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TOPIC: COAL DEMAND FOR POWER GENERATION IN BOTSWANA:- GREENHOUSE GAS EMISSION IMPLICATIONS: A CASE OF MORUPULE-B POWER STATION

A Dissertation submitted to the School of Graduate Studies, University of Botswana in partial fulfilment of the requirements for the degree of Master of Science in Environmental Science.

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ABSTRACT

Botswana has recently experienced severe shortages of electricity resulting in frequent 'load shedding'. It is hoped that existing and planned coal-fired power plants will provide sufficient electricity for the country in the future. A new power station, Morupule-B, has started operating. However, the use of coal for electricity generation is coming under increasing pressure from environmentalists as coal has been identified as one of the fuels contributing seriously to global warming via gaseous emissions produced during its combustion. A further dimension to the situation is added by the fact that Botswana is a country that has chosen to adopt and actively maintain a pro-nature stance to conservation of biotic resources.

All the above factors have created a dilemma: since Botswana has abundant coal reserves, and the resource can be used to generate electricity for the region, what is the scale of repercussions and benefits that would accompany such a development? This project analysed and quantified gaseous emissions from the Morupule-B coal-fired power station in Botswana.

The objectives of this study were: To quantify the total amount of greenhouse gas emissions from the Morupule-B power station in Botswana; to identify the implications of the GHG emissions on Botswana's commitments to international environmental conventions, and to probe, discuss and suggest possible mitigation measures against GHG emissions from the coal fired power generation project.

To achieve these objectives, the project used the Environmental Sustainability conceptual framework and IPCC Emission Factor methodology. It found that Morupule-B produces an estimated 3.8 billion kg of CO_2 equivalent per annum, and therefore that it does not turn Botswana into a net emitter of greenhouse gases. It recommended that Botswana may consider increasing coal-fired power stations but incorporating technological interventions to minimise the release of greenhouse gases and other pollutants into the environment.

<u>KEYWORDS</u>: ENVIRONMENTAL SUSTAINABILITY, COAL, EMISSION FACTORS, ENERGY DEMAND.

APPROVAL

This research has been examined and is approved as meeting the required standards of scholarship for partial fulfillment of the requirements for the degree of Master of Science in Environmental Science.

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STATEMENT OF ORIGINALITY

This work contained in this Dissertation was carried out by the author at the University of Botswana between August 2013 and September 2016. It is original work except where due reference is made and neither has been nor will be submitted for the award of a degree by any other university.

Montwedi Mozila: ………………………………………………………………

Date: ……………………………………………

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Re a leboga Bagaetsho.

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CH_4 – Methane gas

$\mu g/m^3$ – Microgram per cubic metre

ADB – African Development Bank

ADB - Asian Development Bank

APCO - Air Pollution Control Officer

APRC- Air Pollution Registration Certificate

AU- African Union

AWG-LCA - Ad Hoc Working Group on Long-term Cooperative Action

BADEA - Arab Bank for Economic Development in Africa

BCL - Bamangwato Concessions Limited

BDF –Botswana Defence Force

BPC - Botswana Power Corporation

BSTEP - Botswana Solar Thermal Electricity Generation Project

BTC - Botswana Telecommunications Corporation

BWP – Botswana Pula (currency)

CAPP - Central Africa Power Pool

CBM- coal bed methane

CCS - carbon capture storage

CDC - Commonwealth Development Corporation

CDM - Clean Development Mechanism

CERs- Certified Emission Reductions

CFBC - Circulating Fluidized- Bed Combustion

CITES - Convention on the International Trade in Endangered Species of Wild Flora and Fauna

CO_2 – Carbon Dioxide

COMELEC –Comité Maghrébin de l'Electricité

COMESA – Common Market for East and Southern Africa

COP – Conference Of Parties (to the United Nations Framework Convention on Climate Change)

CSO – Central Statistics Office

CV - calorific value

DANIDA - Danish International Development Agency

DEA - Department of Environmental Affairs

DEMS - Department of Engineering and Mechanical Services

DEMS - Department of Engineering and Mechanical Services

DRC – Democratic Republic of Congo

DRC - Democratic Republic of Congo

EAPP - Eastern Africa Power Pool

EBRD - European Bank for Reconstruction and Development

EC -European Community

ECCAS - Economic Commission for Central Africa States

ECOWAS – Economic Commission of West African States

EIA – Environmental Impact Assessment

EIB - European Investment Bank (EIB),

EIB- European Investment Bank

EJ – Exa joules (1018 Joules, a billion-billion joules)

EOCK - Economic Opportunity Cost of Capital

EPA - Environment Protection Agency

ESMP - Environmental and Social Management Plan

EST - environmentally sound technology

FIRR - Financial Internal Rate of Return

GCF - Green Climate Fund

GDP – Gross Domestic Product

Gg – gigagram One Gg is equal to a billion (109) grams, or a thousand tons

GHG – greenhouse gases

GoB - Government of Botswana

Gt – Giga ton (1 billion tons)

GWh – gigawatt hour

GWP – Global Warming Potential

ha- hectare

HFCs - Hydrofluorocarbons

HIV/AIDS – Human Immuno-deficiency Virus / Acquired Immune Deficiency Syndrome

HVDC – High Voltage Direct Current

IBRD - International Bank for Reconstruction and Development (IBRD),

ICBC-SB - Industrial and Commercial Bank of China and Standard Bank Consortium

IEA -International Energy Agency

IEA – International Energy Agency

IEF – International Energy Forum

INDC – Intended Nationally Determined Contributions

IPCC – Intergovernmental Panel on Climate Change

IPP - Independent Power Producer

ISC-AERMOD - Industrial Source Complex Air Dispersion Model

ISO – International Organization of Standards

JBIC -Japan Bank for International Cooperation

JI - Joint Implementation

KFW - Kredietanstalt fur Wiederaufbau

KfW –Kredietanstalt fur Wiederaufbau

kV – Kilo volt (1000 volts)

kWh – kilowatt hour

kWh – kilowatt hour

LNG – liquefied natural gas

m^3- Cubic metre

MDGs - Millennium Development Goals

MEA - multi-lateral environmental agreements

MEP - Mmamabula Energy Project

MFDP – Ministry of Finance and Development Planning

MJ – Mega joules (energy measurement, 1 million joules)

MJ per m^2 per day – mega joules per square metre per day.

MMEWR - Ministry of Minerals, Energy and Water Resources (Botswana)

MODIS – Moderate Resolution Imaging Spectroradiometer

Morupule-A:- First phase of Morupule power station

Morupule-B:- Second phase of Morupule power station.

MRV - Monitoring, Reporting And Verification

Mtoe - million tonne oil equivalent , equivalent to 41,868 MJ or 11,630 GWh

MW – megawatt

NAMAS - Nationally Appropriate Mitigation Actions

NDP – National Development Plan

NDVI – Normalised Difference Vegetation Index

NEPAD – New Partnership for African Development

NEXI - Nippon Export and Investment Insurance

NIB - Nordic Investment Bank (NIB)

NO_2 - Nitrogen Dioxide

NPVREP - National Photovoltaic Rural Electrification Programme

OPEC –Organisation of Petroleum Exporting Countries

OPGW - optical ground wire cable

PC - Pulverised Coal

PFCs - Perfluorocarbons

PM10 - Particulate Matter of 10 Microns in diameter or smaller

PV - photo-voltaic

RAP - Resettlement Action Plan

REC -Regional Electricity Commission

RECS - Rural Electrification Collective Scheme

REDD+ (Reducing Emissions from Deforestation and forest Degradation in developing countries)

REFIT - Renewable Energy Feed-In Tariff

RSA – Republic of South Africa

SADC - Southern African Development Community

SAPP - South African Power Pool

SAPP - Southern Africa Power Pool

SARI - South African Renewable Initiative (SARI)

SBTA - Subsidiary Body for Scientific and Technological Advice

SDG – Sustainable Development Goal

SF_6 - Sulphur hexafluoride

SIDA - Swedish International Development Agency

SSA - Sub-Saharan Africa

STEM - short-term energy market

Thebe - smallest denomination of Botswana currency (1Pula = 100 thebe)

UA - Units of Account (UA), currency denomination of the African Development Bank, which are equivalent to the SDR

UMA - Union of Maghreb Arab

UNCSD – United Nations Conference on Sustainable Development

UNDP – United Nations Development Program

UNEP- United Nations Environment Program

UNFCCC - United Nations Framework Convention on Climate Change

US$-United States Dollar

USAID – United States Agency for International Development

USc – Unites States cent

Vision 2016 - Botswana national long-term vision document

WACC - Weighted Average Cost of Capital

WAPP - West Africa Power Pool

WBG - World Bank guidelines or World Bank Group

WHO - World Health organization

CHAPTER 1: INTRODUCTION TO THE STUDY

1.1 INTRODUCTION

Botswana is a landlocked country located at the centre of Southern Africa. Botswana had a population of 2,024,904 in 2011(CSO, 2011) while the land area is 582,000 km^2 (AfDB / OECD, 2007). Botswana is still a developing country without much industrial output except mining. The manufacturing percentage of GDP in Botswana is below the average in sub-Saharan Africa, and well below the percentage for countries with a similar per capita GDP (Vision 2016, 1997, p. 18). The proceeds of mining (especially diamond mining) have projected Botswana into a mid-income country. Botswana has a government that has chosen to award a high priority to ecological issues, for example Botswana's Wildlife Management Areas (WMAs) cover around 22% of the country (Arntzen, 2003, p. 8). Over 34% of the total land area is under protection in national parks, game reserves or wildlife management areas (African Development Bank, 2009, p. 6). Some of these areas contain unique habitats of ecological importance (such as the Okavango Delta) and cultural significance (such as the Tsodilo Hills) (African Development Bank, 2009, p. 6). Botswana boasts two eco-regions that form part of the Global 200 eco-regions (eco-regions of global conservation priority): the Miombo woodlands and the Okavango system (Botswana Government, 2009, p. 6).

Botswana's energy supply is dominated by fuel-wood, which was reported to contribute 58% to the total primary energy supplied in 2003 (World Bank, 2004, p. 3). Annual national wood demand is estimated to be 1.8 million tons (Masisi, et al., 2011, p. 24). Local energy resources considered to be in abundance in Botswana include coal (200 billion tonnes), sunshine (3,200 hrs at $21MJ/m^2$), biogas (2.2 million cattle, 3kg dung/LSU/day) and fuel wood (200 tonnes/annum)(Seanama Conservation Consultancy, 2012, p. 1). Demand for electricity in Botswana, however, currently outstrips supply: prior to the commissioning of the Morupule-B power plant in 2013, Botswana depended on imports for roughly 80% of her electrical power needs (Adebola, 2011, p. 32), mostly from South Africa (South Africa is the source of most of Botswana's overall imports, accounting for over 70% across various categories of commerce (African Development Bank, 2009)). In 2009, average total demand for electricity was estimated at 500MW (Environmental Research and Policy Solutions, 2009) but the demand grows significantly each year.

Electricity in Botswana is generated mostly from the combustion of coal. There are two functioning coal-fired power stations at Morupule near Palapye in the central district of Botswana; Morupule-A (132MW) and Morupule-B (not yet fully-operational, but designed to produce 600MW in the first-phase alone). In 2013, Botswana Power Corporation cited its main electricity sources as: South African Power Pool (SAPP) imports – 100 to 200 MW; Morupule-B (phase 1, still incomplete then, with only one boiler operational)– up to 150 MW; Morupule-A – 132 MW; Orapa emergency diesel plant - 90 MW; Matshelagabedi emergency diesel plant – 70 MW (Molubi, 2013). By 2014, BPC was still purchasing 58% of Botswana's electricity from other countries (BPC Annual Report, 2015).

‘Load shedding’ exercises (when the power supply company temporarily cuts-off electricity supply to some parts of the country at peak times) have been a common occurrence throughout Botswana, as a desperate measure to control surplus demand. Load shedding leads to productivity losses and increased risks and expenses to households and especially businesses (Ofetotse, Essah, & Yao, 2015, p. 84). Production loss, data loss, damage to equipment and loss of lighting are the most significant sources for inconveniences caused by the power outages (Asgary & Mousavi-Jahromi, 2011, p. 307).

In addressing the national concerns of energy security and the global concerns of expanding access to energy services to meet global development goals such as Sustainable Development Goals (SDGs), government also has to worry about protecting the environment (Seanama Conservation Consultancy, 2012, p. 1). According to Botswana’s national long-term vision, by the year 2016, Botswana intends to have taken strong measures to limit pollution (Vision 2016, 1997, p. 8). This is especially pertinent at this time when the atmosphere is currently suffering from an ever rising concentration of carbon dioxide and other Green House Gases.

1.2 RESEARCH PROBLEM STATEMENT

Coal-fired power stations are known to present environmental challenges, especially with respect to emission of noxious gases such as the oxides of nitrogen, sulphur and carbon. This project evaluated GHG emissions from coal-fired power generation in Botswana within the broader context of environmental sustainability, an investigation that has never been done before. Emission factors for combustion of coal are high: in the region of 87,300 to 101,000 kg of carbon dioxide plus 0.3 to 3kg of methane and 0.5 to 5kg of N_2O, all per terajoule of energy (Gómez, Watterson, Americano, Ha, Marland, & Matsika, 2006). In fact, the combustion of fossil fuels has been highlighted as the main push-factor for the greenhouse effect and global warming, and coal is considered the dirtiest among fossil fuels: In 2009, coal accounted for 43% (12.5 Gt) of global CO_2 emissions from fuel combustion (International Energy Agency, 2011). The Energy sector accounts for an estimated 74.5% of greenhouse gas emissions in the country (Masisi, et al., 2011, p. 34), so it is a worthwhile sector to study in terms of global warming concerns.

Any coal-fired power station project is expected to affect the environment and society in the immediate vicinity very much. Pollution, land-use changes, social restructuring, respiratory health problems and pressures on flora and fauna are all to be expected. However, a power station also brings with it positive changes like enhanced chances of employment, accrual of value in real estate, creation of a market for local businesses, diversification of the economy and the availing of better services to the community. The role of this project is to study, evaluate and discuss such changes within the framework of sustainable development.

Among natural resources in Botswana, there are two whose full harnessing may prove mutually incompatible: on one side flora and fauna, and on the other side coal. A dilemma stems from the fact that the by-products of the combustion of coal harm the living environment. Tourism, for example, is an increasingly important industry in Botswana, accounting for approximately 10% of GDP in 2006 (Masisi, et al., 2011, p. 28) but the sector may be harmed if perceptions of Botswana among would-be visitors change.

