

Existing Matimba Power Station

The existing Matimba Power Station is a dry-cooled, coal-fired pulverised fuel power station comprising six 665 MW units, representing a total nominal capacity of 3 990 MW and a total net maximum capacity of 3 690 MW. The only abatement technology currently employed at the Matimba Power Station is electrostatic precipitation with sulphur trioxide injection to enhance particle collection. No gaseous controls exist. Matimba stacks are 250 m above ground and therefore this aids in the dispersion of particulate and gaseous emissions

Brickworks Operating at Hangklip

The brickworks manufactures approximately 2 million bricks per month (Viviers, 2008), fired by using veld ovens (clamp kilns). Firing by clamp is one of the oldest methods of brickmaking. Despite no longer being used in most parts of the world – having been replaced by coal- and gas-fired kiln operations – firing by clamp is still widely used in South Africa (Scorgie, 2008).

The combustion products (SO_2, NO_x, CO, CO_2) are emitted from fuel combustion during firing. The main source of SO_2 emissions is the raw materials that sometimes contain sulphur compounds. The organic compounds (methane, ethane, Volatile Organic Compounds) are emitted from the firing and drying processes. Hydrogen fluoride (HF) is emitted as a result of the fluorine compounds contained in the raw materials (where applicable).

Based on US-EPA AP42 emission factors given for uncontrolled coal-fired kilns, it is estimated that the kilns result 43.1 tpa of sulphur dioxide emissions of (Scorgie, 2006)

Household Fuel Burning

Despite the intensive national electrification programme a number of households in the Lephalale region continue to burn fuel to meet all or a portion of their energy requirements. The main fuels with air pollution potentials used by households within the Lephalale region are coal, wood and paraffin. It is however pertinent that the proportion of fuel burning households remains small in comparison to the total population grouping. The number of households burning coal, wood and paraffin within the various wards within Lephalale Municipality, described by Census 2001 are illustrated in Table 4-1 to 4-3

Table 4-1 – 4-3 Number of households using fuels for cooking, heating and lighting purposes within Lephalale Municipality wards (Statistics South Africa, 2001)

Table 7-1 Cooking Energy Carrier

Energy Carrier	Ward 1	Ward 2	Ward 3	Ward 4	Ward 5	Total
Electricity	1525	2284	830	1034	1362	7035
Gas	22	33	5	64	80	204
Paraffin	547	41	45	161	267	1061
Wood	91	530	22	2543	2906	6092
Coal	2	1	0	5	13	21
Animal Dung	1	4	5	3	13	26
Solar	8	13	0	7	16	44

Table 4-2 Heating Energy Carrier

Energy Carrier	Ward 1	Ward 2	Ward 3	Ward 4	Ward 5	Total
Electricity	1529	2301	838	1077	1468	7213
Gas	5	22	6	46	69	148
Paraffin	411	26	33	125	214	809
Wood	223	541	15	2503	2807	6089
Coal	2	1	1	10	14	28
Animal Dung	0	2	11	0	3	16
Solar	11	5	1	2	9	28

Table 4-3 Lighting Energy Carrier

Energy Carrier	Ward 1	Ward 2	Ward 3	Ward 4	Ward 5	Total
Electricity	1635	2438	852	1667	2584	9176
Gas	3	12	15	19	7	56
Paraffin	36	16	27	115	161	355
Wood	528	422	16	1944	1894	4804
Coal	-	-	-	-	-	-
Animal Dung	-	-	-	-	-	-
Solar	1	13	13	8	0	35

Despite wood and paraffin being the predominant fossil fuel utilised for cooking and heating the large majority of the approximately 22 000 persons residing within the Lephalale region make use of electricity. It is however worth noting that Ward 4 and 5 are areas most reliant on fossil fuels for heating and lighting requirements.

4.1.4. Current Ambient Air Quality: Interpretation of monitored data

Since 1984 Eskom has undertaken several monitoring campaigns within the Lephalale region, many of which have focused on the continuous monitoring of ambient SO_2 in the vicinity of the Matimba Power Station (Figure 4-3). Monitoring was conducted at Zwartwater for the period October 2001 to September 2003. In September 2003 the Zwartwater monitoring station was relocated to Grootstryd. In 2005 the monitoring station was subsequently relocated to the Marapong Township, as part of the conditions of the Medupi Environmental authorisation. At this time the station was also expanded to include a NO_x analyser. Typically the monitoring stations measured both SO_x and PM10 however for the purposes of these discussions only the SO_2 data will be considered

Additional historical SO_2 monitoring campaigns, relevant to this study included:

- Sampling at five sites (M1-M5) during the August 1991 to January 1992 period;
- Sampling at Waterberg station during the 1984 to 1989 period;

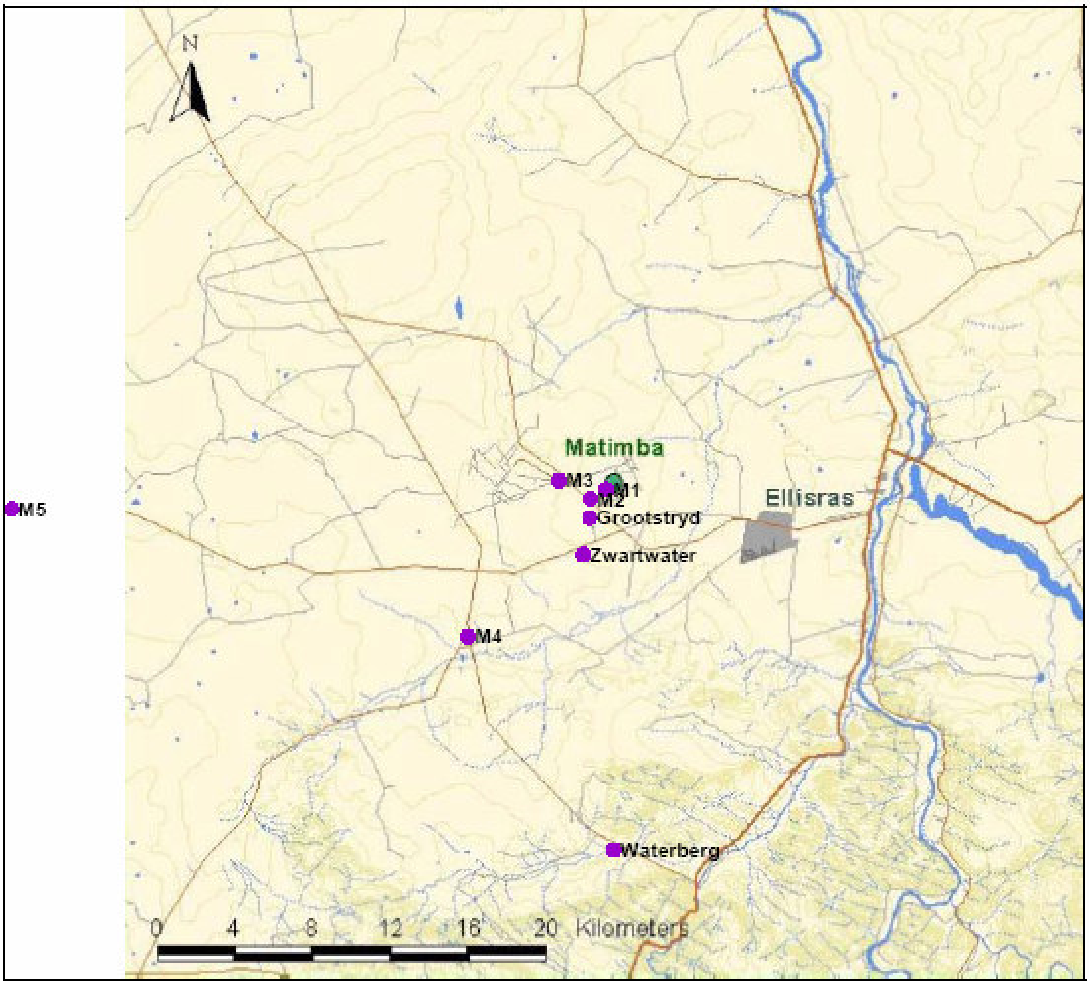


Figure 4-4 Location of all monitoring campaigns in the Lephalale region

Table 4-4 to 4-9 Monitored SO_2 concentrations for the Eskom Monitoring campaign at the Waterberg, Grootstryd and Marapong from August 1991 to January 2002

Table 4-4 Monitoring undertaken at Waterberg during the period

Year	Hourly averages			Daily Averages		
	Proposed SA Standard	Highest Hourly (ug/m^3)	Frequency of exceedance	Proposed SA Standard	Highest Daily (ug/m^3)	Frequency of exceedance
1984	350 µg/m^3	286	0	125 µg/m^3	32	0
1985	350 µg/m^3	64	0	125 µg/m^3	33	0
1986	350 µg/m^3	38	0	125 µg/m^3	24	0
1987	350 µg/m^3	251	0	125 µg/m^3	42	0
1988	350 µg/m^3	271	0	125 µg/m^3	61	0
1989	350 µg/m^3	617	1	125 µg/m^3	108	0
1990	350 µg/m3	337	0	125 µg/m^3	66	0
1991	350 µg/m^3	362	2	125 µg/m^3	44	0

Table 4-5 Monitoring undertaken at Zwartwater during the period 2000-2002

Year	Hourly averages			Daily Averages		
	Proposed SA Standard	Highest Hourly (ug/m^3)	Frequency of exceedance	Proposed SA Standard	Highest Hourly (ug/m^3)	Frequency of exceedance
2000	350 µg/m^3	615	3	125 µg/m^3	72	0
2001	350 µg/m^3	900	6	125 µg/m^3	107	0
2002	350 µg/m^3	423	2	125 µg/m^3	66	0

Table 4-6 Monitoring undertaken at Grootstryd during the period March 2003-December 2006

Year	Hourly averages			Daily Averages		
	Proposed SA Standard	Highest Hourly (ug/m^3)	Frequency of exceedance	Proposed SA Standard	Highest Daily (ug/m^3)	Frequency of exceedance
2003	350 µg/m^3	686	2	125 µg/m^3	90	0
2004	350 µg/m^3	486	2	125 ug/m^3	86	0
2005	350 µg/m^3	492	7	125 µg/m^3	120	0
2006	350 µg/m^3	478	3	125 µg/m^3	75	0

Table 4-7 Monitoring undertaken at Marapong during the period 2006 - 2008

Year	Hourly averages			Daily Averages		
	Proposed SA Standard	Highest Hourly (ug/m^3)	Frequency of exceedance	Proposed SA Standard	Highest Daily (ug/m^3)	Frequency of exceedance
2006	350 µg/m^3	109	0	125 µg/m^3	91	0
2007	350 µg/m^3	110	0	125 µg/m^3	85	0
2008	350 µg/m^3	117	0	125 µg/m^3	90	0

Table 4-8 Monitored SO_2 concentrations for the Eskom Monitoring campaign from January 1991 to December 1992

Monitoring station	Hourly averages			Daily Averages		
	Proposed SA Standard	Highest Hourly (ug/m^3)	Frequency of exceedance	Proposed SA Standard	Highest Daily (ug/m^3)	Frequency of exceedance
M1	350 µg/m^3	434	2	125 µg/m^3	49	0
M2	350 µg/m^3	612	1	125 µg/m^3	75	0
M3	350 µg/m^3	880	7	125 µg/m^3	191	1
M4	350 µg/m^3	531	1	125 µg/m^3	94	0
M5	350 µg/m^3	104	0	125 µg/m^3	28	0

From the above tables it is evident that exceedances of both the hourly and daily proposed South African ambient air quality standards are few, in fact all stations are considered to be in compliance to the proposed standards (88 excedances are allowed of the hourly average). In order to fully develop the above understanding, ambient SO_2 concentrations were sourced from Grootstryd and Marapong. The positions of the monitoring stations are shown relative to the Matimba and Medupi Power Stations, and the residential areas of Marapong and Onverwacht in figure 4-1 and 4-4. The Grootstryd air quality monitoring station can be seen approximately 2.5 km southwest of Matimba Power Station while the Marapong air quality monitoring station can be seen approximately 2.5 km north-east of Matimba. The two air quality monitoring stations lie down- (Grootstryd) and upwind (Marapong) of the Medupi Power Staion. As discussed, from the wind roses the wind the prevailing winds are northeasterly sector winds occurring for more than 50% of the time. This data will be discussed as a base case.

Frequency distributions of ambient SO_2 concentrations are shown in figures 4-5 to 4-8. In Figure 4-5, it can be seen from the measured 24-hour average ambient SO_2 concentrations at Grootstryd during 892 days (from September 2003 to August 2006) for which data is available, that the South Africa daily standard of 125 µg/m3 (same as the EHS guideline value) was never exceeded. Indeed for more than 99% of the time the concentrations were below 60 µg/m3 (Figure 4-6) As has been presented earlier Grootstryd data would reflect (elevated) downwind concentrations, broadly analogous to what would be considered as the zone of highest concentration.

Not unexpectedly, ambient SO_2 concentrations on the upwind side of Matimba, at Marapong are seen to be generally lower than at Grootstryd (Figure 4-7). No exceedances of the proposed South African 24 hour standard are evident at Marapong and the 99th percentile concentration is 36 µg/m3. It is also highly likely that SO_2 emissions from domestic fuel use in Marapong contribute to the measured ambient concentrations in that area.

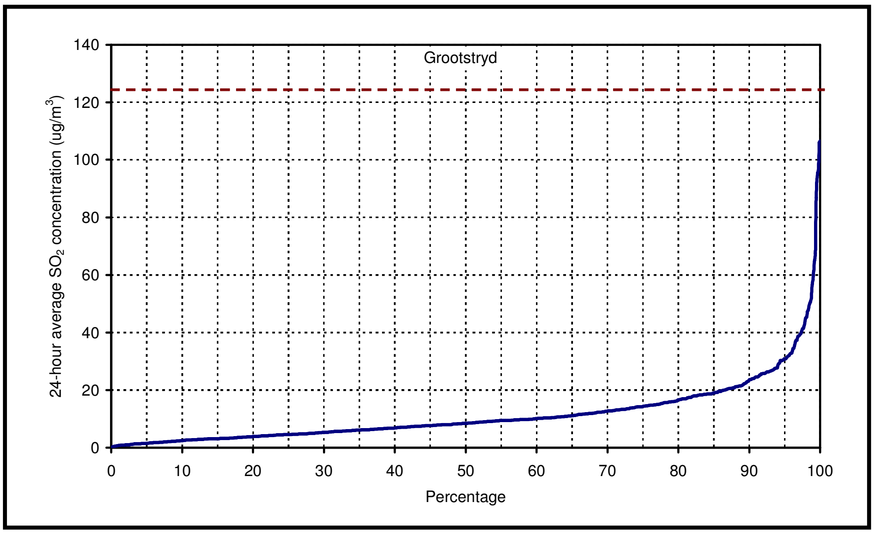


Figure 4-5 Frequency distribution of measured ambient daily SO_2 concentrations at the Grootstryd monitoring station downwind of the Matimba Power Station. The SA 24-hour average SO_2 standard of 125 µg/m^3 is shown by the dashed horizontal line.

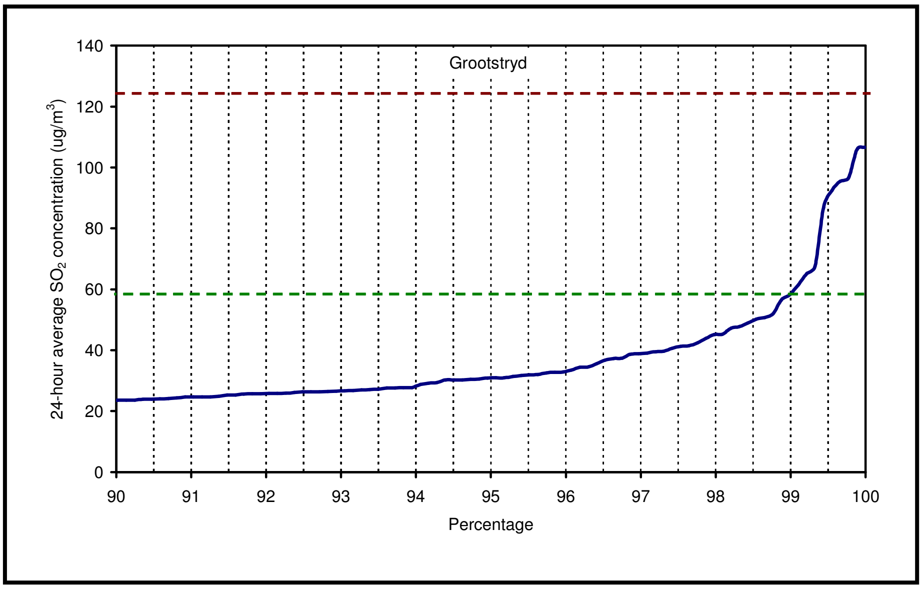


Figure 4-6 Highest 10% of the top graph and includes the 99th percentile at 36 µg/m^3.

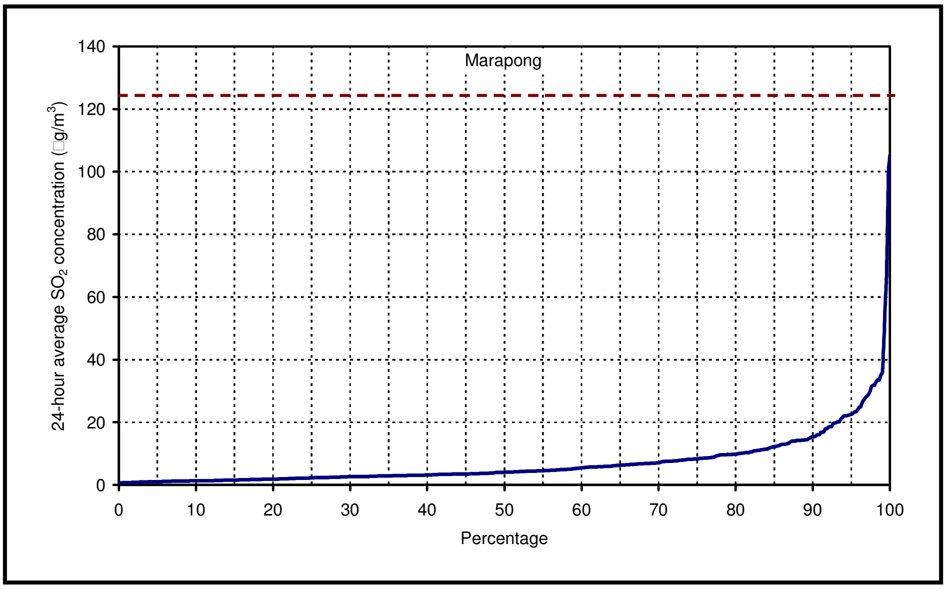


Figure 4-7 Frequency distribution of measured ambient daily SO_2 concentrations at the Marapong monitoring station upwind of the Matimba Power Station. The SA SO_2 standard of 125 µg/m^3 is shown by the dashed horizontal line.

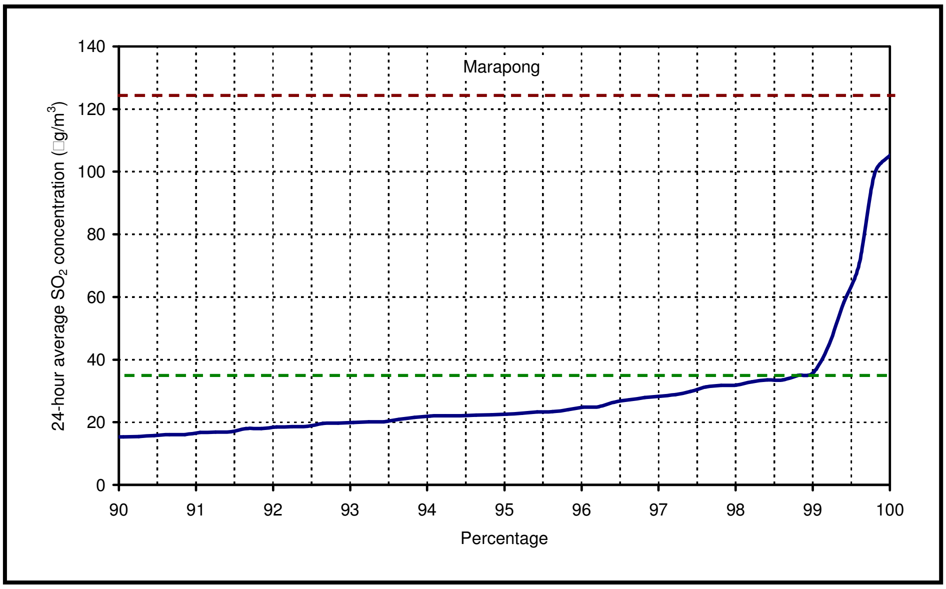


Figure 4-8 Highest 10% of the top graph and includes the 99th percentile at 36 µg/m^3.

Based on the data in Figures 4-5 to 4-8 it is possible to begin to develop a means to suggest which contributors the measured concentrations can be attributed

Since legislation targets the impact of emissions on human health, the concentrations at ground level is what is important.

Previous research undertaken by Eskom-ERID (Turner, 1986 and 2007) has highlighted that the plume of the power station (high level source) typically comes to ground approximately 2 to 5km from the stack, depending on the meteorological conditions. In the Lephalale region, this distance may increase slightly as a result of the high ambient temperatures and strong air currents (Ross, 2008). However, it is highly likely that the point of maximum concentration from the Matimba Power station or any future power station will be within a 10km radius of the source.

In addition to having an understanding as to the distance within which the power station plume is likely to touch the ground, it is possible to apportion the contribution made by emission sources to measurements at a particular monitoring station. This source apportionment is achieved by means of understanding the diurnal signature of a power station. Typically emissions from a high level source, such as a power station come to ground during the day (10:00 – 16:00) when the convective mixing of the atmosphere is at its greatest, bringing the plume to ground. During the night and early morning the temperature inversion, which forms on South African Highveld prevents the plume from coming to ground. Matimba, and all of Eskom's coal fired power stations utilise this principle to ensure maximum dispersion potential by emitting above the inversion layers (Turner, 2007).

In light of the above a review, of the diurnal signatures of all the monitoring stations highlight that all measured emissions from the Matimba power station to varying degrees, depending on their location within the wind field and proximity to the station (figure 4-9 to figure 4-15). Primary peaks in ground level sulphur dioxide concentrations were observed to occur during the morning (10h00 to 12h00) at Zwartwater and M4, whereas M1 and M2 recorded peaks at 13h00, indicating the effect of Matimba power station at these monitoring points. The lower concentrations at M1, although still showing some influence from the Matimba power station, were far lower, probably owing to the stack height and the proximity of this station to the Matimba power station. M3 station, located to the west of the Matimba Power Station, recorded higher ground level concentrations during the afternoon which in view of the prevailing wind direction and the nature of the diurnal signature, was probably influenced by another source. The Waterberg monitoring station generally does not, with the exception of winter show any signature that islikely to be associated with high level releases such as the Matimba power station.

