PROMETHIUM CARBON

Specialist Climate Change Assessment

For the Proposed Mutsho Power Project (CFB Supercritical)

Produced by Promethium Carbon for Savannah Environmental

savannah environmental

27 March 2018

www.promethium.co.za | Tel : +27 11 706 8185 **| Fax:** +27 86 589 3466
BALLYOAKS OFFICE PARK | LACEY OAK HOUSE , 2ND FLOOR | 35 BALLYCLARE DRIVE | PO BOX 131253 | BRYANSTON 2021
PROMETHIUM CARBON (PTY) Ltd / Reg no: 2005/018622/07 / Directors / H Immink, RT Louw, HJ Swanepoel

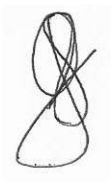
Table of Contents

Declaration of Independence

Robbie Louw, Harmke Immink and Sarah Goodbrand as the authors of this report, do hereby declare their independence as consultants appointed by Savannah Environmental to undertake a climate change assessment for the proposed Mutsho Power Project. Other than fair remuneration for the work performed, the specialists have no personal, financial business or other interests in the project activity. The objectivity of the specialists is not compromised by any circumstances and the views expressed within the report are their own.

Robbie Louw

Harmke Immink



Sarah Goodbrand

Details of Specialist

Promethium Carbon

Promethium Carbon is a South African climate change and carbon advisory company based in Johannesburg. With a view to making a difference in climate change in Africa and a focus on technical expertise, our team of climate change professionals assists businesses, ranging from small enterprises to multinational entities, on their journey towards a low carbon economy. We also assist governments and government institutions in planning for the imminent global carbon-constrained environment. Through our participation on various working groups and standards boards, we have established ourselves as knowledge leaders in the climate space and act as trusted advisors to our clients.

We have been active in the climate change and carbon management space since 2004. Our client base includes many of the international mining houses and industrial companies that are operating in, and from, South Africa. One of our clients was awarded the European Energy Risk Deal of the Year award in 2010 for a carbon credit commercial transaction that Promethium Carbon advised the client on. Promethium Carbon also received the Star Excellence Award in recognition of our outstanding contribution to Africa's Economic Growth and Development. This award was received in Abu Dhabi during the World Future Energy Summit 2014. Furthermore, Promethium Carbon was awarded the title of Best Project Implementer by the British High Commission in 2015.

Promethium Carbon has conducted several climate change impact studies. These studies typically include an estimation of the carbon footprint of the activity or group of activities, as well as the vulnerability of the activity/ies to climate change. Promethium Carbon has been conducting climate change risk and vulnerability assessments as part of the Carbon Disclosure Project since 2008. In addition to this work, Promethium Carbon has also conducted standalone, detailed climate change risk and vulnerability assessments. These standalone assessments include thorough analysis of historical and projected weather data specific to the region in which the client operates. Promethium Carbon's assessment of vulnerability goes beyond core operations to include impacts within the supply chain and broader network of the client.

Robbie Louw

Robbie is the founder and director of Promethium Carbon. He has over 10 years of experience in the climate change industry. His experience (over 28 years) includes research and development activities as well as project, operational and management responsibilities in the chemical, mining, minerals process and energy fields.

Robbie's experience in climate change includes (but is not limited) to:

- Climate change risk and vulnerability assessments: He has conducted assessments with large mining houses.
- Carbon footprinting: He has extensive experience in carbon footprinting. The team under his leadership has performed carbon footprint calculations for major international corporations operating complex businesses in multiple jurisdictions and on multiple continents.
- Climate strategy development: He has developed carbon and climate change strategies for major international corporations.

- Climate change impact and risk assessments: He has developed climate change risk assessments for various companies and projects.

Harmke Immink

Harmke is a Director at Promethium Carbon. Her 12 years of climate change expertise is developed from environmental life cycle assessments, environmental audits and technical performance evaluation. She has a Masters degree in Environmental Measurement Techniques (Sweden), and gained experience across industry sectors through a variety of technical surveys and industry roadmaps.

Harmke's experience in climate change includes (but is not limited) to:

- Climate change risk and vulnerability assessments;
- South African representative for ISO Technical Committee 207 on greenhouse gas standards, including eco-labelling and carbon footprint of products;
- Technical assessor for SANAS accredited: ISO 14065 greenhouse gas validation and verification;
- Part of World Resource Institute technical development team for the Greenhouse Gas Protocol Standard on accounting for goals and targets;
- Climate change related services include greenhouse gas baseline evaluations, a survey for practical sustainable development indicators for Clean Development Mechanism projects, four new or revised methodologies, twelve successful registration of Clean Development Mechanism projects as well as three projects in which she assisted with the issuance of carbon credits;
- Climate change adaptation projects for mining clients, focused on community vulnerabilities and strategically linking with social responsibility;
- Experience in Carbon Disclosure Project, which is a global initiative to collect and distribute high quality information that motivates investors, corporations and governments to take action in the attempt to mitigate climate change. Since 2007, Promethium Carbon's Carbon Disclosure Project clients have been consistently represented in both the top ten disclosure and the performance leadership indices.

Sarah Goodbrand

Sarah is a senior climate change advisor at Promethium Carbon. She has 5 years of work experience and holds the following degrees: Bachelor of Science (University of the Witwatersrand) and Bachelor of Science (Hons) (University of Witwatersrand). She is currently working on her Bachelor of Science (MSc) under the Global Change Institute at the University of the Witwatersrand. Sarah's MSc is focusing on ecosystem-based adaptation to climate change in South African metropoles. Sarah currently works as a climate change advisor specializing in services which include:

- Climate change risk and vulnerability assessments;
- Carbon footprints and water accounting;
- Drafting CDP Climate Change and Water responses;
- Drafting South Africa's Second Biennial Update Report and Third National Communication;
- Assessment of climate change and energy related regulations;
- Carbon emission related work.

1. Introduction

Mutsho Power (Pty) Ltd proposes to develop a 600MW coal based power plant near Makhado (Louis Trichardt), in the Limpopo Province. The project aims to provide new baseload electricity generation capacity for South Africa. The power plant will utilise coal mined at the Makhado Colliery (to be developed roughly 20 km south-east of the project site), to be owned and operated by MC Mining Ltd (MCM) (previously known as Coal of Africa Limited). Once developed the power plant is intended to form part of the Department of Energy's Coal Baseload Independent Power Producer (IPP) Procurement Programme (CBIPPPP).

In accordance with the relevant regulations, an Environmental Impact Assessment process must be completed before project development can proceed. As part of the Environmental Impact Assessment, Promethium Carbon has been appointed to undertake a specialist climate change assessment of the project. This involves assessing the project's prospective contribution to climate change through the emission of greenhouse gases (GHGs) such as carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

A coal fired power plant's contribution to global climate change is dependent on the greenhouse gas emissions produced by the plant and its value chain. The value chain extends from the coal mine to the consumer of electricity. However, the greenhouse gas emissions from any individual source cannot be attributed directly or indirectly with any specific environmental impacts as a consequence of climate change. This assessment focuses on calculating the greenhouse gas emissions and investigating the consequent climate change impacts of the combustion technologies and mitigation options available to the project developer.

This approach is aligned with the principles of the National Environmental Management Act 1998 as it seeks to provide the project developer with the best possible information to evaluate the project's environmental sustainability. For each alternative and mitigation option considered the project development would include the construction of power plant, access roads, raw material handling and storage facilities, water infrastructure, HV powerline infrastructure and a substation.

The broad terms of reference and scope of work for this specialist climate change assessment include the following:

1. Calculating the construction and operational greenhouse gas emissions of the project.
2. Calculating the construction and operational greenhouse gas emissions of the project alternatives.
3. Reviewing the greenhouse gas emissions mitigation options for the project.
4. Conducting an impact assessment of the project, its alternatives and mitigation options by:
    - Considering its contribution to the national emissions inventory and the onset of global anthropogenic climate change;
    - Comparing it against the current national grid baseline with consideration of impacts on the future baseline; and

- Exploring the potential climate change impacts and risks faced by the Makhado (Louis Trichardt) area.

5. Assessing requirements for greenhouse gas emission management activities for the plant's operations.

2. Receiving Environment

Climate change and the impact thereof on society is increasingly of concern. In 2013 CO_2 levels surpassed 400 parts per million (ppm) for the first time in recorded history[1]. Various scenarios have been developed to model both mitigated (reducing emissions) and unmitigated (business as usual) options.

The receiving environment for this project is the global atmosphere. The duration of the impact of the greenhouse gas emissions is considered as effectively permanent as the greenhouse gas emissions produced are assumed to remain in the atmosphere beyond 100 years. The contribution of this single project towards global emissions will be small. However the impact of climate change varies considerably across regions in the world, irrespective of individual project contributions to global emissions.

The Limpopo Province, in which the proposed Mutsho Power Project is to be developed is already host to two of Eskom's coal base load stations, Matimba and Medupi. The bulk of South Africa's coal reserves are situated in the Waterberg[2], Witbank, Highveld, Ermelo, South Rand and KwaZulu-Natal[3]. Fossil fuel based power stations are typically developed in close proximity to the coal reserves.

The Long-Term Adaptation Scenarios predicts that temperatures in Limpopo Province could increase by as much as 2 °C by 2035, by 1 – 2 °C between 2040 and 2060 and by 3 – 6 °C between 2080 and 2100. Rainfall is projected to decrease in the long term. However some studies suggest future increases in rainfall, which attests to the uncertainty in model predictions for the Limpopo Province. Such uncertainty clarifies that the province is likely to experience greater variability in rainfall. A drier future with an increase in evaporation rates can be expected for Limpopo even in the presence of greater, heavier and more erratic rainfall events.

An increase in temperatures and drying could lead to more severe droughts which would negatively impact on the power plant's core operations, value chain and broader network. A lack of water due to drought may cause the power plant to be shut down. Local communities surrounding the power plant will be especially impacted by drought conditions and may have a negative perception regarding the power plant's water consumption. Subject to the water source and pending water use licence, the project may be able to supplement the local community with water, which could potentially reduce the community's vulnerability to drought.

---

1 Earth Science Communications Team, NASA Jet Propulsion Laboratory. https://climate.nasa.gov/climate_resources/24/

2 Fossil Fuel Foundation. 2013. The South African Coal Roadmap.

3 Department of Energy. 2010. South African Energy Synopsis.

The proposed power station falls within an area characterised by Musina Mopane Bushveld vegetation[4]. The vegetation type forms part of the Savanna Biome and the Mopane Bushveld Bioregion. Generally, under climate change the savanna biome is projected to expand its geographic range partly replacing grassland (DEA, 2017). Increased temperatures and hot spells particularly in the Free State and Mpumalanga Provinces will result in drier and hotter climate that is suitable for the savanna biome. Climate change could further result in an increase in woody cover, shifting some areas of the savanna biomes towards woodland or even forest. This bush encroachment and invasion of both alien and indigenous woody plants, will have major implications for the delivery of ecosystem goods and services provided by the grassland biome (DEA, 2017). Loss of the grassland biome will not only change the biodiversity, but could also negatively affect subsistence cattle farming in terms of available grazing areas.

South Africa has six hydrological zones, which reflect the boundaries defined by the water management areas. The Mutsho Power Project will be located within the Limpopo Water Management Area North which falls within Zone 1. Zone 1 includes activities such as irrigated agriculture, power production plants, mining, urban and forestry. It therefore has high water requirements. Population and economic growth within this zone will have an increasing impact on water demand due to a likely reduction in rainfall and significantly increased temperatures, which are expected due to climate change (DEA, 2017).

Global climatic changes cannot be directly attributed to the greenhouse gas emissions from the Mutsho Power Project and cannot be directly linked to any local environmental impacts as a consequence.

3. Methodology

3.1 Estimating Greenhouse Gas Emissions

The carbon footprints (both for the construction and operational phase) presented in this assessment have been guided by the ISO/SANS 14064-1 standard[5]. This standard specifies principles and requirements at the organization level for the quantification and reporting of historical figures of greenhouse gas emissions and removals. The principles of this standard have in this analysis been applied to the project as an organisation to the calculation of the future greenhouse gas emissions of the prospective project.