Studies have been undertaken on the polluting effects of the combustion of fossil fuels. Even locally, Environmental Impact Assessment (EIA) studies have been undertaken (as required by law) for each coal mining and power station project (planned and existing). However, this study sought to consolidate the detached information into a unitary national testament that can be used to closely estimate Botswana's international standing with respect to emissions from coal-fired power stations. The project also gives an alternative view to what has hitherto been the sole mandate of the Botswana government (the government gives periodic reports to international bodies such as the United Nations (UN) to satisfy the requirements of conventions like United Nations Framework Convention on Climate Change (UNFCCC)). Essentially, the study represents the first scientific (non-EIA) evaluation of greenhouse gas emissions from coal-powered energy generation in Botswana. Thus, its results will have a pioneering and baseline status in the country.

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1.3 MAIN AIM OF THE STUDY

This study sought to evaluate the greenhouse gas emissions expected to accompany large-scale coal-fired generation of electricity in Botswana, with specific emphasis on the Morupule-B power station in Morupule near Palapye with a view to offer necessary policy recommendations.

1.4 RESEARCH OBJECTIVES

1. To quantify the total amount of greenhouse gas emissions from the Morupule-B power station in Botswana.

2. To identify the implications of the GHG emissions on Botswana's commitments to international environmental conventions.

3. To probe, discuss and suggest possible mitigation measures against GHG emissions from the coal fired power generation project.

1.5 KEY RESEARCH QUESTIONS

1. How much greenhouse gas emissions occur from Morupule-B and other coal-fired power generation projects in Botswana?

2. Would the scale of emissions be significant enough to result in Botswana becoming a net emitter of greenhouse gases?

3. What technological intervention options exist to mitigate the greenhouse gas emissions emanating from the combustion of coal?

1.6 SIGNIFICANCE OF THE STUDY

This study is important in view of the fact that coal is currently an important mineral that Botswana may exploit to diversify her economy. Botswana is estimated to have over 200 billion metric tons of coal reserves, of which only about a million tons (0.0005 %) are currently mined annually (Fossil Fuel Foundation, 2010). Admittedly, due to technical constraints and economic considerations, not all the reserves are viable for profitable mining under the current paradigm. Botswana has significant potential for environmentally sound technology (EST) application in coal, coal bed methane (CBM), biogas and bio-fuels (Department of Meteorological Services, 2004, p. xi)**.** In fact Botswana has recently been considering the construction of railway tracks to both the Namibian and Mozambican coasts, coal being the principal commodity intended to be conveyed on those tracks (Fichani & Labys, 2003).

However, current conventional wisdom among scientists and environmental activists is predominantly against the continued use of coal. Coal is fast becoming a global pariah (see, for example, Lashof et al., 2007), and some pundits are already flashing headlines like 'The death of coal' and 'Renewables to dethrone King Coal'. The death knell is so persistent that major new projects associated with coal mining (for example the Mmamabula project by CIC Energy and the Mmamantswe project by Aviva) are currently in the doldrums due to uncertainties in view of the direction the debate is taking. Even energy-strapped South-Africa has rejected a power supply contract with CIC energy, on the argument that the country is now looking towards renewable energy resources.

In addressing the coal debate, this study utilised the environmental sustainability conceptual framework. It is important for Botswana as a nation which is so abundantly endowed with coal to interrogate all aspects of arguments surrounding the use of the resource. Furthermore, whilst economy-wise Botswana is heavily dependent on mining, natural biological resources also contribute significantly to the economy, thus Botswana promotes herself as a relatively untainted tourist destination. Botswana is highly vulnerable to climate change effects because of the variable nature of the country's rainfall frequency and magnitude (Masisi, et al., 2011, p. 15).

While information on various aspects of coal generation in Botswana may be gleaned from various sources, it is mostly parochial and of disjointed focus. More synthesised information is to be found in periodic government reports to international agencies like the United Nations. However, some of such reports tend to use aged data; an example being Botswana's Second National Communication to the United Nations Framework Convention on Climate Change published in 2012 – Much of the data alluded to in this report is from 1994 whilst the population data was from 2001 and the data on emissions is for the year 2000. It would be beneficial for more research and publications on this topic to see the light of day, hence this study.

1.7 SCOPE OF THE STUDY AND CHOICE OF STUDY AREA

The study focused on emissions of greenhouse gases at Morupule-B coal-fired power station in Botswana. Technical data was obtained from the power plant to quantify the emissions concerned. The study considered environmental aspects of coal-fired power stations and challenges facing the continued use of coal as a thermal fuel and the mitigation of greenhouse gas emissions. The study also compared overall emissions at a national scale with the carbon absorption of Botswana vegetation to evaluate whether Morupule-B and other sources of emission result in Botswana becoming a net emitter of GHGs or not.

It would have been more fulfilling for this research to tackle both emission sources and emission sinks, but due to time, money and academic programme scope limitations, the study only attempted to quantify sources of emission. Nevertheless, where sinks needed to be considered, credible sources of reference were cited.

CHAPTER 2: LITERATURE REVIEW

Various scholars have studied environmental impacts in general and environmental impacts for various projects, programmes and events. Environmental impact analysis has been accepted worldwide as a gold standard that is compulsory for all large scale projects in most countries. Impact forecasting is a crucial component of the EIA process as it is geared towards predicting problems before they actualize, thus presenting an opportunity to right things from the start. Impacts specifically concerned with extractive mining have been studied by governments, non-governmental organizations and mining companies themselves.

The Intergovernmental Panel on Climate Change (IPCC) has compiled a structured set of guidelines for calculation of county-specific and fuel-specific estimates for greenhouse emissions for various sectors of the economy (Gómez, Watterson, Americano, Ha, Marland, & Matsika, 2006).

For the coal industry in particular, impacts associated with power stations are well documented, for example Corbett, West, & Lawson, (2009). Environmental and health impacts of pollution attributed to coal have also been described by Perrotta (2002)***.*** The Natural Resources Defence Council has published an issue paper authored by a panel of experts (Lashof, Devine, Finamore, Hammel, Hawkins, & Wald, 2007): The paper covers the environmental effects of coal production and coal transportation, and environmental effects of coal use (air pollutants and other pollutants). It also ponders on the future for coal and offers pointers on reducing fossil fuel dependence. While the issue paper discusses coal-induced environmental effects at length, it is not a study *per se* as it is merely descriptive with no express study methods.

Zhai, Totolo, Modisi, Finkelman, Kelesitse, & Menyatso (2009), published a more comprehensive study that depended on analytical sampling from different places on the study area (not to mention that it is local to Botswana): However, the research is limited to the study of abnormal doses of heavy metals in the vicinity of Morupule power station; it does not consider socio-economic and other types of impacts. LeBel (1994), analysed the economic impact of various renewable energy resources vis-à-vis coal. This is an interesting take on the matter but it is limited to economic issues: A similar paper is Fichani & Labys (2003)*.* A study by Gwebu (2002) has attempted to synthesise the energy sector policies in Botswana and their implications for climate change.

For the Mmamabula coal mine and power station and its associated infrastructure, including substations and transmission lines, some specific impact assessment studies have been undertaken: Wheeler (2008) assessed the stance likely to be adopted by World Bank in evaluating whether to fund the project or not (a decision to be made largely on the basis of environmental considerations). A scoping study for the air quality impacts of the proposed substations has also been done (Pillay & Zunckel, 2008). Another specific impact study associated with the Mmamabula project was undertaken by Rooyen (2007). Other literature have focused on ways of minimizing pollution from coal mining / burning by using 'Clean

Energy Mechanisms', for example Coal Industry Advisory Board (2010). Carbon capture and storage (CCS) for Southern Africa has also been explored as a mechanism to mitigate environmental impacts associated with the burning of fossil fuels (Connick, Mikunda, Cuamba, Schultz, & Zhou, 2010).

All the above literature covers different aspects of environmental and socio-economic considerations pertaining to coal mining and combustion in power stations. All these aspects are important to the topic being studied. While there have been individual EIA reports undertaken for various coal-fired power generation projects, there has not yet been a study that synthesized impacts from existing and planned projects to give a holistic portrait. As such, this study will help in its own small way to close the knowledge gap.

2.1 THE GLOBAL COAL ENERGY SCENE

The United Nations Conference on Sustainable Development (in Rio de Janeiro, June 2012) recognised the critical role that energy plays in the development process, as it contributes to poverty eradication, saves lives, improves health and helps provide basic human needs, and that energy is also a key input to production (UNCSD, 2012, p. 22).World energy demand is predicted to increase by 60% between 2002 and 2030 (Advisory Council for Zero Emissions, 2007, p. 10). A 65% global increase above the 2000 primary energy demand (464 EJ, 11,204 Mtoe) is anticipated by 2030 (Sims, Schock, Adegbululgbe, Fenhann, Konstantinaviciute, & Moomaw, 2007). Coal is the World's most abundant and widely distributed fossil fuel, with reserves for all types of coal estimated to be about 990 billion tonnes, enough to last for 150 years at current consumption rates (Coal Industry Advisory Board, 2010, p. 17).

According to IEA estimates, global coal consumption reached 7,238 million tonnes in 2010, of which China accounted for 46 % of consumption, the United States 13 %, and India 9 % (Yang & Cui, 2012, p. 1). Coal consumption grew by 5.4% in 2011 (British Petroleum, 2012, p. 5). Around 75% of global demand for thermal coal is driven by power generation, and more than 40% of global power generation is fuelled by coal (IEA, IFP & OPEC, 2012, p. 7). The global coal trade is estimated to have risen by 13.4 percent in 2010, reaching 1,083 million tonnes (Yang & Cui, 2012, p. 2).

The global demand for coal is expected to more than double between 2004 and 2030, and the IEA has estimated that more than 4,500 GW of new power plants (half in developing countries) will be required in this period (Sims, Schock, Adegbululgbe, Fenhann, Konstantinaviciute, & Moomaw, 2007, p. 265). According to some estimates, 1,199 new coal-fired plants, with a total installed capacity of 1,401,278 megawatts (MW), are being proposed globally, spread across 59 countries - China and India together account for 76 percent of the proposed new coal power capacities (Yang & Cui, 2012, p. 2). As depicted in table 2.1, since 1994, multilateral development banks (MDBs) and industrialized countries' export credit agencies (ECAs) have helped finance 88 new and expanded coal plants in developing countries, as well as projects in Europe, to the tune of more than US$37 billion (Yang & Cui, 2012, p. 18).

Table 2.1: New and expanded coal plants financed by multilateral banks between 1994 and 2011 (Yang & Cui, 2012, p. 18).

PUBLIC FINANCIAL INSTITUTION	COUNTRY OF ORIGIN	TOTAL FINANCING (IN MILLION USS)	NUMBER OF PROJECTS FINANCED
Japan Bank for International	Japan	8,138.65	21
World Bank Group	Multilateral	5,315.49	29
Asian Development Bank (ADB)	Multilateral	3,912.95	21
US Export-Import Bank	United States	3,478.80	17
European Investment Bank (EIB)	Multilateral	2,510.94	9
Nippon Export and Investment	Japan	2,089.48	6
Kreditanstalt fur Wiederaufbau(KfW)	Germany	1,769.15	6
China Development Bank	China	1,680.60	3
Euler Hermes	Germany	1,174.14	5
European Bank for Reconstruction and Development (EBRD)	Multilateral	869.39	9

From table 2.1, it is evident that new coal-fired station projects continue to be undertaken, getting financed by major financial institutions with substantial amounts. The problem is that, coal-fired power plants / power stations account for over 28% of global carbon dioxide (CO_2) emissions (Coal Industry Advisory Board, 2010, p. 15), a share that may rise as more power stations come on board, especially in India and China (Yang & Cui, 2012, p. 2).

2.2 POTENTIAL FOR GROWTH OF THE ENERGY SECTOR IN AFRICA

Energy is often referred to as the engine of a country's economy, without which socio-economic goals cannot be achieved (Department of Meteorological Services, 2004, p. 15). Electricity is the backbone of economic development. At present, the one billion people living in developed (OECD) countries consume around half of the 470 EJ current annual global primary energy use whereas the one billion *poorest* people in developing countries consume only around 4%, mainly in the form of traditional biomass used inefficiently for cooking and heating (Sims, Schock, Adegbululgbe, Fenhann, Konstantinaviciute, & Moomaw, 2007, p. 256). The African continent is the flagship of this sorry state of affairs: 31% of the countries have an electrification rate below or equal to 10% while nearly 70% have an electrification rate below or equal to 30% (Economic Consulting Associates, 2009, p. 7).

Africa's energy demand is expected to grow annually by 5% until 2040 (Fakir, 2012, p. 5). The average price of power in Sub-Saharan Africa is double that of other developing regions, but supply is unreliable (Eberhard, Foster, Briceño-Garmendia, Ouedraogo, Camos, & Shkaratan, 2009, p. 7). Africa accounts for over a sixth of the world's population, but generates *only 4%* of global electricity; Three-quarters of *that* is used by South Africa, Egypt, Libya, Tunisia and Algeria (The Economist, 2007). At 68 gigawatts (GW), the entire generation capacity of the 48 countries of Sub-Saharan Africa is no more than that of Spain (Eberhard, Foster, Briceño-Garmendia, Ouedraogo, Camos, & Shkaratan, 2009, p. 7). Nigeria for example, a vast nation of 150 million people, has a generating capacity of 4,000 MW: By comparison, New-York City alone has a generating capacity of 13,000 MW (EcoPower Africa, 2011). South Africa has nearly a third of the continent's installed capacity – about 40 GW out of the 125 GW (Fakir, 2012, p. 5): Without South Africa, the Sub-Saharan Africa total falls to a mere 28 GW, equivalent to the installed capacity of Argentina (Eberhard, Foster, Briceño-Garmendia, Ouedraogo, Camos, & Shkaratan, 2009, p. 7).

Challenges to investment in energy industry in the developing world include that Energy infrastructure is a capital intensive business characterized by a high fixed to variable costs ratio, and the Infrastructure investment is a long term investment with pay-back periods that may go up to 15 or 20 years (NEPAD / African Union, 2005).

The African continent is large, so there are primarily five power pools acting as specialized agencies of their respective Regional Electricity Commissions (RECs) in Africa:

(i) The Central Africa Power Pool (CAPP) for the Economic Commission for Central Africa States (ECCAS),
(ii) The Comité Maghrébin de l'Electricité (COMELEC) for the Union of Maghreb Arab (UMA),
(iii) The Eastern Africa Power Pool (EAPP) for COMESA,
(iv) The Southern Africa Power Pool (SAPP) for SADC, and
(v) The West Africa Power Pool (WAPP) for ECOWAS

(Infrastructure Consortium for Africa, 2011, p. 7)

Installed capacity is 6,073 MW for CAPP (2009), 27,347 MW for COMELEC (2009), 28,374 MW for EAPP (2008), 49,877 MW for SAPP (2010) and 14,091 MW for WAPP (2010). The installed capacity per thousand habitants is the highest in North and Southern Africa, in terms of kW per thousand habitants: COMELEC (319), SAPP (311), followed by EAPP (74), WAPP (54) and CAPP (49) (Infrastructure Consortium for Africa, 2011, p. 7). As far as electricity mix is concerned, at Africa level, most of the existing capacity is thermal (75%) due to the size of the predominately thermal COMELEC and SAPP systems; Hydropower is predominant in CAPP (86%): In EAPP and in WAPP, the present share of hydro is 24% and 30%, respectively, but this share is expected to grow rapidly as ongoing and future generation investments are mainly in hydropower projects (e.g. Ethiopia: Gibe III with 1870 MW) (Economic Consulting Associates, 2009, p. 7).