Figure 4-9 Diurnal signature for Grootstryd, Marapong and Waterberg stations

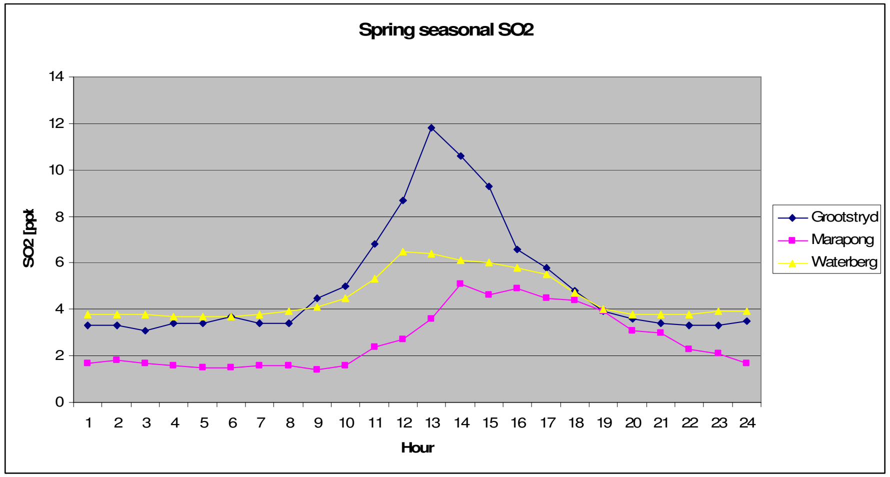


Figure 4-10Diurnal signature for M1-M5 stations

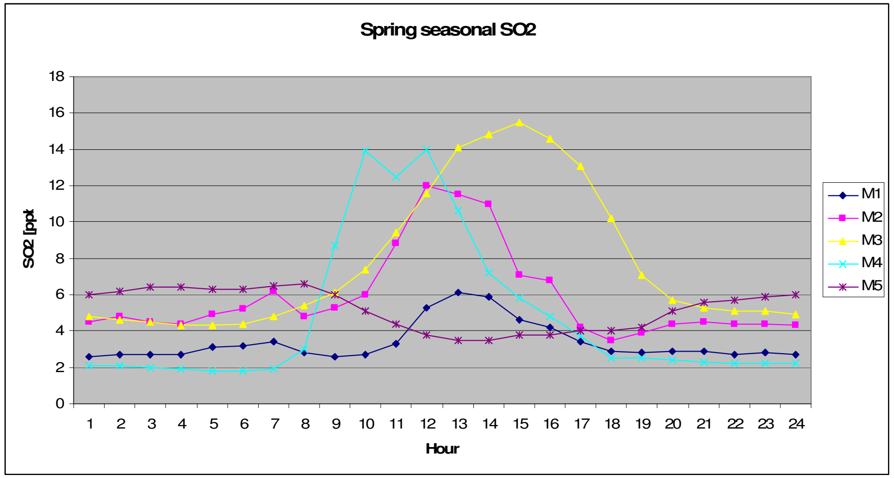


Figure 4-11 Diurnal signature for Grootstryd, Marapong and Waterberg monitoring stations

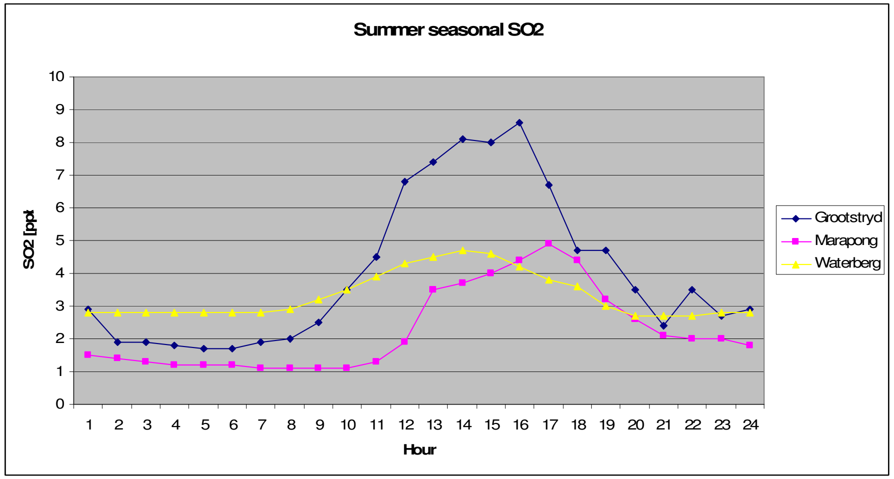


Figure 4-12 Diurnal signature for M1-M5 monitoring stations

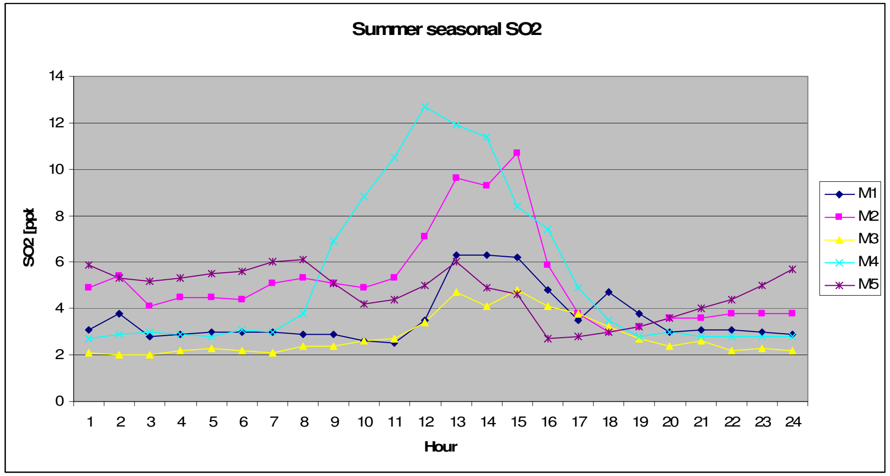


Figure 4-13 Diurnal signature for Grootstryd, Marapong and Waterberg monitoring stations

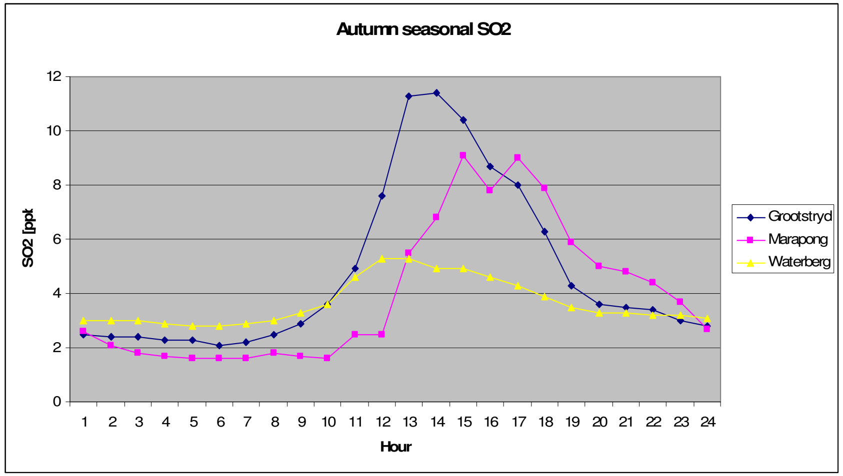


Figure 4-14 Diurnal signature for Grootstryd, Marapong and Waterberg monitoring stations

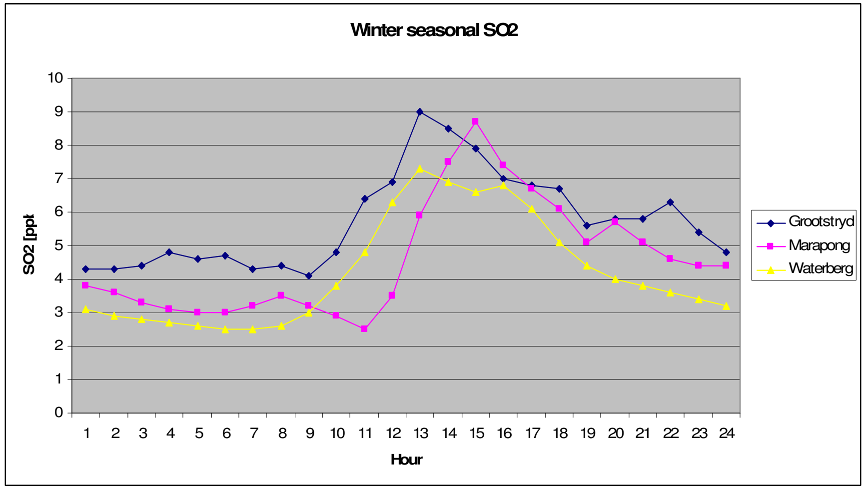
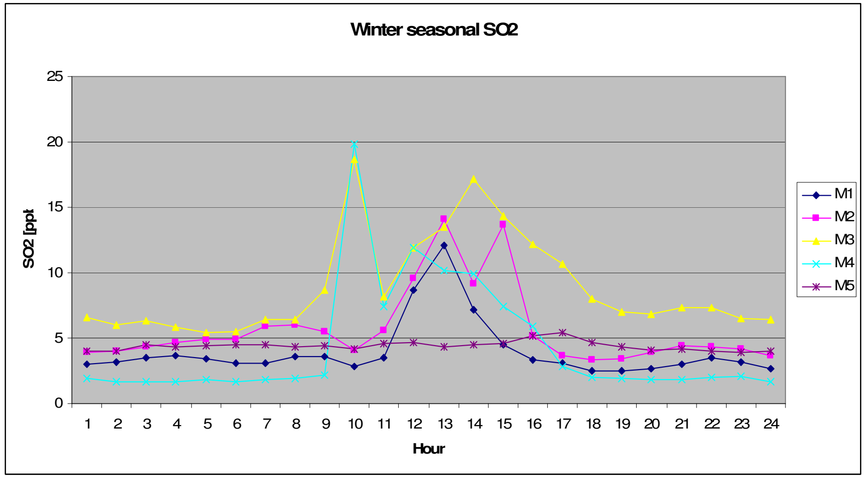


Figure 4-15 Diurnal signature for M1-M5 monitoring stations



The Grootstryd Monitoring station was specifically located to measure the highest ground level concentrations emanating from the Matimba Power Station, within the constraints of locating a monitoring station. It is therefore noted that of all the diurnal signatures across all seasons the monitoring station closely mimics what is to be expected from a high level source (Matimba).

The use of an Eskom developed source apportionment tool, Source Apportionment by Diurnal Signature (SADS) (Turner, 2007) provides a more detailed picture of the exact percentage contribution of the Matimba power station . SADS was undertaken for the monitoring stations at Marapong (highest population densities) and Grootstryd Low population densities – Open farm area) (Figure 4-16 and figure 4-18). It is significant that ambient air quality monitoring conducted in Marapong, the most densly populated area in the vicinity of the power stations, and the area where the potential for inhalation exposure is the highest, that high concentrations of SO_2 are not associated with emissions from the Matimba Power Station power station, but with low-level emissions from motor vehicles and domestic coal combustion, which are localised to Marapong. As expected the SADS assessment confirms that emissions from the Matimba Power Station come to ground south west of the power station, in a region that is very sparsely populated.

It is evident that for all monitoring stations Matimba Power Station contributes less that half of total ground level SO_2 concentration, with significant contributors being various low level sources.

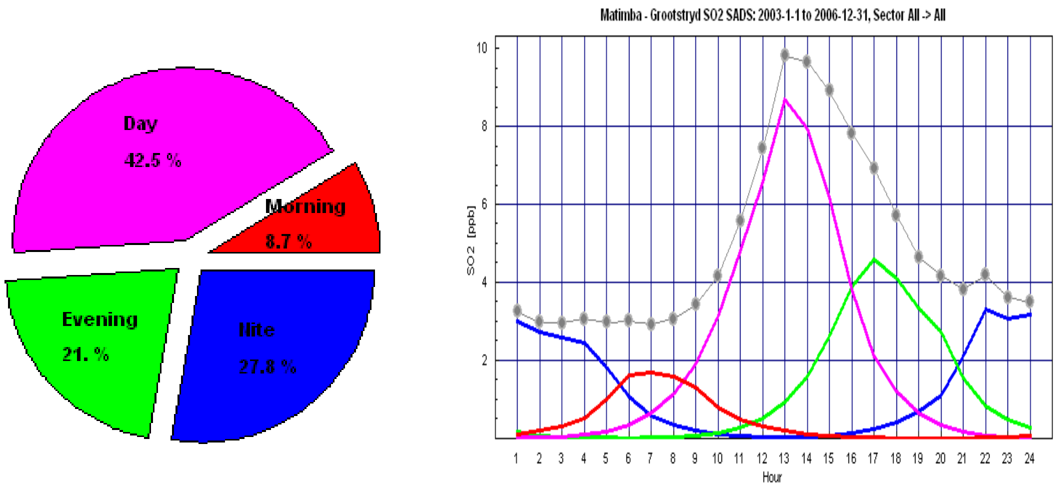


Figure 4-16 SADS analysis of air quality at Grootstryd (highlighting highest contributor to ground level concentrations is from tall stack – Matimba Power Station)

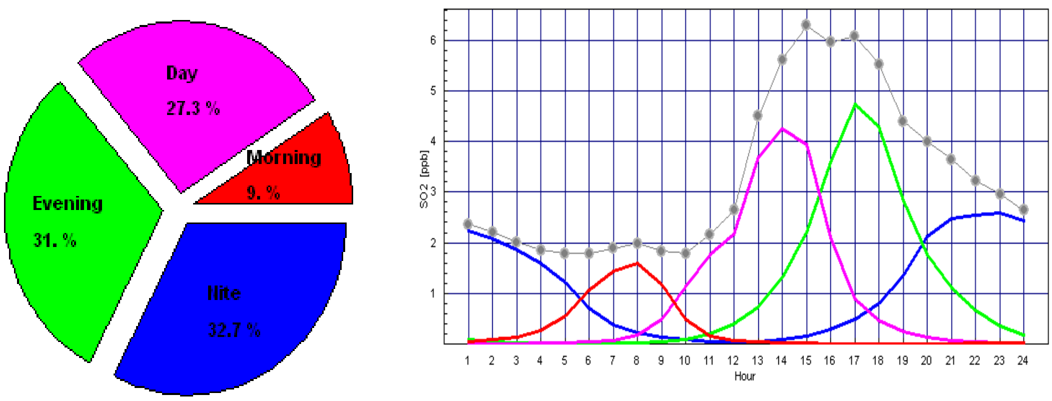


Figure 4-17SADS analysis of air quality at Marapong (highlighting highest contributor to ground level concentrations is low level sources – domestic fires etc)

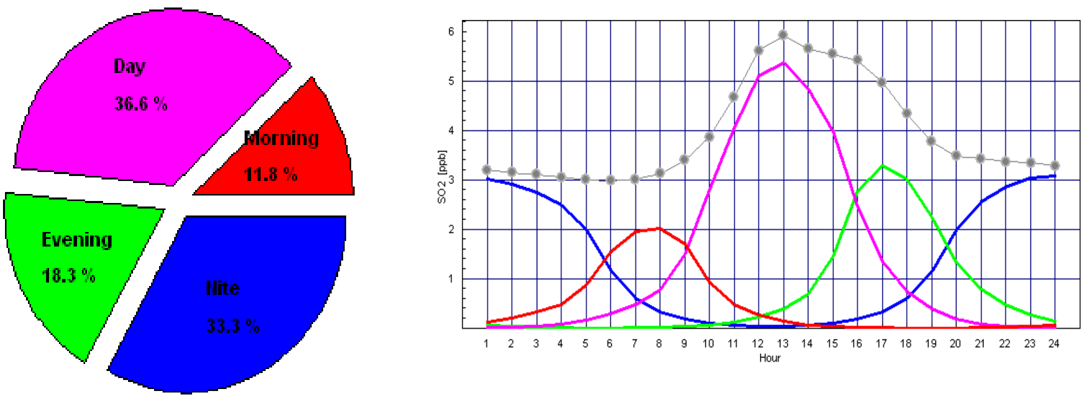


Figure 4-18 SADS analysis of air quality at Waterberg (contributions from both high stack and low level sources)

The above information, when viewed in conjunction with a series of air pollution roses provides a clear indication of the likely sources of pollution in the region and the significance of their relative contribution to air quality. Wind roses for the Grootstryd station show high SO_2 concentrations coinciding with the airflow from the ENE and NE sector (Figure 4-19). As well as with wind from other sectors, which could be a result of recirculation of emissions from the Matimba Power station or alternatively from other sources (e.g. combustion of coal discards or firing at Hanglip brickworks). The strong daytime influence of Matimba power station is clearly evident pollution roses from the Marapong monitoring station (Figure 4-20) clearly indicate night time sources predominantly originating from the western sectors and day time sources from the eastern sectors. As a result of the location of the monitoring station effects from Matimba Power station would be noted from the south western sector.

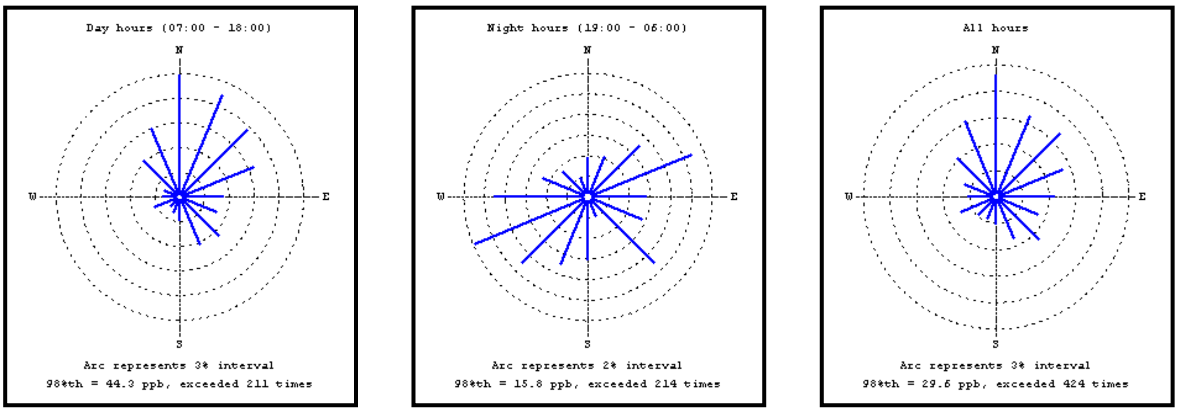


Figure 4-19 Pollution roses taken at the 98 percentile for the Grootstryd monitoring station

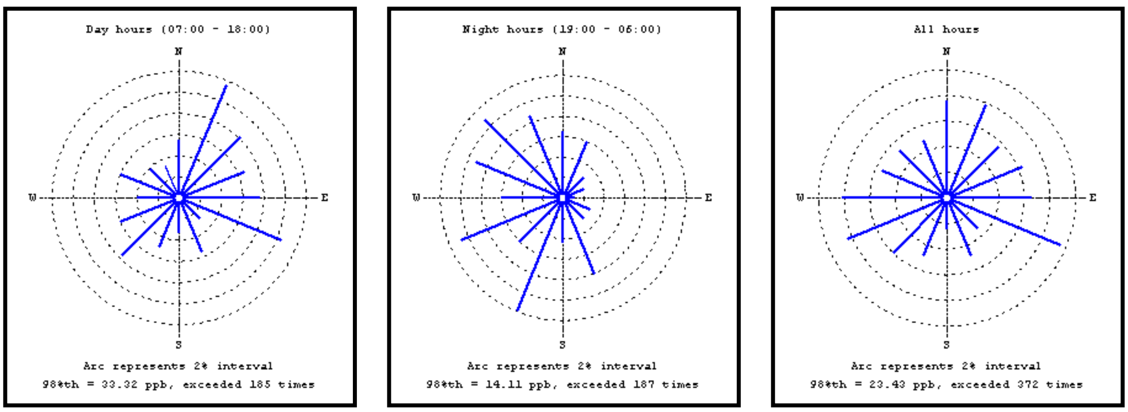


Figure 4-20 Pollution roses taken at the 98 percentile for the Marapong monitoring station

4.2. Air quality Modelling

The CALPUFF atmospheric dispersion modelling system has been run in order to assess the effect of cumulative emissions from Matimba, Medupi, Coal 3 and Coal 4 power stations on ground-level NO_2 and SO_2 concentrations in the Waterberg. CALPUFF, the Californian Puff model, is a Gaussian puff model designed for non-steady state conditions and longer range transport. Studies conducted by Eskom (Ross et al., 2006) have shown that CALPUFF is best suited for modelling emissions from Eskom's tall stacks due to its better representation of the upper air meteorology.

4.2.1. Scenario's modelled

For the purpose of this research report a total of five (5) scenarios were modelled (Table 4-11). Scenario's modelled, although not comprehensive are considered to be in line with feasible alternatives as currently being considered by Eskom in terms of their long term planning for the region.

Table 4-11 Air Quality scenarios modelled – Indication of number units with FGD

	Baseline	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5
	Number of units with FGD					
Matimba	0	0	0	0	0	0
Medupi	-	0	3	6	0	0
Coal 3	-	-	-	-	0	6
Coal 4	-	-	-	-	0	6

In addition to the above scenarios, it was considered prudent, in light of the effect that FGD has on plume buoyancy, to predict the impact that FGD would have on NOx emissions.

4.2.2. Performance of the CALPUFF model

The accuracy of the dispersion model predictions was assessed by comparing the output concentration fields with observations. Monitoring stations used for comparison include the active monitoring site at Grootstryd; the historical active monitoring sites that were run for a 6-month period in 1991/92 (M5, M4, M1). The active monitoring sites are used to assess the accuracy of the maximum one-hour concentrations.

Table 4-12 Performance of the Calpuff model

Monitoring Station	Measured		Predicted	
	Highest Hourly	Frequency of exceedance	Highest Hourly	Frequency of exceedance
Grootstryd	733	14	600	10
M5	602	4	250	1
M4	443	2	500	1
M1	509	2	452	1

CALPUFF adequately predicts the maximum concentrations at a distance of 10 km downwind of Matimba, but under-predicts concentrations close to the power station (at distances of 3 km or less) and further from the power station off the plume centreline. CALPUFF also under-predicts the number of exceedances in close proximity to the power station and further from the power station off the plume centreline, but accurately predicts the number of exceedances 10 km downwind from Matimba. Unfortunately, there are no monitoring sites in the region between 2.5 and 10 km downwind of the power station, which is where exceedances are predicted to occur most frequently.

CALPUFF under-predicts average SO_2 concentration at all monitoring stations, although the magnitude of the under-prediction is worse in close proximity to the power station (<3 km), and further from the power plant off the plume centreline.

Note that a dispersion model is considered to be suitable for use if it predicts concentrations within a factor of two of those observed, and thus can only ever be used to give a rough indication of the implications of various scenarios and configurations.

4.2.3. Dispersion Model Results

Baseline

Consideration of the maximum hourly and daily sulphur dioxide concentrations occurring due to Matimba Power Station operations highlights that exceedances of the proposed South African ambient air quality standards and international air quality limits were predicted within the zones of maximum concentrations (i.e. southwest of the Matimba Power Station). The hourly limit value was also predicted to be exceeded within the residential area of Marapong and along the western boundaries of Onverwacht (with no exceedances predicted for central Onverwacht) (Figure 5-

22). It should, however, be noted that despite the exceedances of the hourly limit, the standards, which allow for a permissible amount of exceedances were in general complied with, throughout the modelling domain (Figure 4-21).

Maximum 1-hour SO_2 concentration (µg/m^3) **Frequency of exceedance of the 350 µg/m^3 one-hour SO_2 limit**

Baseline: Matimba (without FGD) only

(a) ***(b)***

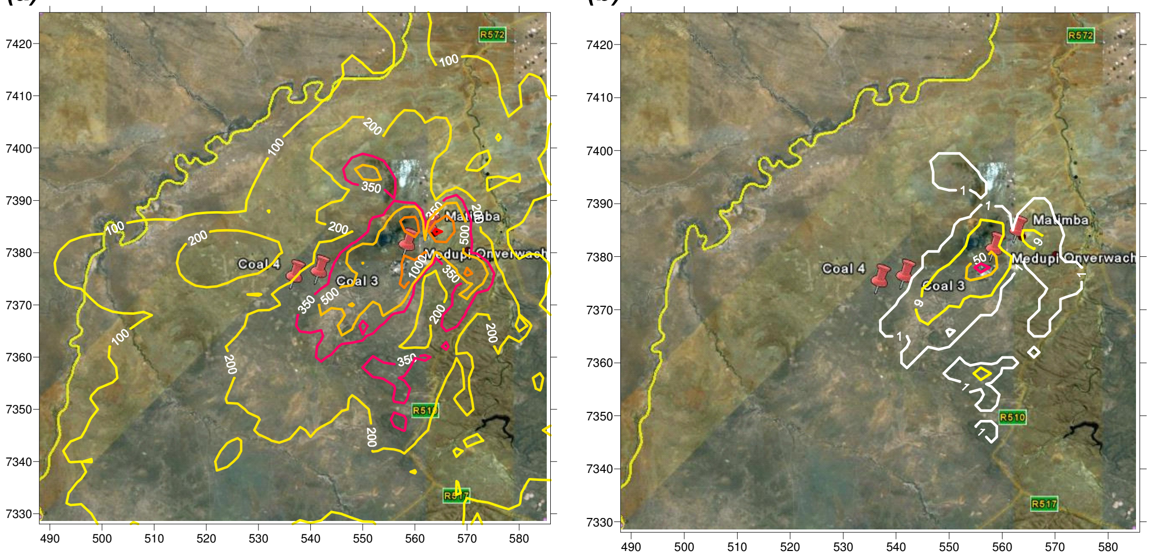


Figure 4-21 Modelled results for Matimba power station without FGD – Hourly averages.

Similarly a comparison of the 24 hourly averages (Figure 4-22 a and b) indicates that in general ambient air concentrations of SO_2 are within compliance throughout the modelling domain, with a single exceedance of the proposed South African daily average been noted at Onverwacht and Marapong. The proposed South African ambient air quality standards (allow for a total of 4 exceedances of the 24 hourly average.

Maximum 24-hour SO_2 concentration

Frequency of exceedance of the 125 µg/m^3 24-hour SO_2 limit

Baseline: Matimba (without FGD) only

(a) ***(b)***

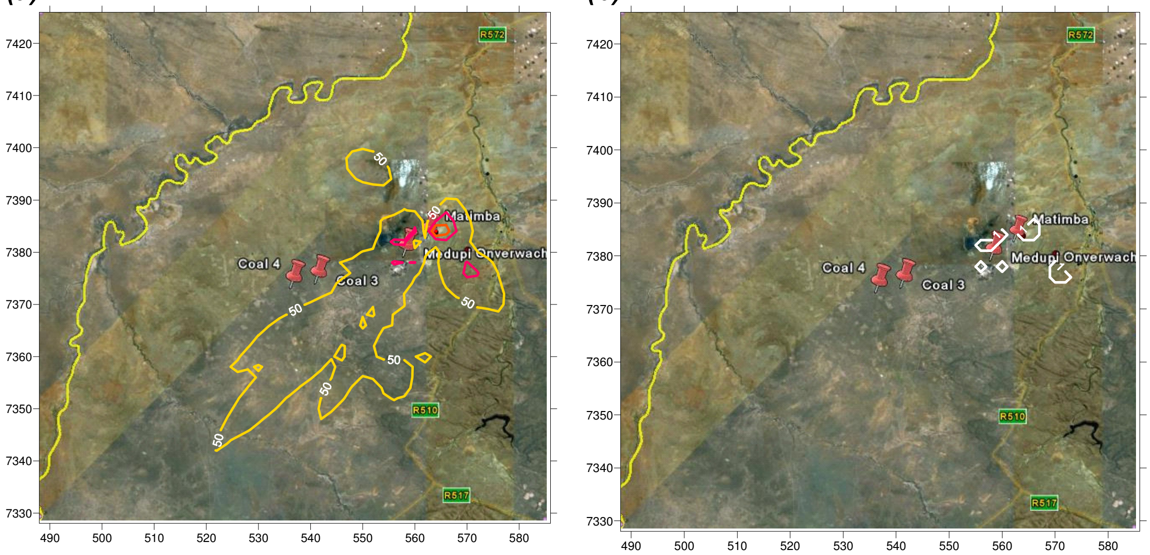


Figure 4-22 Modelled results for Matimba power station without FGD – 24 hourly averages.