The basic principles of SANS 14064-1 aim to ensure that the greenhouse gas information presented within a carbon footprint is a true and fair account. These principles include:

[4] Mucina, L., & Rutherford, M.C., 2006. The Vegetation of South Africa, Lesotho and Swaziland, Strelitzia 19, South Africa.

[5] Standards South Africa. 2006. SANS 14064-1:2006 Greenhouse Gases Part 1: Specification with guidance at the organisational level for the quantification and reporting of greenhouse gas emissions and removals. Pretoria: Standards South Africa.

Relevance	Selecting all the greenhouse gas sources, greenhouse gas sinks, greenhouse gas reservoirs, data and methodologies that are appropriate.
Completeness	Including all the greenhouse gas emissions and removals relevant to the proposed project.
Consistency	Enable meaningful comparisons to be made with other greenhouse gas related information.
Accuracy	Reducing bias and uncertainties as far as is practical.
Transparency	Disclosing sufficient and appropriate greenhouse gas related information to allow intended users to make decisions with reasonable confidence.

Following the SANS 14064-1, the carbon footprint of the power plant's direct combustion emissions was developed through the following process:

- Setting the boundaries of analysis;
- Identifying the greenhouse gas sources inside the boundary;
- Establishing the quantification method that will be applied;
- Selecting or developing greenhouse emission and removal factors; and
- Calculating the greenhouse gas emissions.

The Greenhouse Gas Protocol's Corporate Accounting and Reporting Standard was also used in addition to the SANS 14064-1 standard as a guide in the calculation of the carbon footprint presented in this study. Further details of the boundaries and emissions factors are presented in the subsequent sections of the report.

South Africa has published mandatory *National Greenhouse Gas Emission Reporting Regulations*[6] as well as *Technical Guidelines for Monitoring, Reporting and Verification of Greenhouse Gas Emissions by Industry*[7]. The Technical Guidelines and the Regulations require reporting of direct (scope 1) emissions only, excluding road and off-road transport. Once operational the Mutsho Power Project will be required to report its direct emissions from electricity production (IPCC code: 1A1a *Main Activity Electricity and Heat Production*) to the Department of Environmental Affairs.

In addition to the carbon footprint calculated according to the ISO/SANS 14064-1 standard, the assessment also provides a high level Tier 1 calculation for the Mutsho Power Project in line with the regulations.

[6] Department of Environmental Affairs. 2017. National Environmental Management: Air Quality Act, 2004. (Act No. 39 of 2004). National Greenhouse Gas Emission Reporting Regulations. Notice 275 of 2017. Pretoria.

[7] Department of Environmental Affairs. 2017. Technical Guidelines for Monitoring, Reporting and Verification of Greenhouse Gas Emissions by Industry. Pretoria.

3.2 Climate Change Impact of Greenhouse Gas Emissions

The EIA reporting requirements listed below set out the criteria to describe and assess an environmental impact. It is these criteria that are used to assess the climate change impacts associated with the greenhouse gas emissions from the Mutsho Power Project in terms of their contribution to the national greenhouse gas inventory.

Nature	A description of what causes the effect, what will be affected and how it will be affected.
Extent (E)	An indication of whether the impact will be local (limited to the immediate area or site of development) or regional, and a value between 1 and 5 will be assigned as appropriate (with 1 being low and 5 being high).
Duration (D)	An indication of the lifetime of the impact quantified on a scale from 1-5. Impacts with durations that are; very short (0–1 years) are assigned a score of 1, short (2-5 years) are assigned a score of 2, medium-term (5–15 years) are assigned a score of 3, long term (> 15 years) are assigned a score of 4 or permanent are assigned a score of 5.
Magnitude (M)	An indication of the consequences of the effect quantified on a scale from 0-10. A score of 0 implies the impact is small, 2 is minor, 4 is low and will cause a slight impact, 6 is moderate, 8 is high with sizable changes, and 10 is very high resulting drastic changes. The context within which the EIA reporting requirements were developed to describe and assess environmental impacts, have yet to be applied to greenhouse gas emissions that have a global impact. For this reason a materiality threshold was defined. Global emissions were estimated at 34 billion tCO_2e based on 2015 figures. South African national emissions were estimated at 544 314 gigagrams CO_2e based on 2010 figures, which is approximately 1.6% global emissions. The magnitude of a project is considered high if the emissions are equivalent to 0.1% of global emissions and small if below 0.01% of global emissions.
Probability (P)	An indication of the likelihood of the impact actually occurring estimated on a scale of 1–5. A score of 1 implies that the impact is very improbable, 2 is improbable, 3 is probable, 4 is highly probable and 5 is definite with the impact occurring regardless of any prevention measures.

Significance (S)	A weighting based on a synthesis of the characteristics described above and can be assessed as low (< 30 points), medium (30-60 points) or high (> 60 points). The significance points are calculated as: S = (E + D + M) x P.

The status of the impact will be described as; positive, negative or neutral. Additional details will also be provided on the degree to which the impact can be reversed and the degree to which the impact may cause irreplaceable loss of resources. The extent to which the impact can be mitigated will also be highlighted.

3.3 Comparison with Technological Alternatives and Mitigation Options

The greenhouse gas emissions and climate change impacts of the project case are evaluated on two levels. The emissions and impacts are firstly compared against the technological alternatives set out in the tender requirement of the baseload independent power producers programme. Secondly the emissions and impacts of the project case are contrasted against a set of possible mitigation options that are not within the scope of the baseload energy tender requirements. Both of these evaluations are considered within the context of South Africa's national inventory and trajectory for greenhouse gas emissions. The functioning of a power plant and its climate change impacts are not affected by seasonality and so this study did not require any special considerations in this regard.

3.4 Causal Chain Analysis

In order to identify the greenhouse gas effects of an action, it is useful to first consider how the action is implemented by identifying the relevant inputs and activities associated with implementing action. A causal chain is a conceptual diagram tracing the process by which the action leads to greenhouse gas effects through a series of interlinked logical and sequential stages of cause-and- effect relationships (Greenhouse Gas Protocol, 2014). Mapping the causal chain can help identify effects not previously identified. The causal chain developed during this assessment has been guided by the Greenhouse Gas Protocol and World Resource Institute's *Policy and Action Standard.*

3.5 Impact of Climate Change on the Project

The vulnerability assessment conducted for this project considered the climate change impacts faced by the Mutsho Power Project during the construction and operational phases. Vulnerability relates to the degree to which a system is susceptible to, and unable to cope with, adverse effects of climate change, including climate variability and extremes. Vulnerability is a function of the character, magnitude and rate of climate change and variation to which a system is exposed, its sensitivity and its adaptive capacity[8].

Using guidance from the International Council on Mining and Metals (ICMM), the assessment considered risks within the core operations of the power station, the power station's value chain as well as the broader network[9]. The broader network includes local communities surrounding the power station as well as the local, provincial and national government.

The Task Force on Climate-Related Financial Disclosures (TCFD) has recently published new thinking around climate change risks. The TCFD divided climate-related risks into two major categories:

- Transition risks: Transitioning to a lower-carbon economy may entail extensive policy, legal, technology, and market changes to address mitigation and adaptation requirements related to climate change. Depending on the nature, speed, and focus of these changes, transition risks may pose varying levels of financial and reputational risk for the proposed Mutsho Power Project.
- Physical risks: Physical climate change risks can be event driven (acute) or longer-term shifts (chronic) in climate patterns. Physical risks may have financial implications for the proposed Mutsho Power Project, such as direct damage to assets and indirect impacts from supply chain disruption.

4. Project Description

The proposed Mutsho Power Project will use the circulating fluidised bed combustion technology. Circulating fluidised bed combustors function by blowing upward jets of air to suspend coarse particles of solid fuel in the furnace during the combustion process (Utt and Giglio, 2012). Gases and solids circulate and mix turbulently in the furnace. More effective heat transfer and chemical reactions are enabled through this circulatory action, much like a bubbling fluid. The circulating fluidised bed has a cyclone filter to separate solid material from the hot flue gases which leave the exhaust of the furnace. To achieve complete combustion the solids from the filter are then recirculated into the bed. It is relatively simple to calibrate circulating fluidised bed plants to burn a range of different mixtures of solid fuels. There are cases of individual plants varying their fuel mixes from 100% biomass to 100% coal (Oravainen and Karki, 2007).

Circulating fluidised bed plants have a further technological advantage in that they are able to successfully reduce the amount of sulphur released therefore limiting the contribution to acid rain within the region. Limestone is added to the combustion bed, where it reacts and bonds with the sulphur dioxide, thus preventing the release into the atmosphere and removing the requirement for costly wet scrubbers.

[8] Parry, ML, Canziani, OF, Palutikof, JP, van der Linden, PJ and Hanson, CE. (eds.) Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change, Cambridge University Press.

[9] International Council on Mining and Metals (ICMM). 2013. Adapting to a changing climate: implications for the mining and metals industry. https://www.icmm.com/website/publications/pdfs/climate-change/adapting-to-climate-change

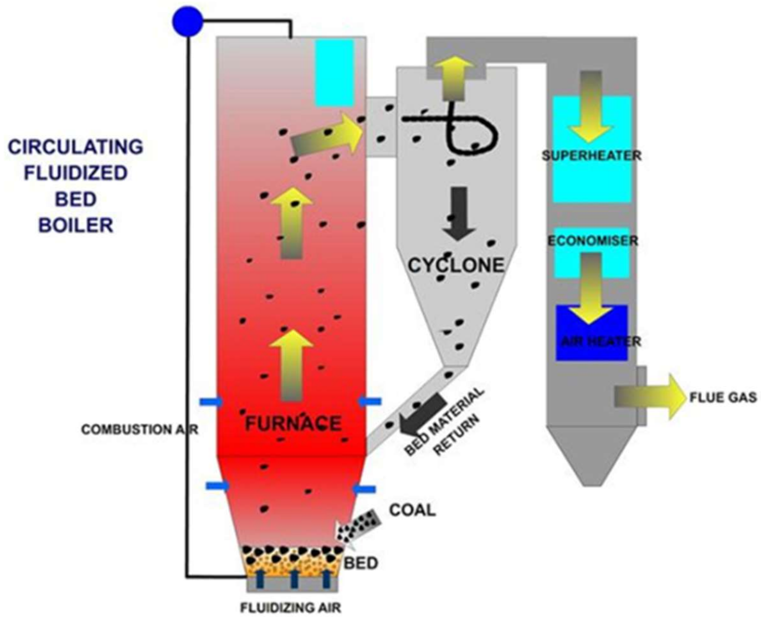


Figure 1: Schematic diagram of a CFB combustor

The proposed site for the Mutsho Power Project is presented in Figure 2.