2.3 SUPPLY AND DEMAND FOR ELECTRICITY IN THE SAPP REGION

The South African Power Pool (SAPP) SAPP comprises all the twelve mainland SADC member countries, nine of which are part of the interconnected grid, which carries around 97% of the energy produced by SAPP countries (Economic Consulting Associates, 2009, p. 10). The 2009 operational statistics give the following generation mix for SAPP: 74.3% coal, 20.1% hydro, 4% nuclear and 1.6% diesel and gas (Economic Consulting Associates, 2009). The recommended SAPP Pool Plan has an increased role for oil and gas plants for peaking and reserve capacity, hence the projected generation mix for the year 2025 is 56% coal, 26% hydro, 2% nuclear and 22% diesel and gas (Economic Consulting Associates, 2009, p. 17).

One of the unique features of SAPP is the history of successful electricity trading despite political and security concerns: The exception is the sabotage of the Cahora-Bassa HVDC link to South Africa that interrupted supply for 17 years (Economic Consulting Associates, 2009, p. 15).

SAPP's focus has thus been:

- to improve the reliability and security of the existing regional grid;
- to facilitate the expansion of the grid to connect non-operating members;
- to introduce a Short-Term Energy Market (STEM) to facilitate the trading of surplus energy not committed under existing contracts.

(Economic Consulting Associates, 2009, p. 16).

In 2007, the 12 SADC countries that comprise SAPP had a combined population of 226 million and GDP of US$330 billion (Economic Consulting Associates, 2009, p. 14). Prior to 1995, there were two main power-integration regions: the South African Customs Union (SACU – incorporating South Africa, Botswana, Namibia, Lesotho and Swaziland) region, which was largely thermal-generation based, while the rest of the SADC countries constituted a hydro-based collective in the north (Musaba, 2010).

The Inga site on the Congo River in the Democratic Republic of Congo (DRC), with 40,000 MW of hydropower potential, is a prime focus for future electricity supplies for the SAPP region (Economic Consulting Associates, 2009, p. 16). However, instability in the DRC and neighbouring countries tend to turn-off potential investors from developing the project.

In 2009, access to electricity in SAPP ranged from 75% in South Africa, through medium level of access for (respectively) 40% in Zimbabwe, 35% in Namibia, 30% in Zambia, 28% in Swaziland and 25% for Botswana, and lower levels of access in other countries: 17% for Angola, 15% for Mozambique, 11% for Tanzania, 10% for Malawi, 9% for Lesotho and 8% for DRC (Infrastructure Consortium for Africa, 2011, p. 55).

2.4 SUPPLY AND DEMAND OF ELECTRICITY IN BOTSWANA

In 2011, national supply continued to be predominantly sourced through imports, with domestic generation contributing only up to 11%: Eskom (RSA) accounted for 68%, and the balance of 21% was secured from the Southern African Power Pool (SAPP) member utilities (Botswana Power Corporation, 2012). Botswana has chosen to follow the path of cost-effectiveness rather that energy security, preferring to co-operate with its neighbours to benefit from economies of scale in electricity generation and supply, as attested-to by the Vision 2016 document (Vision 2016, 1997, p. 34): This has led to under-investment in domestic power plants in favour of cheap electricity imports from South Africa.

Table 2.4 highlights some of the investment statistics for Botswana Power Corporation. Note that the corporation has incurred straight losses from 2009 to 2011.

Table 2.4: Some Botswana Power Corporation statistics from 2008 to 2011 (Source: BPC Yearbook 2011, p.8)

	2011	2010	2009	2008
Electricity Revenue Sales (P'000)	1,512,236	1,135,474	1,069,559	938,555
Net profit/(Loss) (P’000)	(796,620)	(1,572,169)	(133,623)	111,143
Return on revalued fixed assets (%)	-6%	-11%	-9%	-2%
Total unit sales (GWh)	3,118	3,151	2,917	2,889
Total generation (sent out) and imports (GWh)	3,617	3,414	3,369	3,210
Total consumers	251,773	214,170	198,615	196,755
Plant capacity (MW)	132	132	132	132
System maximum demand (MW)	553	553	503	493
Average selling price per unit (Thebe/kWh)	48	36	36	31

2.4.1 BACKGROUND INFORMATION ON COAL-FIRED ELECTRICITY GENERATION IN BOTSWANA

In Botswana, energy planning is guided by the Botswana Energy Master Plan, which was originally developed in 1966 (Environmental Research and Policy Solutions, 2009, p. 6). Botswana Power Corporation (BPC) was established in 1970 as a statutory body to generate and supply electricity to the entire country. The Ministry of Minerals, Energy and Water Resources (MMEWR) has responsibility for the issuance of licenses for the generation and supply of electricity (USAID, 2008). Electricity, like other utilities, has been the sole mandate of designated state enterprises; however, of late the country appears to be heading towards a legislative licensing regime that embraces independent power producers (IPPs) (USAID, 2008).

Coal has been mined at Morupule since 1976, with 900,778 tons extracted in 1994 alone (CSO, 2000). Coal reserves in Botswana are estimated to amount to 212.8 billion tons (Department of Meteorological Services, 2001, p. 24). Nonetheless, much of the country remains rural in lifestyle, hence the dominance of wood as a fuel among most households, as evidenced by Table 2.4.1 from 1994/1995.

Table 2.4.1: Primary and net energy supply for 1994 /95 in Botswana (Source: CSO, 2000)

Energy supply	**Primary**	**energy supply**	**Net energy**	**supply**
	TJ	**%**	**TJ**	**%**
Coal	21 906	23.70	4 338	5.53
Fuelwood	54 116	58.54	54 116	69.00
Renewable energy (solar and biogas)	36	0.04	36	0.05
Electricity	1 054	1.14	4 971	6.34
Petroleum products	15 324	16.58	14 969	19.09
Total	92 436	100	78 430	100

BPC has developed from operating just a small, oil-fired power station in Gaborone (which was commissioned in 1970 and dismantled in 1989) (Botswana Government, 2004, p. F4) to being a truly national provider of electricity. The Grid-based Rural Electrification Programme was initiated in 1975 with the intention to promote the productive use of electricity in rural areas in order to facilitate economic development and alleviate poverty through electrifying selected villages in Botswana (Environmental Research and Policy Solutions, 2009, p. 6). The Government initiated the Rural Electrification Program in 1975 with assistance from the Swedish International Development Agency (SIDA) (Botswana Power Corporation, 2012). The project involved the connection of 11 villages, including Kanye, Molepolole, Ramotswa and Mochudi, to the national grid. In 1987, another project to provide power supplies to the major villages of Serowe, Palapye, and Mahalapye was implemented with financial assistance from the Danish International Development Agency (DANIDA) (Botswana Power Corporation, 2012).

2.4.2 OVERVIEW OF EXISTING AND PLANNED POWER STATIONS IN BOTSWANA

2.4.2.1 HISTORICAL

In the 1980s there were some transformations in the Botswana energy sector: The 4 MW Maun diesel station was put out of use after the commissioning of the 132 kV Francistown - Maun line: at one point the Department of Engineering and Mechanical Services had in operation a total of 20 MW of installed diesel generated power in rural areas nationwide (African Development Bank, 1997, pp. 3-4). Since the implementation of Morupule Power Project, BPC's installed generating capacity has changed from 109 MW in 1982 to 197 MW in 1986 powered by 132 MW generation at Morupule, and 65 MW (available: 45 MW) at Selibe-Phikwe: The coal-fired power station at Selibe-Phikwe was decommissioned in 1995/6 (African Development Bank, 1997, p. 5). Botswana Ash used to generate 20 MW for its own use (Department of Meteorological Services, 2001, p. 24).

2.4.2.2 EXISTING INSTALLATIONS

MORUPULE-A

Morupule Colliery was established in 1973 by the Botswana Power Corporation (BPC) to supply coal to Bamangwato Concession Limited (BCL) Copper/Nickel mine's on-site coal fired power station (Botswana Mining Exhibition, 2009). Later, Morupule colliery also supplied coal to the Morupule Power Station, initially a 132 MW mine-mouth, dry cooled power plant run by the Botswana Power Corporation (Botswana Mining Exhibition, 2009). The initial Morupule Power Project (MPP) was supposed to be the first phase of a three-staged development aiming at installation of 90 MW in 1988, 90 MW in 1990 and an additional 110 MW later on in order to reach 420 MW installed capacity by the year 2000 (African Development Bank, 1997, p. 2).

In order to finance the Morupule-A project, in 1981 the Government of Botswana (GOB) obtained financial assistance from the African development Bank Group (ADB), the Arab Bank for Economic Development in Africa (BADEA), the Commonwealth Development Corporation (CDC), the European Investment Bank (EIB), Export Credit, the International Bank for Reconstruction and Development (IBRD), the *Kredietanstalt fur Wiederaufbau* (KFW),the Kuwait Fund, the Nordic Investment Bank (NIB) and the Saudi Fund and the United Kingdom Government (African Development Bank, 1997, p. 2).

An Air Quality Impact Report compiled by Airshed Planning Professionals in 2004 indicated that the first phase of Morupule Power Station (Morupule-A) contributed approximately 32.6%, 0.3% and 0.01% of the country's total CO_2, NO_2 and CH_4 emissions respectively (African Development Bank, 2009, p. 13). The nature of Morupule coal is sub-bituminous and the sulphur content averages 1.5 % with 21 % ash content with an average calorific value of 23 MJ/kg, moisture free basis (World Bank, 2004). Morupule-A is currently (2016) closed for refurbishment but is expected to be back in operation by 2020 (Mott MacDonald (Pty) Ltd, 2014, p. 8).

MORUPULE-B

The project consists in the construction of an initial 600 MW (4 x 150 MW) coal fired power plant and associated transmission infrastructure. BPC had also initiated the feasibility study for Morupule-B Phase II (consisting in an additional 600 MW of capacity), (African Development Bank, 2009, p. 2). The total Project cost for Morupule-B is estimated to be US$600 million (2004 prices) for the first 400 MW (Table 2.4a depicts a breakdown of overall sources of funding: most of the money had to be borrowed from international banks). The unit cost are estimated at US$ 1,500 per kW and this cost estimate includes capital costs and all soft costs, that is, owners engineering and project management costs, pre-financial close, legal costs, as well as interest during construction (World Bank, 2004). If high efficiency boilers/ or other cleaner coal technologies are installed at Morupule, the project costs could be in the range of US$ 800- 1000 million for 600 MW (100MW x 6) capacity (World Bank, 2004).

Table 2.4a: Financing plan for Morupule-B project (Source: African Development Bank, 2009, p.iii)

SOURCE	AMOUNT (UA MILLION)	INSTRUMENT
ADB	139.30	Loan
MIC Grant (ADB)	0.60	Grant
WB	98.2	Loan
ICBC-Standard Bank	535.7	Loan
GoB	131.6	
TOTAL COST	**905.4**	

Table 2.4b highlights reasons for some of the choices and courses of action pertaining to the Morupule-B power plant: for example, two options for boiler technology were considered, namely (i) Circulating Fluidized- Bed Combustion (CFBC) and (ii) Pulverised Coal (PC) boilers. The CFBC boiler technology was preferred over PC because it is better suited to the type of coal found in Botswana (African Development Bank, 2009, p. 5). CFBC boilers process solid fuel where the fuel is suspended in a mixture of superheated air and sand, collectively called "fluidized bed": Reagents like limestone are added and temperatures are controlled to directly capture the sulphur and reduce the formation of Nitrogen Oxides (African Development Bank, 2009, p. 5). For CFBC, two technologies were considered, namely (i) sub-critical steam conditions and (ii) super-critical steam conditions. The latter was considered in order to achieve higher efficiency level but it was found that there is limited experience with this technology (African Development Bank, 2009, p. 5). Besides, the single unit size is more than the BPC grid can sustain if there is an unplanned outage of the unit: For the above reasons, the application of CFBC super-critical boiler technology was rejected (African Development Bank, 2009, p. 5).

Pulverised Coal,Super-Critical technology was considered. Traditionally, the plants which adopted the Super-Critical technology were of large capacity, with boilers of more than 500 MW each (e.g. Matimba and Medupi of Eskom) (African Development Bank, 2009). Given the nature of the BPC's power system and the electricity grid limitation, the application of the PC super-critical boiler technology was also rejected (African Development Bank, 2009, p. 5).

Table 2.4b: Alternatives to the Morupule-B project (Source: African Development Bank, 2009, p.6)

Alternative	Brief description	Reasons for rejection
Generation		
No new generation capacity built / Reliance on power imports	**Botswana currently needs to import >80% of power consumed nationally**	**Due to the regional power crisis, neighbouring countries will considerably reduce exports to Botswana over coming years and totally discontinue firm exports by 2013. Imports will therefore no longer be available over coming years and the economic cost of not meeting the demand for electricity would be enormous.**
Other power sources	**(i) Coal Bed Methane; (ii) Solar (iii) Oil**	**Reserves not proven yet; (ii) Not possible to develop in scalable and timely manner to meet supply deficits over medium-term; (iii) Considerably more expensive and volatile (fuel would need to be imported). Would not provide the same level of energy self-reliance.**
Plant size	**Plant size of 600 MW with 4x150 MW units was selected**	**While a smaller plant size (400 MW) was originally considered, it was rejected to ensure that Botswana becomes self-sufficient. Implementing 4x150 MW units was identified as the least-cost configuration by taking into account the condition of the electricity grid.**
Boiler technology	**Super-critical versus sub-critical boiler**	**Sub-critical CFBC boiler technology chosen over PC and CFBC supercritical due to the fact that CFBC is more suited to the type of coal and grid limitations in Botswana.**
Transmission		
Voltage of transmission line	**220 kV or 765 kV instead of 400 kV lines**	**The 400 kV option was deemed to be optimal for Botswana's transmission system based on the 10 Year Transmission Development study conducted in 2006/7.**

The total Project cost for Morupule-B is estimated to be US$600 million (2004 prices) for the first 400 MW (World Bank, 2004). The unit cost are estimated at US$ 1,500 per kW and this cost estimate includes capital costs and all soft costs, that is, owners engineering and project management costs, pre-financial close, legal costs, as well as interest during construction (World Bank, 2004). If high efficiency boilers or other cleaner coal technologies are installed at Morupule, the project costs could be in the range of US$ 800- 1000 million for 600 MW (100MW x 6) capacity (World Bank, 2004).