Scenario 1: Matimba and Medupi (No FGD)

The highest ground-level SO_2 concentrations are predicted to occur to the north-east of the power stations, at a distance of between 1 and 5 km from the power stations (Figure 4-23(a)). However, these very high concentrations are only an isolated event, and exceedances of the proposed SO_2 ambient air quality standard occur most frequently to the south-west of the power stations, with the zone of maximum influence centred to the south-west of the power stations.

Over 230 exceedances of the proposed hourly SA standards for SO_2 are predicted at some locations (Figure 4-23b). It should however be noted that these exceedances are predominantly along the south western centreline and occur relatively close to the power station (within a 7km radius). The South African ambient air quality standards are human health based and therefore the requirement for complying to such standards will be monitored in populated areas(*pers comms*, DEA (Chief Director Air Quality)). This is due to the fact that a primary objective of the Act is the protection of human health – all proposed standards are human health based. Maximum ground level SO2 concentrations between 500 and 350 ug/m3 occur along the western and southern boundaries of Onverwaght and Marapong respectively (Figure 4-23a). Similarly at these points the proposed hourly SO_2 limit is exceeded a maximum of 5 times compared to the standards that allow for 88 exceedances per year.

Maximum 1-hour SO_2 concentration (µg/m^3) **Frequency of exceedance of the 350 µg/m^3 one-hour SO_2 limit**

Scenario 1: Matimba and Medupi without FGD

(a) ***(b)***

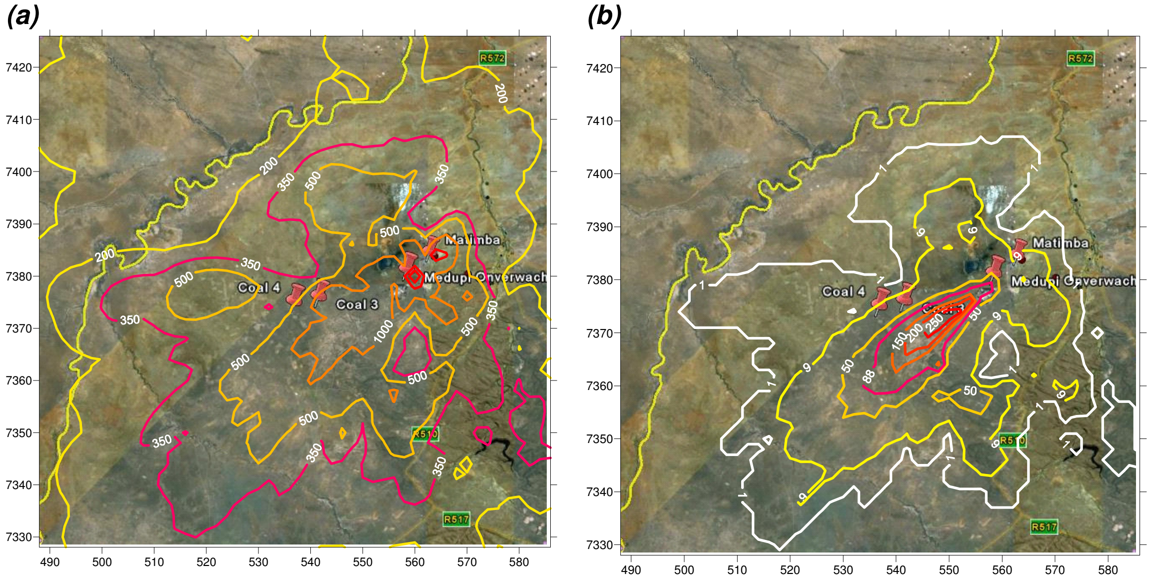


Figure 4-23 Modelled results for Matimba and Medupi power stations without FGD – 1-hourly averages

The proposed 24-hour SO_2 ambient standard is only exceeded in sporadic pockets in close proximity to the power stations (Figure 4-24b). Moreover, only a single exceedance of the 24-hour standard was predicted over major population centres. The South African Standards permits up to 4 exceedances of the daily standard in such areas.

Maximum 24-hour SO_2 concentration | **Frequency of exceedance of the 125 µg/m^3 24-hour SO_2 limit**

Scenario 1: Matimba and Medupi without FGD

(a) ***(b)***

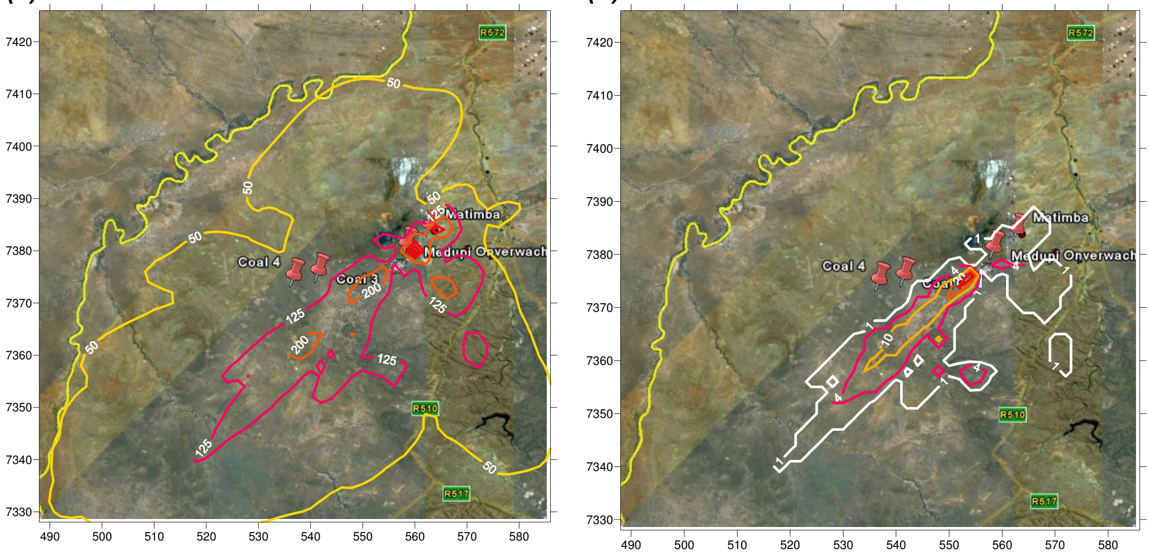


Figure 4-24 Modelled results for Matimba and Medupi power stations without FGD – 24-hourly averages

Scenario 2 and 3

Even with the inclusion FGD on either three or six units an area of non compliance to the hourly SO_2 standards are predicted. Highest ground level concentrations (above 350 µg/m^3) are still predicted to occur over the western and southern boundaries of Onverwacht and Marapong for both scenarios (Figure 4-25a). Perhaps though the most significant difference between the two scenarios is that the installation of FGD on 3 units is associated with an area of non compliance south west of the power stations but within 10km (Figure 4-25b). The installation of FGD on six units with FGD will result in complete compliance to the hourly standards (Figure 4-25a-b)

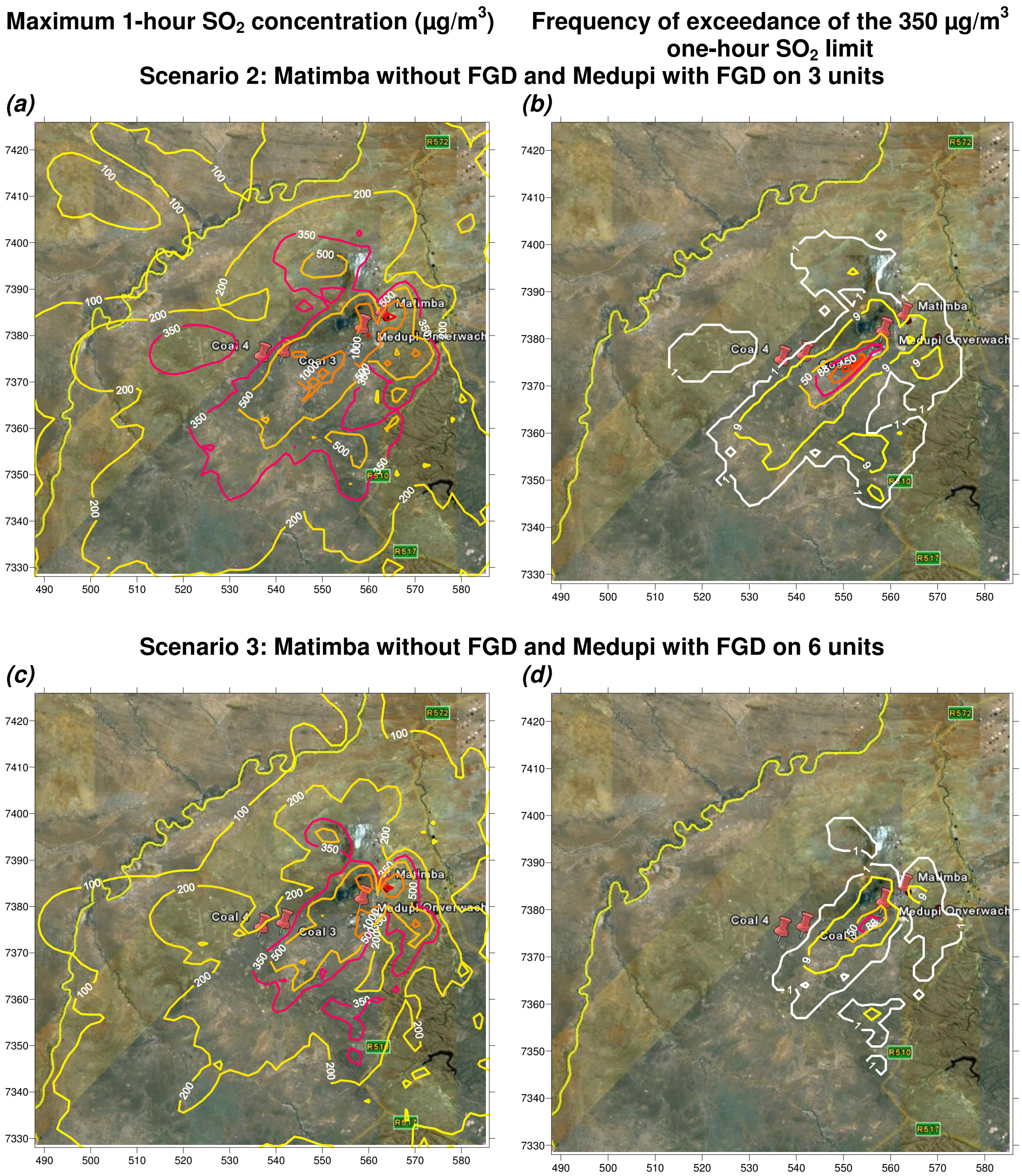


Figure 4-25 Modelled results for **Matimba without FGD and Medupi with FGD on 3 units** ***and*** **Matimba without FGD and Medupi with FGD on 6 units** ***– 1-hourly averages***

The inclusion of FGD on either 3 or all six units at the Medupi power station will result in compliance to the proposed South African ambient air quality standards throughout the modelling domain.

The 24-hourly standard is predicted to be exceeded four times in a narrow south westerly centreline with single exceedances associated with Onverwacht and Marapong (Figure 4-26b). A similar pattern is associated with the installation of FGD on all six units although the extent is significantly reduced with only isolated exceedances predicted in close proximities to the power stations (Figure 4-26d)

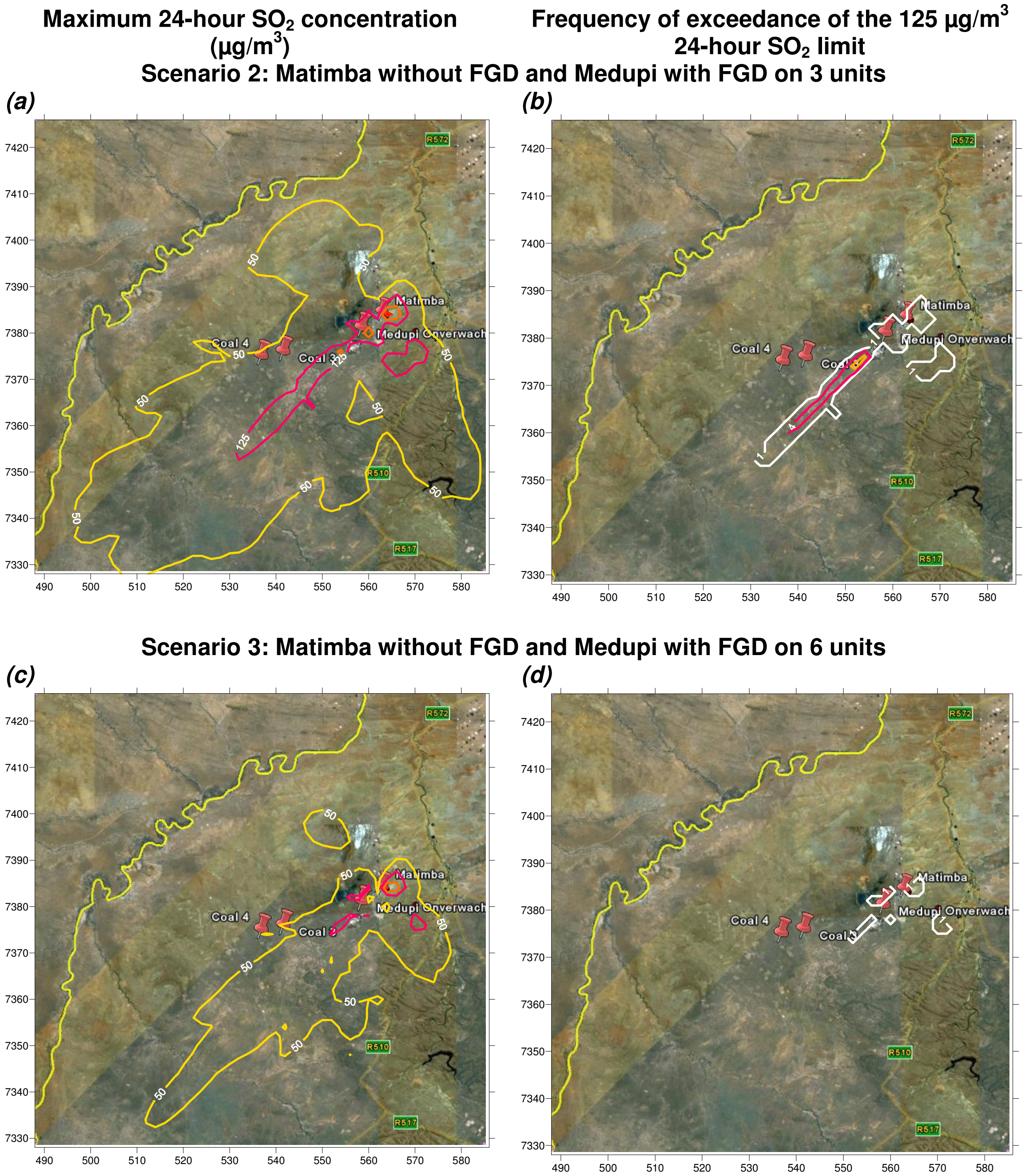


Figure 4-26Modelled results for **Matimba without FGD and Medupi with FGD on 3 units** ***and*** **Matimba without FGD and Medupi with FGD on 6 units** ***– 24-hourly averages***

Scenario 4: Matimba, Medupi, Coal 3 and Coal 4, all without FGD

As expected, the exclusion of FGD on all future coal fired power stations in the region would result in significant concentrations of SO_2 in close proximity to all power stations and in the south western sector of the modelling domain (Figure 4-27a). However what is of interest is that in terms of allowed frequencies of exceedances

Eskom would be in compliance to the hourly standards, over all populated areas (Figure 4-27b). This is however likely to be a result of the relatively high amount of allowable exceedances permitted by the standard compared to international standards. Significant non compliance will be encountered up to 50km from the power stations.

Maximum 1-hour SO_2 concentration (µg/m^3) **Frequency of exceedance of the 350 µg/m^3 one-hour SO_2 limit**

Scenario 4: Matimba, Medupi, Coal 3 and Coal 4, all without FGD

(a) ***(b)***

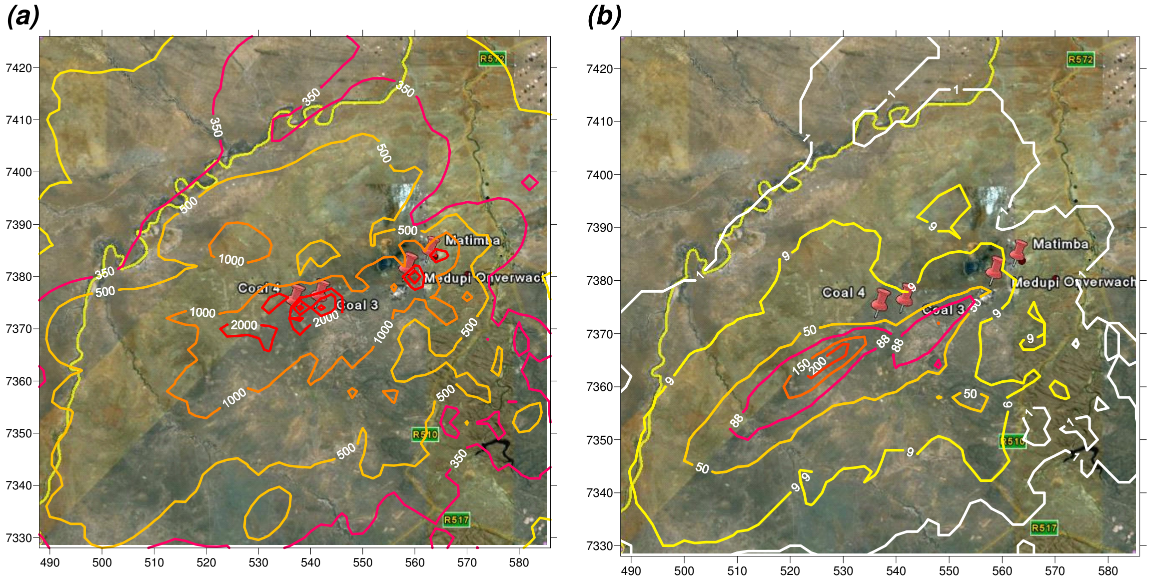


Figure 4-27 Modelled results for* Matimba, Medupi, Coal 3 and Coal 4, all without FGD – *1-hourly averages

Similarly to the modelled predictions for the 1-hourly averages extensive non compliance to the 24hourly standards are predicted in the event that no FGD be included on any of the future coal fired power stations (Figure 4-28). The most significant areas of non compliance remains the south western sector. The proposed 24hour standard will be complied with in all population areas.

Maximum 24-hour SO_2 concentration ($\mu g/m^3$) | **Frequency of exceedance of the 125 $\mu g/m^3$ 24-hour SO_2 limit**

Scenario 4: Matimba, Medupi, Coal 3 and Coal 4, all without FGD

(a) *(b)*

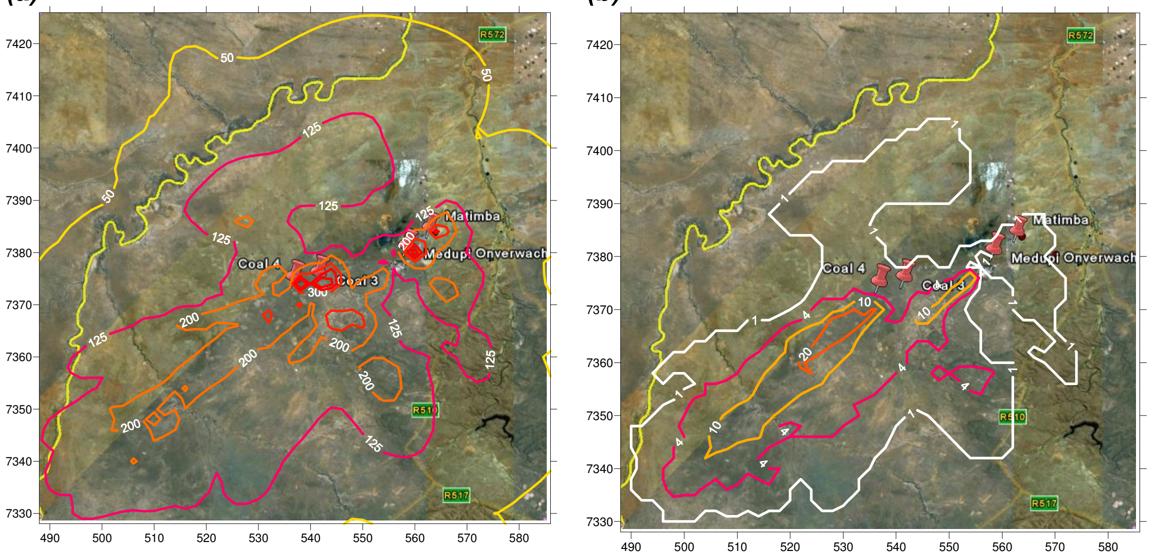


Figure 4-28 Modelled results for* Matimba, Medupi, Coal 3 and Coal 4, all without FGD *– 24-hourly averages

Scenario 5: Matimba without FGD and Medupi, Coal 3 and Coal 4 with FGD

Despite the inclusion of FGD on Medupi, Coal 3 and Coal 4 the ambient air quality limit for the hourly averaging period will be exceeded throughout the modelling domain (Figure 4-29). The standard is estimated to be exceeded up to 250 times within a 8km distance from Medupi Power Station. The standard will however be complied with in all populated areas, which will record predicted 8 exceedances compared to the allowed 88 (Figure 4-29b). .

Maximum 1-hour SO_2 concentration (µg/m^3) **Frequency of exceedance of the 350 µg/m^3 one-hour SO_2 limit**

Scenario 5: Matimba without FGD and Medupi, Coal 3 and Coal 4 with FGD

(a) ***(b)***

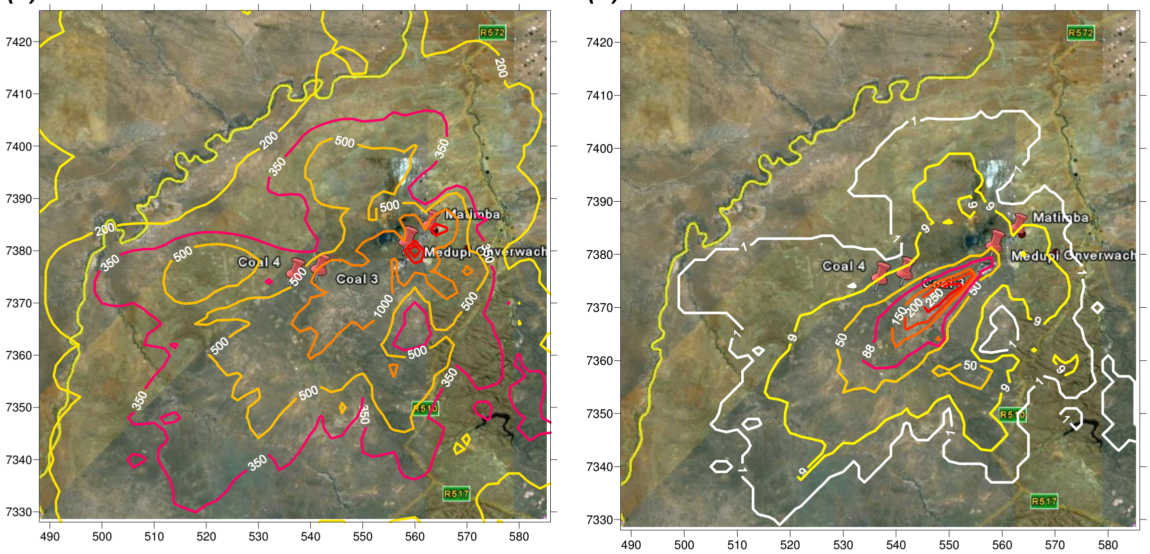


Figure 4-29 **Matimba without FGD and Medupi, Coal 3 and Coal 4 with FGD –** ***1-hourly averages***

Generally compliance with the 24-hourly limit will be complied with except for a distance of 20km along the south western centre line (Figure 4-30a-b).