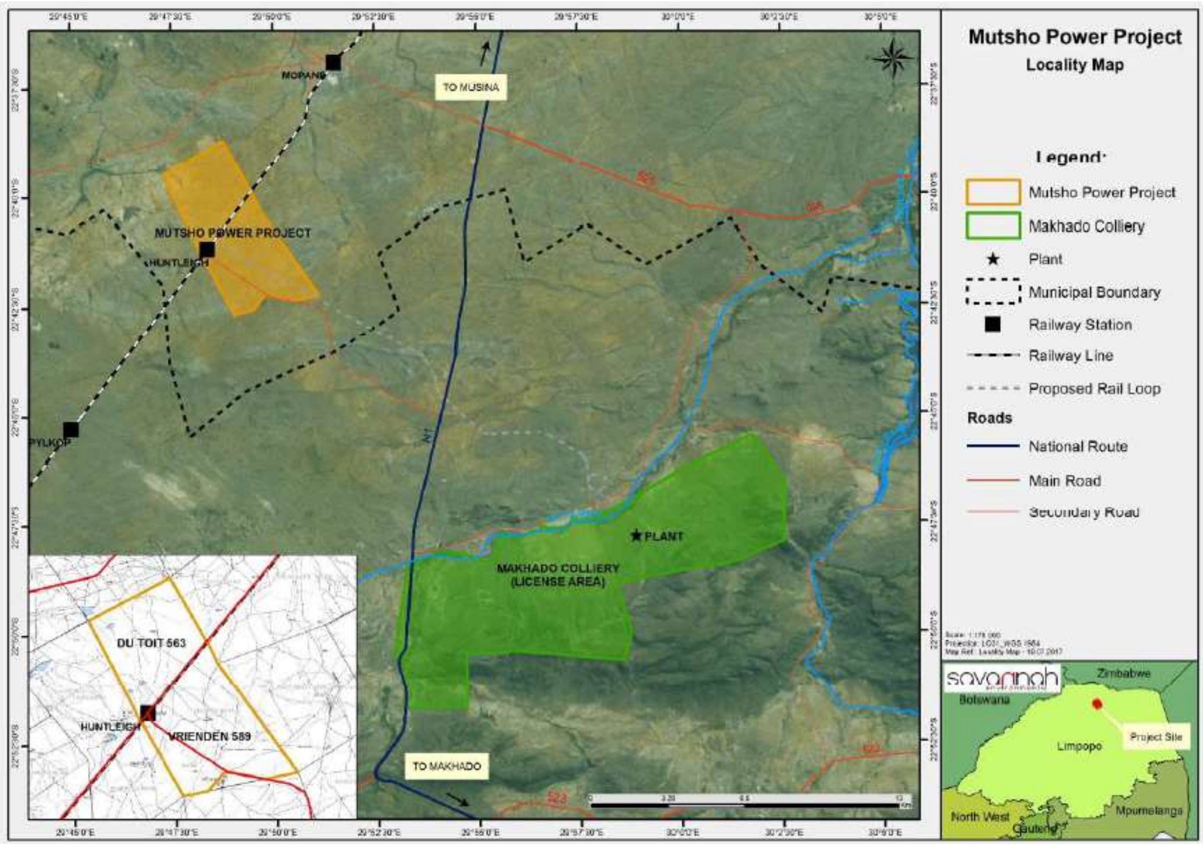


Figure 2: Proposed site for the Mutsho Power Project.

The proposed Mutsho Power Plant is planned to include the following key components and infrastructure:

- Power island consisting of:
  - Circulating Fluidised Bed (CFB) boiler technology operating at Supercritical (SC) efficiencies;
  - Electrostatic Precipitator (ESP) systems and flue stacks;
  - Direct air-cooling (dry cooling) systems;
  - Balance of plant components (including steam turbines and generators etc.);
- Coal and limestone/lime rail spur and or road offloading systems;
- Upgrading or establishment of a rail siding;
- Coal crusher and raw material handling equipment;
- Strategic and working coal stockpile;
- Limestone or lime storage and handling area;
- Onsite ash dump to accommodate the ash and other by-products generated throughout the life span of the power plant. (dry-ashing is proposed to reduce the water requirements of the plant);
- Water infrastructure:
  - Raw water storage dams;
  - Water supply[10] pipelines and booster stations;
  - Pollution control dams;
  - Water treatment plant;
  - Wastewater treatment plant (buried sanitary sewage treatment system - treated by secondary biological contact oxidation process);
  - Storm water management systems;
- HV Yard and substation components with HV overhead transmission lines connecting to the Eskom infrastructure;
- Control room, office/administration, workshop storage and logistics buildings;
- Upgrading of external roads and establishment of internal access roads;
- Security fencing and lighting.

The Mutsho Power Project will source coal from the Makhado Colliery (under development) approximately 20 km south-east of the plant. The coal will be transported to the plant either via rail or road. A 22 km railway loop is proposed between the Makhado Colliery and existing Huntleigh railway siding, but is still to be developed.

Due to the water scarcity within the region, the plant will make use of dry cooling methods, which require up to 15 times less water than wet cooling. The water resource and supply options for the power plant are being investigated by a specialist acknowledged by the Department of Water and Sanitation. For this reason bulk water supply options are excluded from the current scope of work and will be assessed through a separate application for Authorisation. According to an initial high-

[10] Bulk water supply options are excluded from the scope of this assessment.

level assessment of water supply options for the power plant, the following will be considered in further investigations:

- Transfer of treated effluent from the Makhado Rietvly Wastewater Treatment Works (WWTW)
- Transfer from dams in Zimbabwe (alternative to above).
- Direct abstraction from the Limpopo River.

4.1 Setting the Boundaries of Climate Change Impact Analysis

The boundaries for this climate change impact analysis are set in terms of SANS 14064 part 1. The emissions calculations for the Mutsho Power Project construction and operation are applied based on the control approach. With this approach, the emissions are recorded from all the facilities, sites or operations that are controlled by the project owner, within the boundary of the facility.

A large proportion of the total greenhouse gas emissions calculated for the lifecycle of a coal fired power plant can be attributed to the plant's direct combustion emissions (Hondo, 2005). The carbon footprint presented in this study accounts for the direct and indirect operational emissions from the combustion of fuel as well as the direct and indirect construction emissions.

4.2 Emissions Factors

It is important that the emission factors used in carbon footprint calculations are appropriate for the local context and relevant to the technology being assessed. Local emission factors, such as the grid emission factor, have been sourced from the reports of Eskom as it is the main electricity generator of the country. Other recognised emission factors have also been sourced from South Africa's *Draft Technical Guidelines for Monitoring, Reporting and Verification of Greenhouse Gas Emission by Industry*[11] which is based on the 2006 Intergovernmental Panel on Climate Change's Guidelines[12].

These emissions factors are presented in tonnes of carbon dioxide equivalent (tonne CO_2e) and consider the global warming potential of all emitted greenhouse gases including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

A detailed list of the emission factors and other factors used in the calculation of the carbon footprints is summarised in Table 1.

[11] Department of Environmental Affairs. 2015. Draft Technical Guidelines for Monitoring Reporting and Verification of Greenhouse Gas Emissions by Industry [Online]. Available at: https://www.environment.gov.za/sites/default/files/legislations/technicalguidelines_monitoringreportingandverification_ghg.pdf

[12] IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2 Energy [Online]. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf

Pm

Table 1: Summary of emission factors and key values in the carbon footprint of the Mutsho Power Project

	Value	Unit	Source
Direct (scope 1)			
Diesel	0.0032	tCO_2e/l diesel	South African Technical Guidelines (2017)
HFO (assumed to be similar to auxiliary boiler fuel)	0.0012	tCO_2e/l fuel	South African Technical Guidelines (2017)
Coal	0.096	tonne CO_2e/GJ	South African Technical Guidelines (2017)
Project Coal Calorific Value	23.76	GJ/tonne	Project developer
Net efficiency (LHV)	40	%	Project developer
Project Coal Sulphur Content	1	%	Project developer
Sulphur removed	81.8	%	Project developer
Limestone – emissions from decarbonisation	0.44	tonne CO_2/tonne $CaCO_3$	Calculated
Renewable Biomass	0	tonne CO_2e/GJ	IPCC (2006)
Biomass Calorific Value	17	GJ/tonne	Grass SA (2016)
Molar Ratio for SO_2/S	2.00	tonne SO_2/tonne S	Calculated
Molar Ratio for $CaCO_3$/SO_2	1.56	tonne $CaCO_3$ / tonne SO_2	Calculated
Sewage Treatment Facility (anaerobic)	0.48	kg CH_4/kg BOD	South African Technical Guidelines (2017) and supporting calculation sheet from DEA.[13]
Wastewater treatment – degradable organic component	13.505	kg BOD/population/year	South African Technical Guidelines (2017) and supporting calculation sheet from DEA
Methane correction factor (MCF) for an anaerobic digester or reactor	0.80	%	South African Technical Guidelines (2017) and supporting calculation sheet from DEA
GWP for Methane	23	tCO_2e/t CH_4	South African Technical Guidelines (2017)
Energy indirect (scope 2)			

[13] South African Department of Environmental Affairs

	Value	Unit	Source
Electricity[14]	0.98	tCO_2e/MWh	Eskom 2017 Integrated Annual Report
Other indirect (scope 3)			
Fuel & Energy Related Activities (not incl. in scope 1 or scope 2)			
Production and distribution of diesel	0.55266	kg CO_2e/litre	DEFRA (2017)
Production and distribution of HFO	611.4	kgCO2e/tonne	DEFRA (2017)
Purchased Products			
Production of cement	765	kg CO2e/tonne cement	PPC Integrated report 2017
Production of steel	1.9	kg CO2e/kg	Greenhouse Gas Abatement in Energy Intensive Industries (2003)
Upstream Transportation and Distribution			
Heavy Goods Vehicle	0.1055	kg CO_2e/tonne.km	DEFRA (2017)
Employee Commuting			
Average local bus	0.10259	kg CO_2e/passenger.km	DEFRA (2017)

4.3 Assumptions and Limitations

The climate impact assessment of this specialist study is linked to the extent to which the calculated carbon footprint represents the proposed Mutsho Power Project. This relies on information provided by the project developers. The following assumption were made with respect to the calculation of direct (scope 1) emissions of the Mutsho Power Project (Table 2).

Table 2: Assumptions made with respect to the emissions calculation.

	Value	Unit
Load factor	88.5	%
$CaCO_3$ content in limestone	88.9	%

In addition, the amount of electricity that will be consumed during the construction phase was assumed to be approximately 7 000 MWh, based on information gathered from other coal fired power plant studies.

[14] Used specifically for electricity consumption during the construction phase.

5. Technological Project Alternatives and Mitigation Options

5.1 Technological Project Alternative

The technology qualification criteria of the Department of Energy's Coal Baseload Independent Power Producer Procurement Programme have been considered when identifying the project alternatives. It is required by this programme that the bidding power plants (Mutsho in this case) be baseload energy generators. Therefore, intermittent renewable energies, such as solar photovoltaics and wind, have not been considered in this analysis. It is also specified by the programme that the power plants make use of either circulating fluidised bed or pulverised fuel combustion technologies. For this reason the alternative technology assessed in this section will be pulverised fuel.

5.1.1 Subcritical CFB

Subcritical steam burning CFB plants can have overall thermal efficiencies of 36%. The term subcritical refers to the pressure of the boiler, which operates below the critical pressure point. Subcritical boilers operate in conditions where the liquid reaches saturation temperature but with bubbles still forming. These types of boilers can be more water and emissions intensive when compared to supercritical boilers.

5.1.2 Pulverised Fuel

Pulverised fuel is a well-established technology used worldwide and is the predominant technology used by Eskom. In pulverised coal combustion, coal is ground into a fine powder with particles smaller than 75 um (Utt and Giglio, 2012). A portion of the combustion air is used to blow this powdered coal directly into the burner where the fine coal particles burn almost as efficiently as a gas.

Pulverised fuel plants are sensitive to the grade of coal used and typically require low sulphur bituminous coal (Utt and Giglio, 2012). These plants require additional scrubbing technologies to manage sulphur emissions from the flue gas. This incurs an additional capital cost and generally requires additional water and energy during operation.

Pulverised coal technology is relatively inflexible in terms of coal quality and requires a dedicated milling circuit. A screening and crushing plant is also required to ensure consistent quality in terms of sizing, ash, moisture and volatiles content.