It is estimated that the Morupule-B project will increase household access-to-electricity rates from 47% (2009) to 80% by 2016, which is in line with Botswana's energy strategy of increasing energy access to all its citizens (Environmental Research and Policy Solutions, 2009, p. 6).

2.4.2.3 PLANNED POWER PLANTS

MMAMABULA

The Government of Botswana has given the go-ahead for the development of the Mmamabula power plant by an Independent Power Producer (IPP), CIC Energy. The Mmamabula Energy Project was initially projected to be very large; planned to produce up to 4,800MW of electricity, mainly for sale into neighbouring South Africa with a percentage reserved for BPC (USAID, 2008). A downsized configuration of the project is to supply 1200 MW: 300 MW for BPC and 900 MW for Eskom (African Development Bank, 2009, p. 2). However, the timing for the implementation of Mmamabula is not yet clear, in part due to un-concluded power purchase agreements and hurdles in the mobilisation of finance. The development of the Mmamabula Energy Project (MEP) may turn Botswana into a net electricity exporter.

In the current environment of shortages of power in South Africa, a major thermal project in a stable, well-managed economy (the Mmamabula project in Botswana) is likely to look more attractive as a reliable source of supply than a low-cost hydropower plant in a country which has lived through decades of instability (the Inga project in the DRC) and which also requires a much longer transmission network (Economic Consulting Associates, 2009, p. 16).

MMAMANTSWE

An Independent Power Producer (IPP), Aviva Energy, is in the process of planning and designing a 1,050 MW coal power station at Mmamantswe Coalfield in the Kgatleng District of Botswana (Connick, Mikunda, Cuamba, Schultz, & Zhou, 2010, p. 11). The actual size of the Mmamantswe Power Station is yet to be finalised, but current scenarios are for 3 x 350MW units, with a capacity to expand at a later stage (for a total of 2000MW) (World Bank, 2012).

2.4.2.4 PLANNED PROJECTS FOR COAL MINING ONLY (FOR EXPORT)

ASENJO ENERGY

Boosting the international corporate shareholders Aquila (Mauritius), Sentula (South African) and Jonah Capital (Asenjo Energy, 2010), Asenjo Energy has interests in several coal projects around Botswana;

1. The Dukwe Project, with gross in-situ coal amounting to 1,014 million tons at 22MJ/kg calorific value and 19% ash content when washed (Asenjo Energy, 2010).

2. The Western Mmamabula project, with gross in-situ coal amounting to 8,059 million tons at 25MJ/kg calorific value and an ash content of only 15% when washed (Asenjo Energy, 2010).

3. The Lechana / Tshimoyapula project: 1,651 million tons of coal at 27MJ/kg and only 12% ash content when washed (Asenjo Energy, 2010).

4. Kodibeleng: at the time of writing, not much information was available on this project.

2.4.3 INVESTMENT REQUIREMENTS FOR COAL-FIRED POWER STATIONS

BPC has signed a coal supply agreement with Morupule Coal mine for the period 2012-2032, the agreed total coal supply to BPC for the period being pegged at 42,716,920 tonnes (Kelesitse, 2012). In 1999, a three year Energy Supply Agreement was entered into with Barloworld for the operation of the Ghanzi Diesel Power Station: The cost of generating a unit of electricity at this station stood at about P1.47 compared to the selling price of P0.31, resulting in an average annual subsidy by Government of about P10 million over the duration of the agreement (Government of Botswana, 2009).

In order to attract more investors to the mining sector, the Government of Botswana amended The Mines and Minerals Act in 1999. The amendment introduced the retention licence, which confers some rights on prospectors to retain their mineral rights for a limited period while mobilizing resources to undertake the mining (under the old regime, they had to 'use it or lose it') (Matshediso, 2005, p. 206). Royalty charges have been revised downwards from 5 to 3% for minerals such as coal. The fiscal regime has also been sweetened by the introduction of a generalized tax regime of 25% applicable to all minerals except diamonds. Also introduced is a 100% capital write-off in the year of investment, with an allowance for unlimited carry forward of losses (Matshediso, 2005, p. 206).

During NDP 8, the Government of Botswana adopted the policy of maintaining a balance between local generation and imports to obtain a least cost mix: Consequently, expansion of local generation was deferred to take advantage of the relatively cheap power in the region (Government of Botswana, 2009). A general weakness in the historical cost-based pricing structure in the region has been to discourage new investments (Government of Botswana, 2009). Whilst this policy enabled BPC to meet the requirements of the economy in a cost effective manner, it lulled the country into a state of complacency resulting in chronic underinvestment in the power-generation sector. The country currently suffers from bouts of load-shedding and an ever-looming uncertainty of supply due to this short-sighted policy.

Most of the new coal and hydro power projects in the recommended SAPP Plan are estimated to be around 7.5 to 8 USc/kWh (Economic Consulting Associates, 2009, p. 25). Gas turbine plants for peaking purposes average 22 USc/kWh. In contrast, in 2008 Eskom's average cost of electricity sold was 2.27 USc/kWh and its average selling price was 2.33 USc/kWh (Economic Consulting Associates, 2009, p. 25): Sales of electricity to neighbouring countries were at an even lower average price of 1.70 USc/kWh. This is the reason why potential regional projects oriented to supplying South Africa have so far not been able to compete with Eskom's extremely low cost structure (Economic Consulting Associates, 2009, p. 25).

The results of financial and economic analyses on Morupule-B support the implementation of the project: The Base Case FIRR is estimated at 6.7%, which is greater than BPC's estimated Weighted Average Cost of Capital (WACC) of 5.0% and the Base Case EIRR is estimated at 24.9%, which is greater than the assumed Economic Opportunity Cost of Capital (EOCK) in Botswana of 12.0% (all rates are expressed in real terms) (African Development

Bank, 2009, p. 10). The level of the returns computed in the financial and economic analyses are impacted by the prevailing low tariff levels and the very high cost of alternative technologies respectively (African Development Bank, 2009, p. 10).

The Government of Botswana (GoB) has successfully mobilized the required external financial resources for the Morupule-B phase 1 project from the Industrial and Commercial Bank of China and Standard Bank Consortium (ICBC-SB) and the IBRD (African Development Bank, 2009, p. 2). ICBC-SB signed a 20 year loan agreement for US$ 825 million on the 15th June 2009 (African Development Bank, 2009, p. 2). Capital funding requirements (per megawatt of electricity produced) have shot up since the 1980s (African Development Bank, 2009, p. 2). Table 2.4c shows the breakdown of components of the Morupule-A plant by cost and by financier: The figures under consideration were much less than those for corresponding aspects of the Morupule-B project over 20 years later.

Table 2.4c: Funding breakdown for project components of Morupule-B Phase 1 (Source: African Development Bank, 2009, p.4)

	Component name	Est. cost (UA million)	Component description
A	Power Plant (including the fuel for commissioning)	688.1	• Supply and installation of a 600 MW pulverised coal fired power plant comprising 4 units of 150 MW each • Fuel used during the commissioning of each of the 4 generating units prior to full commercial operation
B	Water Supply System Development	50.7	• Includes an interconnection to the existing North-South Carrier and, as a backup, new water supply developments including wells and pipelines
C	Power Transmission System and Substations	150.8	• One 400kV, 105 km transmission line from Morupule "B" to an existing 400/220 kV substation near Selibe-Phikwe (Phokoje substation). Line to include optical ground wire cable (OPGW) for optic fibre telecommunication facilities • A new 400/220 kV substation to be developed about 60 km from Gaborone (Isang substation), • One 400 kV, 215 km transmission line from Morupule "B" to Isang 400/220 kV substation, a new substation referred to above. Line to include optical ground wire cable (OPGW) for optic fibre telecommunication facilities. • Reactive Power Compensation equipment to be installed for secure transfer of up to 530 MW to either Phokoje or Isang after loss of any one of the 400 kV transmission lines connecting the power plant to the grid • Inter-tie line 400/220 kV power transformer to link the existing Morupule "A" to the proposed Morupule-B power plant • Automatic Generation Control Equipment
D	Technical Assistance	2.8	• Control Area Establishment • Training of Power Plant Operators • Harmonic Studies • Feasibility Study of 200 MW Concentrating Solar Power • Carbon Capture Readiness
E	Project Supervision & Management	13.0	• Consultancy Services for Project Supervision and Management • Environmental and Social Management Plan (ESMP), including Resettlement Action (RAP)
	Total	905.4	

2.5 FURTHER ISSUES ASSOCIATED WITH COAL IN BOTSWANA

2.5.1A BOTSWANA'S NATURAL VEGETATION RESOURCE

Forests store about 45% of the world's terrestrial carbon in wood, leaves, roots and soil, (Romijn, et al., 2015), a process called sequestration of carbon. Earth observing satellite data analyses, together with field-based national forest inventories provide data on forest cover and forest cover change at national scale (Romijn, et al., 2015). Satellite data, for example the 250 m resolution MODIS (Moderate Resolution Imaging Spectroradiometer) time series database, can be used to undertake spatial assessments of Normalized Difference Vegetation Index (NDVI) measurements, as a surrogate indicator of green vegetation cover (Dougill, et al., 2016). Ecological surveys may also be undertaken by sampling along transects in a study area (Dougill, et al., 2016). Allometric relations are also used in ecology and forestry as an empirical framework to quantify biomass by measurements of structural or morphological parameters such as tree crown diameter (Meyer, et al., 2014).

Compared to many countries in the northern hemisphere, Botswana is not yet heavily industrialised. The landscape still has large expanses of virtually undisturbed vegetation, and woody biomass loading ranges from 3.6 to 4.3 tons per ha per annum for shrub savannah to 4.8 to 10.6 tons per ha per annum for dense forest (Mzezewa, 2009, p. 5). An estimated 20% of the land is forested land while permanent pasture covers 45% (Leete et al*.,* 2013). The natural vegetation of Botswana is varied: there is Miombo woodland in the north-east (Chobe), swamp vegetation in the north-west (Okavango) and mopani woodland in some parts of the eastern-central, north-east. The centre of the country represents a transition zone between tree savanna with mixed broad-leafed and microphyllous species in the northern part and gradually changes to microphyllous species dominated areas in the south and south-west (Mishra et al*.,* 2015).

In 2010, Botswana was estimated to have 11,351,000 hectares of forest cover (Naidoo et al*.,* 2013, p. 41). The forest carbon stock was estimated to be 646 MtC (Naidoo et al*.,* 2013, p. 41), thus giving a carbon density of 57tC/ha. Botswana is believed to be a net sink for greenhouse gases (Department of Meteorological Services, 2001, p. 11). However, other studies estimate the annual rate of deforestation (2005-2010) to be around 1% (Naidoo et al*.,* 2013, p. 9). Due to evidence of active desertification in some parts of Botswana, there have been efforts to rehabilitate degraded rangelands, for example in the Boteti sub-district (Perkins, et al., 2011).

Climatic projections suggest that Southern African savanna systems will experience an increased aridity due to higher mean temperatures and more highly variable mean annual precipitation (Mishra et al*.,* 2015): This would further reduce the greenhouse gas absorption capacity of Botswana's natural vegetation resource. Industrialisation, agriculture and the expansion of human settlements as the population increases are also likely to encroach into natural vegetation sites.

2.5.1 BOTSWANA'S INTERNATIONAL ENVIRONMENTAL AGREEMENTS

Botswana has ratified several multi-lateral environmental agreements (MEAs) that have been developed under the auspices of the United Nations. The MEAs that are within the mandate of the Ministry of Environment, Wildlife and Tourism deal with the themes of climate change, drought and desertification, biological diversity and waste management. The specific agreements are the following (Keatimilwe et al*.,* 2007, p. 1):

- Vienna Convention for the Protection of the Ozone Layer, 1985
- Montreal Protocol on Substances that Deplete the Ozone Layer, 1987
- United Nations Framework Convention on Climate Change, 1992 (including the Kyoto Protocol, 1997)

UNDER WASTE MANAGEMENT AND POLLUTION CONTROL;

- Basel Convention on the Control of Trans-boundary Movement of Hazardous Wastes and their Disposal, 1989
- Stockholm Convention on Persistent Organic Pollutants, 2001

(Keatimilwe et al*.,* 2007, p. 1).

BOTSWANA'S OTHER COMMITMENTS TO INTERNATIONAL ENVIRONMENTAL CONVENTIONS

- Wetlands of International Importance (RAMSAR Convention 1971)
- Convention on Biological Diversity (1992)
- The Convention on the International Trade in Endangered Species of Wild Flora and Fauna (CITES 1973)
- Convention to Combat Desertification (1994)
- Convention for the Protection of World Cultural and Natural Heritage (1998)

(Department of Meteorological Services, 2001, p. 42).

Botswana ratified the United Nations Framework Convention on Climate Change (UNFCCC) on 27 January, 1994, and the Convention came into force on 27 April, 1994 (Department of Meteorological Services, 2001, p. 3). Botswana's GHG emission was 7,168.7Gg CO_2 equivalent in 2000 and removal was 42,941 Gg CO_2 equivalent (Masisi, et al., 2011, p. 4). The net emission after accounting for the removal was -35,506.777 Gg CO_2 equivalent, thus indicating that Botswana was a net sink in 2000 (Masisi, et al., 2011, p. 4).

2.5.1.1 UNFCCC

The most general and overarching international agreement aimed at controlling greenhouse gas emissions is known as the United Nations Framework Convention on Climate Change (UNFCCC) (Wara, 2006, p. 10). The UNFCCC has been signed by 196 parties (UNFCCC, 2015), 192 of whom are signatories to the Kyoto Protocol. The UNFCCC acknowledges that climate change is a cross-cutting and persistent crisis (UNCSD, 2012, p. 4). Although the goal defined by the UNFCCC is very ambitious, the Convention contains no provisions that compel action to accomplish it: Rather, it lays out a process through which various protocols containing more specific commitments might be negotiated (Wara, 2006, p. 11). This is the framework under which the Kyoto Protocol of 1997, which entered into force in 2005, was negotiated (Johannsdottira & McInerney, 2016).

2.5.1.2 BOTSWANA'S INTENDED NATIONALLY DETERMINED CONTRIBUTION

Under the auspices of UNFCCC, Botswana has declared its Intended Nationally Determined Contribution to the reduction of GHG (INDC). Botswana has committed to reduce her GHG emissions for the base year 2010 by 15% by the year 2030 (Government of Botswana, 2015). The GHG emission estimate for the year 2010 was 8307 Gg of CO_2 equivalent (Government of Botswana, 2015, p. 1).