Maximum 24-hour SO_2 concentration (µg/m^3) **Frequency of exceedance of the 125 µg/m^3 24-hour SO_2 limit**

Scenario 5: Matimba without FGD and Medupi, Coal 3 and Coal 4 with FGD

(a) ***(b)***

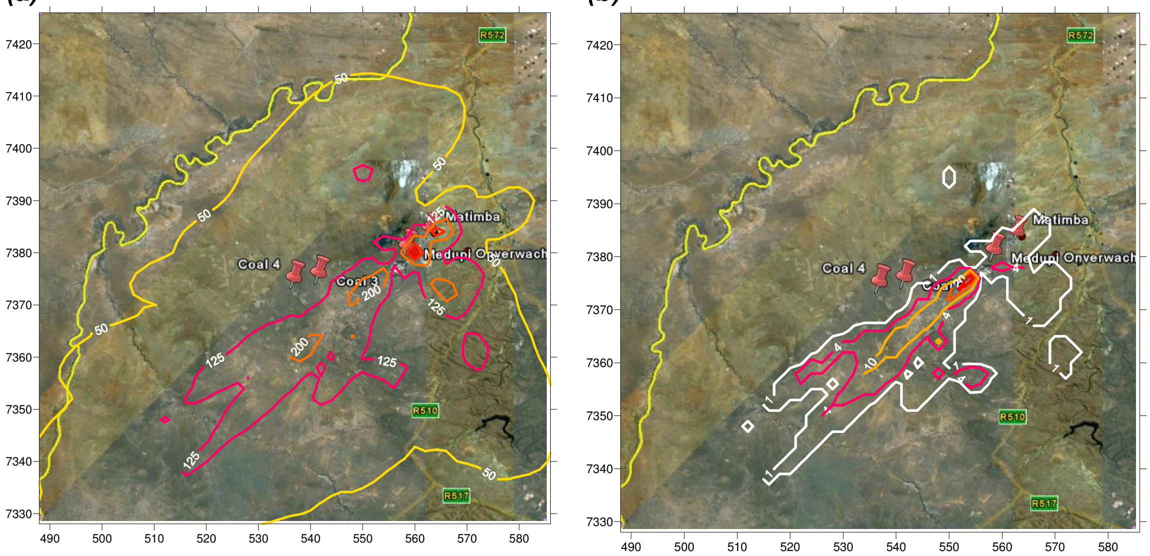


Figure 4-30 **Matimba without FGD and Medupi, Coal 3 and Coal 4 with FGD –** ***24-hourly averages***

Table 4-13 Proposed South African Limits for SO_2

1	2	3	4
Exposure period	**Averaging period**	**Limit value µg/m³**	**Number of permissible exceedences per annum**
Hourly limit value for the protection of human health	1 h	200	88
Daily limit value for the protection of human health	24 h	40	0

Nitrogen Dioxide

The installation of FGD on Medupi Power Station, in order to reduce SO_2 emissions, could potentially negatively impact on ground-level concentrations of other emissions, particularly nitrogen oxides, from the stack as a result of reduced plume buoyancy.

An evaluation of potential impacts on NO_x concentrations across all modelled scenarios (Figure 4-31a-l) indicating that despite the noted slight increase in NO_x ground level concentrations, with the inclusion of FGD (particularly through the comparison of scenario 5) there is very little risk of exceeding ambient NO_2 standards in the vicinity of Matimba and Medupi power stations. The entire region is predicted to be in compliance with the one-hour ambient NO_2 standard. At most 5 exceedances per annum of the target limit value of 200 ug/m^3 (9 exceedances are allowed) are predicted to occur in a small zone north-east of Matimba power station. Moreover, there is little confidence in these predictions as they appear to be an isolated event.

Annual average NO_2 concentrations are predicted to be well below the ambient annual NO_2 standard of 40 g/m^3. As expected, annual average NO_2 concentrations are highest downwind (south-west) of the power stations. Annual average NO_2 concentrations are less than 7 g/m^3 (Appendix 7)

Table 4-14Proposed South African limits for NOx

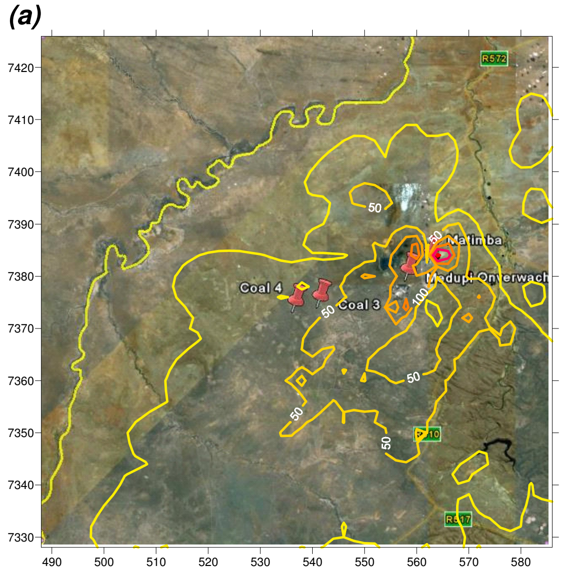
1	2	3	4
Exposure periods	**Averaging period**	**Limit value µg/m³**	**Number of permissible exceedances per annum**
Hourly limit value for the protection of human health	1 h	200	88
Annual limit value for the protection of human health	Calendar year	40	0

Maximum 1-hour NO_2 concentration (ug/m^3)

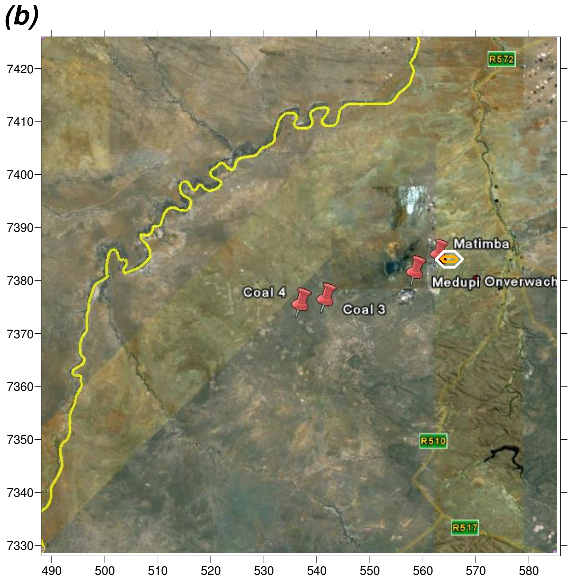
Frequency of exceedance of the 200 □g/m^3 one-hour NO_2 limit

Baseline: Matimba (without FGD) only

(a)

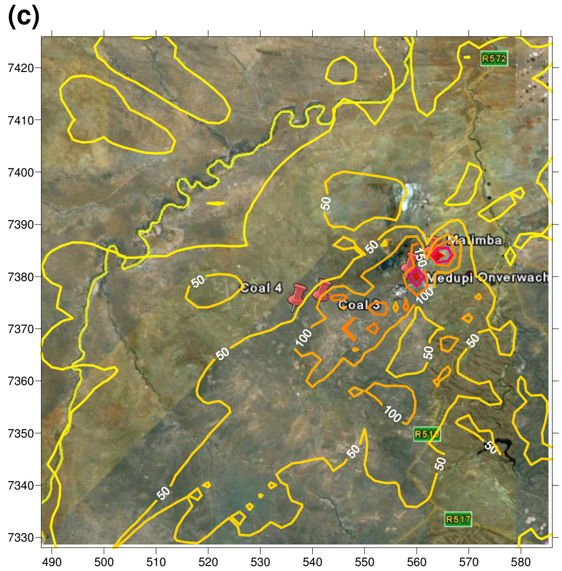


(b)

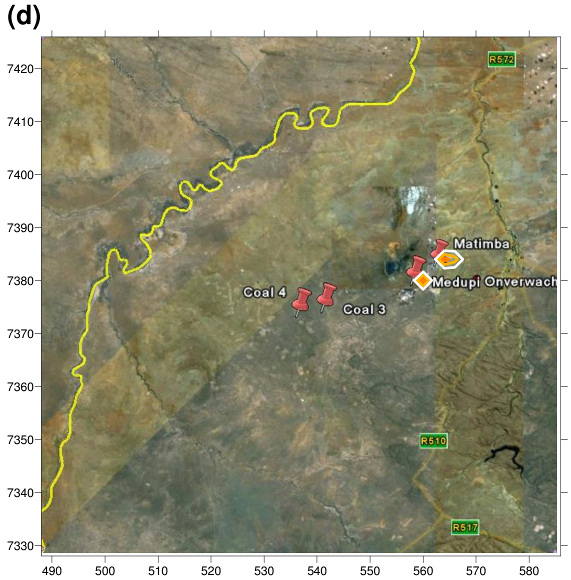


Scenario 1: Matimba and Medupi without FGD

(c)

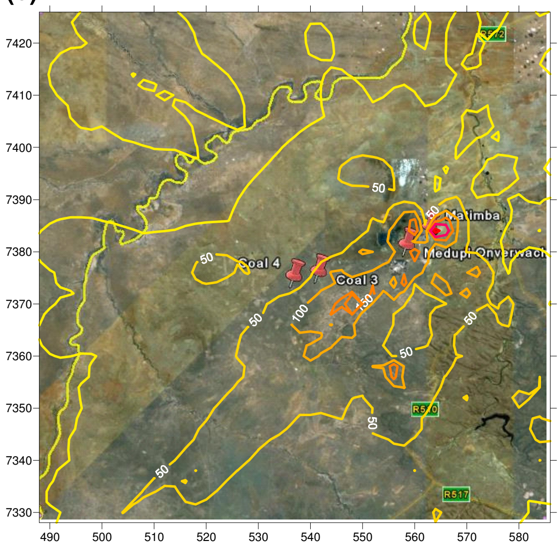


(d)

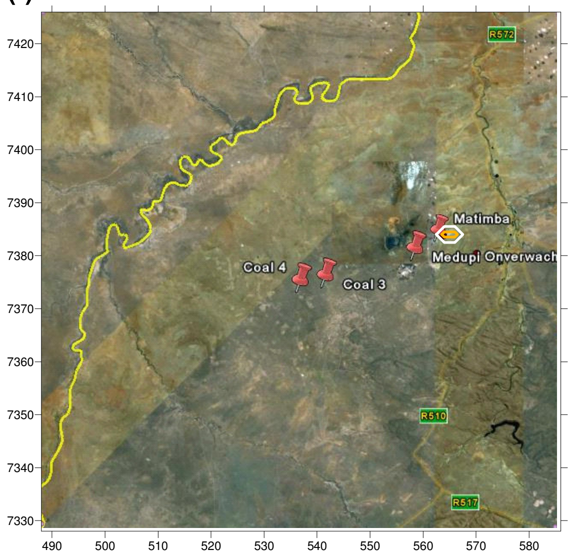


Scenario 2: Matimba without FGD and Medupi with FGD on 3 units

(e)

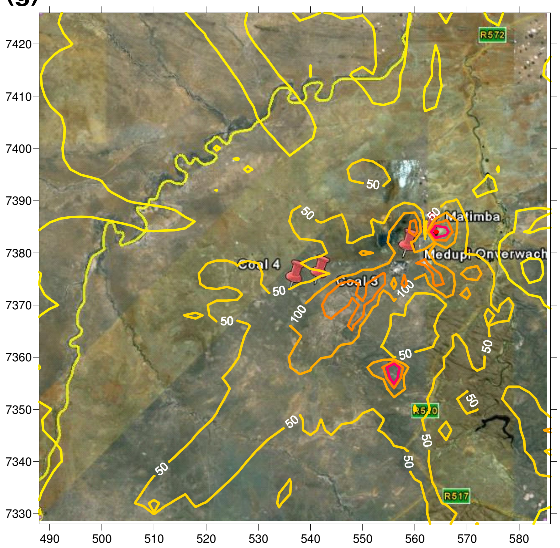


(f)

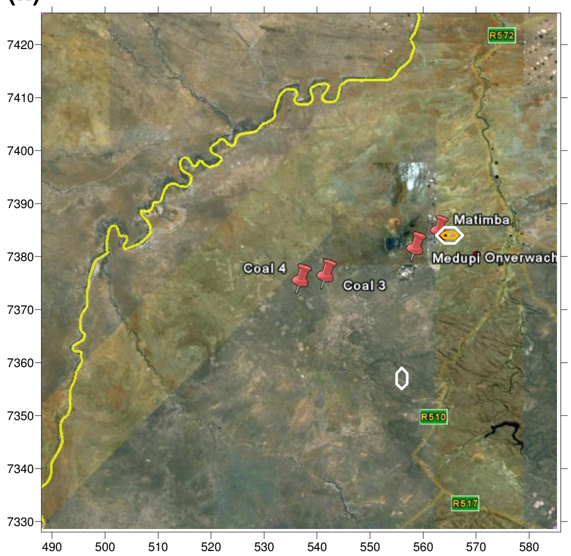


Scenario 3: Matimba without FGD and Medupi with FGD on 6 units

(g)



(h)



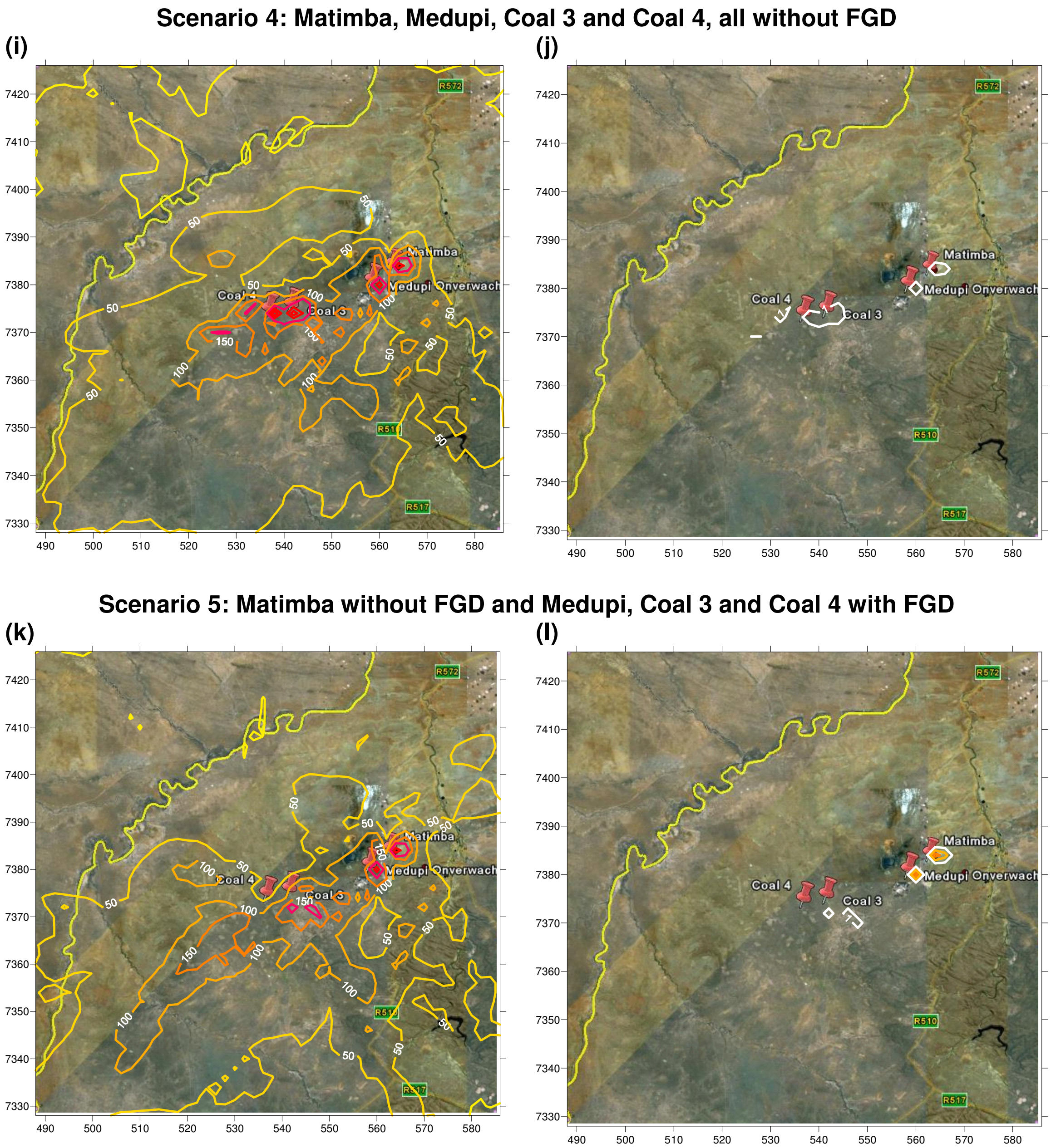


Figure 4-31 Dispersion model results for the effects of FGD on NOx dispersion (all scenarios)

4.3. Summary

Current ambient air quality in the vicinity of Matimba Power Station is in compliance to the proposed South African Ambient Air Quality Standards, despite various isolated exceedances being recorded at the relevant monitoring stations.

The inclusion of Medupi will result in potential non-compliance to ambient air quality standards. However the areas of non compliance will be limited to a zone of maximum concentration downwind of the power stations and not in any populated areas, which are predominantly located upwind of the power stations. It is however foreseeable that should Eskom not install FGD, this exclusion zone south west of the power station will need to be maintained through influencing the local authority spatial development plans. However in light of the likely population growth in the area such an exclusion zone may be difficult and costly to maintain and the possibility of some future FGD retrofit may be seen as a more feasible option in terms of costs and socio-political pressures that may arise.

Based on both monitored and modelled data there does not seem to be a clear need for the current inclusion of FGD at Medupi Power Station as the distribution of area of high sulphur dioxide concentrations are unlikely to be located in any populated area, since the standards are human health based this will be the over-riding motivation for the inclusion of FGD.

5. CONCLUDING REMARKS

Medupi is the first of the large base load power stations to be constructed as part of Eskom’s new build programme. As a result of the increased demand that has accompanied economic growth in South Africa, it is claimed that an estimated 40 000 MW of additional capacity needs to be constructed by 2025, in order to ensure alignment with the ASGISA objectives. Old power stations that had been mothballed in the days of excess capacity are being returned to service, a second coal fired plant in Mpumalanga Province (Kusile) and peaking plants such as open cycle gas turbines and pumped storage schemes are being constructed. Renewable energy (particularly hydro, solar and wind) will make an increased contribution to total capacity in the future.

A positive Record of Decision (RoD) in terms of the South African Environmental Conservation Act (No. 73 of 1989) for Medupi Power Station was issued prior to the finalisation of local ambient and emission standards (21 September 2006). The environmental authorisation, in addition to several other conditions, required that Medupi comply to both current and future air quality standards as well as be constructed to be FGD ready.

As has been illustrated the issue of *‘compliance’* and *‘FGD readiness’* and indeed the potential need and justification of FGD in light of such conditions constitutes the evaluation of a range of legislative technical and environmental considerations, which would need to be identified as part of a Multi Criteria Decision making process

The installation of FGD at Medupi would require considerable thought with respect to the power stations layout and design. Almost every aspect of the plant would be affected by the FGD. However the extent to which the power station incorporates the various FGD requirements depend on the potential risk that the power station will be exposed through various phases of its operating life cycle, as related to the air quality and legislative requirements at the same point in time.

Chapter 5

5.1. Environmental Impacts

At the outset it must be strongly recognised that Eskom's choice of a wet FGD system is arguably not the most optimum solution, when evaluated against various environmental criteria. Such an argument is largely based on the technologies water consumption. The technologies production of Gypsum cannot be considered as a strong enough motivation, in light of the absence of gypsum markets in the Lephalale region. Nonetheless discussion in previous chapters did provide a means for highlighting key environmental considerations which should be taken into account, when evaluating the need for FGD as a means for the station meeting air quality standards.

From the modelling data it is evident that Medupi Power will generally be in non compliance to ambient air quality standards within the south west sector of the modelling domain.

The only way to achieve compliance with international SO_2 standards would be to install flue gas desulphurisation (FGD) at Medupi. Flue gas desulphurisation would be associated with a series of potentially negative environmental consequences including:

- Increased water consumption
- Mining and transportation of the sorbent (itself a scarce resource)
- Production and disposal of additional waste
- The visible plume, which impacts negatively on aesthetics
- Reduced dispersion potential due to the lowering of flue gas exit temperature, which may increase ground level concentrations of other pollutants emitted from the stack, and
- Reduced efficiency of the power station, resulting in increased coal consumption and increased greenhouse gas emissions per unit of electricity produced

The inhalation-related health risks due to power station operations in the Waterberg area are predicted to be relatively low due to the limited exposure potential. Only about 22 000 people are estimated to live within 25 km of Matimba power station based on the 2001 census data, with the majority of the people residing upwind of the power stations. Approximately 17 000 people reside in Marapong, and approximately 3 000 people reside in the Lephalale/Onverwacht area. Medupi Power Station is to be built on the farm Naauwontkomen, and the ash dump will be on farm Eenzaamheid. Prevailing winds in the Waterberg area are from the north-east

5.2. Water Scarcity

The scarcity of water supply in the Waterberg region is a cause for concern and perhaps the single biggest motivation for the possible exclusion of FGD or at the very least the postponing of any decision to allow for the identification of alternative technologies , that are less water intensive. It is estimated that Medupi with FGD will require in the order of 7.2Mm^3/a. currently, only 5 Mm^3/a of water is immediately available. It is therefore predicted that this allocation will be exceeded with the commissioning of Medupi's third unit in 2012.

Additional water for the area is planned to be obtained from an extensive transfer scheme, bringing water from the Crocodile West catchment area. This water will be reliant on return flows into the catchment. However in the context of future development in the Lephalale area, even such a scheme which is estimated to transfer an additional 230 Mm^3/a into the region is considered to be insufficient when viewed in the context of the coal resource. It is estimated that, taking into account future development potential the scheme will only be able to supply sufficient water for Medupi and an additional 2-3 power stations, with FGD. Given that the coal resource has the potential to provide coal for at least an additional 24 coal fired power stations the limiting nature of water availability is of significant concern. It is therefore unlikely that the Waterberg region will see a mass of simaltanious development of coal fired power stations. Perhaps a more sustainable option will be to exploit the coal resource over an extended period of time, never allowing more than 2-4 coal fired power stations to operate in the region at any given time. Such an option would require a significant effort, by Eskom, to diversify its energy mix in light of its aging generating fleet, limited coal reserves in the Mpumalanga area as well as water restrictions in the Waterberg region. The planning, motivation and management of such a diversification would need to be subjected to further research and analysis.

It is imperative that any future coal fired power stations implement the necessary water conservation strategies, such as the dry cooling technologies which will be employed at Medupi and is currently utilised by Matimba. The installation of both dry and wet FGD technology is considered to be a direct contradiction to such strategies.

5.3. Air Quality Compliance

In terms of the Equator principles Medupi is a Category A (high risk) project. Medupi will comply with the World Bank PM10 (50 mg/Nm^3) and NO_x (750 mg/Nm^3) emission standards due to the installation of a low NO_x boiler (with guaranteed emission rate of 650 mg/Nm^3) and particulate abatement technology, but not with the SO_2 ambient standards.

The power station, with estimated SO_2 emissions in excess of 1000 tons per day will not comply with both the EHS and World Bank Guidelines. SO_2 emissions from Medupi will probably average around 3 750 mg/Nm^3 which is considered to be in compliance to proposed South African SO_2 emission limits for existing plant. The motivation for such a classification would be based on the fact that Medupi will be under construction when the standards come into effect and capital and design decisions would have already been undertaken.

Non compliance to the various international guidelines, in terms of the Equator Principles needs to be viewed within the context of the caveat contained in the equator principles which states that (EHS guidelines, 2004):

"If less stringent levels or measures are appropriate in view of specific project circumstances, the client will provide full and detailed justification for any proposed alternatives. This justification will demonstrate that the choice for any alternate performance levels is consistent with the overall requirements of this Performance Standard"

Any interaction with international agencies will need to be made aware of such a caveat and agreement as to its interpretation will need to be achieved. Moreover, in accordance to the *EHS General Guidelines*, WHO air quality guidelines are to be used only in the absence of local air quality standards.

Medupi both singularly and cumulatively, will comply within all populated areas, with the proposed ambient air quality standards which allows for 88 exceedances of the hourly SO_2 average of 350ug/m^3. It is however important to note that Eskom is likely to be in non compliance to the hourly SO_2 standards directly downwind of Medupi. Currently no persons live within this area. Eskom may need to engage the local municipality to ensure that future residential development does not occur downwind of Medupi and Matimba or alternatively purchase the required property in order to establish an exclusion zone.

Proposed standards will be sent out to the public for comment during the first quarter of 2009. Government is aiming to finalize ambient air quality and emission standards by September 2009

5.4. Impact on Human health

Human health will not be significantly affected by emissions from the power station. National and international ambient air quality standards will be complied with in all residential areas once Medupi, without FGD, is operational. The inhalation-related health risks due to power station operations in the Waterberg area are predicted to be relatively low due to the limited exposure potential. Only about 22 000 people are estimated to live within 25 km of Matimba power station based on the 2001 census data, with the majority of the people residing upwind of the power stations.

In light of the location of the majority of the residential areas being upwind of Medupi the addition of future coal fired power stations is unlikely to significantly alter the cumulative contribution of Medupi to health risk in these areas.

Assessing the need for FGD for Medupi is complex and one that would likely require the careful input of all criteria into an appropriate multi criteria decision making tool. It is acknowledged that despite the station being in non compliance to air quality standards, such non compliance is restricted to close proximity of the station and immediately downwind. An area where there are no large population groupings. In addition the severe limitations on water availability place significant restrictions on the feasibility of FGD, particularly the choice of FGD technology made by Eskom.

5.5. Recommendation

Despite the above, Eskom as an organisation is seeking public and private financing for the Medupi project. Potential lenders generally comply to the equator principles, which in turn refer to the World Bank air quality standards. Experience has indicated that, in the majority of cases, the banking sector applies the equator principles strictly to the person/organisation applying for the loan, with little room for negotiation, resulting in the likelihood of Eskom installing FGD high.

The timing of installing FGD, should it be installed is also a critical issue, as water for the FGD will only be available post 2014, making it necessary for the plant to be made FGD ready.