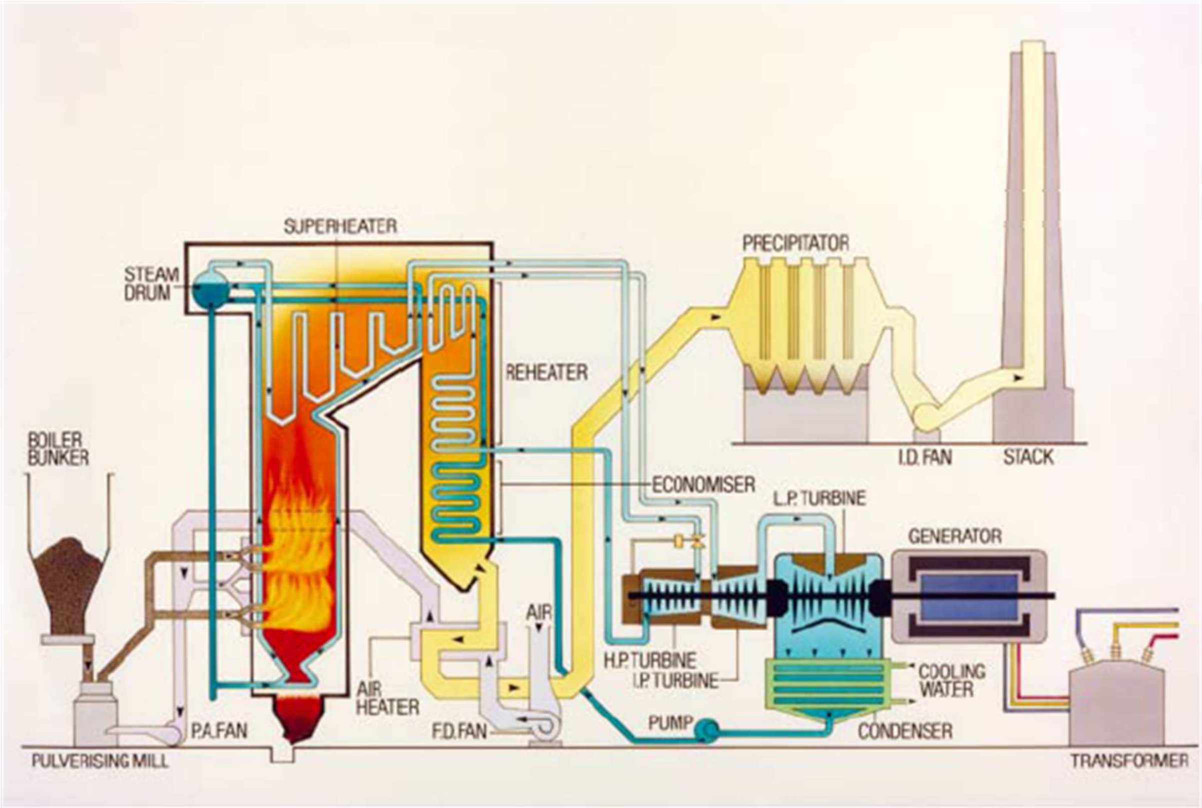


Figure 3: Typical coal-fired power station using PC technology.

5.2 Greenhouse Gas Mitigation Options

It is important to consider future technological mitigation options that the developer may be able to incorporate as the lifetime of a coal fired power plant can reach (or even exceed) 30 years. Thus, this analysis has also considered the combination of biomass and solar thermal energy together with the stipulated coal combustion technology to mitigate greenhouse gas emissions. Decision makers should be aware of these hybrid options as they can prevent a lock-in of high emitting fossil fuel technologies. Developers should also be aware of these hybrid options such that the power station could be designed in such a way that this option can be implemented in the future if necessary. Information with respect to the costs and efficiencies of these technologies was derived from the Electric Power Research Institute (EPRI) 2010 Report titled *Power Generation Technology Data for the Integrated Resource Plan of South Africa*. The mitigation options presented in this assessment are beyond the scope of the tender requirements in the baseload programme. However, they could be considered for future inclusion within the power plant if required to minimise emissions. It is currently uncertain whether these mitigation options will be allowed under the power purchase agreements.

5.2.1 Concentrated Solar Power (CSP)

A possible solution to the reduction of CO_2 emissions from conventional thermal energy generation plants is the integration of thermal energy from CSP. During the day solar energy can be harnessed through the use of technologies such as, parabolic troughs or solar towers, which heat a working fluid (oil or molten salt). This heated fluid is then used as a supplementary source of thermal energy to produce steam and power a turbine.

There are hybrid coal fired power plants in existence, such as the Martin Station in Florida, which supplement a portion of their energy requirements from an accompanying CSP plant (Miller, 2013). These hybrid plants require significantly more capital expenditure than standard coal fired plants, although they are more affordable than stand-alone CSP operations. However, for sizable generation capacities large areas of land are required, 2.75ha per MW of capacity (Miller, 2013). The risks associated with changes in the future price of coal can to some extent be buffered by the substitution of coal for sunlight where fuel costs are reduced. This mitigation option does however have a high technology risk as the technology integration has not been commercialised on a large scale as yet.

5.2.2 Coal Grades Used in Circulating Fluidised Bed Combustion

Coal is classified through the carbon content, sulphur content and calorific, into a variety of grades (Bhattacharya et al., 2013). Higher grade coal, with a higher calorific value, requires the burning of less coal for an equivalent energy output. As the emissions factor for coal is based on its calorific value the coal grade does not have a direct impact on greenhouse gas emissions. However, higher grades of coal typically have a lower sulphur content and higher calorific value so less coal is required per unit energy produced and less SO_2 is released per unit of energy produced. Consequently, there is less SO_2 to capture when higher grades of coal are burnt. In a circulating fluidised bed plant, the SO_2 released during combustion is captured through a lime stone reaction in the furnace. This reaction emits CO_2 as a by-product and thus the use of higher calorific coal will reduce these CO_2 emissions.

5.2.3 Alternative fuels

Circulating fluidised bed combustors are highly flexible in their use of different fuels such as biomass and refuse derived fuel. As such, the co-firing of coal with alternative fuels is therefore a realistic mitigation option. The substitution of coal with an alternative fuel such as biomass presents an opportunity to directly reduce the CO_2 emissions associated with fossil fuel combustion as sustainable locally sourced biomass is effectively carbon neutral (DEFRA, 2015) on the condition that a renewable fuel source is used. This can in turn also reduce the CO_2 emissions associated with desulphurisation of the flue gas as SO_2 emissions from biomass combustion for example is less than that from coal. The overall CO_2 emissions will thus be reduced.

It is possible to source biomass with calorific values up to 18 GJ/tonne; however this biomass is still a more expensive fuel than coal. Self-cultivation and harvesting, where no profit margins are included, can significantly reduce the costs of biomass. However, a power plant the size of Mutsho would require significant quantities of biomass for combustion and thus a large amount of farm land, as biomass yields can range from 10-40 tonnes per hectare per year.

5.2.4 Carbon Capture and Storage and Enhanced Coal Bed Methane Recovery

The South African National Energy Development Institute (SANEDI) has established a centre for Carbon Capture and Storage. The Centre has developed a roadmap for the ultimate commercialisation of carbon capture and storage by 2025. Making provisions for the future addition of carbon capture and storage technologies to new fossil fuel power plants would be advisable to prospective fossil based project developers. The proposed Mutsho Power Project is however located relatively far from potential CCS storage sites.

5.3 Technology Option Costs

The cost of various technology options, are useful to consider when comparing different technologies such as circulating fluidised bed (CFB), pulverised fuel, alternative fuels such as biomass and concentrated solar power (CSP). A summary of these technology options is presented in Table 3. These figures were produced for the 2016 Integrated Energy Plan.

Table 3: Comparison of the capital and operating costs of the assessed combustion technologies, adapted from EPRI (2010).

Cost of Technology	Technology Circulating Fluidised Bed	Circulating Fluidised Bed + 25% biomass + 10% CSP	Pulverised Fuel
Overnight Capital Costs (Million R/MW)	36.78	93.31	37.33
Fixed Operating Cost per year (Million R/MW)	0.53	0.996	0.531

The cost analysis for the project's mitigation options can also be considered in comparing the costs between locally sourced coal and locally sourced alternative fuels such as biomass, this is presented in (Table 4). The cost figure for biomass is presented in a range so as to represent both purchased biomass and biomass from self-cultivation. It is apparent that the cost estimates presented in the table appear large in terms of tonnes of fuel. However, these relative cost disparities decrease significantly when considering the cost per unit of stored energy (GJ) due to the relatively low calorific values of the discard coal. The fuel cost per GJ of self-cultivated biomass is in fact lower than that for discard coal.

Table 4: Cost comparison for discard coal and biomass fuels useable in a CFB combustor.

	Fuel Type		
Cost of Fuel	**Coal**	**Biomass Price Range**	
R/tonne	332.75	700	200
R/GJ	14.00	41.18	11.76

Using these figures, the effective fuel costs per MWh of electricity produced for each of the assessed combustion technologies have been calculated and summarised in Figure 4. The effective fuel cost per MWh are calculated based on the cost of each fuel type and the relative energy conversion efficiency of the combustion technology. Based on the consulted resources (EPRI, 2010) and the project information provided, it is assumed that circulating fluidised bed combustion (38% overall plant efficiency) is more efficient than pulverised fuel (37% overall plant efficiency). In the above fuel cost estimates it is assumed that 25% biomass is co-fired within the circulating fluidised bed combustor augmented with 10% thermal energy from CSP. These assumptions are carried through to the analysis of the mitigation options.

Figure 4 illustrates that under the assumed fuel prices the more efficient fuel to energy conversions achieved by the proposed circulating fluidised bed combustion technology result in lower fuel costs than the pulverised fuel alternative when firing coal. The co-firing with higher cost biomass expectedly increases the effective fuel cost. However, in the case of low cost biomass the effective fuel cost is actually reduced due to the lower cost per unit energy of the fuel. The inclusion of biomass also presents large co-benefits to the creation of jobs and skills in the green economy. The increased fuel cost associated with high cost biomass can to some extent be offset by the inclusion of solar thermal energy which has a zero fuel cost.

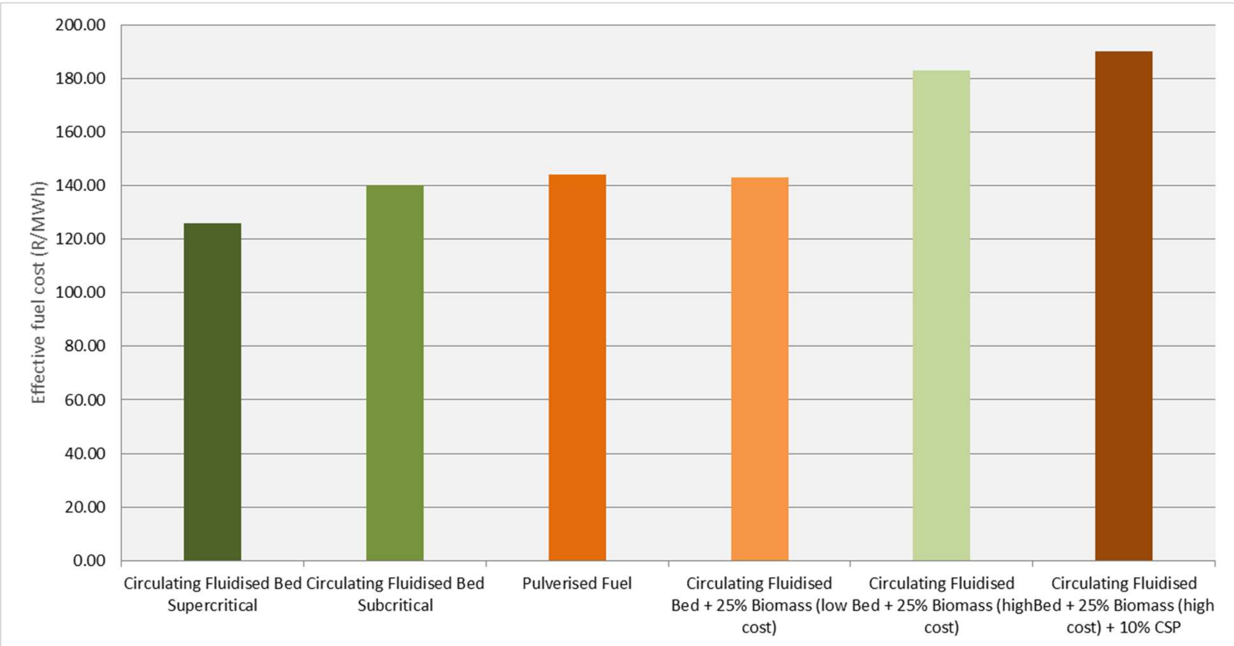


Figure 4: Comparison of the effective fuel costs for the assessed combustion technologies for a 600 MW capacity.