In order to achieve this target, the Government of Botswana plans to develop a national policy and a long term low carbon strategy, a national adaptation plan, Nationally Appropriate Mitigation Actions (NAMAs), to identify appropriate technologies, to develop knowledge management, to educate the public and to develop a financial mechanism for emission control (Government of Botswana, 2015). Botswana's INDC further estimates that to achieve the set target of 15% GHG emission reduction by 2030, the country would require approximately USD18.4 billion (Government of Botswana, 2015, p. 2): The INDC, however, does not specify how it arrived at this figure; Neither does it spell out how the funds may be sourced. Overall, the INDC is a shallow document that lacks specifics, thus would benefit from more details.

2.5.1.3 THE KYOTO PROTOCOL

The Kyoto Protocol establishes binding caps on emissions for developed nation parties and parties with economies in transition (United Nations, 2016). These caps are limits on emissions of GHGs during the 2008-2012 period and are set as reductions below each party's 1990 emission level of six GHGs: CO_2, methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), and sulphur hexafluoride (SF_6) (UNFCCC, 2014).

The Kyoto Protocol follows the fundamental UNFCCC principle of "common but differentiated responsibility" which recognizes that the burden of responsibility should fall heaviest on the countries which have historically emitted the greatest quantity of GHGs (Marciano, 2011, p. 1). Whilst The Kyoto Protocol is a vehicle under the auspices of UNFCCC, it should be noted that not all parties to the UNFCCC are signatories to The Kyoto Protocol. The Kyoto Protocol includes various “flexible mechanisms” aimed at reducing the cost of compliance for the Annex I parties, including provisions allowing parties to trade their allowable emissions (Wara, 2006, p. 11).

Carbon Markets are very cost-effective tools for mitigating emissions because they stimulate investments in innovative low-carbon energy-efficient technologies (Johannsdottira & McInerney, 2016). However, African countries have hardly used the opportunity to implement projects that benefit from any of the mechanisms under the Kyoto Protocol (Röttgers & Grote, 2014). Such mechanisms include Joint Implementation (JI), Emission Trading and the Clean Development Mechanism (CDM) (Marciano, 2011, p. 2).

Even though The Kyoto Protocol would have officially expired in 2012 (Thurner & Varughese, 2013), the second commitment period was initiated in 2012 (UNFCCC, 2015), hence its mechanisms continue to be used.

2.5.1.4 CLEAN DEVELOPMENT MECHANISM (CDM)

Global warming is one of the most difficult and important challenges facing the international community, and arguably the most substantial effort to address this problem to date is the Kyoto Protocol (Wara, 2006, p. 5) of which the Clean Development Mechanism (CDM) is a component. The stated purpose of the Clean Development Mechanism is to help developing (non-Annex 1) countries achieve sustainable development, and assist industrialized (Annex I) countries in complying with their emission reduction commitments (Marciano, 2011, p. 1). The Clean Development Mechanism, a market-based trading mechanism created by the Kyoto Protocol, functions by delivering a subsidy to the developing world in return for lower emissions of greenhouse gases (UNFCCC, 2014).

The CDM was intended as a zero-sum instrument, allowing high emissions in developed countries in exchange for corresponding decreased emissions in developing countries, with no net impact on global GHG emissions (Spalding-Fecher et al*.,* 2012). CDM awards certified emission reductions (CERs) to qualifying projects; the CERs are then sold to developed countries, which use them to meet a part of their reduction commitments under the Kyoto Protocol (Marciano, 2011, p. 1). CDM is a market in that its subsidy is delivered through the creation of Certified Emissions Reductions (CERs, also known as "offset credits"): the tradable credits are also usable as compliance instruments for developed nations' Kyoto obligations (Wara, 2006, p. 7).

CDM has been criticized for not committing the largest developing nations, most notably China and India, to binding emissions reductions (Council on Foreign Relations, 2013), and for making significant concessions to particular parties such as the Russian Federation and Ukraine being allowed to join the Protocol with commitments of a 0% reduction below 1990 levels (Wara, 2006, p. 12). Trade in CERs currently runs to an estimated $10bn a year, fuelling a gigantic, global carbon trading market that is raking in huge profits for financing companies, consulting firms, brokers, and other market players (Marciano, 2011, p. 2). An example of an active CDM project in southern Africa is a large-scale afforestation project in the Democratic Republic of the Congo, the Ibi Batéké degraded savannah afforestation project for fuelwood production (Naidoo et al*.,* 2013, p. 23).

Being a developing country party to the Kyoto Protocol, Botswana could utilise the CDM vehicle to develop renewable energy projects.

2.5.1.5 JOINT IMPLEMENTATION

Under the auspices of the Kyoto Protocol, the Joint Implementation mechanism allows a country with an emission reduction or limitation commitment under the Kyoto Protocol to earn emission reduction units from an emission-reduction or emission removal project in a different country (UNFCCC, 2014). The sponsoring party benefits from a flexible and cost-efficient means of fulfilling a part of their obligations, while the host party benefits from foreign investment and technology transfer (UNFCCC, 2014). An example of usage of Joint Implementation is the coal mine methane utilisation project on the Shcheglovskaya-Glubokaya Coal Mine in Ukraine; a project in partnership with The Netherlands (UNFCCC, 2016).

Joint Implementation has specifically been designed as an instrument that operates solely within and among Annex 1 parties to the Kyoto protocol (developed countries) (Arhin & Atela, 2015, p. 46); as such, countries like Botswana are excluded from its scope.

2.5.1.6 EMISSION TRADING

International Emissions Trading permits countries to sell excess capacity of emissions "permitted" but not used (according to national targets) to countries exceeding their targets (Johannsdottira & McInerney, 2016). Using an emission rights trading scheme to manage its own overall emission ceilings, each country allocates the amount of rights under its ceiling to domestic companies (Röttgers & Grote, 2014): If those companies exceed their individual quotas, they may purchase 'spare credits' from companies within the developed world.

Since Emission Trading under the auspices of UNFCCC is specifically designed to be between Annex 1 (developed country) parties, it automatically excludes parties like Botswana.

2.5.1.7 REDD+

REDD-plus ('Reducing Emissions from Deforestation and forest Degradation in developing countries, and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks in developing countries') is an initiative of the UNFCCC from 2005 (Foundation for International Environment Law and Development, 2012, p. 4). The basic idea behind REDD+ is that countries willing and able to reduce emissions from deforestation should be financially compensated for doing so (Parker et al*.,* 2009, p. 14).

Many people, especially the poor, depend directly on ecosystems for their livelihoods, their economic, social and physical well-being, and their cultural heritage (UNCSD, 2012, p. 5). REDD+ is motivated by the fact that forests provide essential ecosystem services beyond carbon storage – such as watershed protection, water flow regulation, nutrient recycling, rainfall generation and disease regulation (Parker et al*.,* 2009, p. 13), so its goals dovetail with the principle of environmental sustainability.

In 2007 the COP-13 meeting of the UNFCCC adopted the 'Bali Action Plan', which provided the basis for the negotiations on REDD-plus (Foundation for International Environment Law and Development, 2012, p. 4). This has been followed by further decisions at the COPs in Cancun (2010) and Durban (2011) (Foundation for International Environment Law and Development, 2012, p. 4). The main body for the REDD-plus negotiations has been the Ad Hoc Working Group on Long-term Cooperative Action under the Convention (AWG-LCA), together with the Subsidiary Body for Scientific and Technological Advice (SBSTA) (Foundation for International Environment Law and Development, 2012, p. 5). COP 17 In Durban also launched the Green Climate Fund, which will include REDD+ (Foundation for International Environment Law and Development, 2012, p. 4).

2.5.1.8 NAMAs

The Nationally Appropriate Mitigation Actions (NAMAs) concept was first adopted in Bali in 2007 and formalized in the 2009 Copenhagen Accord and the 2010 Cancun Agreements of the United Nations Framework Convention on Climate Change (UNFCCC) (Röser et al*.,* 2011, p. 4). NAMAs are a new policy instrument which provides a mechanism for finance, technology and capacity building transfer from developed to developing countries to support efforts to mitigate climate change (Röser & Vit, 2012).

Being a relatively new concept, NAMAs have not yet fully developed: for example, NAMAs that were presented so far vary significantly with regard to their level of detail on proposed actions, expected GHG mitigation and co-benefits, and proposed monitoring, reporting and verification (MRV) methods (Röser et al*.,* 2011, p. 6). Under NAMA, unilateral mitigation actions undertaken by developing countries are only subject to domestic Measurement, Reporting and Verification (MRV) (Schwarte et al*.,* 2012, p. 3), and results should be reported every two years as part of their national communications. Probably the most successful NAMA currently in the implementation stage is the South African Renewable Initiative (SARI), which aims to mobilise funding, both domestic and international, and increase sector expertise to stimulate renewable energy in South Africa through 2030 (DLA Piper, 2012, p. 3).

There are three types of NAMAs under discussion, based on the sources of funding (Röser, Tilburg, Davis, & Höhne, 2011, p. 5):

1. Unilateral NAMAs which are financed and supported entirely by the host country,
2. Supported NAMAs which are supported internationally,
3. NAMAs Financed through carbon credits

International finance for NAMAs is likely to come from bilateral and multilateral sources, and through the planned Green Climate Fund (Röser et al*.,* 2011, p. 5). Supporting climate finance from Annex I countries is likely to flow through various channels. The most prominent financial facility proposed to fund NAMAs is the Green Climate Fund (GCF), earmarked to process an estimated US$ 100 billion per year once (and if) it becomes operational (Schwarte et al., 2012, p. 7).

Botswana has submitted NAMAs under the type 'Policies and programmes' (under both 'Unilateral NAMAs' and 'Supported NAMAs' categories), and had not yet submitted anything by 2011 under 'Emission targets' (see Röser et al., 2011, p. 6). The NAMA tool or mechanism is still abstract (Röser et al., 2011, p. 14). A detailed definition of NAMA does not yet exist at the international policy level: Different NAMA typologies are emerging based on different activities and scope (Röser & Vit, 2012, p. 1).

This project has opted not to use NAMAs as the guiding principle for research as the methodology is yet to become fully developed and information on NAMAs in Botswana is still too scarce to serve for detailed analysis.

2.5.2 AIR POLLUTION AND EMISSIONS

After analysing the source of GHG emissions in the atmosphere, it is evident that, worldwide, an estimated 83% of total GHG emissions are related to energy, primarily the burning of fossil fuels (Connolly, 2011, p. 24). In 2000, 1,950.64 Gg CO_2 eq. were emitted into the atmosphere from electric energy production in Botswana, comprising 26.2% of total national GHG emissions (Masisi, et al., 2011, p. 36). The Air Quality Impact Report compiled by *Airshed Planning Professionals* in 2004 indicated that the initial phase of the Morupule Power Station (Morupule-A) contributed approximately 32.6%, 0.3% and 0.01% of the country's total CO_2, NO_2 and CH_4 emissions respectively (African Development Bank, 2009, p. 13). Table 2.5a shows that in 1994, the energy sector contributed about 41% of all greenhouse gas emissions produced, making energy one of the major sources of GHG for the entire country (in comparison the industry sector accounted for only about 2.2 % of all GHG emissions (Department of Meteorological Services, 2001, p. 12).

Table 2.5a: Summary of GHG emissions and removals in 1994 (Source: Department of Meteorological Services, 2001, p.12)

Greenhouse gas source and sink categories	CO_2 (Gg/ year)	CH_4 (Gg/ year)	N_2O (Gg/ year)	CO_2 equivalent (Gg/ year)
All energy	3038	25	1	3 866
Industrial processes			0.7	211
Agriculture		169	5	5 067
Land use change and forestry	-38 734			-38 734
Waste		8		172
Total (net national emission removal)	-35 697	126	7	-29 418

In the year 2001, the power sector in Botswana accounted for an estimated was 19% of the global warming potential of all GHGs in the country, second only to agriculture at 55% (Table 2.5b).

Table 2.5b: Percentage contribution of national emissions by various economic sectors (Source: Department of Meteorological Services, 2001, p.32)

Economic Sector	CO_2	CH_4	N_2O	All gases GWP	Main sources of emissions
Power generation (total Electricity generated in the country)	53	0	7	19	Coal-fired power station
Households	2	6	1	4	Fuelwood
Transport	24	0	4	9	Petrol
Mining and Industry	16	6	12	11	Explosives
Government	4	0	1	1	Petrol and diesel
Agriculture	1	84	75	55	Savannah burning, Enteric fermentation from cattle
Trade and Hotel	0	0	0	0	LPG and paraffin

The IPCC Tier 1 methodology and default emission factors were used throughout, except for the CO_2 emission factor for coal. An emission factor of92 tCO_2/TJ was used instead of the IPCC default value of 95tCO_2/TJ, based on the characteristics of the coal mined in Botswana. The energy content of the coal is low (24.0 MJ/kg), as is the carbon content, at 53.9% (Department of Meteorological Services, 2001, p. 34).

Using information from Table 2.5a, in 1994 the GHG emissions from the energy sector were 3,866 Million tons CO_2 equivalent, of which (from table 2.5b) 19% was attributed to coal-fired electricity generation.

19% X 3,866 Million tons CO_2 equivalent = 734.54 Million tons CO_2 equivalent

2.5.2.1 AIR POLLUTION AND EMISSIONS FROM POWERS STATIONS ON BOTSWANA-SOUTH AFRICA BORDER

It is worth emphasising that emissions do not follow geographical boundaries, but various gases depend on the dispersion mechanism dictated by the continuous random movement of the air. There are several planned and existing coal-combustion projects on both sides of the Botswana-South African border to the south-east of Botswana / north-east of South Africa. Table 2.5c is a summary of the GHG emission estimates for all the coal projects in the region straddling the border between both Kgatleng & Central disricts on the Botswana side, and the Limpopo province on the South African side.