Ambient air quality monitoring in Marapong should continue until Medupi is fully operational. Measurements will therefore continue to check for any non-compliance with South African air quality legislation in Marapong or any other populated areas in the Waterberg as a result of emissions from Medupi Power Station. Should it become necessary, Medupi can be retrofitted with FGD most probably during the stations half life refurbishment, at which point the likelihood of the availability of alternative technologies is considered high.

It is necessary to further extend discussions with the various government departments to try and source additional water, by means of various transfer schemes. Significantly, the scarcity of water availability remains an important consideration

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ANNEXURE 1: SULPHUR DIOXIDE CACULATIONS FOR MEDUPI POWER STATION

NO FGD

MEDUPI INPUT DATA (800 MW, 37% Efficiency, 35% Ash, 20.5 MJ/kg CV)	@ 1.2% S	UNITS
Load factor	90.00	%
Specified gas volume flow rate	1106.60	Am^3/s
Specified gas temperature	130.00	°C
MWh sent out	34058.88	GWh SO
Emission	3800.00	mg/Sm^3
Number of boilers	6.00	#

RESULTS		UNITS
Specified gas volume flow rate	680.76	Sm^3/s
Tons emitted per annum/boiler	73422.49	TPA
kg/MWh SO	12.935	kg/MWh SO
Tons emitted per annum/station	440534.97	TPA
Tons emitted per day/station	1206.95	TPD

90% Removal Efficiency on 3 Units ONLY

MEDUPI INPUT DATA (800 MW, 37% Efficiency, 35% Ash, 20.5 MJ/kg CV)	@ 1.2% S	UNITS
Load factor	90.00	%
Specified gas volume flow rate	1106.60	Am^3/s
Specified gas temperature	130.00	°C
MWh sent out	34058.88	GWh SO
Emission	2090.00	mg/Sm^3
Number of boilers	6.00	#

RESULTS		UNITS
Specified gas volume flow rate	680.76	Sm^3/s
Tons emitted per annum/boiler	40382.37	TPA
kg/MWh SO	7.114	kg/MWh SO
Tons emitted per annum/station	242294.23	TPA
Tons emitted per day/station	663.82	TPD

90% Removal Efficiency on 6 Units

MEDUPI INPUT DATA (800 MW, 37% Efficiency, 35% Ash, 20.5 MJ/kg CV)	@ 1.2% S	UNITS
Load factor	90.00	%
Specified gas volume flow rate	1106.60	Am^3/s
Specified gas temperature	130.00	°C
MWh sent out	34058.88	GWh SO
Emission	330.00	mg/Sm^3
Number of boilers	6.00	#

RESULTS		UNITS
Specified gas volume flow rate	680.76	Sm^3/s
Tons emitted per annum/boiler	6376.16	TPA
kg/MWh SO	1.123	kg/MWh SO
Tons emitted per annum/station	38256.98	TPA

Tons emitted per day/station	104.81	**TPD**

ANNEXURE 2: SUMMARY OF DEATILED DESIGN IMPLICATIONS FOR THE INSTALATION OF FGD (E-*On*, 2008, Eskom, 2009)

Package Description	Item	Design Implications of FGD Retrofit
Boiler	1.	FGD plant will necessitate larger fans. It must be considered whether to keep the current ID Fan design, and employ a Booster Fan for FGD retrofit. Or adjust current ID Fan with option to add blades for FGD Retrofit.
	2.	Fan motor will be larger than originally planned.
	3.	Life Cycle Cost decision on RGGH option will affect decision regarding Fan selection.
	4.	Following RGGH decision, specify final water requirement for FGD retrofit.
	5.	Fuel Oil Plant position will need revisiting with HP.
	6.	Ducting terminal points with will need revisiting with HP.
	7.	Pneumatic conveyance of Flyash from PJFF will need review.
Low Pressure Services	8.	Piping and Pump Station will be required from new FGD Raw water dam.
Water Treatment	9.	Ultra Filtration Plant would require expansion for additional water treatment requirement. Space may be an issue.
	10.	Effluent holding pond will be required.
	11.	May need integrated Waste water treatment plant (partly optional).
	12.	Level of organics in sorbent will be impacted due to utilizing raw water from Crocodile dam.
Chimney & Silo's	13.	Actual position of chimney must be defined ASAP.
	14.	New chimney location will require additional GIs.
	15.	Lime Silo will influence this package if required.
	16.	Acid Drain system from collectors on chimney must link to other systems.
Main Civils	17.	WTP redesign would have significant implication on Main Civils.
Enabling/Construction Site Facilities	18.	Design details for FGD & Chimney foundation excavations are required. (High Priority as FGD could be required for Unit 6).
	19.	There may be an impact on services and roads if chimney is moved further out.
Control & Instrumentation	20.	FGD C&I requirements & associated information must be provided.
	21.	For Bravo FGD package, Instrumentation is included, but Control is not. Therefore this package cannot be transferred easily to Medupi.

Laboratory & On-line Analysers	22.	Additional space may be necessitated in Laboratory for FGD requirements and additional equipment.
Ash Dump & Dams	23.	Concept design for Ash Dump currently in progress. What will gypsum footprint be, and can we co-dispose ash & gypsum?
Ash Dump Equipment & Overland Conveyor	24.	Overland Gypsum Conveyor & Dumping equipment will be required. (Note: Option of co-disposal of ash & gypsum will affect whether two separate conveyors are required or one combined conveyor).
	25.	If we have separate Gypsum conveyor, would this be single-bed or dual-bed?
	26.	Gypsum conveyor will follow Ash conveyor to Ash Dump. Should both conveyors be included in P28?
Reservoirs	27.	Additional Raw water Dam for FGD would be required.
Terrace Coal & Ash System	28.	Terrace Gypsum & Limestone Conveyors will be required.
	29.	Tippler Station will be required.
Miscellaneous Buildings	30.	Additional technical buildings to accommodate FGD retrofit.

ANNEXURE 3: WATER DEMAND AND SUPPLY MODEL

Model and figures assisted by Alwyn vd Merwe

Water requirements for Scenario 1 – No Sasol Plant
Peaks Indicated
Unit: million m^3/annum or million m^3/month

USER	Delivery Area	2008	2009	2010	2011
		Total	Total	Total	Total
ESKOM INDUSTRIAL DEMAND					
Matimba Power Station	Industrial Eskom Lephalale	3.600	3.600	3.600	3.600
Medupi Power Station (with FGD)	Industrial Eskom Lephalale	0.876	0.719	0.713	1.775
Future Eskom Power Station 3 (CF-2 with FGD)	Industrial Eskom Steenbokpan				
Future Eskom Power Station 4 (CF-3 with FGD)	Industrial Eskom Steenbokpan				
Sub-Total (Eskom)		**4.476**	**4.319**	**4.313**	**5.3748**
Peak factor		**1.000**	**1.000**	**1.000**	**1.0000**
Sub-Total Peaks Included (Eskom)		**4.476**	**4.319**	**4.313**	**5.3748**
COAL MINES INDUSTRIAL DEMAND					
Exxaro					
Mining activities near Lephalale	Industrial Exxaro Lephalale	2.785	3.053	3.414	4.239
Mining activities near Steenbokpan	Industrial Exxaro Steenbokpan				
Mine for Eskom Power Station 3	Industrial other mines				1.100
Mine for Eskom Power Station 4	Industrial other mines				

Sub-Total (Coal Mines)		**2.785**	**3.053**	**3.414**	**5.3390**
SASOL INDUSTRIAL DEMAND					
Sub-Total (Sasol)					
MUNICIPAL DEMAND					
Current households (including Marapong)	Municipal demand Lephalale	3.127	3.215	3.175	3.111
Industrial/Commercial/Educational Development					
At Lephalale	Municipal demand Lephalale	0.769	1.033	1.136	1.404
At Steenbokpan	Municipal demand Steenbokpan				
Power stations					
Medupi	Municipal demand Lephalale				0.334
Power station 3	Municipal demand Steenbokpan				
Power station 4	Municipal demand Steenbokpan				
Mining (Exxaro) (incl on mine potable)	Municipal demand Lephalale	0.341	0.789	1.216	1.799
Mining (Exxaro) (Steenbokpan)	Municipal demand Steenbokpan				
Temporary Construction Workers					
At Lephalale	Municipal demand Lephalale	0.633	1.339	1.343	1.609
At Steenbokpan	Municipal demand Steenbokpan				
Mafutha Town (Sasol) at Steenbokpan	Municipal demand Steenbokpan				
Mafutha 1&2 (Plant Potable)	Municipal demand Steenbokpan				

Sub-Total (Municipal)		**4.870**	**6.375**	**6.870**	**8.258**
Peak factor		**1.000**	**1.000**	**1.000**	**1.000**
Sub-Total Peaks Included (Municipal)		**4.870**	**6.375**	**6.870**	**8.258**
Total Demand Excluding Irrigation (+Peaks)		**12.131**	**13.747**	**14.597**	**18.972**
Irrigation allocation		**16.000**	**16.000**	**16.000**	**16.000**
TOTAL: SCENARIO 1		**28.131**	**29.747**	**30.597**	**34.972**
Water available from Mokolo Dam		39.100	39.100	39.100	39.100
Potential return flow (50%)		2.435	3.188	3.435	4.129
Water to be transferred from Crocodile River (West)					-0.395

Lephalale/Steenbokpan Split (Delivery through pipe)	**Delivery Area**	**2008**	**2009**	**2010**	**2011**
		Total	**Total**	**Total**	**Total**
Lephalale Demand Centre	Municipal demand Lephalale	4.870	6.375	6.870	8.258
	Industrial Exxaro Lephalale	2.785	3.053	3.414	4.239
	Industrial Eskom Lephalale	4.476	4.319	4.313	5.375
Sub-total		**12.131**	**13.747**	**14.597**	**17.872**
Steenbokpan Demand Centre	Municipal demand Steenbokpan				
	Industrial Exxaro Steenbokpan				
	Industrial Sasol				
	Industrial Eskom Steenbokpan				
	Industrial other mines				1.100
Sub-total					**1.100**
Total		**12.131**	**13.747**	**14.597**	**18.972**

Demand on Mokolo Dam		**2008**	**2009**	**2010**	**2011**

		Total	Total	Total	Total
Interim (deliver period up to December 2014)		28.144	29.763	30.607	35.027
Possible minimum demand (recovery periods)		26.970	28.475	28.970	30.358
Long term demand (up to December 2030)		28.131	29.747	30.597	33.872

Pipelines from Mokolo Dam (Installed capacity)		**13.500**	**13.500**	**13.500**	**31.385**
Existing Exxaro Pipeline		13.500	13.500	13.500	4.500
Interim Pipeline					26.885
Refurbished Exxaro Pipeline					

2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**
3.600	3.600	3.600	3.600	3.600	3.600	3.600	3.600	3.600
2.930	5.085	9.400	13.492	14.000	14.000	14.000	14.000	14.000
0.431	0.719	0.713	3.513	8.041	13.066	15.000	15.000	15.000
					0.431	0.719	0.713	3.513
6.9606	**9.404**	**13.714**	**20.605**	**25.641**	**31.097**	**33.319**	**33.313**	**36.113**
1.0000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
6.9606	**9.404**	**13.714**	**20.605**	**25.641**	**31.097**	**33.319**	**33.313**	**36.113**
5.413	6.914	8.845	14.451	20.480	21.611	21.816	21.816	21.816
0.045	0.137	0.262	1.290	2.055	2.867	3.322	4.200	4.890
2.300	2.800	2.800	4.000	5.000	5.000	5.000	5.000	5.000
				1.100	2.300	2.300	2.800	2.800
7.7580	**9.851**	**11.907**	**19.741**	**28.635**	**31.778**	**32.438**	**33.816**	**34.506**

3.046	2.978	2.910	2.839	2.767	2.692	2.617	2.604	2.630
1.689	1.650	1.827	2.185	2.087	2.071	2.074	2.095	2.116
0.092	0.649	0.892	0.965	1.030	1.480	1.647	1.653	1.614
0.521	0.509	0.497	0.485	0.473	0.460	0.447	0.445	0.449
	0.636	0.988	1.129	1.375	1.328	1.289	1.283	1.296
					0.552	0.853	0.841	1.100
2.692	2.828	3.683	5.581	5.847	5.893	5.905	6.007	6.098
0.277	1.350	1.394	1.347	1.541	2.425	2.410	2.374	2.376
1.715	1.316	1.227	0.833	0.209	0.064			
0.124	0.771	1.290	1.362	1.035	1.167	1.310	1.297	0.888
10.156	**12.686**	**14.707**	**16.726**	**16.363**	**18.132**	**18.553**	**18.599**	**18.568**
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
10.156	**12.686**	**14.707**	**16.726**	**16.363**	**18.132**	**18.553**	**18.599**	**18.568**
24.875	**31.941**	**40.328**	**57.072**	**70.639**	**81.007**	**84.310**	**85.729**	**89.187**
16.000	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**
40.875	**47.941**	**56.328**	**73.072**	**86.639**	**97.007**	**100.310**	**101.729**	**105.187**
39.100	39.100	39.100	39.100	39.100	39.100	39.100	39.100	39.100
5.016	5.958	6.708	7.682	7.664	8.482	8.622	8.651	8.840
1.839	8.902	17.333	26.371	39.945	49.496	52.586	53.976	57.311
2012	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**

Annexure 3

Total	Total	Total	Total	Total	Total	Total	Total	Total
9.664	9.281	10.143	11.923	11.383	11.180	11.043	11.151	11.294
5.413	6.914	8.845	14.451	20.480	21.611	21.816	21.816	21.816
6.530	8.685	13.000	17.092	17.600	17.600	17.600	17.600	17.600
21.606	**24.880**	**31.988**	**43.466**	**49.463**	**50.391**	**50.459**	**50.567**	**50.710**
0.493	3.405	4.564	4.803	4.980	6.952	7.510	7.448	7.274
0.045	0.137	0.262	1.290	2.055	2.867	3.322	4.200	4.890
0.431	0.719	0.713	3.513	8.041	13.497	15.719	15.713	18.513
2.300	2.800	2.800	4.000	6.100	7.300	7.300	7.800	7.800
3.269	**7.062**	**8.339**	**13.606**	**21.176**	**30.616**	**33.851**	**35.162**	**38.477**
24.875	**31.941**	**40.328**	**57.072**	**70.639**	**81.007**	**84.310**	**85.729**	**89.187**

2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**
40.939	48.002	56.433	**73.153**					
31.764	31.381	27.985	26.723	26.183	25.980	25.843	25.951	26.094
37.414	37.981	38.843	40.623	40.083	39.880	39.743	39.851	39.994

49.328	**53.828**	**53.828**	**53.828**	**53.828**	**53.828**	**53.828**	**53.828**	**53.828**
40.328	40.328	40.328	40.328	40.328	40.328	40.328	40.328	40.328
9.000	13.500	13.500	13.500	13.500	13.500	13.500	13.500	13.500

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**
3.600	3.600	3.600	3.600	3.600	3.600	3.600	3.600	3.600	3.600
14.000	14.000	14.000	14.000	14.000	14.000	14.000	14.000	14.000	14.000
15.000	15.000	15.000	15.000	15.000	15.000	15.000	15.000	15.000	15.000

8.041	13.066	15.000	15.000	15.000	15.000	15.000	15.000	15.000	15.000
40.641	**45.666**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
40.641	**45.666**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**
21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816
5.430	5.460	5.845	6.120	6.120	6.120	6.120	6.120	6.120	6.120
5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
4.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
36.246	**37.276**	**37.661**	**37.936**	**37.936**	**37.936**	**37.936**	**37.936**	**37.936**	**37.936**
2.657	2.683	2.710	2.737	2.765	2.793	2.821	2.849	2.877	2.906
2.137	2.159	2.180	2.202	2.224	2.247	2.269	2.292	2.315	2.338
1.776	1.972	2.062	1.985	1.892	0.473	0.474	0.475	0.476	0.478
0.454	0.459	0.463	0.468	0.472	0.477	0.482	0.487	0.492	0.497
1.309	1.322	1.336	1.349	1.362	1.376	1.390	1.404	1.418	1.432
1.207	1.270	1.283	1.296	1.309	1.322	1.336	1.349	1.362	1.376
6.161	6.223	6.285	6.348	6.412	6.476	6.541	6.607	6.673	6.740
2.395	2.419	2.443	2.442	2.376	2.395	2.419	2.443	2.468	2.493

0.791	1.062	1.068	0.616	0.327					
18.886	**19.569**	**19.830**	**19.443**	**19.139**	**17.559**	**17.731**	**17.906**	**18.082**	**18.260**
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
18.886	**19.569**	**19.830**	**19.443**	**19.139**	**17.559**	**17.731**	**17.906**	**18.082**	**18.260**
95.773	**102.510**	**105.091**	**104.979**	**104.675**	**103.095**	**103.267**	**103.442**	**103.618**	**103.796**
16.000	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**
111.773	**118.510**	**121.091**	**120.979**	**120.675**	**119.095**	**119.267**	**119.442**	**119.618**	**119.796**
39.100	39.100	39.100	39.100	39.100	39.100	39.100	39.100	39.100	39.100
9.047	9.253	9.381	9.414	9.406	8.779	8.866	8.953	9.041	9.130
63.677	70.204	72.609	72.460	72.166	71.215	71.302	71.389	71.477	71.566

2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Total	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**
11.408	11.523	11.639	11.755	11.873	11.993	12.113	12.235	12.357	12.481
21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816
17.600	17.600	17.600	17.600	17.600	17.600	17.600	17.600	17.600	17.600
50.824	**50.939**	**51.055**	**51.171**	**51.289**	**51.409**	**51.529**	**51.651**	**51.773**	**51.897**
7.477	8.046	8.192	7.687	7.266	5.566	5.618	5.671	5.725	5.778
5.430	5.460	5.845	6.120	6.120	6.120	6.120	6.120	6.120	6.120
23.041	28.066	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000
9.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
44.949	**51.571**	**54.037**	**53.807**	**53.386**	**51.686**	**51.738**	**51.791**	**51.845**	**51.898**
95.773	**102.510**	**105.091**	**104.979**	**104.675**	**103.095**	**103.267**	**103.442**	**103.618**	**103.796**

2021	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Total	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**

26.208	26.323	26.439	26.555	26.673	26.793	26.913	27.035	27.157	27.281
40.108	40.223	40.339	40.455	40.573	40.693	40.813	40.935	41.057	41.181

53.828	**53.828**	**53.828**	**53.828**	**53.828**	**53.828**	**53.828**	**53.828**	**53.828**	**53.828**
40.328	40.328	40.328	40.328	40.328	40.328	40.328	40.328	40.328	40.328
13.500	13.500	13.500	13.500	13.500	13.500	13.500	13.500	13.500	13.500

Scenario 2 – Including Sasol	**Delivery Area**	**2008**	**2009**	**2010**
		Total	**Total**	**Total**
ESKOM INDUSTRIAL DEMAND				
Matimba Power Station	Industrial Eskom Lephalale	3.600	3.600	3.600
Medupi Power Station (with FGD)	Industrial Eskom Lephalale	0.876	0.719	0.713
Future Eskom Power Station 3 (CF-2 with FGD)	Industrial Eskom Steenbokpan			
Future Eskom Power Station 4 (CF-3 with FGD)	Industrial Eskom Steenbokpan			
Sub-Total (Eskom)		**4.476**	**4.319**	**4.313**
Peak factor		**1.000**	**1.000**	**1.000**
Sub-Total Peaks Included (Eskom)		**4.476**	**4.319**	**4.313**
COAL MINES INDUSTRIAL DEMAND				
Exxarro				
Mining activities near Lephalale	Industrial Exxaro	2.785	3.053	3.414

	Lephalale			
Mining activities near Steenbokpan	Industrial Exxaro Steenbokpan			
Mine for Eskom Power Station 3	Industrial other mines			
Mine for Eskom Power Station 4	Industrial other mines			
Sub-Total (Coal Mines)		**2.785**	**3.053**	**3.414**
SASOL INDUSTRIAL DEMAND				
Construction	Industrial Sasol			
CTL Facility (Mafutha 1 + Mafutha 2)	Industrial Sasol			
Coal mining and beneficiation	Industrial Sasol			
Sub-Total (Sasol)				
MUNICIPAL DEMAND				
Current households (including Marapong)	Municipal demand Lephalale	3.127	3.215	3.175
Industrial/Commercial/Educational Development				
At Lephalale	Municipal demand Lephalale	0.769	1.033	1.136
At Steenbokpan	Municipal demand Steenbokpan			
Power stations				
Medupi	Municipal demand Lephalale			
Power station 3	Municipal demand Steenbokpan			
Power station 4	Municipal demand Steenbokpan			
Mining (Exxaro) (incl on mine potable)	Municipal demand Lephalale	0.341	0.789	1.216
Mining (Exxaro) (Steenbokpan)	Municipal demand			

	Steenbokpan			
Temporary Construction Workers				
At Lephalale	Municipal demand Lephalale	0.633	1.339	1.343
At Steenbokpan	Municipal demand Steenbokpan			
Mafutha Town (Sasol) at Steenbokpan	Municipal demand Steenbokpan			
Mafutha 1&2 (Plant Potable)	Municipal demand Steenbokpan			
Sub-Total (Municipal)		**4.870**	**6.375**	**6.870**
Peak factor		**1.000**	**1.000**	**1.000**
Sub-Total Peaks Included (Municipal)		**4.870**	**6.375**	**6.870**
Total Demand Excluding Irrigation (+Peaks)		**12.131**	**13.747**	**14.597**
Irrigation allocation		**16.000**	**16.000**	**16.000**
TOTAL: SCENARIO 8		**28.131**	**29.747**	**30.597**
Water available from Mokolo Dam		39.100	39.100	39.100
Potential return flow (50%)		2.435	3.188	3.435
Water to be transferred from Crocodile River (West)				

Lephalale/Steenbokpan Split (Delivery through pipe)	**Delivery Area**	**2008**	**2009**	**2010**
		Total	**Total**	**Total**
Lephalale Demand Centre	Municipal demand Lephalale	4.870	6.375	6.870
	Industrial Exxaro Lephalale	2.785	3.053	3.414
	Industrial Eskom Lephalale	4.476	4.319	4.313
Sub-total		**12.131**	**13.747**	**14.597**
Steenbokpan Demand Centre	Municipal demand Steenbokpan			

	Industrial Exxaro Steenbokpan			
	Industrial Sasol			
	Industrial Eskom Steenbokpan			
	Industrial other mines			
Sub-total				
Total		**12.131**	**13.747**	**14.597**

Demand on Mokolo Dam		**2008**	**2009**	**2010**
		Total	**Total**	**Total**
Interim (deliver period up to December 2014)		28.144	29.763	30.607
Possible minimum demand (recovery periods)		26.970	28.475	28.970
Long term demand (up to December 2030)		28.131	29.747	30.597

Pipelines from Mokolo Dam (Installed capacity)		**13.500**	**13.500**	**13.500**
Existing Exxaro Pipeline		13.500	13.500	13.500
Interim Pipeline				
Refurbished Exxaro Pipeline				

2011	**2012**	**2013**	**2014**	**2015**	**2016**	**2017**	**2018**	**2019**	**2020**
Total	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**
3.600	3.600	3.600	3.600	3.600	3.600	3.600	3.600	3.600	3.600
1.775	2.930	5.085	9.400	13.492	14.000	14.000	14.000	14.000	14.000
	0.431	0.719	0.713	3.513	8.041	13.066	15.000	15.000	15.000
						0.431	0.719	0.713	3.513
5.3748	**6.9606**	**9.404**	**13.714**	**20.605**	**25.641**	**31.097**	**33.319**	**33.313**	**36.113**

1.0000	**1.0000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
5.3748	**6.9606**	**9.404**	**13.714**	**20.605**	**25.641**	**31.097**	**33.319**	**33.313**	**36.113**
4.239	5.413	6.914	8.845	14.451	20.480	21.611	21.816	21.816	21.816
	0.045	0.137	0.262	1.290	2.055	2.867	3.322	4.200	4.890
1.100	2.300	2.800	2.800	4.000	5.000	5.000	5.000	5.000	5.000
					1.100	2.300	2.300	2.800	2.800
5.3390	**7.7580**	**9.851**	**11.907**	**19.741**	**28.635**	**31.778**	**32.438**	**33.816**	**34.506**
0.500	1.000	2.000				0.500	1.000	2.000	
0.375	1.000	1.500	3.500	5.000	24.250	32.375	32.500	35.500	36.750
0.375	0.750	1.000	2.250	3.000	4.250	5.375	5.750	6.000	7.250
1.2500	**2.7500**	**4.500**	**5.750**	**8.000**	**28.500**	**38.250**	**39.250**	**43.500**	**44.000**
3.111	3.046	2.978	2.910	2.839	2.767	2.692	2.617	2.604	2.630
1.404	1.689	1.650	1.827	2.185	2.087	2.071	2.074	2.095	2.116
0.001	0.155	1.238	1.694	2.539	2.956	3.019	3.346	4.667	5.522
0.334	0.521	0.509	0.497	0.485	0.473	0.460	0.447	0.445	0.449
		0.636	0.988	1.129	1.375	1.328	1.289	1.283	1.296
						0.552	0.853	0.841	1.100
1.799	2.692	2.828	3.683	5.581	5.847	5.893	5.905	6.007	6.098
	0.277	1.350	1.394	1.347	1.541	2.425	2.410	2.374	2.376
1.609	1.715	1.316	1.227	0.833	0.209	0.064			