6. Project Impacts

A power plant's greenhouse gas emissions determine its contribution to global climate change. The impact of the project is analysed in terms of global emissions, South Africa's National Greenhouse Gas Inventory, the grid trajectory and the project alternatives.

6.1 Impact of project emissions on South Africa's National Greenhouse Gas Inventory and Climate Change

The Mutsho Power Project's lifetime greenhouse gas emissions are summarised in Table 5 below. The emissions are grouped into direct and indirect sources for both the construction and operational phases of the plant's lifetime.

Table 5: Summary of the carbon emissions calculated for the 600 MW Mutsho Power Project

	Construction Annual Emissions	Construction Cumulative Emissions (4 – 5 years)
Direct (scope 1)	6 500 tCO_2e/year	32 700 tCO_2e
Energy indirect (scope 2)	1 300 tCO_2e/year	6 800 tCO_2e
Other indirect (scope 3) – upstream	9 200 tCO_2e/year	46 200 tCO_2e
	Operation Annual Emissions	**Operation Cumulative Emissions (30 years)**
Direct (scope 1)	4 000 000 tCO_2e/year	121 000 000 tCO_2e
Energy indirect (scope 2)	-	-
Other indirect (scope 3) - upstream	15 300 tCO_2e/year	460 000 tCO_2e

Based on the estimated annual MWhs of electricity that the plant will generate and assuming a plant lifetime of 30 years, the Mutsho Power Project is expected to directly emit approximately 121 million tonnes CO_2e into the atmosphere over its lifetime as a result of coal combustion alone. The carbon emissions from the combustion of fuel (coal) dwarf the emissions from all other sources and this is highlighted in Figure 5 below.

Once operational the Mutsho Power Project will be required to report its direct emissions from electricity production to the Department of Environmental Affairs, as per the National Greenhouse Gas Reporting Regulations. Mutsho's direct emissions would be classified as IPCC code: 1A1a *Main Activity Electricity and Heat Production*. The emissions calculated as per the Tier 1 methodologies set out in the Technical Guidelines equate to 4 million tCO_2e for electricity production.

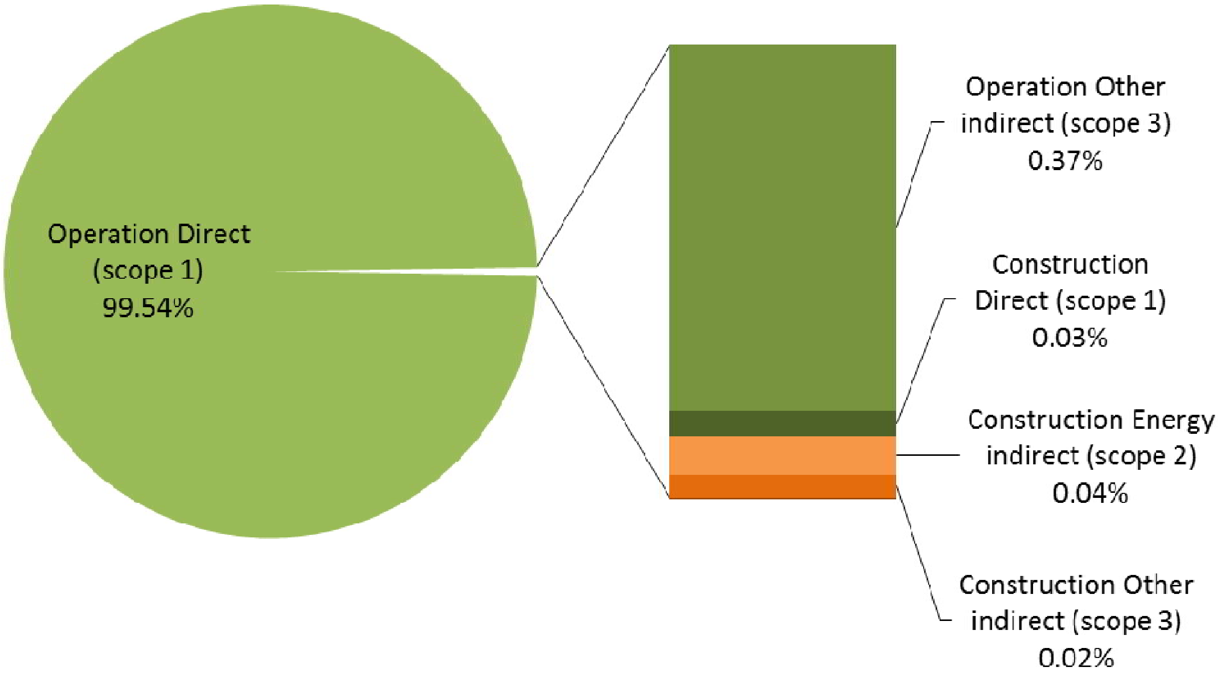


Figure 5: Distribution of lifetime GHG emissions (121 million tCO_2e) from the 600 MW Mutsho Power Project

The estimated carbon emissions from the combustion of fossil fuels for the proposed coal fired power plant were calculated based on the coal and energy estimates provided. The greenhouse gas emissions can also be quoted as an intensity figure in tonnes of CO_2e per MWh of electricity produced as presented in Table 6 below.

Table 6: Summary of the direct carbon emissions for the circulating fluidised bed (CFB) technology compared to the pulverised fuel (PF) technology alternative.

Source of Carbon Emissions			
Technology	**Coal Combustion**	**Limestone Desulphurisation**	**Total**
Circulating Fluidised Bed Supercritical	0.864 tCO_2e/MWh	0.004 tCO_2e/MWh	0.868 tCO_2e/MWh
Circulating Fluidised Bed Subcritical	0.960 tCO_2e/MWh	0.005 tCO_2e/MWh	0.965 tCO_2e/MWh
Pulverised Fuel	0.831 tCO_2e/MWh	0.002 tCO_2e/MWh	0.833 tCO_2e/MWh

It is calculated that the Mutsho Power Project will produce 0.87 tonnes CO_2e per net MWh of electricity generated[15]. This equates to the emission of 4 million tonnes CO_2e per year based on

[15] The Mutsho Power Projects efficiency was calculated assuming a heat rate of 9.26 MJ/kWh and a load factor of 88.5%. The project developer supplied the coal calorific value of 23.76 GJ/tonne and a net efficiency of 40%.

the expected annual MWhs of electricity to be generated by the plant. Considering South Africa's most recent Greenhouse Gas National Inventory Report 2000-2010 (2014) the power plant's annual emissions would account for 0.8 % of South Africa's national emissions (excluding sinks from forestry and other land use).

South Africa's Intended Nationally Determined Contribution (INDC) submitted in Paris in 2015 sets out a national emissions trajectory up to 2050. South Africa's emissions are expected to peak between 2020 and 2025, plateau for approximately a decade and decline in absolute terms thereafter. Based on this trajectory the project's annual emissions would remain within a range of 0.68% - 1.05% of national emissions over the period between 2025 and 2030. With national emissions forecast to decline after 2035, the plant could account for 0.97% - 1.96% of national emissions if it is still operational in 2050.

In addition to the INDC, the figure below outlines the carbon dioxide emissions constraint considered in the base case of the draft IRP Update from November 2016[16]. In line with Government policy to reduce greenhouse gas emissions, the IRP update applies the moderate decline annual constraints as an instrument to reduce national emissions. This might change in the future in line with the Department of Environmental Affairs mitigation system and climate change act.

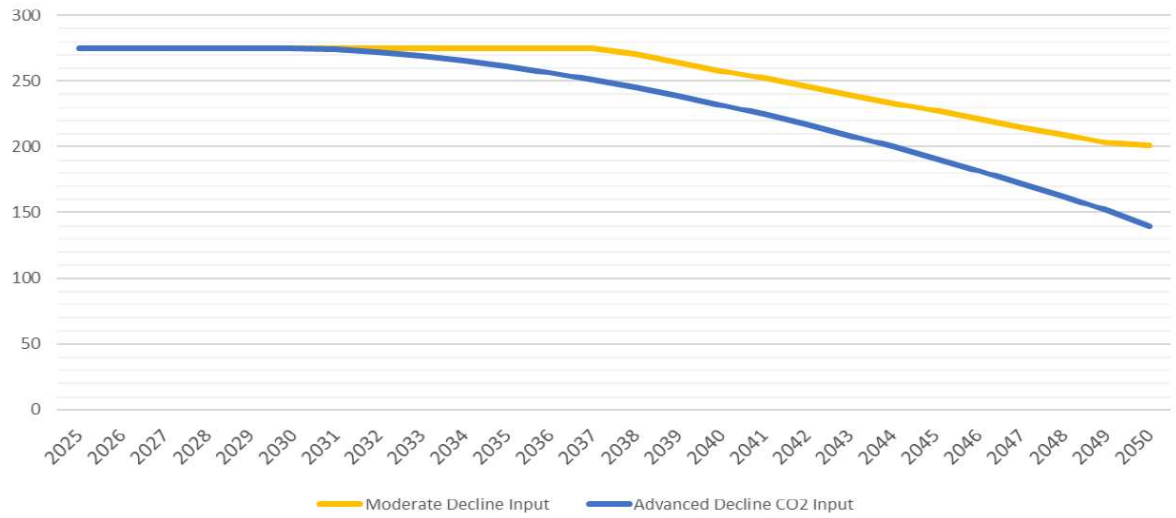


Figure 6: The moderate and advanced emissions decline trajectory 2015 - 2050.

Anthropogenic climate change as a global phenomenon is caused by the accumulated greenhouse gas emissions from global emitting sources. The greenhouse gas emissions from the Mutsho Power Project, when considered in isolation, are unlikely to have any specific significant impact on global climate change. The specific greenhouse gas emissions from the power plant cannot be linked directly to any particular climate change effects. Despite this there is a collective responsibility to address the global challenge of climate change and each actor has an individual responsibility to minimise its own negative contribution to the issue. As such the environmental impact of the

[16] Department of Energy. 2016a. Integrated Resource Plan Update Assumptions, Base Case Results and Observations [Online]. Available at: http://www.energy.gov.za/IRP/2016/Draft-IRP-2016-Assumptions-Base-Case-and-Observations-Revision1.pdf

project can be considered in terms of its contribution to national greenhouse gas emissions. The project's environmental impact during the construction phase is presented in Table 7 and the impact during the operational phase is presented in Table 8.

As a single source the impact of the Mutsho Power Project's greenhouse emissions during operation is considered to be minor in magnitude due to its 0.8% contribution to national emissions. In 2015, South Africa's national emissions (490 million tCO_2e) contributed 1.45 % towards global emissions of 33.83 billion tCO_2e[17].

It is certain that the combustion of coal will produce greenhouse gas emissions and that the greenhouse gas emissions will contribute to the national inventory and climate change which will negatively affect the world's population. Based upon these criteria, the proposed power plant is likely to have an impact with a medium significance score (30 – 60 points). The duration that greenhouse gases are assumed to remain in the atmosphere renders the impact effectively irreversible with the impacts of anthropogenic climate change in many cases resulting in the irreversible loss of resources.

The context within which the EIA reporting requirements were developed to describe and assess environmental impacts, have yet to be applied to greenhouse gas emissions that have a global impact. For this reason a materiality threshold was defined. The magnitude of a project is considered high if the emissions are equivalent to 0.1% (34 million tCO2e based on 2015 figures of global emissions) and small if below 0.01% (3.4 million tCO2e based on 2015 figures) of global emissions.

Table 7: Summary of the climate change impacts of the estimated GHG emissions from the proposed Mutsho Power Project during the construction phase.