Table 2.5c: Emission estimates of critical pollutants from the various energy projects in the Botswana-South Africa border area (Source: World Bank, 2012)

PROJECTS	OUTPUT	SO_2	SO_2 (with sulphur	PM_{10}	NO_2
	(MW)	(Tonnes per annum)			
SOUTH AFRICA:					
Matimba	3,990	263,259	263,259	6,175	96,461
Medupi	4,800	363,895	191,045	7,429	116,043
Mafutha		120,801	12,080	7,600	71,601
Coal 3	5,400	363,895	36,390	8,357	130,549
Coal 4	5,400	363,895	36,390	8,357	130,549
SOUTH AFRICA TOTAL:	**19,590**	**1,475,745**	**539,164**	**37,918**	**545,203**
BOTSWANA:					
Morupule-A	118	8, 946	895	183	2,853
Morupule-B	1,200	90, 974	9,097	1,857	29,011
Mmamabula	2,700	107, 198	107,198	4,081	54,049
Mmamantswe	2,000	151, 623	15,162	3,095	48,351
BOTSWANA TOTAL:	**6,018**	**358, 741**	**132,352**	**9,216**	**134,264**
GRAND TOTAL:	**25,608**	**1, 834, 486**	**671,516**	**47,134**	**679,467**

The Mmamantswe project in the Kgatleng District of Botswana is one of the projects expected to develop coal-fired power stations in the near future. For the Mmamantswe project, Dispersion simulation of ambient particulate and gaseous concentrations and dust fallout from the power plant and associated infrastructure (i.e. ash disposal site etc.), for both construction and routine operating conditions (no information on upset conditions was available) were undertaken using the regional *Industrial Source Complex - American Meteorological Society/Environmental Protection Agency Regulatory Model* (ISC-AERMOD) model for a stack height of 150m (Mmereki, 2012). Three sets of criteria were referenced, namely World Bank guidelines (WBG), the World Health organization (WHO) guidelines, and Botswana's air quality legislation. The WGB guidelines provide guidance on acceptable emission limits for thermal Power Plants and General Ambient Air Quality. Botswana's legislation also provides ambient air quality guidelines for various pollutants and is given preference in the impact assessment (Mmereki, 2012).

2.5.3 TECHNOLOGICAL INTERVENTIONS TO MINIMISE THE IMPACTS OF COAL-FIRED POWER STATIONS

Whilst coal-fired power stations are associated with severe pollution, there are some technological interventions that can be employed to reduce such impacts. The use of dry-cooling through the use of air cooled condensers as opposed to a wet cooling tower system will reduce water consumption by as much as 70 to 90% (African Development Bank, 2009, p. 6). This intervention is especially relevant to water-stressed countries like Botswana. The installation of electrostatic precipitators can also help to minimise particulate emissions from power plants.

The Johannesburg Plan of Implementation of the World Summit on Sustainable Development in 2002 called for the promotion and facilitation the transfer and diffusion of environmentally sound technologies and corresponding know-how, in particular to developing countries, on favourable terms, including on concessional and preferential terms (UNCSD, 2012, p. 47). However, technology interventions that improve the emission credentials of power plants come at a trade-off to efficiency: At the current state of technology, units retrofitted with CO_2 capture would suffer a decrease in efficiency of up to 12 percentage points, and consume perhaps 20% to 30% more fuel per unit of electricity supplied (Coal Industry Advisory Board, 2010, p. 15).

2.5.3.1CARBON CAPTURE AND STORAGE

SASOL, a South-African energy company, has proposed to the Botswana Government on the possibility of storing CO_2 from its South-African operations in Botswana (Connick et al*.,* 2010, p. 13). The Government of Botswana is reluctant to allow the construction of a carbon capture storage (CCS) plant in Botswana: Senior government officials inferred that government is still monitoring global developments regarding such storage plants, and that it would be too risky to embark on such a project before its pros and cons are known (Coninck et al., 2010, p. 13, *citing Botswana Daily News article: 'carbon capture too risky'* Dated 12 December 2007).

Experts agree that CO_2 capture and storage technology (CCS), together with improved energy conversion efficiency, is a near term solution to reducing carbon dioxide emissions from fossil fuel power generation on a *massive* scale: they believe that Its *immediate* deployment is vital if we are to avoid more catastrophic consequences of climate change (Advisory Council for Zero Emissions, 2007, p. 7). Despite most of the technology elements being available, CCS is still not deployed for two key reasons (Advisory Council for Zero Emissions, 2007, p. 5):

1. The costs and risks still outweigh the commercial benefits
2. The regulatory framework for CO_2 storage is not sufficiently defined.

However, some observers regard CCS as a safe and efficient method of capturing and storing billions of tonnes of CO_2 emissions underground for thousands of years, and believe that CCS represents the bridge to a sustainable energy system, with some claiming that "Indeed, if deployed to its full potential, it could reduce CO_2 emissions in the EU by 56% by 2050, compared to today” (Advisory Council for Zero Emissions, 2007, p. 11).

2.5.4 NON-EMISSION ENVIRONMENTAL IMPACTS OF POWER STATIONS

Over and above the emissions from power stations, there are other environmental impacts associated with coal-fired power generation. These include water usage, solid wastes and land cover / land use impacts. The total raw water used at Morupule power plant for the year 2010/11 stood at 570,695 m^3 while the 2009/10 usage was 393,188 m^3 (Botswana Power Corporation, 2012, p. 13). The area required for the Morupule-B plant is approximately 476 ha (World Bank, 2012) while the proposed area that has been assessed for the Mmamabula energy project (including ancillary services) is approximately 3000 ha (World Bank, 2012). For solid wastes, BPC disposed a total of 37,167 tonnes of fly ash in 2009/10 through sales to a local cement manufacturer (Botswana Power Corporation, 2012, p. 13).

2.5.5 SOCIO-ECONOMIC IMPLICATIONS OF COAL-FIRED POWER STATIONS

In Botswana, the majority (90%) of the rural population continues to depend on fuelwood for everyday energy needs (Government of Botswana, 2009). In 1994, water and electricity were reported as contributing only 2.2% of the GDP of Botswana (Department of Meteorological Services, 2001, p. 11), and One quarter of the electricity consumed in Botswana was imported from the southern African power pool. Nearly 50% of methane emissions from Botswana in 1994 were reported to originate from enteric fermentation in livestock (Department of Meteorological Services, 2001, p. 12). Electricity sales totalled 807 GWh in 1986, with 40% for Bamangwato Concessions Limited (BCL) alone (African Development Bank, 1997, p. 4).

The government of Botswana has undertaken an accelerated rural electrification process, so the total usage of electricity nationally continues to rise. Over the NDP 8 period, rural electrification was ramped-up from the initial 14 villages annually to 72 villages over a period of two years (Government of Botswana, 2009). Electricity tariffs were only increased twice; in February 1999 and June 2002, by 5% in each instance (Government of Botswana, 2009). Rural Electrification Collective Scheme (RECS) was reviewed in April 2000 allowing for a decrease of upfront connection costs from 10% to 5% and repayment of the remaining 95% over 15 years instead of 10 years (Government of Botswana, 2009).

National energy security is challenged by the volatility of international oil prices (which in 2008 alone saw prices rise from below US$60 /barrel to over US$140 /barrel and back to below US$50 /barrel) (Mzezewa, 2009, p. 29). It is imperative upon all countries to ensure that they have internal energy sources or at least diversify the places from which they source fuels: Botswana is however landlocked and continues to depend overly on South-Africa for her energy imports; Nearly 100% of the petrol, diesel and paraffin fuel marketed in Botswana is imported by the five multi-national oil companies (*Puma, Shell, Caltex, Total* and *Engen*) mainly from South Africa (UNEP, 2012, p. 11).

Even though energy and environment issues affect livelihoods directly, the general public appears not to be too interested in engaging the coal companies in a meaningful dialogue as far as environmental issues are concerned; for example, a public meeting was held at

Palapye main *Kgotla* on September 4, 2007 to discuss environmental issues associated with the Morupule-B project: However, the meeting was attended by only 31 people, including the consultancy team and representatives from BPC (African Development Bank, 2009, pp. 8-9).

2.5.6 INTERNATIONAL STANDARDS IN THE ENERGY SECTOR

The International Organization for Standardisation (ISO) was founded in 1947, and now has a membership of 160 national standards institutes from countries in all regions of the world (ISO, 2009). ISO develops and publishes International Standards across themes such as quality management, environmental management, social responsibility, energy management, risk management, food safety management and medical devices (ISO, 2016). ISO currently has a portfolio of more than 18,000 standards (ISO, 2009). Two broad standards pertinent to this study are ISO 14000 (Environmental Management) and ISO 50000 (Energy Management).

The ISO 14000 family of standards provides practical tools for companies and organizations of all kinds looking to manage their environmental responsibilities (ISO, 2016). Within the broader framework of ISO 14000, there are specific standards that focus on specific aspects, for example: environmental systems (ISO 14001:2015), communications (ISO 14063:2006), international greenhouse gas (GHG) accounting and verification (ISO 14064:2006), environmental performance (ISO 14031:2013) labelling (ISO 14021:2016), life cycle analysis (ISO 14040 / 14044:2006) (ISO, 2016).

The ISO 50000 family of standards are designed to provide guidance for energy management. ISO 50001:2011 outlines specifications for establishing, implementing, maintaining and improving an energy management system (ISO, 2016). The function of an energy management system is to allow an organization to follow a systematic method in achieving continued enhancement of energy performance, including efficiency, use and consumption (ISO, 2016). ISO 50001:2011 specifies requirements applicable to energy use and consumption, including measurement, documentation and reporting, design and procurement practices for equipment, systems, processes and personnel that contribute to energy performance (ISO, 2016).

Energy and environmental management standards are important because they provide systematic benchmarks with specific minimum deliverables for organisations. Nowadays governments, civic society organisations and individual consumers increasingly expect organisations to demonstrate genuine concern for the environment. ISO standards serve as a tool to audit organisations for compliance, so environmental and energy standards are relevant to this study since it addresses GHG emissions by a particular power station.

2.6 ENERGY ALTERNATIVES

2.6.1 SOLAR ENERGY

There is tremendous potential to be realized from solar energy. The proportion of solar radiation that reaches the Earth's surface is more than 10,000 times the current annual global energy consumption (Sims et al*.,* 2007, p. 278). Botswana has a tremendous potential for solar energy that must be exploited, especially for rural communities not catered for by the national grid (Vision 2016, 1997). The mean annual solar insolation is 21 MJ per m^2 per day, one of the highest radiation levels in the world (Mzezewa, 2009, p. 5). There are over 3,200 hours of sunshine per year, cloudy days are relatively few; on average there are over 300 days of sunshine annually (Mzezewa, 2009, p. 22). Botswana Solar Thermal Electricity Generation Project (BSTEP) is a project that intends to implement a one-megawatt (1MW) solar demonstration project in Botswana. The Vision 2016 document further suggests that Botswana be developed as a centre of excellence for solar energy technology (Vision 2016, 1997, p. 34).

Technology has not yet developed to a stage where the costs associated with exploiting solar energy at a large scale become lower than simple costs for usage of fossil fuels (Baker *et al.,* 2013). Botswana has a long history of disseminating solar PV (photo-voltaic) technologies to communities. Previous notable projects that have been undertaken include: Manyana PV pilot project, Motshegaletau centralised PV pilot project, the National Photovoltaic Rural Electrification Programme (Department of Meteorological Services, 2004, pp. 17-18). Solar International is providing solar PV off-grid mini-grids and in some instances hybrid with diesel generator sets (Department of Meteorological Services, 2004). An example of where these have been tried in Botswana is the Remote Area Development Programme in the following areas:

- Central District Council: Mokgenene 52 km West of Dibete and Khwee 60 km south west of Letlhakane where 20 panels of 300 Wp (6 kW) were installed in each settlement (Department of Meteorological Services, 2004, p. 18);

- Ghanzi District Council: New Xade where 12 panels of 3600 Wp each (42 kW) and a 3-phase diesel generator set were installed (Department of Meteorological Services, 2004, p. 18).

The cost of harnessing solar energy is still significantly above that of a coal plant investment per kW, especially at utility level (Reichelstein & Yorston, 2013). The uptake of solar electricity is still very low at 0.23 percent of households countrywide (Masisi, et al., 2011, p. 72). There are other vulnerabilities associated with photovoltaic systems, for example, during the NDP 8 period, the National Photovoltaic Rural Electrification Programme (NPVREP) had about 70% customers in default of payment, while also, solar panels belonging to various institutions (mainly Police, Botswana Defence Force (BDF), and Botswana Telecommunications Corporation) were stolen, leading to financial losses of about P8 million (Government of Botswana, 2009). However, with the abundance of solar energy in

Botswana, there is potential for solar pumping, solar water heating, passive solar designs, solar PV and solar cooking (Department of Meteorological Services, 2004, p. xi).

2.6.2 OTHER ALTERNATIVE ENERGY RESOURCES

Fossil fuels still dominate energy consumption globally, with a market share of 87%. Renewable energy continues to gain but today accounts for only 2% of energy consumption globally (British Petroleum, 2012, p. 1). However, Large-scale renewable power is the largest CDM project category, and registered CDM projects have accounted for more than 110,000 MW of renewable electricity capacity globally over the last 10 years (Spalding-Fecher et al., 2012, p. 9). Coal-bed methane gas has been discovered in the north-eastern part of Botswana, estimated by the developers at a commercially viable quantity of 12 trillion cubic feet (Masisi, et al., 2011, p. 26).

Botswana has a potential to produce bio-fuels (biodiesel from Jatropha seeds, ethanol from sweet sorghum and bio-gel) (Mzezewa, 2009, p. 22). However, long gestation periods (3 to 5 years) in bio-fuels for the investments to start showing returns (Mzezewa, 2009, p. 29) and market insecurity are de-motivating factors. As for wind energy, it is not considered very viable in the context of Botswana's geography; Average wind speeds range from only 2.0 to 3.5 m/s, considered too low for viable wind based power generation (Mzezewa, 2009, p. 5). The utilisation of landfill waste, abattoir waste and manure to generate biogas for domestic, institutional and industrial use is feasible (Department of Meteorological Services, 2004, p. xi), but it may only be at small localized scales.