0.006	0.399	3.275	4.594	4.619	2.613	1.193	1.844	3.737	3.738
				2.993	5.823	5.667	5.508	8.131	10.855
0.023	0.063	0.094	0.219	0.313	1.516	2.023	2.031	2.219	2.297
8.288	**10.557**	**15.873**	**19.032**	**24.863**	**27.206**	**27.388**	**28.325**	**34.403**	**38.478**
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
8.288	**10.557**	**15.873**	**19.032**	**24.863**	**27.206**	**27.388**	**28.325**	**34.403**	**38.478**
20.252	**28.025**	**39.629**	**50.402**	**73.209**	**109.983**	**128.512**	**133.332**	**145.032**	**153.098**
16.000	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**
36.252	**44.025**	**55.629**	**66.402**	**89.209**	**125.983**	**144.512**	**149.332**	**161.032**	**169.098**
39.100	39.100	39.100	39.100	39.100	39.100	39.100	39.100	39.100	39.100
4.130	5.048	6.252	7.110	8.469	8.627	9.252	9.471	10.158	10.794
0.122	5.010	16.617	27.413	41.799	78.293	96.232	100.791	111.865	75.275

2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	Total	Total	Total	Total	Total	Total	Total	Total	Total
8.258	9.664	9.281	10.143	11.923	11.383	11.180	11.043	11.151	11.294
4.239	5.413	6.914	8.845	14.451	20.480	21.611	21.816	21.816	21.816
5.375	6.530	8.685	13.000	17.092	17.600	17.600	17.600	17.600	17.600
17.872	**21.606**	**24.880**	**31.988**	**43.466**	**49.463**	**50.391**	**50.459**	**50.567**	**50.710**
0.030	0.893	6.593	8.889	12.940	15.824	16.207	17.282	23.252	27.185
	0.045	0.137	0.262	1.290	2.055	2.867	3.322	4.200	4.890
1.250	2.750	4.500	5.750	8.000	28.500	38.250	39.250	43.500	44.000
	0.431	0.719	0.713	3.513	8.041	13.497	15.719	15.713	18.513
1.100	2.300	2.800	2.800	4.000	6.100	7.300	7.300	7.800	7.800
2.380	**6.419**	**14.749**	**18.414**	**29.743**	**60.520**	**78.121**	**82.873**	**94.465**	**102.388**
20.252	**28.025**	**39.629**	**50.402**	**73.209**	**109.983**	**128.512**	**133.332**	**145.032**	**153.098**

2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Total	Total	Total	Total	Total	Total	Total	Total	Total	Total

36.308	44.110	55.717	66.513	89.368					
26.229	26.932	26.740	26.012	26.723	26.183	25.980	25.843	25.951	26.094
33.872	37.414	37.981	38.843	40.623	40.083	39.880	39.743	39.851	39.994

38.102	**59.402**	**63.902**	**63.902**	**63.902**	**63.902**	**63.902**	**63.902**	**63.902**	**63.902**
4.500									
33.602	50.402	50.402	50.402	50.402	50.402	50.402	50.402	50.402	50.402
	9.000	13.500	13.500	13.500	13.500	13.500	13.500	13.500	13.500

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**
3.600	3.600	3.600	3.600	3.600	3.600	3.600	3.600	3.600	3.600
14.000	14.000	14.000	14.000	14.000	14.000	14.000	14.000	14.000	14.000
15.000	15.000	15.000	15.000	15.000	15.000	15.000	15.000	15.000	15.000
8.041	13.066	15.000	15.000	15.000	15.000	15.000	15.000	15.000	15.000
40.641	**45.666**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
40.641	**45.666**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**	**47.600**
21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816
5.430	5.460	5.845	6.120	6.120	6.120	6.120	6.120	6.120	6.120
5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
4.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000	5.000
36.246	**37.276**	**37.661**	**37.936**	**37.936**	**37.936**	**37.936**	**37.936**	**37.936**	**37.936**

37.000	56.250	64.000	64.000	64.000	64.000	64.000	64.000	64.000	64.000
8.000	9.500	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
45.000	**65.750**	**74.000**	**74.000**	**74.000**	**74.000**	**74.000**	**74.000**	**74.000**	**74.000**
2.657	2.683	2.710	2.737	2.765	2.793	2.821	2.849	2.877	2.906
2.137	2.159	2.180	2.202	2.224	2.247	2.269	2.292	2.315	2.338
5.598	5.253	5.252	5.206	5.146	5.156	5.181	5.205	5.257	5.310
0.454	0.459	0.463	0.468	0.472	0.477	0.482	0.487	0.492	0.497
1.309	1.322	1.336	1.349	1.362	1.376	1.390	1.404	1.418	1.432
1.207	1.270	1.283	1.296	1.309	1.322	1.336	1.349	1.362	1.376
6.161	6.223	6.285	6.348	6.412	6.476	6.541	6.607	6.673	6.740
2.395	2.419	2.443	2.442	2.376	2.395	2.419	2.443	2.468	2.493
3.231	1.493	1.068	0.616	0.327	0.192	0.098			
10.964	11.074	11.185	11.298	11.411	11.526	11.641	11.758	11.876	11.995
2.313	3.516	4.000	4.000	4.000	4.000	4.000	4.000	4.000	4.000
38.425	**37.870**	**38.205**	**37.962**	**37.805**	**37.960**	**38.177**	**38.393**	**38.738**	**39.087**
1.000	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**	**1.000**
38.425	**37.870**	**38.205**	**37.962**	**37.805**	**37.960**	**38.177**	**38.393**	**38.738**	**39.087**
160.312	**186.561**	**197.466**	**197.498**	**197.341**	**197.496**	**197.713**	**197.929**	**198.274**	**198.623**
16.000	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**	**16.000**
176.312	**202.561**	**213.466**	**213.498**	**213.341**	**213.496**	**213.713**	**213.929**	**214.274**	**214.623**
39.100	39.100	39.100	39.100	39.100	39.100	39.100	39.100	39.100	39.100

10.959	10.894	10.976	11.024	11.033	11.121	11.219	11.318	11.431	11.546
81.271	86.858	89.391	89.371	89.206	163.275	163.394	163.512	163.743	163.977

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**
11.408	11.523	11.639	11.755	11.873	11.993	12.113	12.235	12.357	12.481
21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816	21.816
17.600	17.600	17.600	17.600	17.600	17.600	17.600	17.600	17.600	17.600
50.824	**50.939**	**51.055**	**51.171**	**51.289**	**51.409**	**51.529**	**51.651**	**51.773**	**51.897**
27.016	26.347	26.567	26.207	25.931	25.968	26.064	26.159	26.381	26.606
5.430	5.460	5.845	6.120	6.120	6.120	6.120	6.120	6.120	6.120
45.000	65.750	74.000	74.000	74.000	74.000	74.000	74.000	74.000	74.000
23.041	28.066	30.000	30.000	30.000	30.000	30.000	30.000	30.000	30.000
9.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000	10.000
109.488	**135.623**	**146.412**	**146.327**	**146.051**	**146.088**	**146.184**	**146.279**	**146.501**	**146.726**
160.312	**186.561**	**197.466**	**197.498**	**197.341**	**197.496**	**197.713**	**197.929**	**198.274**	**198.623**

2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Total	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**	**Total**
26.208	26.323	26.439	26.555	26.673	26.793	26.913	27.035	27.157	27.281
40.108	40.223	40.339	40.455	40.573	40.693	40.813	40.935	41.057	41.181

63.902	**63.902**	**63.902**	**63.902**	**63.902**	**75.656**	**75.656**	**75.656**	**75.656**	**75.656**
50.402	50.402	50.402	50.402	50.402	62.156	62.156	62.156	62.156	62.156
13.500	13.500	13.500	13.500	13.500	13.500	13.500	13.500	13.500	13.500

ANNEXURE 4: DIURNAL and SADS DATA ALL GRAPHS

Grootstryd Monitoring Station

Matimba - Grootstryd wind rose, 2003-1-1 1 to 2006-12-31 24

Category [m/s]	0-0.5	0.5-2.5	2.5-5	5-7	7-10	>10	Sum
N	0.8	3.7	2.3	0.3	0.	0.	7.1
NNE	1.	5.8	1.2	0.	0.	0.	8.
NE	0.9	6.4	5.9	0.3	0.	0.	13.5
ENE	1.	10.3	7.5	0.2	0.	0.	19.
E	1.1	9.1	0.6	0.	0.	0.	10.8
ESE	0.9	3.8	0.2	0.	0.	0.	4.9
SE	1.	1.9	0.3	0.	0.	0.	3.2
SSE	1.1	1.4	0.2	0.	0.	0.	2.7
S	1.4	2.	0.3	0.	0.	0.	3.7
SSW	1.4	2.6	0.7	0.1	0.	0.	4.8
SW	1.5	3.	0.5	0.1	0.	0.	5.1
WSW	1.2	3.2	0.2	0.	0.	0.	4.6
W	1.1	2.2	0.1	0.	0.	0.	3.4
WNW	0.9	1.2	0.1	0.	0.	0.	2.2
NW	0.8	1.5	0.2	0.	0.	0.	2.5
NNW	0.8	2.2	1.3	0.1	0.	0.	4.4
Sum	16.9	60.3	21.6	1.1	0.	0.	99.95

-Grootstryd + Matimba Sulphur dioxide seasonal diurnal variation, Years 2003-2006

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Mean [ppb]	2.9	1.9	1.9	1.8	1.7	1.7	1.9	2.	2.5	3.5	4.5	6.8	7.4	8.1	8.	8.6	6.7	4.7	4.7	3.5	2.4	3.5	2.7	2.9

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Mean [ppb]	2.5	2.4	2.4	2.3	2.3	2.1	2.2	2.5	2.9	3.6	4.9	7.6	11.3	11.4	10.4	8.7	8.	6.3	4.3	3.6	3.5	3.4	3.	2.8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Mean [ppb]	4.3	4.3	4.4	4.8	4.6	4.7	4.3	4.4	4.1	4.8	6.4	6.9	9.	8.5	7.9	7.	6.8	6.7	5.6	5.8	5.8	6.3	5.4	4.8

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Mean [ppb]	3.3	3.3	3.1	3.4	3.4	3.7	3.4	3.4	4.5	5.	6.8	8.7	11.8	10.6	9.3	6.6	5.8	4.8	3.9	3.6	3.4	3.3	3.3	3.5

Pie Chart Info				
Colour	Segment	Hours [h]	Perc. [%]	Mean Conc.[ppb]
	Morning	10-Jun	8.7	0.43
	Day	16-Oct	42.5	2.08
	Evening	16-20	21	1.03
	Nite	20-Jun	27.8	1.36
	Background	0-24	n/a	n/a

Diurnal Graph Info

Colour	Segment	1	2	3	4	5	6	7	8	9	10	11	12
Line	Morning	0.1	0.18	0.3	0.51	0.98	1.61	1.69	1.57	1.28	0.79	0.48	0.31
Line	Day	0.01	0.01	0.03	0.07	0.16	0.33	0.63	1.13	1.9	3.15	4.78	6.59
Line	Evening	0.08	0.03	0.01	0	0	0	0.01	0.02	0.05	0.12	0.25	0.49
Line	Nite	3.06	2.74	2.6	2.46	1.83	1.05	0.58	0.34	0.19	0.1	0.05	0.03
Dot	Calculated	3.24	2.96	2.95	3.05	2.97	3	2.92	3.05	3.43	4.15	5.56	7.43
Dot	Measured	3.24	2.96	2.95	3.05	2.97	3	2.92	3.05	3.43	4.15	5.56	7.43

Colour	Segment	13	14	15	16	17	18	19	20	21	22	23	24
Line	Morning	0.18	0.1	0.05	0.02	0.01	0	0	0	0	0.01	0.02	0.05

Line	Day	8.69	7.93	6.18	3.79	2.11	1.2	0.65	0.33	0.15	0.07	0.03	0.01
Line	Evening	0.9	1.55	2.55	3.78	4.41	3.87	2.77	1.71	0.98	0.56	0.31	0.16
Line	Nite	0.04	0.07	0.13	0.23	0.4	0.65	1.24	2.12	2.68	3.54	3.24	3.26
Dot	Calculated	9.82	9.65	8.91	7.83	6.92	5.72	4.65	4.16	3.82	4.17	3.6	3.49
Dot	Measured	9.82	9.65	8.91	7.83	6.92	5.72	4.65	4.16	3.82	4.17	3.6	3.49

Marapong: Monitoring Station

Matimba - Marapong wind rose, 2006-1-1 1 to 2009-1-31 24

Category [m/s]	0-0.5	0.5-2.5	2.5-5	5-7	7-10	>10	Sum
N	1.1	3.7	0.6	0.	0.	0.	5.4
NNE	0.5	4.4	1.3	0.	0.	0.	6.2
NE	0.4	7.3	3.	0.1	0.	0.	10.8
ENE	0.5	9.	5.5	0.6	0.	0.	15.6
E	0.6	8.4	3.3	0.2	0.	0.	12.5
ESE	0.6	6.6	1.6	0.1	0.	0.	8.9
SE	0.5	4.9	0.3	0.	0.	0.	5.7
SSE	0.6	3.7	0.2	0.	0.	0.	4.5
S	0.5	2.8	0.2	0.	0.	0.	3.5
SSW	0.5	1.6	0.6	0.1	0.	0.	2.8
SW	0.4	1.5	0.5	0.	0.	0.	2.4
WSW	0.5	1.3	0.3	0.	0.	0.	2.1
W	0.3	2.	0.9	0.1	0.	0.	3.3
WNW	0.5	3.1	0.6	0.	0.	0.	4.2
NW	1.5	3.4	0.4	0.	0.	0.	5.3
NNW	2.5	3.9	0.3	0.	0.	0.	6.7
Sum	11.5	67.6	19.6	1.2	0.	0.	99.95

-Marapong + Matimba Sulphur dioxide seasonal diurnal variation, Years 2006-2009

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	1.5	1.4	1.3	1.2	1.2	1.2	1.1	1.1	1.1	1.1	1.3	1.9

	13	14	15	16	17	18	19	20	21	22	23	24
Mean [ppb]	3.5	3.7	4.	4.4	4.9	4.4	3.2	2.6	2.1	2.	2.	1.8

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	2.6	2.1	1.8	1.7	1.6	1.6	1.6	1.8	1.7	1.6	2.5	2.5

	13	14	15	16	17	18	19	20	21	22	23	24
Mean [ppb]	5.5	6.8	9.1	7.8	9.	7.9	5.9	5.	4.8	4.4	3.7	2.7

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	3.8	3.6	3.3	3.1	3.	3.	3.2	3.5	3.2	2.9	2.5	3.5

	13	14	15	16	17	18	19	20	21	22	23	24
Mean [ppb]	5.9	7.5	8.7	7.4	6.7	6.1	5.1	5.7	5.1	4.6	4.4	4.4

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	1.7	1.8	1.7	1.6	1.5	1.5	1.6	1.6	1.4	1.6	2.4	2.7

	13	14	15	16	17	18	19	20	21	22	23	24
Mean [ppb]	3.6	5.1	4.6	4.9	4.5	4.4	3.9	3.1	3.	2.3	2.1	1.7

-Marapong + Matimba Sulphur dioxide monthly diurnal variation, 2006-1-1 to 2009-1-31

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	1.3	1.1	1.	0.9	0.9	0.9	0.9	1.	0.9	0.8	0.8	1.1

13	14	15	16	17	18	19	20	21	22	23	24
1.2	1.5	2.1	3.1	3.9	4.3	3.	2.4	1.7	1.5	1.5	1.5

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	2.2	2.	1.8	1.6	1.7	1.6	1.6	1.6	1.5	1.6	2.1	3.6

13	14	15	16	17	18	19	20	21	22	23	24
8.1	8.7	9.8	10.	11.1	8.8	5.3	4.2	3.6	3.5	3.3	2.6

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	1.4	1.3	1.1	0.9	0.8	0.9	0.9	1.	0.9	0.9	1.8	1.3

13	14	15	16	17	18	19	20	21	22	23	24
2.9	5.9	6.7	5.9	7.2	8.	5.9	4.1	3.7	2.8	2.3	1.6

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	2.5	2.2	2.1	2.	2.	1.9	1.8	2.1	1.9	1.8	3.2	3.8

13	14	15	16	17	18	19	20	21	22	23	24

9.3	9.	13.9	9.4	11.3	8.4	6.	4.7	4.8	4.6	3.8	3.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean [ppb]	4.7	3.2	2.6	2.4	2.3	2.3	2.7	2.9	2.8	2.3	2.8	2.9

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
5.1	5.5	7.	8.6	8.7	7.	5.9	6.6	6.7	6.9	5.7	4.2

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean [ppb]	3.9	3.4	2.9	2.7	2.6	2.7	3.	3.2	2.8	2.4	2.3	2.9

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
6.2	6.	6.9	7.4	5.7	5.3	4.8	4.8	4.9	4.9	4.7	5.

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean [ppb]	4.8	4.6	4.	3.7	3.6	3.6	3.8	4.1	4.	3.8	3.4	4.6

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
6.7	8.7	11.	8.8	9.5	8.3	6.1	6.3	5.3	5.1	4.8	4.8

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean [ppb]	2.8	2.9	3.1	3.	2.7	2.7	2.8	3.1	2.9	2.5	1.9	3.1

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
5.	7.8	8.1	6.	4.7	4.6	4.3	6.1	5.1	3.8	3.8	3.5

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**

Mean [ppb]	2.4	2.4	2.3	2.1	2.	1.9	2.3	2.4	1.9	1.7	2.5	4.1

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
5.2	5.6	5.3	6.4	5.2	5.4	4.3	3.7	3.5	2.6	2.7	2.5

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean [ppb]	1.5	1.5	1.2	1.2	1.2	1.2	1.4	1.3	1.3	2.1	2.9	2.

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
2.8	4.8	3.2	4.2	3.9	3.5	4.	3.2	3.6	2.6	2.	1.5

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean [ppb]	1.3	1.6	1.6	1.4	1.3	1.2	1.2	1.1	1.1	1.2	2.	2.1

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
2.7	5.	5.2	4.3	4.5	4.3	3.4	2.5	2.	1.6	1.6	1.2

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean [ppb]	1.1	1.1	1.1	1.1	1.1	1.	1.	1.	1.	1.	1.1	1.3

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
1.9	1.7	1.6	1.8	2.	1.7	2.	1.7	1.4	1.5	1.4	1.5

	Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**
Monthly Mean [ppb]	1.6	4.2	2.9	4.8	4.7	4.2	5.5	4.	3.3	2.4	2.3	1.4

Matimba - Marapong Sulphur dioxide Source Apportionment by Diurnal Signature (SADS)
2006-1-1 1 to 2009-1-31 24

	Pie Chart Info			
Colour	**Segment**	**Hours [h]**	**Perc. [%]**	**Mean Conc.[ppb]**
	Morning	6-10	9.	0.3
	Day	10-16	27.3	0.9
	Evening	16-20	31.	1.02
	Nite	20-6	32.7	1.08
	Background	0-24	n/a	n/a

Diurnal Graph Info													
Colour	**Segment**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Line	Morning	0.04	0.08	0.13	0.25	0.55	1.05	1.45	1.58	1.18	0.49	0.16	0.06
Line	Day	0.	0.	0.	0.01	0.01	0.03	0.06	0.17	0.49	1.13	1.77	2.16
Line	Evening	0.08	0.03	0.01	0.	0.	0.	0.01	0.01	0.04	0.09	0.19	0.39
Line	Nite	2.24	2.09	1.85	1.6	1.22	0.71	0.37	0.22	0.13	0.07	0.04	0.03
Dot	Calculated	2.37	2.2	2.	1.86	1.79	1.79	1.89	1.99	1.83	1.79	2.16	2.64
Dot	Measured	2.37	2.2	2.	1.86	1.79	1.79	1.89	1.99	1.83	1.79	2.16	2.64

Colour	**Segment**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**

Line	Morning	0.03	0.01	0.01	0.	0.	0.	0.	0.	0.	0.	0.01	0.02
Line	Day	3.7	4.25	3.94	2.11	0.87	0.45	0.24	0.12	0.06	0.03	0.01	0.
Line	Evening	0.73	1.29	2.21	3.59	4.74	4.3	2.82	1.76	1.11	0.65	0.35	0.17
Line	Nite	0.04	0.07	0.14	0.27	0.47	0.78	1.34	2.12	2.47	2.55	2.59	2.44
Dot	Calculated	4.5	5.62	6.3	5.97	6.09	5.53	4.41	4.01	3.64	3.23	2.96	2.64
Dot	Measured	4.5	5.62	6.3	5.97	6.09	5.53	4.41	4.01	3.64	3.23	2.96	2.64

Matimba - Waterberg sub station wind rose, 1984-1-1 1 to 1992-12-31 24

Category [m/s]	0-0.5	0.5-2.5	2.5-5	5-7	7-10	>10	Sum
N	1.6	3.4	1.5	0.2	0.2	0.	6.9
NNE	1.6	4.1	2.2	0.3	0.1	0.	8.3
NE	2.2	5.1	3.8	1.3	0.4	0.	12.8
ENE	3.1	8.6	5.5	2.2	0.6	0.	20.
E	2.5	4.9	5.1	1.2	0.2	0.	13.9
ESE	1.4	1.2	0.3	0.1	0.1	0.	3.1
SE	0.9	0.6	0.3	0.1	0.1	0.	2.
SSE	0.7	0.5	0.2	0.1	0.1	0.	1.6
S	0.7	0.8	0.5	0.1	0.1	0.	2.2
SSW	0.7	0.8	0.3	0.1	0.1	0.	2.
SW	1.2	2.5	0.7	0.2	0.1	0.	4.7
WSW	1.2	8.6	1.9	0.1	0.1	0.	11.9
W	0.8	2.4	0.9	0.2	0.1	0.	4.4
WNW	0.6	0.8	0.2	0.1	0.	0.	1.7
NW	0.7	0.7	0.3	0.1	0.	0.	1.8
NNW	1.	1.1	0.3	0.2	0.	0.	2.6
Sum	20.9	46.1	24.	6.6	2.3	0.	99.95

Matimba - station sub Waterberg Sulphur dioxide seasonal diurnal variation, Years 1984-1992

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean [ppb]	2.8	2.8	2.8	2.8	2.8	2.8	2.8	2.9	3.2	3.5	3.9	4.3

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
4.5	4.7	4.6	4.2	3.8	3.6	3.	2.7	2.7	2.7	2.8	2.8

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean [ppb]	3.	3.	3.	2.9	2.8	2.8	2.9	3.	3.3	3.6	4.6	5.3

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
5.3	4.9	4.9	4.6	4.3	3.9	3.5	3.3	3.3	3.2	3.2	3.1

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean [ppb]	3.1	2.9	2.8	2.7	2.6	2.5	2.5	2.6	3.	3.8	4.8	6.3

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
7.3	6.9	6.6	6.8	6.1	5.1	4.4	4.	3.8	3.6	3.4	3.2

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Mean [ppb]	3.8	3.8	3.8	3.7	3.7	3.7	3.8	3.9	4.1	4.5	5.3	6.5

13	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
6.4	6.1	6.	5.8	5.5	4.7	4.	3.8	3.8	3.8	3.9	3.9

Matimba - station sub Waterberg Sulphur dioxide monthly diurnal variation, 1984-1-1 to 1992-12-31

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	2.7	2.6	2.6	2.6	2.6	2.6	2.7	2.8	3.1	3.5	4.1	4.

13	14	15	16	17	18	19	20	21	22	23	24
4.4	4.2	4.1	4.1	3.6	3.4	2.9	2.7	2.6	2.6	2.7	2.7

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	2.8	2.9	2.9	2.8	2.8	2.8	2.8	2.9	2.9	3.2	3.8	4.3

13	14	15	16	17	18	19	20	21	22	23	24
3.9	3.6	3.3	3.2	3.1	2.8	2.6	2.4	2.5	2.5	2.7	2.7

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	2.8	2.7	2.7	2.7	2.6	2.6	2.7	2.8	3.	3.2	3.9	4.1

13	14	15	16	17	18	19	20	21	22	23	24
4.3	4.2	4.6	4.1	3.8	3.3	2.9	2.8	2.9	2.9	2.9	2.7

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	3.	3.	3.	3.	3.	3.	3.1	3.2	3.5	3.7	4.6	5.8

13	14	15	16	17	18	19	20	21	22	23	24
5.2	5.1	4.6	4.3	4.	3.8	3.5	3.3	3.2	3.1	3.1	3.1

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	3.3	3.2	3.1	3.1	3.	2.9	2.9	3.	3.5	4.	5.4	6.

13	14	15	16	17	18	19	20	21	22	23	24
6.3	5.3	5.5	5.5	5.2	4.5	4.2	3.9	3.8	3.6	3.6	3.5

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	2.8	2.5	2.3	2.2	2.1	2.1	2.	2.1	2.6	3.6	4.5	5.8

13	14	15	16	17	18	19	20	21	22	23	24
7.2	6.4	6.1	6.4	5.9	4.8	4.2	3.9	3.7	3.5	3.2	2.9

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	3.3	3.2	3.2	3.	2.9	2.9	2.8	2.9	3.3	4.2	4.9	6.

13	14	15	16	17	18	19	20	21	22	23	24
6.9	7.8	7.3	7.4	6.5	6.	5.1	4.4	4.2	4.	3.7	3.5

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	3.1	3.	2.9	2.8	2.7	2.6	2.6	2.8	3.	3.5	5.1	7.