Nature: The Greenhouse gas emissions produced as a result of constructing the proposed coal power plant contribute to the global phenomenon of anthropogenic climate change. Numerous global changes are likely to manifest as a consequence of climate change, although none that can be attributed directly or indirectly to the specific greenhouse gas emissions of any individual source, such as the construction of the Mutsho Power Project. The annual emissions from the construction of the power plant represent less than 0.01% of global emissions (based on 2015 figures) and 0.01% of South Africa's National Greenhouse Gas Inventory (based on 2010 figures).		
	Without Mitigation	**With Mitigation**
Extent	Global (5)	Global (5)
Duration	Permanent (5)	Permanent (5)
Magnitude	Small (0)	Small (0)
Probability	Definite (5)	Definite (5)
Significance	**Medium (50)**	**Medium (50)**
Status	Negative	Negative
Reversibility	None	None
Irreplaceable loss of resources?	Yes	Yes
Can impacts be mitigated?	Yes	-

[17] https://ourworldindata.org

Mitigation: Mitigating emissions from the construction of this power plant would reduce its contribution to national emissions and climate change. Mitigation options could include the use of biodiesel in construction vehicles.
Residual risks: The risks associated with climate change will still be prevalent even with efforts to mitigate the project's greenhouse gas emissions during the construction phase. This is due to the vast number of other sources of greenhouse gas emissions around the world.

Table 8: Summary of the climate change impacts of the estimated GHG emissions from the proposed Mutsho Power Project during the operational phase.

Nature: The Greenhouse gas emissions produced as a result of coal combustion in the power plant contribute to the global phenomenon of anthropogenic climate change. Numerous global environmental changes are likely to manifest as a consequence of climate change, although none that can be attributed directly to the specific greenhouse gas emissions of any individual source, such as the Mutsho Power Project. The annual emissions from the operational phase of the power plant represent 0.012% of global emissions (based on 2015 figures) and 0.76% of South Africa's National Greenhouse Gas Inventory (based on 2010 figures).		
	Without Mitigation	**With Mitigation**
Extent	Global (5)	Global (5)
Duration	Permanent (5)	Permanent (5)
Magnitude	Minor (2)	Small (0)
Probability	Definite (5)	Definite (5)
Significance	**Medium (60)**	**Medium (50)**
Status	Negative	Negative
Reversibility	None	None
Irreplaceable loss of resources?	Yes	Yes
Can impacts be mitigated?	Yes	-
Mitigation: The power plant would need to mitigate its greenhouse gas emissions in order to mitigate its contribution to national emissions and climate change. Section 5.2 of this report discusses options for mitigating the power plant's greenhouse gas emissions which primarily involve hybridising the power plant by substituting the source of thermal energy away from coal towards more carbon neutral sources.		
Residual risks: The risks associated with climate change will still be prevalent even with efforts to mitigate the project's greenhouse gas emissions. This is due to the vast number of other sources of greenhouse gas emissions around the world.		

There are options to mitigate the greenhouse gas emissions from the construction and operation phases of the power plant; however these options are not able to alter the impact that the greenhouse emissions will have on climate change in terms of the extent, duration or probability. It is only the magnitude of the greenhouse gas emissions impact that can be reduced by reducing the quantity of emissions.

The mitigation options presented in this study can to some extent reduce the magnitude of the plant's emissions impact in terms of the power plant's contribution to the national greenhouse gas emissions. The plants emissions (magnitude) during operation, with and without mitigation, are both classified as small as per the methodology described in section 3.2 (EIA requirements). This methodology was developed to describe and assess environmental impacts, and has yet to be applied to greenhouse gas emissions that have a global impact. Therefore while mitigation projects for the Mutsho Power Project are intended to reduce emissions, the current methodology to assess the magnitude of emissions does not provide granular detail for the project's emissions which are considered as small. Therefore the impact table above records the same significance score for the project with and without mitigation.

There will still be risks associated with climate change even if the emissions from the Mutsho Power Project are mitigated due to the cumulative nature of climate change impacts resulting from the greenhouse gas emissions from all the world's sources. In light of this and the collective responsibility to reduce global greenhouse gas emissions it is also useful to consider the impact of the power plant's greenhouse gas emissions (mitigated and unmitigated) compared against the technology alternative and national baseline.

6.2 Impact Compared against the Baseline of South Africa's National Grid

The Integrated Resource Plan (IRP) 2010 Update was released in 2013. The plan outlines the country's electricity future in terms of the projections of generation capacities and carbon emissions. The grid emission factors can be calculated for each year and can serve as an estimation of the national emissions intensity baseline for electricity generation. The figure below plots the project's emission factor against the forecasted grid emission factors for the national electricity supply, as estimated from the IRP.

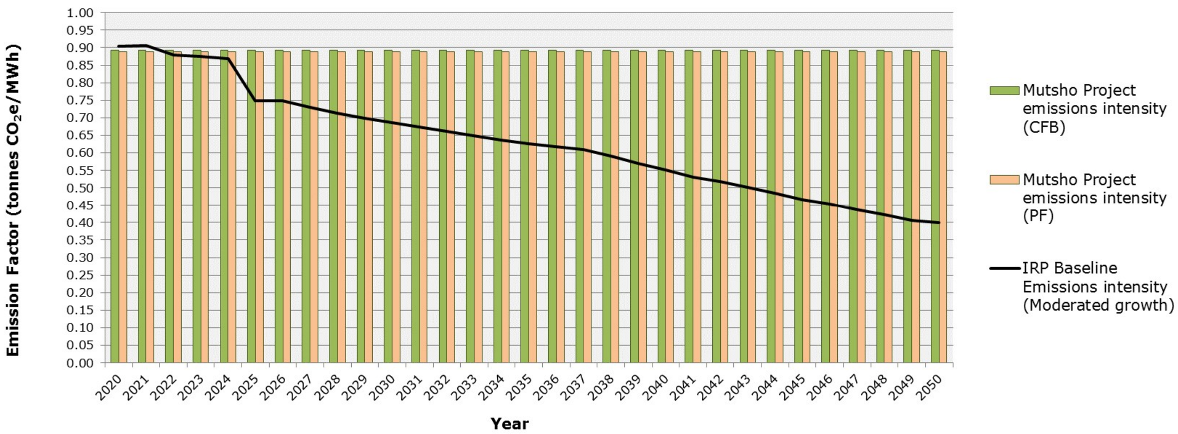


Figure 7: Forecast of the emission factors for the national grid and project in tonnes CO2e per MWh based on projections in the IRP 2010 Update (2013) for the policy adjusted scenario.

The carbon emissions intensity of the proposed Mutsho Power Project will be 0.87 tCO2e per MWh. This is comparable to the expected national emissions intensity projected for 2020 to 2022. Depending on national policy, the timing of the IPP procurement programme and assuming a construction time of four to five years the power plant's greenhouse gas emissions intensity at the start of its operational life (2025 or 2026) would be above the expected national baseline intensity. It should however be noted that the Coal Baseload Independent Power Producer (IPP) Procurement Programme has taken into account the 2050 emissions projections. The impacts of high emissions from coal fired power stations are expected to be offset by increases in low emission generation capacity and the decommissioning of less efficient Eskom power plants.

The calculated emissions intensity for the Mutsho Power Project will in fact be similar to Eskom's newer coal plants that will continue to form part of South Africa's base load in the future, such as the newly built super critical Medupi (0.89 tonnes CO_2e per MWh) and Kusile (0.9 tonnes CO_2e per MWh). Eskom's older active coal plants, range between 0.89 - 1.26 tonnes CO_2e per MWh.

6.3 Impact Compared Against Technology Alternatives and Mitigation Options

The emissions intensity of the project can be compared against the alternative combustion technology (pulverised fuel) and the future mitigation options available to the project developer. The forecasted national baseline for the emission intensity of electricity generation can also be benchmarked against these options. The emissions intensities (tonnes CO_2e per MWh) of the circulating fluidised bed project case, the pulverised fuel alternative and the mitigation options are summarised in Figure 8 below and compared against the baseline national emissions levels for electricity generation for 2020 and 2025.

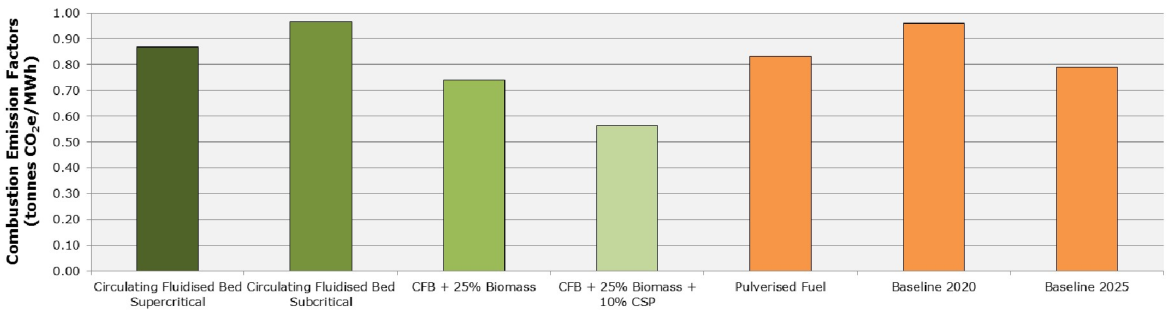


Figure 8: Comparison of the emissions levels of the proposed CFB project case against the technology alternative, mitigation options and the forecasted national electricity generation baselines for 2020 and 2025.

At 0.87 tonnes CO_2e per MWh, the emissions intensity of the project case is marginally higher than the pulverised fuel combustion alternative, which has an intensity of 0.88 tonnes CO_2e per MWh. Like circulating fluidised bed combustion, pulverised fuel has an emissions level slightly below what is projected for the national baseline in 2020, although it is also above the emissions levels projected for 2025.

In terms of the possible future mitigation options, the co-firing of 25% of alternative fuel (such as biomass) with coal in a circulating fluidised bed combustor results in a significant reduction of emissions below the project case. Due to the carbon neutrality of sustainably harvested biomass (if not transported great distances) the percentage of biomass in the fuel mix directly relates to the percentage of emission reductions effected. However in this case, the project is located near Musina which could result in the biomass being transported long distances, which may affect the feasibility of including biomass. The addition of 10% zero carbon thermal energy from an additional CSP unit reduces emissions by a further 10%.

The co-firing of 25% biomass in the circulating fluidised bed combustor would produce an emission intensity of 0.76 tonnes CO_2e per MWh. This figure is 4% below the projected emission intensity for the national grid electricity for 2025. The addition of 10% solar thermal energy reduces this figure to as low as 0.58 tCO_2e/MWh, 26% below the 2025 forecasted baseline. A causal chain of the associated emissions impacts on the national emissions intensity for the selection of circulating fluidised bed combustion technology is presented in Figure 9 below.

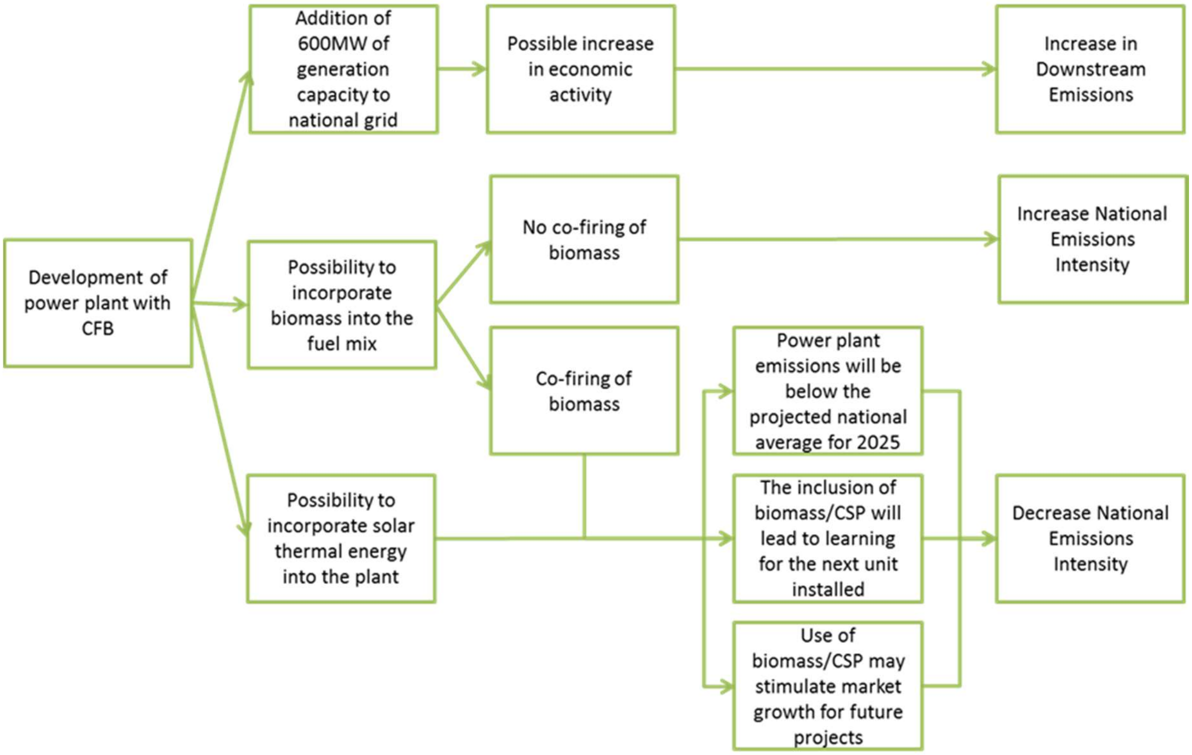


Figure 9: Causal chain of GHG associated emissions intensity impacts resulting from the development of the Mutsho Power Project.