2.7 RESEARCH GAP

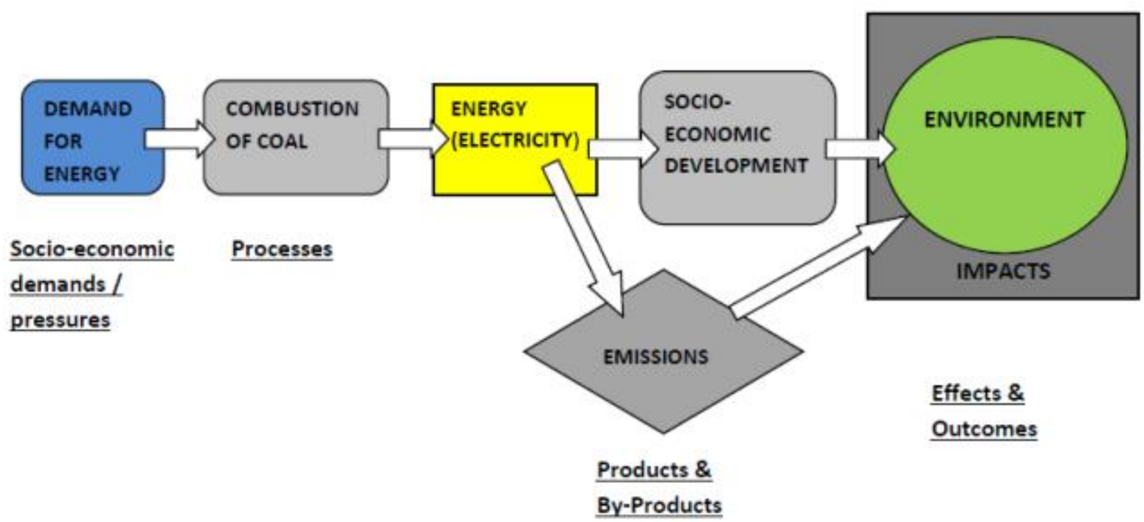
While information on various aspects of coal generation in Botswana may be gleaned from various sources, it is mostly parochial and of disjointed focus. More synthesised information is to be found in periodic government reports to international agencies like the United Nations. However, some of such reports tend to use aged data; an example being Botswana's Second National Communication to the United Nations Framework Convention on Climate Change published in 2012 – Much of the data alluded to in this report is from 1994 whilst the population data was from the 2001 census and the data on emissions is for the year 2000. It would be beneficial for more research and publications on this topic to see the light of day, hence this study.

2.8 CONCEPTUAL FRAMEWORK

The conceptual framework is the guiding principle behind the research. The framework contributes to a research report in at least two ways because it identifies research variables, and also clarifies relationships among the variables (McGaghie *et al.,* 2001, p. 923). The conceptual framework ‘‘sets the stage’’ for presentation of the specific research question that drives the investigation being reported (McGaghie et al., 2001, p. 923). A *conceptual framework* is a network, or “a plane,” of interlinked concepts that together provide a comprehensive understanding of a phenomenon or phenomena (Jabareen, 2009, p. 51).

Figure 2.8 depicts the sequential linkages among attributes of coal-fired power generation, especially the greenhouse-gas emission aspect. Note that the diagram somewhat resembles a gun pointing back at the shooter, with greenhouse-gas emissions as the trigger (to represent the suicidal effect by man of pumping GHGs into the atmosphere). The energy produced (electricity) is however a desired and very useful output to society. The objective is to evaluate the scale of the two opposing outcomes and to form an informed opinion on the best course of action. Figure 2.8, together with the concept of Environmental Sustainability, was the guiding conceptual framework for this research, together with the concept of environmental sustainability.

Figure 2.8: Conceptual Framework diagram for emission impacts of coal-fired generation of electricity.



2.8.1 ENVIRONMENTAL SUSTAINABILITY

Environmental sustainability could be defined as a condition of balance, resilience, and interconnectedness that allows human society to satisfy its needs while neither exceeding the capacity of its supporting ecosystems to continue to regenerate the services necessary to meet those needs nor by our actions diminishing biological diversity (Morelli, 2011, p. 23). Definitions of 'Environmental Sustainability' are often overshadowed and befuddled by the ubiquitous definitions of 'Sustainable Development' in literature. 'Environmental sustainability' can be regarded as a subset of 'ecological sustainability' (Morelli, 2011, p. 23).

In practice, environmental sustainability can be approached from preventive "do no harm" (or safeguard) approach, to a proactive "do good" approach (which includes direct interventions, or stewardship, to improve the environments and mainstreaming of environmental concerns) (World Bank, 2008, p. 19). "Do no harm" environmental safeguards are designed so that potential adverse impacts of development projects are adequately identified, assessed and addressed through application of a relevant environmental assessment policy (World Bank, 2008, p. 24). The "Doing good" approach can be considered under three subheadings—stewardship, mainstreaming, and protecting the local and global commons (World Bank, 2008, p. 25).

There are serious real-world impediments, however, to the achievement of environmental sustainability; even assuming that there exists favourable political will, knowledge, and institutional capacity, exogenous factors will limit governments and to resolve tough environmental problems (World Bank, 2008, p. 72). Fundamental economic drivers, population growth, economic expansion, and poverty, external factors such as market, governance, and institutional failures, as well as political instability and civil unrest in fragile states all contribute to environmental degradation (World Bank, 2008, p. 72).

In an attempt to alleviate poverty by 2015, the United Nations adopted the Millennium Declaration, made up of eight Millennium Development Goals (MDGs), in September 2000 to address peace, security, development, human rights and fundamental freedoms (UNDP, 2006, p. 7). Millennium Development Goal 7 (MDG 7) sought to ensure environmental sustainability by 2015 (UNDP, 2006, p. 8): this shows that environmental sustainability is one of the main priority items on the international agenda. Millennium Development Goal 7 sought to integrate the principles of sustainable development into country policies and programmes and to reverse the loss of environmental resources (UNDP, 2006, p. 8). Indicators of environmental sustainability (the ecological aspect of it) were:

- Proportion of land area covered by forests
- Ratio of area protected to maintain biological diversity to surface area
- Energy use per $1 GDP
- Carbon dioxide emissions (per capita) and consumption of ozone-depleting chlorofluorocarbons
- Proportion of population using solid fuels (UNDP, 2006, p. 13)

It is worth noting that three of the above five indicators alluded directly to either energy or carbon emissions, which are key themes in this research.

The Millennium Development Goals have now been superseded by Sustainable Development Goals (SDGs), which still address the same pertinent issues. The SDG framework was adopted on September 25th 2015 as a set of goals to end poverty, protect the planet, and ensure prosperity for all by 2030 (United Nations, 2016). The following Goals are directly concerned with environmental sustainability;

- Goal 7: Affordable and Clean Energy
- Goal 11: Sustainable Cities and Communities,
- Goal 12: Responsible Consumption and Production,
- Goal 13: Climate Action,
- Goal 14: Life Below Water,
- Goal 15: Life on Land (United Nations, 2016).

According to the Botswana national long-term vision document (Vision 2016), by the year 2016 it was hoped that economic growth and development in Botswana will be environmentally sustainable (Vision 2016, 1997, p. 8). Vision 2016 also anticipated that there would be a fully integrated approach towards conservation and development. Vision 2016 was also in favour of the achievement of intergenerational equity as it advocates attitude towards natural resources that pay attention to a fair distribution between present and future generations (Vision 2016, 1997, p. 8). Botswana expresses deep support for the 'Green Economy' concept, as expressed in Botswana's initial submission to the United Nations Conference on Sustainable Development (UNCSD) (Botswana Government, 2011, p. 4). A 'Green Economy' is one which is low-carbon, resource efficient and socially inclusive (Botswana Government, 2011, p. 4). The Botswana Government viewpoint is further crystallized by insinuations to the effect that:

> *The current economic archetypes which support policies towards economic growth should be interrogated for their sustainability and their inadequacy in dealing with issues such as social equity, poverty eradication, ecological imbalance, environmental degradation, loss of biodiversity and climate change.*
>
> (Botswana Government, 2011, p. 3).

This project was guided by the concept and conceptual framework of Environmental Sustainability.

2.8.1.1 JUSTIFICATION FOR USING INVIRONMENTAL SUSTAINABILITY FRAMEWORK

The United Nations Conference on Sustainable Development in Rio de Janeiro in 2012 reaffirmed that climate change is one of the greatest challenges of our time, and expressed profound alarm that emissions of greenhouse gases continue to rise globally (UNCSD, 2012, p. 33). The UNCSD conference expressed deep concern that all countries, particularly developing countries, are vulnerable to the adverse impacts of climate change, and are already experiencing increased impacts including persistent drought and extreme weather events, sea level rise, coastal erosion and ocean acidification (UNCSD, 2012, p. 33). The Rio+20 conference out-come document, *The Future we want*, highlighted the importance of conservation of biodiversity, enhancing habitat connectivity and building ecosystem resilience (UNCSD, 2012, p. 35).

CHAPTER 3: RESEARCH METHODOLOGY

3.1 INTRODUCTION

This study sought to estimate the greenhouse gases emitted by the Morupule-B coal-fired electricity-generation station in Botswana.

3.2 DATA COLLECTION METHODS

Information on coal samples, technical processes and emission records was requested and obtained from the Morupule-B (Phase 1) power station. IPCC (Intergovernmental Panel on Climate Change) emissions factors were used in calculations to estimate emission levels. Document review was also undertaken to source credible secondary data relevant to the study. Furthermore, direct field visits were undertaken to Morupule for the author to familiarise himself with the study-area, and also to confirm issues raised by other data collection methods: A fact-finding trip was undertaken by the researcher to Morupule from the 13th to the 18th of April 2015 to collect data and to get a first-hand overview of the study area.

Data was collected on coal sample quality; comprising moisture content of coal, calorific value, ash content and volatile matter content – all of which are routinely sampled on a daily basis. Data was also taken on proximate chemical analysis of ash from the boilers – also sampled daily by technicians at the power station. Finally, data was also collected on the amounts of those gaseous substance emissions the power station measures, being dust, SO_2, NOx and O_2. Physical observation of Morupule-B's Safety, Health and Environment (SHE) procedures was also undertaken in practice. The researcher was also granted access to in-house documentation and records pertaining to Safety, Health and Environment.

Data indicating annual coal production and usage amounts from 2005 to 2015 was obtained from Statistics Botswana (See Central Statistics Office, Electricity Generation and Distribution-Q4 2015) (Statistics Botswana, 2016), the Department of Mines (see Department of Mines, 2009, p. 17), and the International Energy Agency (see International Energy Agency, 2016). An estimate of the greenhouse gas absorption potential of Botswana's woody biomass for the year 2000 was obtained from the Ministry of Environment, Wildlife and Tourism (see Masisi et al., 2011). Mathematical operations were carried out using IPCC emission-factor calculations, as will be outlined in section 3.3.1.2.

3.2.1 LINKAGES BETWEEN METHODOLOGY AND RESEARCH OBJECTIVES

The various aspects of the methodology of the project were aligned with each of the three research objectives as elaborated below:

1. *"To quantify the total amount of greenhouse gas emissions expected to occur annually from Morupule-B coal-fired power station in Botswana"*. This objective was achieved from emission factor calculations, used in conjunction with coal usage statistics. Coal usage quantity at Morupule-B (Phase 1) was provided by the Shift Manager as being 60 to 70 tonnes per hour for each of the four boilers when operating at full capacity. The type of coal mined at Morupule is medium to low grade sub-bituminous (Grynberg, 2012, p. 12), which has a default emission factor of 96,100 kg of carbon dioxide per TJ on a Net Calorific Basis (Gómez et al., 2006, p. 16). Calculations were done by multiplying the total quantity of coal used annually and the default emission factor to give the estimated GHG emission as the CO_2equivalent (see chapter 4.3).

2. *"To identify the implications of the GHG emissions on Botswana's commitments to international environmental conventions".* This objective was achieved by both emission factor calculations and document review. The calculated quantity of the GHG emissions was compared with Botswana's greenhouse gas absorption potential by woody biomass (obtained from the Ministry of Environment, Wildlife and Tourism: see Masisi, et al., 2011), to establish whether the additional emissions from Morupule-B (Phase 1) would in any way tip the scale to make Botswana a net emitter of GHGs. Treaty Documents for international air quality agreements such as UNFCCC were consulted to establish whether the expected additional emissions from Morupule-B and its planned expansion phases would cause Botswana to infringe on any international environmental conventions she has entered into (see chapter 4.4).

3. *"To probe, discuss and suggest possible mitigation measures against GHG emissions from the coal fired power generation projects".* This objective was achieved by direct field visits and document review. Various reports on technological interventions to ameliorate GHG emissions and other forms of pollution associated with the usage of fossil fuels for the generation of electricity were consulted to seek possible solutions. Such possible solutions include several permutations of Carbon Capture and Storage (CCS) (see chapter 4.5). These were discussed in the context of Botswana's socio-economic status and level of technical sophistication.

3.3 GENERAL METHODOLOGY

The general approach of this research was analysis of greenhouse-gas emissions associated with the Morupule-B power station and other power stations around Botswana. This is informed by the fact that there is no routine direct measurement of GHGs by power stations: Emission factors are used as a proxy mechanism for the estimation of GHGs, an international practice endorsed even by global environmental stewardship bodies. Furthermore, even if a researcher was to bring their own equipment (assuming that they would afford its very considerable costs), installing such to the chimneys would be a large operation that would need the power station to be momentarily switched off, with large scale economic and social repercussions.

3.3.1 JUSTIFICATION FOR USING EMISSION FACTORS

Conversion factors are used to calculate and quantify emissions from various greenhouse gases based upon their global warming impacts so that they can be expressed in monetary terms for carbon trading schemes such as the clean development mechanism (Wara, 2006, p. 9). As such, emission factors would be a useful method to use as they have been ingrained in the international language of environmental studies. Already, emission factors have been embraced by international agencies like the United Nations organisation and its subsidiaries. Many stakeholders have called for the use of standardized approaches, such as default values, standardized baseline emission factors, emission baselines set on a sectoral or even country-wide level (CDM Policy Dialogue, 2012, p. 64), instead of disjointed and incompatible approaches. Emission Factors are also used in the REDD+ framework (see for example; Parker et al., 2009, p. 105). The International Energy Agency also uses emission factors (International Energy Agency, 2011, p. 4).

Emission factors also provide the added flexibility of differentiated levels of operation, depending on availability of data (Bergk, Heidt, & Knörr, 2013): This makes the emission factor method applicable even in smaller and less research-intensive countries like Botswana. Advantages of the emission factor mechanism for Botswana are that basic data such as coal usage statistics are used to make fairly accurate GHG emission estimates (Mittal, Sharma, & Singh, 2010). The fact that the emission factor mechanism replicates results measured from a similar situation makes estimating emissions cheaper, especially for less economically developed countries.

The main limitation of emission factors is one of reproducibility of a scenario: no two power stations (even of the same technology, including boilers) undertake the combustion process in exactly the same way: there will always be some small variations in process specifications- even a particular power station will experience variation throughout its useful life (ICF International, 2015). Table 3.3 depicts the sector split used by IPCC to differentiate energy sources.