13	14	15	16	17	18	19	20	21	22	23	24
7.8	6.3	6.4	6.7	5.9	4.5	4.	3.6	3.4	3.4	3.3	3.2

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	3.5	3.5	3.4	3.4	3.4	3.3	3.4	3.5	3.6	3.8	4.9	7.7

	13	14	15	16	17	18	19	20	21	22	23	24
	7.5	6.8	6.6	6.2	5.9	5.1	4.1	3.9	3.8	3.7	3.6	3.7

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	4.3	4.2	4.2	4.2	4.2	4.2	4.3	4.4	4.7	5.5	6.3	6.5

	13	14	15	16	17	18	19	20	21	22	23	24
	6.9	6.7	6.3	6.7	6.2	5.	4.3	4.1	4.2	4.1	4.4	4.3

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	3.6	3.6	3.7	3.6	3.6	3.6	3.7	3.7	4.	4.2	4.7	5.1

	13	14	15	16	17	18	19	20	21	22	23	24
	4.7	4.4	4.8	4.4	4.3	3.8	3.6	3.3	3.5	3.7	3.7	3.7

	1	2	3	4	5	6	7	8	9	10	11	12
Mean [ppb]	3.1	3.1	3.1	3.	3.	3.	3.1	3.2	3.5	3.8	3.9	4.5

	13	14	15	16	17	18	19	20	21	22	23	24
	5.3	6.1	6.1	5.2	4.6	4.4	3.4	3.	3.1	3.1	3.1	3.2

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Monthly Mean [ppb]	3.2	3.	3.2	3.7	4.1	3.9	4.6	4.1	4.5	5.	4.	3.8

Matimba - Waterberg sub station Sulphur dioxide Source Apportionment by Diurnal Signature (SADS)
1984-1-1 1 to 1992-12-31 24

Pie Chart Info				
Colour	**Segment**	**Hours [h]**	**Perc. [%]**	**Mean Conc.[ppb]**
	Morning	6-10	11.8	0.47
	Day	10-16	36.6	1.45
	Evening	16-20	18.3	0.72
	Nite	20-6	33.3	1.31
	Background	0-24	n/a	n/a

Diurnal Graph Info													
Colour	**Segment**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Line	Morning	0.11	0.2	0.32	0.48	0.86	1.53	1.94	2.02	1.71	0.93	0.47	0.26
Line	Day	0.01	0.02	0.04	0.08	0.16	0.28	0.46	0.77	1.49	2.78	4.05	5.11
Line	Evening	0.06	0.03	0.01	0.	0.	0.	0.	0.01	0.02	0.05	0.11	0.22
Line	Nite	3.02	2.9	2.73	2.49	1.99	1.17	0.6	0.33	0.18	0.09	0.05	0.03
Dot	Calculated	3.2	3.14	3.1	3.05	3.	2.98	3.01	3.12	3.4	3.86	4.68	5.62
Dot	Measured	3.2	3.14	3.1	3.05	3.	2.98	3.01	3.12	3.4	3.86	4.68	5.62

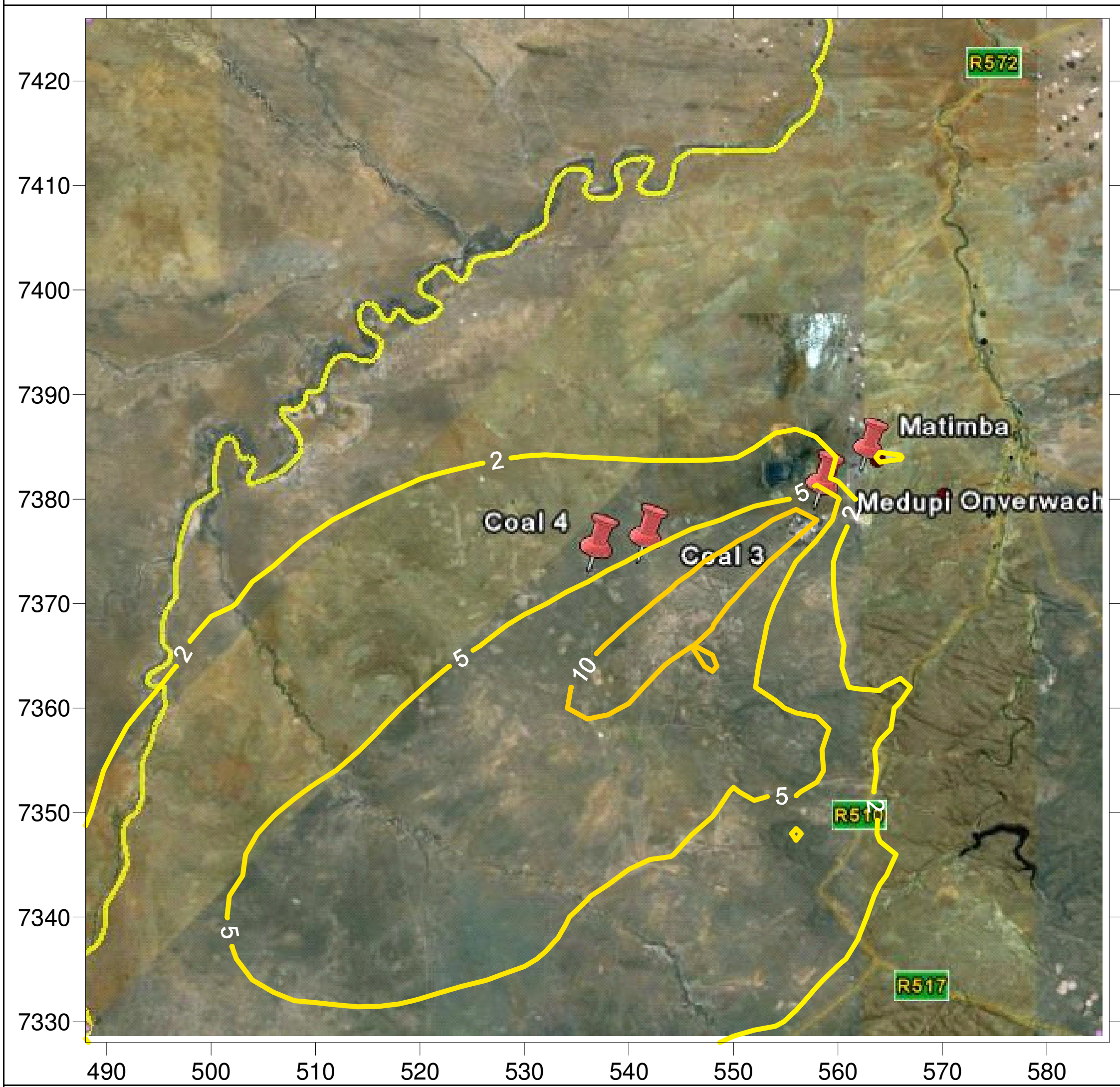
Colour	**Segment**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
Line	Morning	0.14	0.06	0.03	0.01	0.	0.	0.	0.	0.	0.01	0.03	0.06

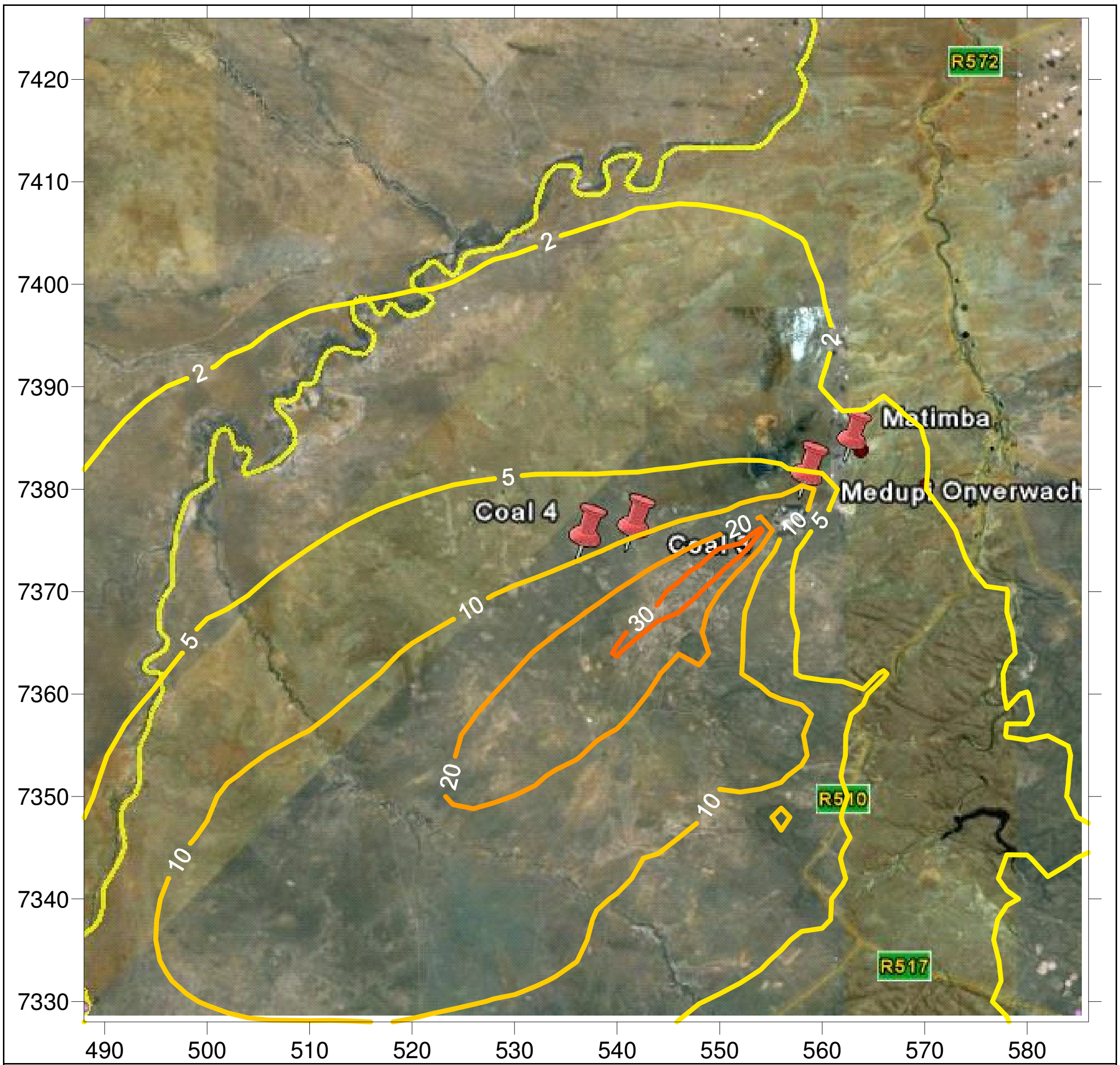
Line	Day	5.37	4.85	3.97	2.47	1.35	0.74	0.38	0.19	0.08	0.04	0.02	0.01
Line	Evening	0.39	0.68	1.45	2.76	3.29	3.01	2.25	1.33	0.78	0.47	0.26	0.13
Line	Nite	0.03	0.05	0.1	0.18	0.33	0.59	1.14	1.97	2.55	2.85	3.04	3.08
Dot	Calculated	5.92	5.65	5.54	5.42	4.97	4.34	3.77	3.48	3.42	3.37	3.34	3.28
Dot	Measured	5.92	5.65	5.54	5.42	4.97	4.34	3.77	3.48	3.42	3.37	3.34	3.28

ANNEXURE 5 SULPHUR DIOXIDE CONCENTRATIONS ALL SCENARIOS – ANNUAL AVERAGES

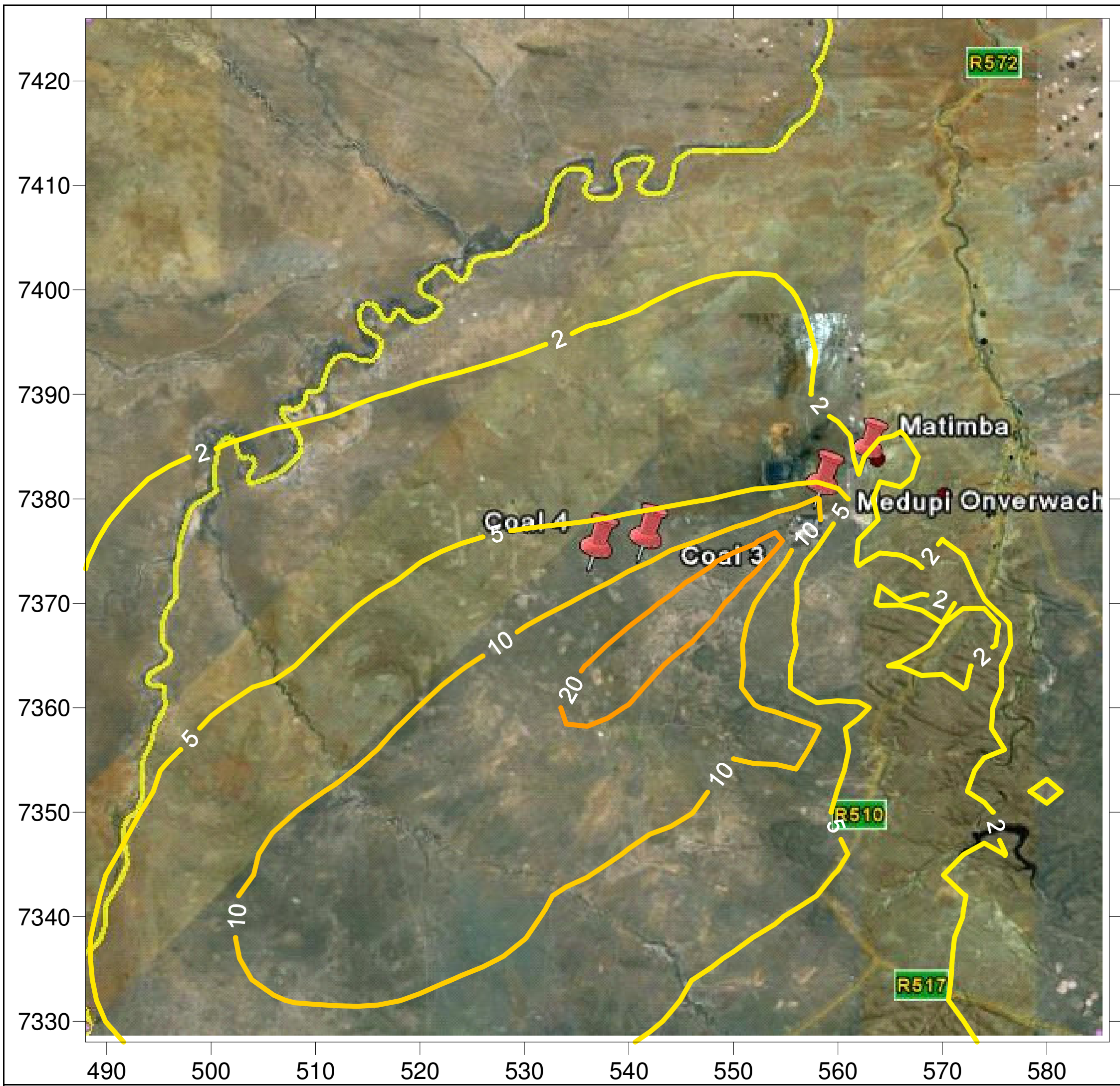
SULPHUR DIOXIDE CONCENTRATIONS

Annual concentrations

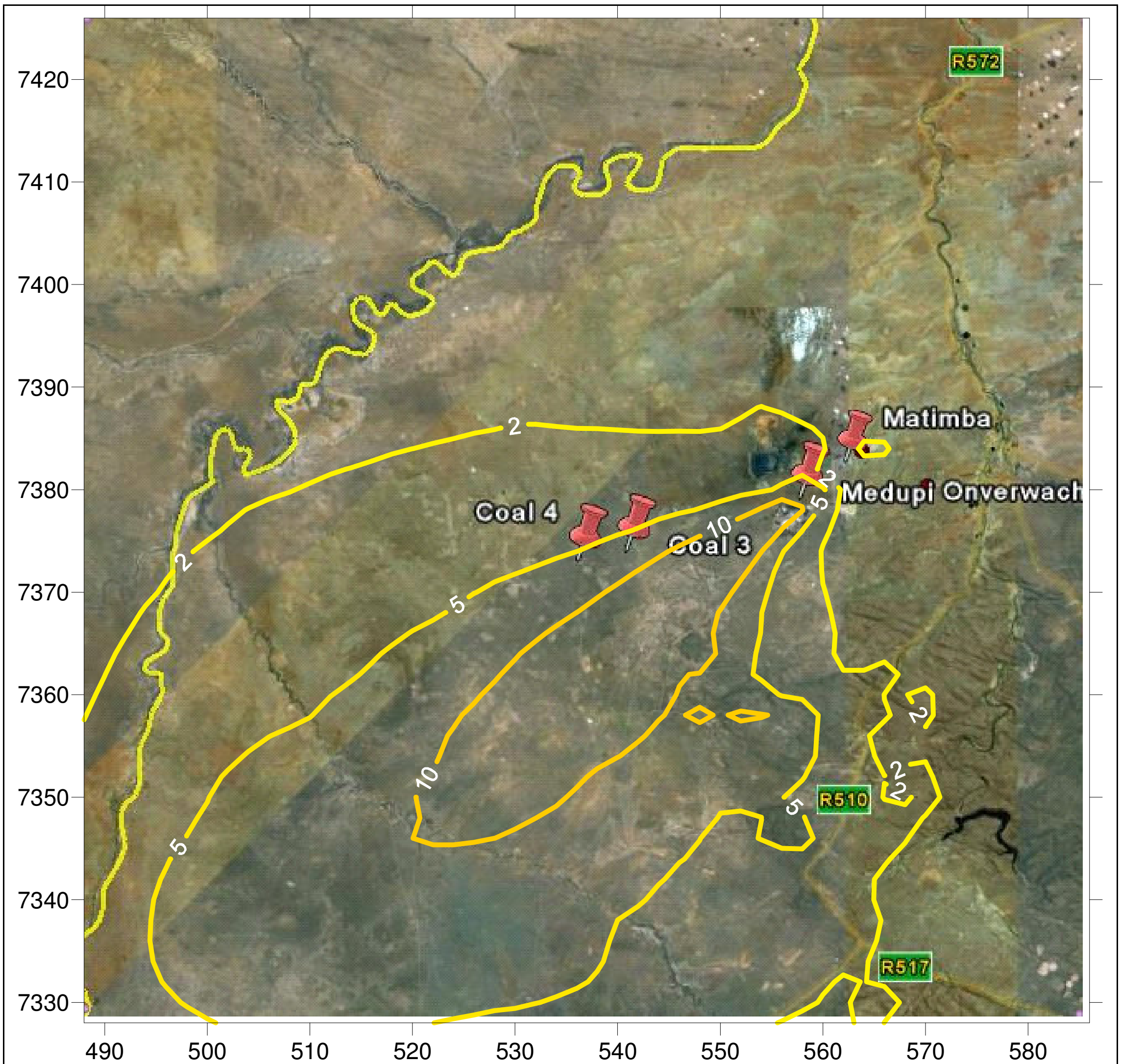
Annual SO_2 concentration ($\mu g/m^3$)
Scenario 0: Matimba (without FGD) only

Scenario 1: Matimba and Medupi without FGD



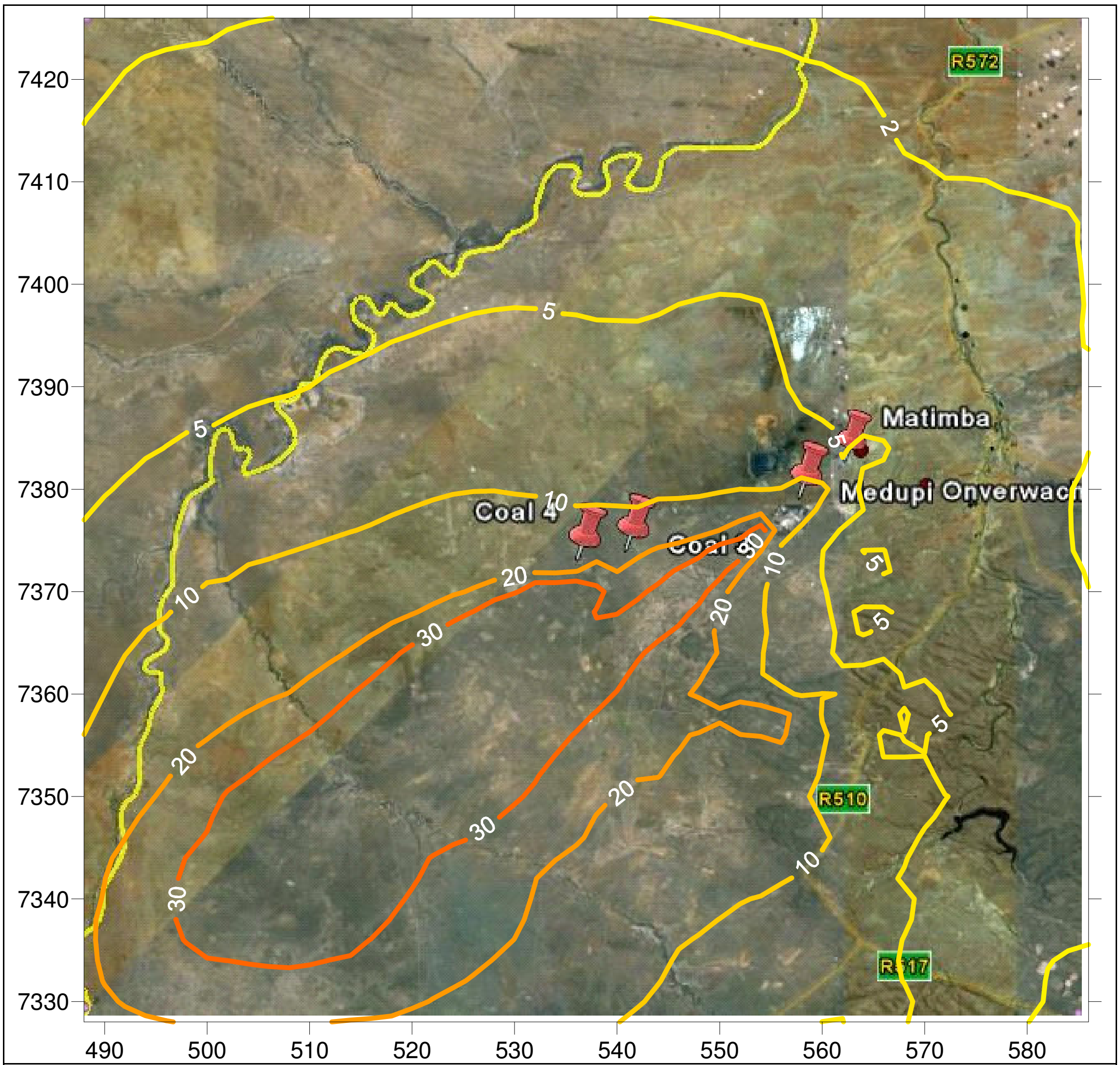
Scenario 2: Matimba without FGD and Medupi with FGD on 3 units