6.4 Impact of Climate Change on the Project

The Mutsho Power Project focuses on risks across core operations, value chain and broader network for a mitigated emissions scenario and an unmitigated emissions scenario. The risks are classified as either low or high depending on the emissions scenario. Physical risks are higher and transitional risks are lower under an unmitigated emissions scenario, as this scenario is expected to increase global temperatures by 6 °C which could for example increase the risk of heat stress (Table 9).

Typically, physical risks are lower and transitional risks are higher under a mitigated emissions scenario that aims to keep temperature increases at 2 °C or below. The mitigated emissions scenario is supported by the Paris Agreement and will be achieved as countries set ambitious Nationally Determined Contributions (NDC). As countries work towards compiling their

Nationally Determined Contributions, additional regulations may be put in place to limit emissions from fossil fuel intensive industries or encourage renewable energy development.

Table 9: Scenario analyses for the proposed Mutsho Power Project.

Risks	Baseline scenario with no greenhouse gas mitigation by global community	Scenario with mitigation to limit temperatures below 2°C
Core Operations – Mutsho Power Project		
Heat stress		
Drought		
Regulatory obligations		
Value Chain – coal supply from the Makhado Colliery		
Disrupted supply chain		
Regulatory obligations		
Broader Network – Musina Local Municipality, Vhembe District		
Heat stress		
Reduced agricultural yields		
Water supply disruptions		

Legend	
High risk	
Low risk	

6.4.1 Core Operations

Core operations for this assessment include the Mutsho Power Project. The core operations are expected to be exposed to both physical and transitional risks as a consequence of climate change.

Physical risks

As indicated by both South Africa's Draft Third National Communication and the Long Term Adaptation Scenarios, temperatures are expected to increase in the Limpopo Province. Rising temperatures increase the intensity and frequency of heat waves and wind speed. Higher temperatures results in a greater number of people at risk of heat-related medical conditions. Heat stress directly impacts on labour productivity. Labour productivity is projected to decline significantly under a high emissions scenario.

The long term scenarios also include significantly reduced rainfall, which could lead to extended drought periods. This would negatively impact potable water supply. Apart from process disruptions, reduced availability of potable water could disrupt the use of the office buildings, change houses and medical buildings. Drought conditions may be further exacerbated as the proposed power station will fall within the Limpopo Water Management Area North, which is already a water stressed area. Power stations have first right to water, according to South African law. This however will not prevent social concern around water restrictions for other water users or communities, which could potentially feed social unrest.

The physical risks mentioned above, are specific to the operational phase of the proposed power plant. However it should be noted that the construction period of the power plant may still experience higher temperatures and drought conditions caused by climate change, in the near future.

Transitional risks

The power station will have regulatory obligations associated with greenhouse gas emissions. The Department of Environmental Affairs' regulations are associated with greenhouse gas emissions reporting (National Greenhouse Gas Emissions Reporting Regulations [18]) and emissions management (Declaration of Greenhouse Gases as Priority Air Pollutants[19] and National Pollution Prevention Plans Regulations). The draft Climate Change Legal Framework has been submitted to industry for comment. Once finalised it may mandate these facilities to develop carbon budgets.

Under the National Greenhouse Gas Emissions Reporting Regulations, the Mutsho Power Project would be required to report greenhouse gas emissions from electricity production. The reason for this is because the power station would exceed the reporting threshold of 10 MW thermal installed capacity for stationary combustion, specified in the regulations. Road and off-road transport has been excluded from reporting requirements, up to 2020.

The South African Carbon Tax Bill remains under development but an updated draft was published in December 2017[20]. At the currently proposed effective tax rate of R 48/tCO_2e, the Mutsho Power Project may be liable for up to R 200 million in carbon tax per year. Under the current design Mutsho's carbon tax liability would be balanced against the renewable energy levy to avoid pass through costs in the electricity tariff. However the second phase carbon tax design has yet to be specified.

6.4.2 Value Chain

The value chain of the Mutsho Power Project would include the coal sourced from the Makhado Colliery, as well as feedstocks such as diesel or limestone. It is expected that the value chain will be exposed to both physical and transitional risks, as a consequence of climate change.

Physical risks

The intensity and variability of rainfall is increasing, meaning that while rainfall events will be scarce, when they do occur they will be more intense than normal. Intense storms could damage or wash away infrastructure or transport routes. This could negatively impact logistics, labour and the supply of products such as coal, diesel or limestone. The supply chain for the construction

[18] Department of Environmental Affairs. 2017. National Greenhouse Gas Emission Reporting Regulations. National Environmental Management: Air Quality Act, 2004. https://www.environment.gov.za/sites/default/files/legislations/nemaqa39of2004_nationalgreenhousegasemissionreporting_gn40762.pdf

[19] Department of Environmental Affairs. 2017. Declaration of Greenhouse Gases as Priority Air Pollutants. National Environmental Management: Air Quality Act, 2004. https://www.environment.gov.za/sites/default/files/legislations/nemaqa39of2004_declarationofgreenhousegasesaspriorityairpollutants_gn40996.pdf

[20] National Treasury. 2017. Draft Carbon Tax Bill [Online]. Available at: http://www.treasury.gov.za/public%20comments/CarbonTaxBll2017/

phase of this project may be impacted by storm damage or flooding, as the project is situated near Musina which is more than 300 km from the nearest Eskom power plant. The increased probability of storms may however impact on Mutsho's transmission of power.

Transitional risks

During the construction phase, the power station will require, building materials such as cement, and steel. The prices of these products may increase when the Carbon Tax Bill is implemented. This could ultimately increase the cost of construction for the Mutsho Power Project. The uncertainty surrounding the post 2020 carbon tax regime poses a significant risk of escalating costs.

6.4.3 Broader Network

The broader network of the proposed Mutsho Power Project includes the local community, as well as local, provincial and national government. It is expected that the local community will be exposed primarily to the physical risks, associated with climate change.

Physical risks

The proposed Mutsho Power Project falls within the Musina Local Municipality.

The Vhembe District Municipality has identified service delivery, infrastructure development, socio-economic development, poverty and unemployment as key issues. The municipality aims to address poverty and unemployment through socio-economic development and improved service delivery. Agriculture, forestry and fishing and mining contribute 35% and 30% to the economy of Musina, respectively.

The Limpopo Climate Change Adaptation Strategy Report (2015) highlights the vulnerability of communities to climate change. Community vulnerabilities include low health indices and reduced adaptive capacity. The low health indices are attributed to the prevalence of HIV/AIDS, tuberculosis and poor nutrition in the area.

Rising temperatures and drier conditions could result in crop failure and negatively impact on the local agriculture. The communities may also experience heat stress and water disruptions. Limpopo has been prone to flooding in recent years and climate change is likely to exacerbate this risk. Floods have the potential to damage housing structures, electricity and water supply. They can also increase the spread of illnesses such as diarrhoea through communities. The Mutsho Power Project will most likely source their work force from the local town – Musina. If the community within Musina is negatively impacted by drought, heat waves or floods it may prevent employees from going to work. This could disrupt productivity at the power station.

7 Impact of Carbon Pricing

It is important to note that the mitigation options of alternative fuels such as biomass and/or concentrated solar power would increase the cost of the project. As such, the option may not initially be attractive to the project developer. However, in the presence of a carbon tax or a carbon budget it may become financially viable to mitigate carbon emissions. This would be the case if the cost of the tax was higher than the cost of mitigation.

In addition to the developing carbon tax in South Africa, it is expected that by 2030 the country may be in alignment between the international carbon price and the domestic South African price[21]. A number of projections of this international carbon price are presented in Figure 10.

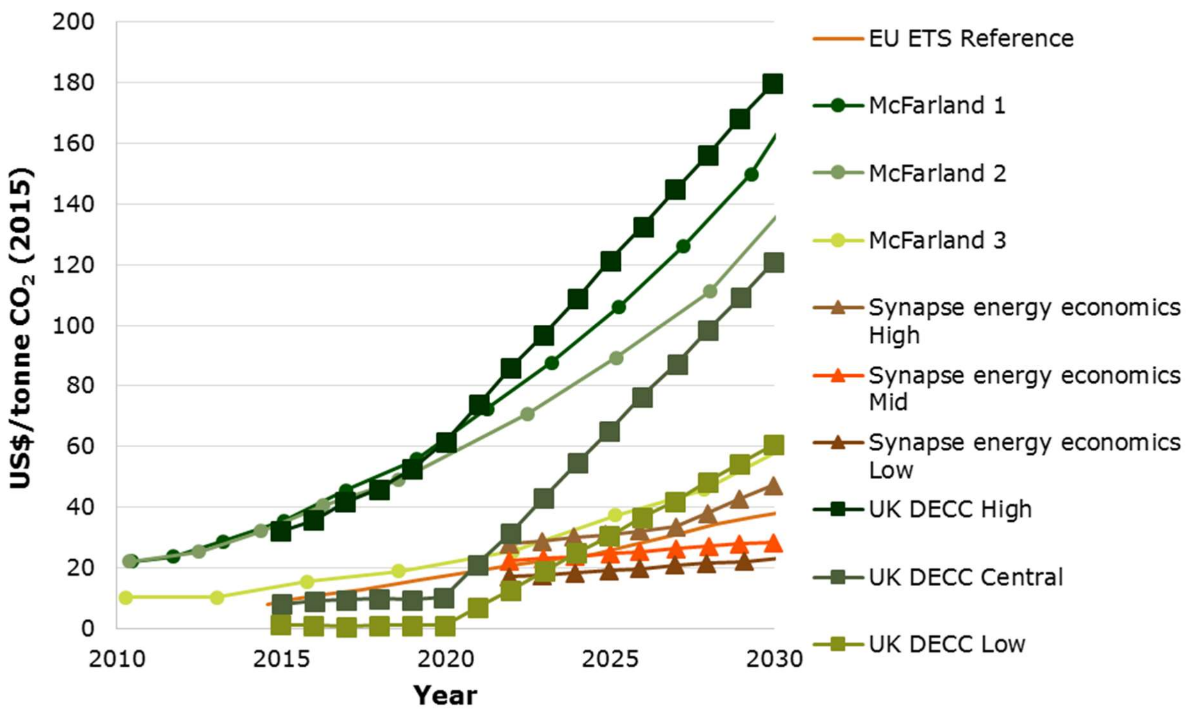


Figure 10: Summary of international carbon price projects from various scenario studies (Promethium Carbon, 2017).

While the estimates of the international carbon price vary widely it is useful to consider what impact these prices may have on the operating costs of the power station in the future. As such it is advisable that where possible investments are made, to enable the implementation of mitigation options as they are required.

[21] Article 6 of the Paris Agreement makes provision for the creation of an international carbon market.

8 Operational Emissions Management

Once the project developer commits to a combustion technology the power plant will effectively become locked into an emissions trajectory. Other than incorporating the hybrid mitigation options or carbon capture discussed already there is likely to be very limited scope to reduce the operational emissions from the power plant in the future. Even if the emissions trajectory cannot be significantly reduced it is important that the operation be managed in such a way that the power plant does not produce more greenhouse gas emissions than it should.

In light of this, it is important to consider the condition of the coal used in a circulating fluidised bed combustor as it can affect the heat output of the furnace which in turn affects the boiler and consequently the energy produced by the turbine. Coal with a high moisture content consumes energy in evaporation and thus burns less efficiently (Bhattacharya *et al.*, 2013). Similarly fuel burning rates and heat generation can be affected by the size of the coal particles used in a circulating fluidised bed combustor. Therefore, when coal supplies are crushed to the wrong size and become wet, larger quantities of coal are required per MWh of electricity produced. This results in more CO_2e being produced per MWh of electricity generated.

Therefore, the management of operational emissions is directly linked to the management and maintenance of coal stockpiles and coal crushers. Such facilities are thus important to include within a Carbon Management Plan for the power plant. The Plan Do Check Act (PDCA) approach within the ISO 9001 Quality Management System Requirements presents an attractive model for these sorts of plans. The most effective plans will also extend carbon management into the everyday organisation practices and be supported by a good governance structure with high level responsibility.

As part of the management plan it is specifically recommended that the coal be stored in such a way that it is protected from unnecessary moisture exposure. Similarly the storage and transportation of the coal must be appropriate so as to not crush the coal beyond its useful size. Further maintenance and monitoring of the coal crushers will ensure that the coal particles are optimally sized.

Monitoring is valuable in assessing the effectiveness of any carbon management plan. Monitoring can be extended beyond the measurement of plant performance and can also include measuring the moisture content and size of the coal particles supplied to the furnace. This information can be checked against the coal storage conditions, transport systems and crusher performance to determine any limiting processes. The monitoring of the on-site electricity demands which form part of the plant's parasitic load requirements are also important as they effectively reduce the amount of exportable electricity per tonne of CO_2 emitted. It is also advisable to consider the inclusion of direct emissions measurement systems as the specific monitoring carbon emissions will become a requirement as part of the carbon tax and may even require Tier 3, direct emissions measurement, in the future. While highly recommended, the authorisation of the plant's construction is not conditional on the inclusion of the carbon management approach described above.

9 Opinion on the Project

Our opinion of this project is set within the context of global climate change commitments. South Africa's commitment under the Paris Agreement, is the latest international communication that speaks to the energy plans for the country and informs the Department of Energy's baseload independent power producers programme.

The proposed power plant will produce greenhouse gas emissions that will contribute to anthropogenic climate change and its ensuing impacts. The extent, duration and probability of the plant's greenhouse gas emissions impacts on climate change will be considerable. The magnitude of the construction phase is considered small and the operational phase considered minor. The overall significance from the single source power plant's impact during construction and operational phases, on global emissions and thus climate change is rated as medium. As with any issue of common concern to humanity, it is important that each actor makes an effort to minimise its own negative contribution to the issue so as to take a shared responsibility, particularly in the cases of coal fired power plants, such as Mutsho.

This plant has the potential to contribute almost 2% of the forecasted national inventory for 2050. However, the plant is only likely to contribute 0.75% of the national electricity supply forecasted for 2050. Considering the overall significance of the impact of the greenhouse gas emissions it is important to explore the possible technological alternatives for the plant as well as mitigation options.

Subcritical CFB and coal fired pulverised fuel are the technology alternatives available to the project developer under the Coal Baseload Programme. Both technologies will produce emissions intensities above the 2025 forecasted national baseline of greenhouse gas emissions from electricity generation. The limited water resources in the area of operation are unlikely to support subcritical CFB and the wet scrubbing systems required for pulverised fuel combustion.

The power plant's higher emissions intensity than the forecasted national baseline is to some extent acceptable as the national baseline includes intermitted renewable energy generation. Stable baseload power generation can support higher levels of intermittent renewable energy generation. Therefore even with a higher emission intensity (CO_2e/MWh) of baseload, the overall emission intensity of the grid can be reduced.

The scale at which greenhouse gas emissions will be produced by the plant does warrant that the emissions are mitigated where possible. It was demonstrated in this analysis that there are options to improve the emissions intensity of circulating fluidised bed combustion. These options include the design of the facility to allow for the future co-firing of alternative fuels (such as biomass) in the circulating fluidised bed combustor and incorporating solar thermal energy from CSP units, should this be required. While these options are beyond the scope of the bid requirements and are not currently possible under the IPP, they present useful insight for the project developer and possible future hybridisations for the plant.

The most effective technological option to reduce the power plant's carbon emissions and consequent impact on climate change is co-firing with an alternative fuel (such as biomass) in the circulating fluidised bed. However the transport distance, cultivation and source of alternative fuel needs to be considered with respect to financial feasibility. Incorporating thermal energy from an additional CSP plant, although comparatively expensive in capital, is similarly effective. A 142 MW CSP plant (without storage facilities) would be required to augment 10% of the power station's thermal energy demands.

The emission intensity of the power plant can be reduced to below the projected national baseline of emissions intensity for electricity generation through co-firing with 25% of an alternative fuel (such as biomass) in the fuel mix. It is possible to calibrate circulating fluidised combustors to use varying mixes of fuels and thus biomass could be incorporated into the fuel mix gradually so as to decrease the plant's emissions in line with the projected national grid or other emissions obligations.

Under current costs of technology and fuel the expected net present value (NPV) of the costs for circulating fluidised bed which co-fires with 25% high cost biomass is approximately 31% higher than a circulating fluidised bed plant without co-firing. This is primarily due to the higher purchase costs of biomass although these can be significantly reduced through self-cultivation and harvesting, where third-party profit margins are avoided. Co-firing with 25% low cost (self-cultivated) biomass actually increases the NPV of the power plant by 12%. Co-firing biomass in a power plant such as Mutsho may encourage development and growth in the local biomass market which may lower future costs and stimulate the future uptake of biomass based combustion technologies. A similar process could be considered for the inclusion of solar thermal energy from CSP. From this perspective, the Mutsho Power Project could reduce the emission intensity of national electricity grid.

The Mutsho Power Project could also maintain the opportunity to significantly reduce its future carbon emissions and consequent climatic impact by making provisions for the future instalment of carbon capture and storage (CCS) technology. In addition the options for future mitigation efforts, the development and implementation of an effective carbon management plan and emissions monitoring system will assist in tracking and minimising GHG emissions on a daily basis.

This study concludes that the use of circulating fluidised bed combustion technology in the Mutsho Power Project is likely to be the most suitable option based on the technological requirements of the Coal Baseload Programme. The circulating fluidised bed combustion technology does present opportunities for emissions reductions through the design of the facility in such a way that the future co-firing with alternative fuels (such as biomass) can be considered. It is therefore recommended here that the future mitigation opportunities of; co-firing with low carbon fuels, incorporating of solar thermal energy, capturing and storing carbon and implementing management and monitoring plans are considered in detail by the project developer depending on financial feasibility and water availability. However the Department of Energy's Coal Baseload

Independent Power Producer (IPP) Procurement Programme (CBIPPPP) does not currently account for hybridisation.

10 References

Bhattacharya, C., Banerjee, N. and Sadhan Sarkar, H. 2013. Economics of Removal of Coal Moisture in Thermal Power Generation with Waste Heat Recovery. International Journal of Emerging Technology and Advanced Engineering **3**(3): 22-28.

Department of Environmental Affairs. Long Term Adaptation Scenarios Flagship Research Programme [Online]. Available at: http://www.sanbi.org/sites/default/files/documents/documents/ltassummary-policy-makers2013high-res.pdf (Accessed: 15/10/2017).

Department of Energy. 2014. Integrated Resource Plan for Electricity 2010-2030 [Online]. Available at: http://www.energy.gov.za/IRP/irp%20files/IRP2010_2030_Final_Report_20110325.pdf (Accessed: 15/10/2017).

Department of Environmental Affairs. 2015. Draft Technical Guidelines for Monitoring Reporting and Verification of Greenhouse Gas Emissions by Industry [Online]. Available at: https://www.environment.gov.za/sites/default/files/legislations/technicalguidelines_monitoringreportingandverification_ghg.pdf (Accessed: 15/10/2017).

Department of Environmental Affairs. 2015. South Africa's Intended Nationally Determined Contribution (INDC) [Online]. Available at: https://www.environment.gov.za/sites/default/files/docs/sanational_determinedcontribution.pdf (Accessed: 15/10/2017).

DEFRA. 2015. Greenhouse gas reporting - Conversion factors 2015 [Online]. Available at: https://www.gov.uk/government/publications/greenhouse-gas-reporting-conversion-factors-2015 (Accessed: 15/10/2017).

EPRI. 2010. Power Generation Technology Data for Integrated Resource Plan of South Africa [Online]. Available at: http://www.energy.gov.za/IRP/irp%20files/Tech_Data_for_Integ_Plan_of_South_Africa_July_08_2010_Final.pdf (Accessed: 15/10/2017).

Eskom. 2011. COP17 Fact Sheet [Online] Available at: http://www.eskom.co.za/OurCompany/SustainableDevelopment/ClimateChangeCOP17/Documents/Air_quality_and_climate_change.pdf (Accessed: 15/10/2017).

Eskom. 2015. Eskom Fact Sheet [Online]. Available at: http://www.eskom.co.za/IR2015/Documents/Eskom_fact_sheets_2015.pdf (Accessed 15/10/2017).

Hondo, H. 2005. Life cycle GHG emission analysis of power generation systems: Japanese case. *Energy* **30**: 2042–2056.

International Organization for Standardization. 2015. *ISO 9001:2015 Quality Management System Requirements*. Geneva: International Organization for Standardization.

IPCC. 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2 Energy [Online]. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_2_Ch2_Stationary_Combustion.pdf (Accessed: 15/10/2017).

Miller, K. 2013. Hybrid Solar Thermal Integration at Existing Fossil Generation Facilities [Online]. Available at: www.eskom.co.za/.../RenewableEnergy/.../G3CSP_FossilHybridMillerFINAL.pptx (Accessed: 15/10/2017).

Mining Weekly. 2015. S African coal exports unsustainable at long-term prices – Prevost [Online]. Available at: http://www.miningweekly.com/article/s-african-coal-exports-unsustainable-at-long-term-prices-prevost-2015-11-04 (Accessed: 15/06/2016).

Maurstad, O. 2005. An Overview of Coal Based Integrated Gasification Combined Cycle (IGCC) Technology [Online]. Available at: https://sequestration.mit.edu/pdf/LFEE_2005-002_WP.pdf (Accessed: 15/10/2017).

National Treasury. 2015. Draft Carbon Tax Bill [Online]. Available at: http://www.treasury.gov.za/public%20comments/CarbonTaxBill2015/Carbon%20Tax%20Bill%20final%20for%20release%20for%20comment.pdf (Accessed: 15/10/2017).

Oravainen, H. and Karki, J. 2007. Co-firing Techniques for wood and Coal: Review of the Various Co-firing Concepts in Europe [Online]. Available at:

https://www.unece.org/fileadmin/DAM/timber/workshops/2007/belgrade/Presentations/oravainen2.pdf (Accessed: 15/10/2017).

SACCCS. 2010. CCS Roadmap and Strategy [Online]. Available at: http://www.sacccs.org.za/roadmap/ (Accessed: 15/10/2017).

Standards South Africa. 2006. *SANS 14064-1:2006 Greenhouse Gases Part 1: Specification with guidance at the organisational level for the quantification and reporting of greenhouse gas emissions and removals.* Pretoria: Standards South Africa.

Utt, J. and Giglio, R. 2012. Technology comparison of CFB versus pulverized fuel firing for utility power generation. *The Journal of the Southern African Institute of Mining and Metallurgy* **112**: 449-454.

White, C., Smith, D., Jones, K., Goodman, A., Jikich, S., LaCount, R., DuBose, S., Ozdemir, E., Morsi, B. and Schroeder, K. 2005. Sequestration of Carbon Dioxide in Coal with Enhanced Coalbed Methane Recovery A Review. *Energy & Fuels* **19**(3): 659-724.