Scenario 3: Matimba without FGD and Medupi with FGD on 6 units

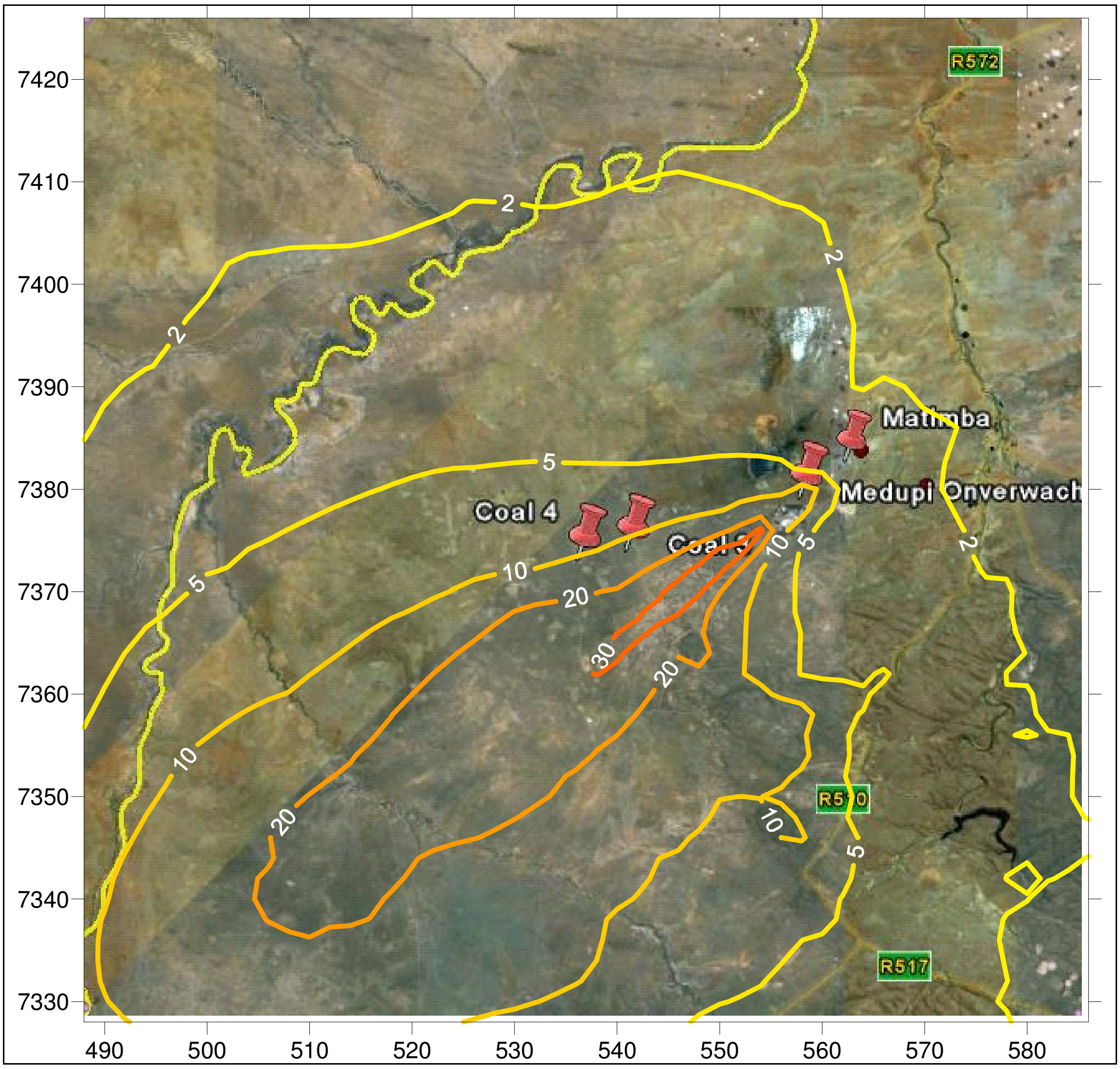


Scenario 4: Matimba, Medupi, Coal 3 and Coal 4, all without FGD



Scenario 5: Matimba without FGD and Medupi, Coal 3 and Coal 4 with FGD

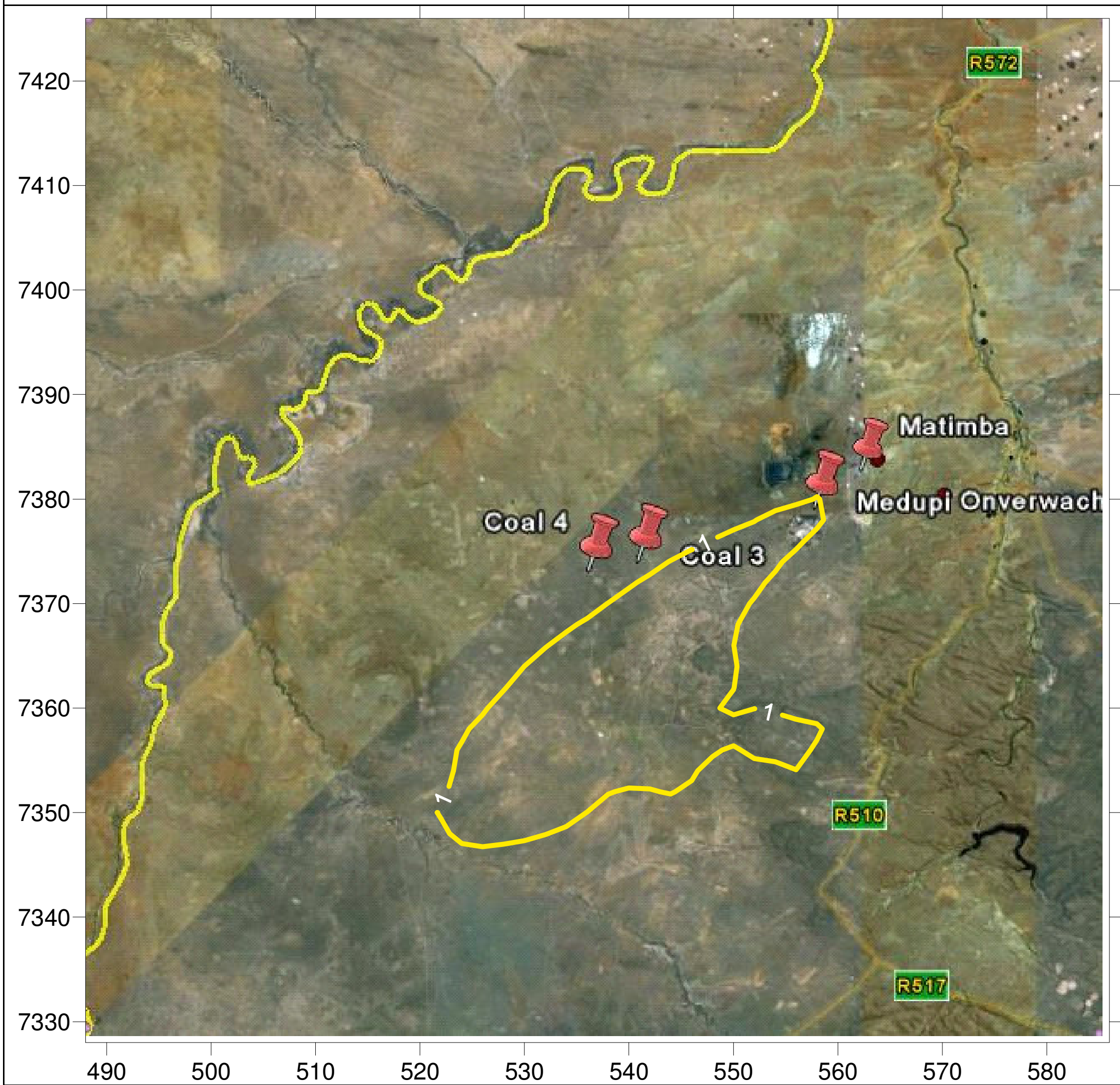
Annexure 5

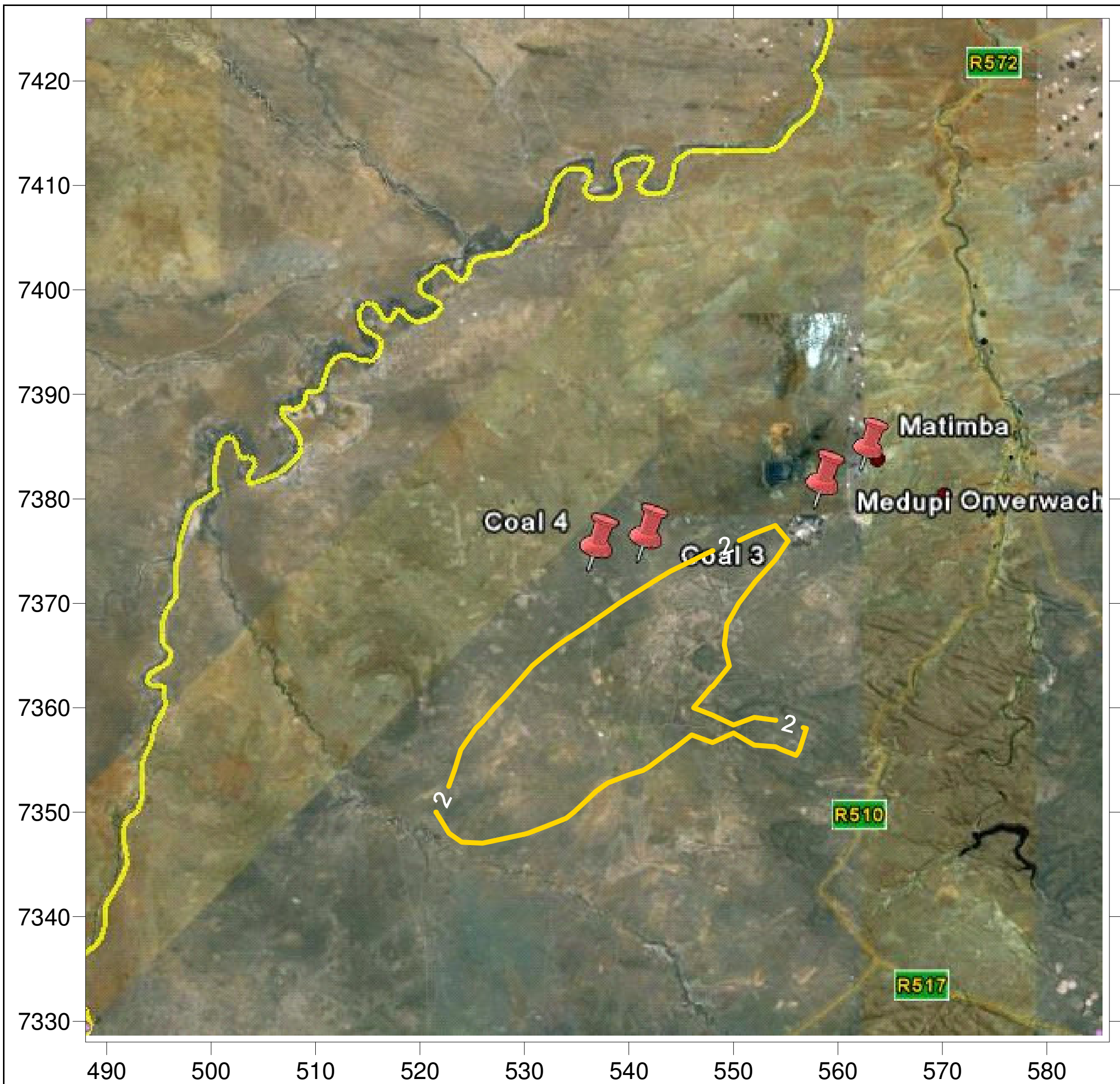

7420
7410
7400
7390
7380
7370
7360
7350
7340
7330
490
500
510
520
530
540
550
560
570
580
R572
Medupi
Onverwach
Coal 4
2
5
10
20
30
R517

ANNEXURE 6 NITROGEN DIOXIDE CONENTRATIONS ALL SCENARIOS – ANNUAL AVERAGES

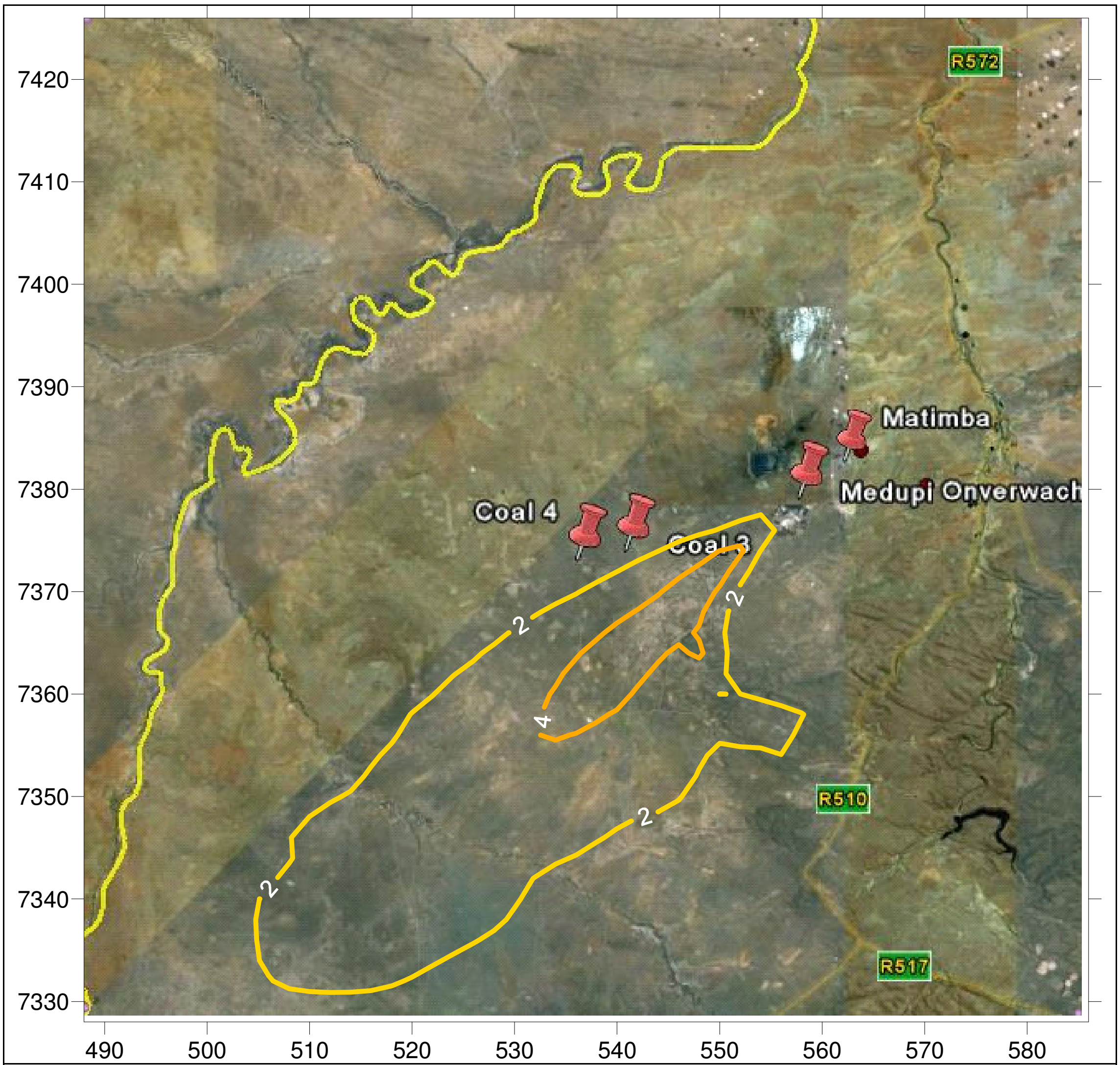
NITROGEN DIOXIDE CONCENTRATIONS

Annual concentrations

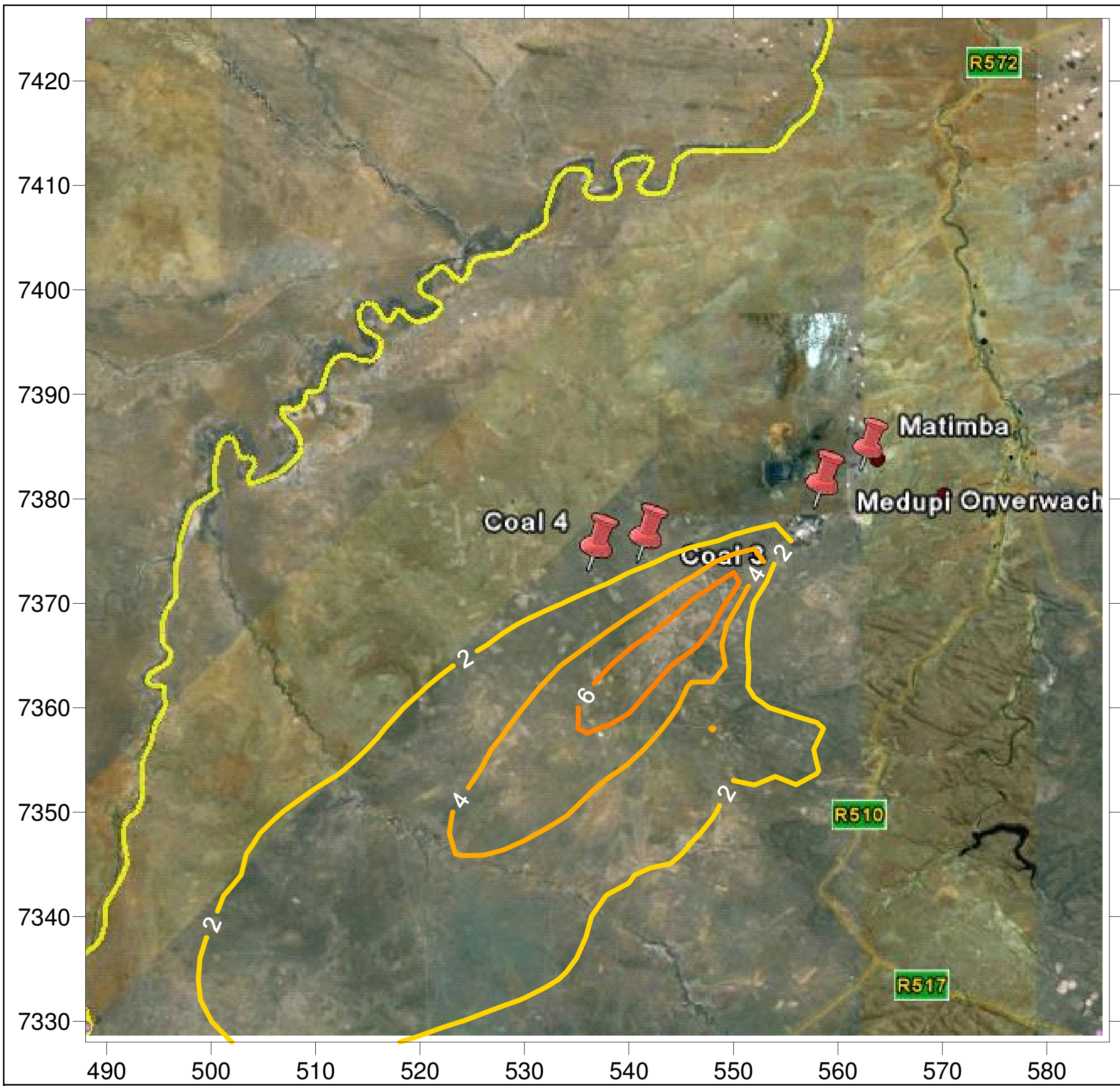
Annual NO_2 concentration ($\mu g/m^3$)
Scenario 0: Matimba (without FGD) only

Scenario 1: Matimba and Medupi without FGD



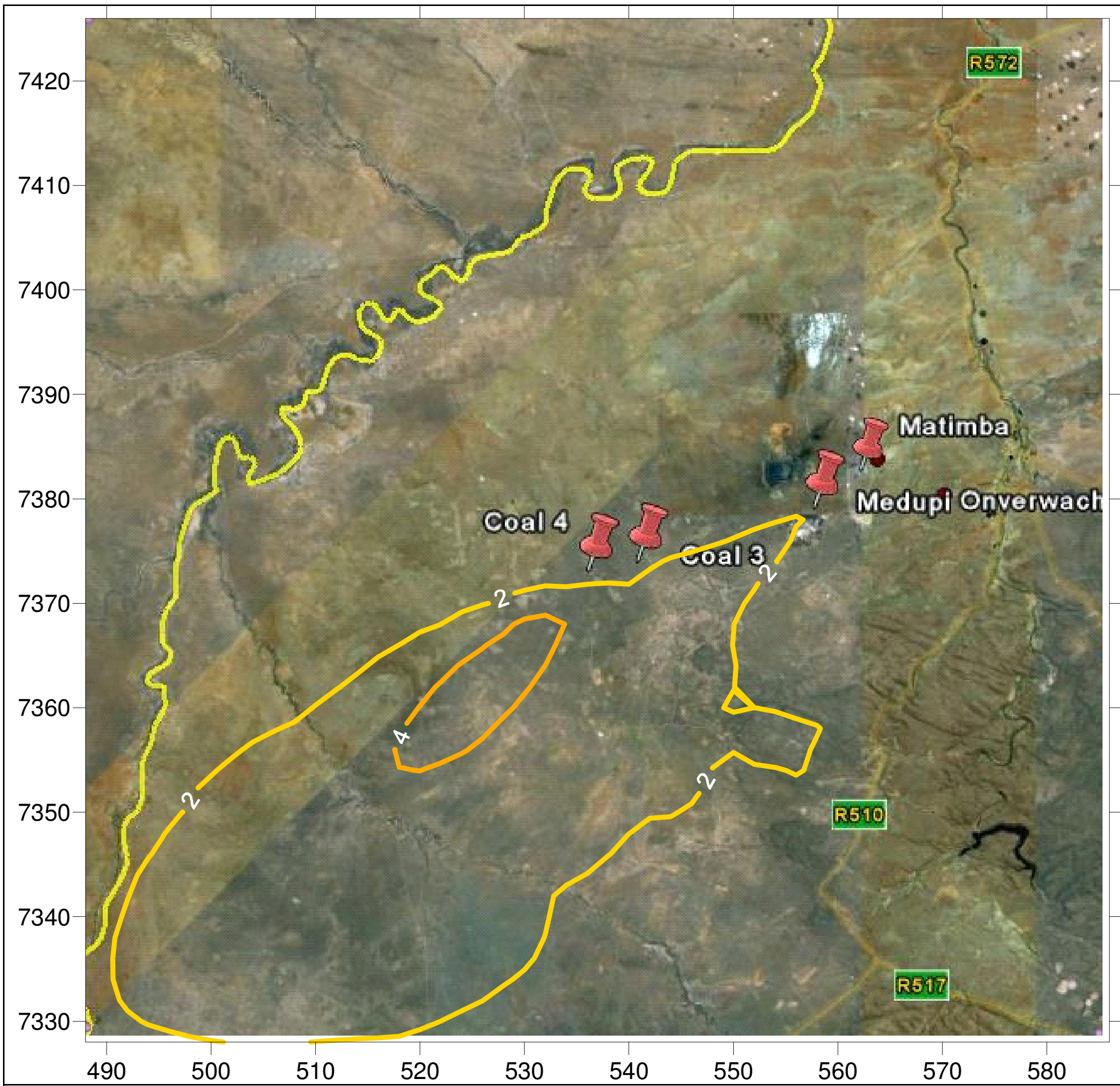
Scenario 2: Matimba without FGD and Medupi with FGD on 3 units



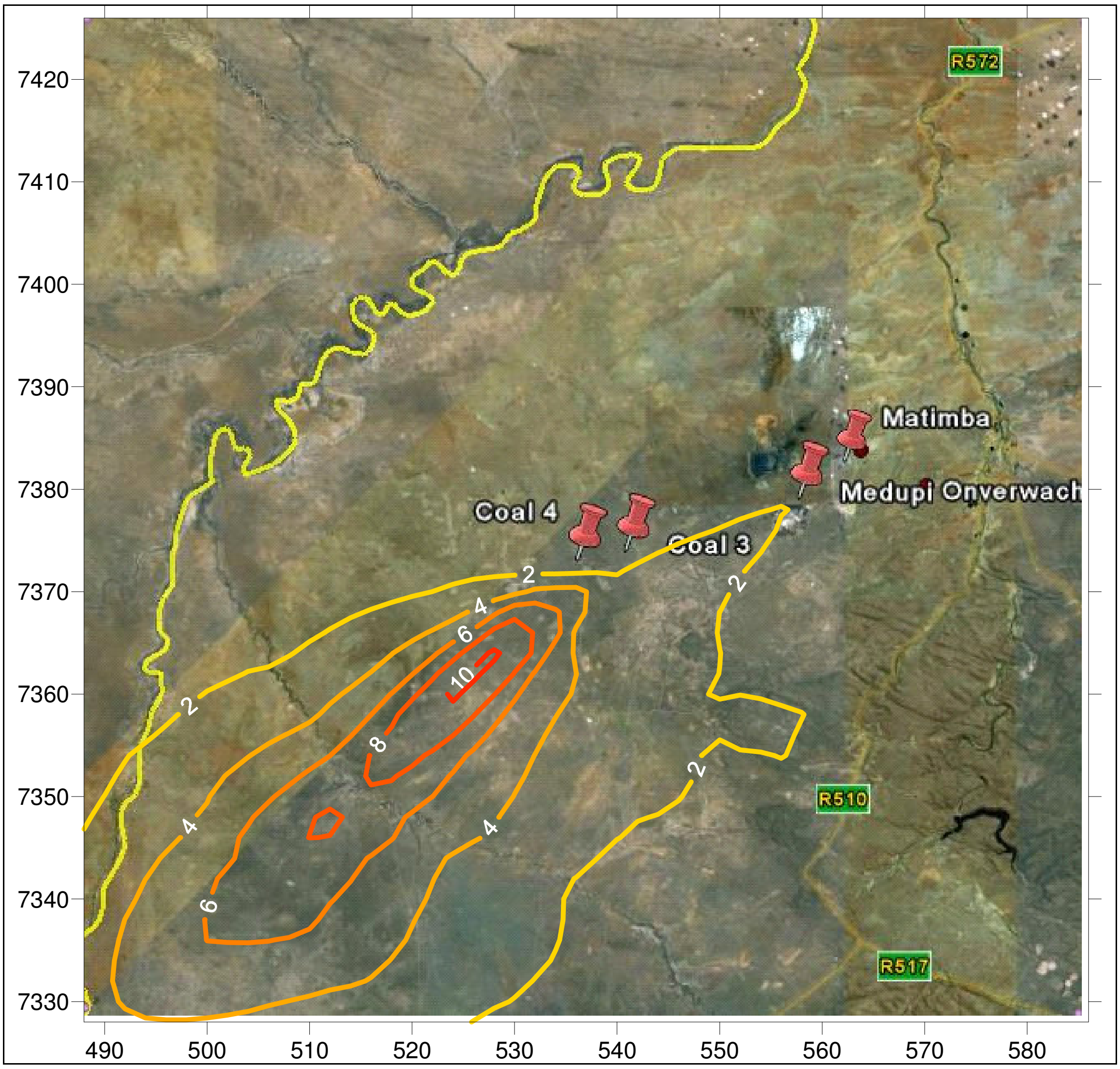
Scenario 3: Matimba without FGD and Medupi with FGD on 6 units



Scenario 4: Matimba, Medupi, Coal 3 and Coal 4, all without FGD



Scenario 5: Matimba without FGD and Medupi, Coal 3 and Coal 4 with FGD


R572
Matimba
Medupi Onverwacht
Coal 4
Coal 3
R510
R517
2
4
6
8
10
7420
7410
7400
7390
7380
7370
7360
7350
7340
7330
490
500
510
520
530
540
550
560
570
580