Table 3.3: Detailed IPCC emission factor sector-split for stationary combustion (Source: Gomez et al., 2006, p.7)

Detailed sector split for stationary combustion				
Code number and name				**Definitions**
1 ENERGY				**All GHG emissions arising from combustion and fugitive releases of fuels. Emissions from the non-energy uses of fuels are generally not included here, but reported under Industrial Processes and Product Use.**
1 A Fuel Combustion Activities				**Emissions from the intentional oxidation of materials within an apparatus that is designed to raise heat and provide it either as heat or as mechanical work to a process or for use away from the apparatus.**
1A 1	**Energy Industries**			**Comprises emissions from fuels combusted by the fuel extraction or energy-producing industries.**
1A 1	**a**	**Main Activity Electricity and Heat Production**		**Sum of emissions from main activity producers of electricity generation, combined heat and power generation and heat plants. Main activity producers (formerly known as public utilities) are defined as those undertakings whose primary activity is to supply the public. They may be in public or private ownership. Emissions from own on-site use of fuel should be included.** **Emissions from auto-producers (undertakings which generate electricity/heat wholly or partly for their own use, as an activity that supports their primary activity) should be assigned to the sector where they were generated and not under 1A1a. Auto-producers may be in public or private ownership.**
1A 1	**a**	**i**	**Electricity Generation**	**Comprises emissions from all fuel use for electricity generation from main activity producers except those from combined heat and power plants.**

3.3.1.2 EMISSION FACTORS – TECHNICAL DETAILS

In order to be able to collate and compare emission data from various sources in different geographical areas, international agencies have devised emission factors as a tool to reasonably estimate emissions from different operations. An emission factor is a tool that is used to estimate air pollutant emissions to the atmosphere by relating the quantity of pollutants released from a source to some activity associated with those emissions (Environment Protection Agency, 1997, p. 7). In general, emissions of each greenhouse gas from stationary sources are calculated by multiplying fuel consumption by the corresponding emission factor (Gómez et al*.,* 2006, p. 11). Emission factors are usually expressed as the weight of pollutant emitted divided by a unit weight, volume, distance, or duration of the activity emitting the pollutant (Environment Protection Agency, 1997, p. 7).

Emission factors are used to estimate a source's emissions by the general equation (Environment Protection Agency, 1997, p. 7):

$$\mathbf{E = A \times EF \times [1-(ER/100)]}$$

Where:

E = emissions,
A = activity rate,
EF = uncontrolled emission factor, and
ER = overall emission reduction efficiency, %.

Greenhouse gas emissions from stationary combustion can also be calculated according to the following equation (Gómez *et al.,* 2006, p. 11):

$$\mathbf{Emissions_{ghg,\ fuel} = Fuel\ Consumption_{fuel} \bullet Emission\ Factor_{ghg,\ fuel}}$$

Or total emissions by greenhouse gas (Gómez *et al.,* 2006, p. 11):

$$\mathbf{Emissions_{ghg} = \Sigma Emissions_{ghg,fuel}}$$

Different greenhouse gases have different global warming potentials, a fact that is factored in when devising emission factors. The global warming potential is expressed as the destructive effect of a unit of that gas compared to an equal unit of carbon dioxide gas.

The study considered physical environmental impacts, social impacts and economic impacts that can be anticipated in conjunction with coal-fired power stations in Botswana. The study considered both positive and negative impacts. Impacts were also considered on the basis of being onsite or offsite; direct or indirect. Various mitigation mechanisms were also be explored and linked to specific impacts.

Figure 3.3.1 shows the generalised decision tree for estimating emissions using the emission factor mechanism.

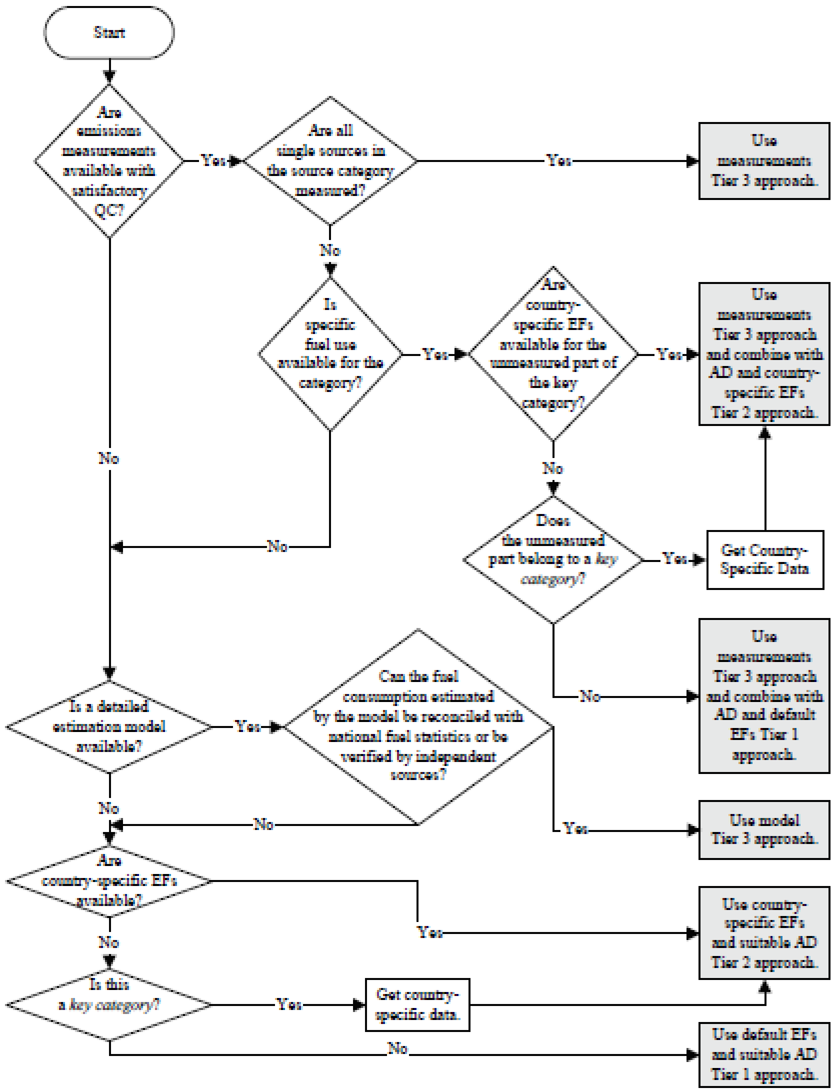


Figure 3.3.1: Generalised Decision Tree for estimating emissions from stationary combustion (Source: IPCC 2006, p. 15)

Table 3.3.1 details the default emission factors for stationary combustion in the energy industries (kg of greenhouse gas per TJ on a Net Calorific Basis (Source: IPCC, 2006, p.16)). Table 3.3.2 shows the global warming potential of various GHGs. Both of these tables show various facets of the destructive effects of GHGs in measurable terms.

Table 3.3.1: Default emission factors for stationary combustion in the energy industries (kg of GHG per TJ on a net calorific basis (Source: IPCC, 2006, p.16))

Fuel	CO_2			CH_4			N_2O		
	Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper	Default Emission Factor	Lower	Upper
Anthracite	98 300	94 600	101 000	1	0.3	3	1.5	0.5	5
Coking Coal	94 600	87 300	101 000	1	0.3	3	1.5	0.5	5
Other Bituminous Coal	94 600	89 500	99 700	1	0.3	3	1.5	0.5	5
Sub-Bituminous Coal	96 100	92 800	100 000	1	0.3	3	1.5	0.5	5
Lignite	101000	90 900	115 000	1	0.3	3	1.5	0.5	5
Oil Shale and Tar Sands	107 000	90 200	125 000	1	0.3	3	1.5	0.5	5
Brown Coal Briquettes	97 500	87 300	109 000	1	0.3	3	1.5	0.5	5
Natural Gas	56 100	54 300	58 300	1	0.3	3	0.1	0.03	0.3

The type of coal mined at Morupule is medium to low grade sub-bituminous (Grynberg, 2012, p. 12).

The paper considered current clean energy mechanisms, philosophies enshrined in the Kyoto Protocol and current sentiments of climate change / global warming, United Nations Framework Convention on Climate Change (UNFCCC), sustainable development but within the context of economic and technological feasibility. The study also considered new technology such as Carbon Capture and Storage (CCS) as well as alternative renewable energy resources.

3.3.1.3 GLOBAL WARMING POTENTIALS

As demonstrated in Table 3.3.2, Global Warming Potentials (GWPs) highlight the importance of addressing small but significant emissions of certain GHGs (Wara, 2006, p. 10). Different methods can be used to estimate emissions from most categories. The selection of a particular method will depend on the desired degree of estimation detail, the availability of activity data and emission factors, and the financial and human resources available to complete the inventory (UNFCCC, 2009, p. 12). In most cases, emission factors are simply averages of available data of acceptable quality, and are generally assumed to be representative of long-term averages for all facilities in the source category (Environment Protection Agency, 1997, p. 7).

Table 3.3.2: Global warming potentials of some of the major greenhouse gases (Source: Department of Meteorological Services, 2001, p.31)

Greenhouse Gas	Formula	Global Warming Potential
Carbon dioxide	CO_2	1
Methane	CH_4	21
Nitrous oxide	N_2O	310
Nitrogen oxides	NO_X	40
Carbon Monoxide	CO	3
Sulphur Hexafluoride	SF_6	239

Good practice is to use the most disaggregated, technology-specific and country-specific emission factors available, particularly those derived from direct measurements at the different stationary combustion sources (Gómez et al*.,* 2006, p. 24). In IPCC terminology, the lowest ranking or simplest method is "Tier 1", while more elaborate methods are "Tier 2" and "Tier 3" (UNFCCC, 2009, p. 12):

- Tier 1: fuel combustion from national energy statistics and default emission factors;
- Tier 2: fuel combustion from national energy statistics, together with country-specific emission factors, where possible, derived from national fuel characteristics;
- Tier 3: fuel statistics and data on combustion technologies applied together with technology-specific emission factors; this includes the use of models and facility level emission data, where available.

(Gómez et al*.,* 2006, p. 6)

In the IPCC format of emission factors, category 1A1ai is for 'Electricity Generation' and *c*omprises emissions from all fuel use for electricity generation from main activity producers except those from combined heat and power plants (Gómez et al*.,* 2006, p. 7). This is the category that was used for this study.

3.4 RESEARCH LIMITATIONS

This research was limited by time, scope and financial constraints. The research was done within the framework of the University of Botswana, Masters' Degree in Environmental Science programme as a semester course. The research therefore followed the traditional scale and scope of a student project.

The project compared emissions from coal fired power stations with the overall carbon-sinking potential of Botswana's vegetation: whilst the project estimated by calculating emissions itself, it fully relied on referenced sources for carbon-sink potential, which limits the scope of the study. Another limitation is that the project has not used mathematical modelling in its analysis, despite modelling being a dextrous tool for studying emissions and indeed atmospheric science in general. The project also tended to use averaged values due to persistent variations to factors such as boiler availability, coal quality, cycle variations and random variations.

The research was not fully able to compensate for externalities. The "countervailing factors problem", a constraint in terms of assessing the ultimate impact of a particular project in terms of ambient environmental quality, and the "attribution problem" are likely to complicate efforts to determine cause-and-effect relationships (World Bank, 2008, p. 96). When considering possible emissions from planned expansions to the Morupule power plant, an assumption was made that they would still use similar technology to that used at the Morupule-B (Phase 1) plant: in reality, they are likely to benefit from more enhanced technology and thus have higher efficiencies and lower emissions per unit of electricity produced.

3.5 EXPECTED OUTCOMES OF THE STUDY

The expected outcomes of this study included, among others, an estimate of Botswana's position, in a few years' time, as either a net carbon sink or a net emitter. The study also set out to offer locally-appropriate suggestions for mitigation of emissions or impacts thereof. The study also intended to produce a detailed catalogue of the coal industry in Botswana and emissions associated with it. A full write-up of this thesis will be availed to various stakeholders in both hard copy and soft copy formats.

3.6 DISSEMINATION OF FINDINGS

As per standard procedure at the University of Botswana, the findings of this study will be accessible to the entire university community as it will be part of the research repository in both the university library and at the School of Graduate Studies. The findings of this study will further be shared with important stakeholders in the environmental fraternity of Botswana, including: the Department of Environmental Affairs, The Department of Meteorological Services, The Department of Mines, The Department of Energy Affairs, *Somarelang Tikologo* and the Faculties of Science at both the University of Botswana and Botswana International University of Science and Technology, an initiative to be spearheaded by the author. A request will also be made for the study to be posted on the

University of Botswana website under the Department of Environmental Science portal. The study will also be shared with Botswana Power Corporation and the Ministry of Minerals, Energy and Water Affairs, as stated in the research permit.

CHAPTER 4: RESULTS

4.1 INTRODUCTION

This chapter is about presenting and discussing the findings of the study within the context of the objectives and key research questions. In addition to this *Introduction* section, the chapter is structured into four other sections, being 4.2: General information sourced during the site visit to Morupule in April 2015 – the information includes general environmental information not specifically about GHGs, but which will be of interest to other researchers.

Section 4.3 relates to GHG emissions from Morupule-B power station. This section addresses the first research objective of this study ("*To quantify the total amount of greenhouse gas emissions from the Morupule-B power station in Botswana*").

Section 4.4 relates the results of the study to the second research objective ("*To identify the implications of the GHG emissions on Botswana's commitments to international environmental conventions*").

Section 4.5 suggests and discusses possible mitigation measures against GHG emissions from coal fired power generation projects, in fulfilment of the third and final research objective.

4.2 GENERAL INFORMATION ABOUT MORUPULE POWER PLANTS

According to information on the technical specification sheets, the currently idle Morupule-A Power Plant used four pulverised coal (PC) boilers. At 33MW, for coal with 1% sulphur, it burned 13 to 16 tonnes of coal per hour producing 130 to 160 kg of sulphur, therefore about 260 to 320 kg per hour of sulphur dioxide. It has a 100m long chimneystack with 2.2 m internal diameter and a 7.41 m wind shield and electrostatic precipitators.

Morupule-B uses circulating fluidised bed boilers. The bed material is sand and it is heated by a diesel burner powered by fuel oil. Coal is added to the bed at an optimal temperature above 500 degrees Celsius. Limestone (calcium carbonate) is also added to remove sulphur dioxide. Large external fans (with external heat exchangers) constantly supply an optimal amount of air for complete combustion. Air destined to the furnace goes through a pre-heater where it is heated to about 250 degrees first. Water is also passed through a convective pass for pre-heating to about 250 degrees (in a unit called an 'economiser').

After combustion, exhaust gases enter the convective pass at around 890°C. The gases are subsequently cooled to around 140°C, which is both an economic and environmental consideration (to re-use some of the waste heat and to avoid exhausting gases that are too hot into the atmosphere). Morupule-B has a stack of 150m height and 3.65m diameter designed to emit gases at 130°C. Electrostatic precipitators are installed at the outlet for exhaust gases to trap fly-ash so as to minimise exhaust of suspended solids. Fly ash is stored in lagoons which however result in some contaminants seeping underground. To monitor these effects, there are sample boreholes. The fly ash can be used for bricks and cement (Botswana Power Corporation, 2012, p. 13).

On a daily basis, each of the four Morupule-B boilers uses about 400 tons of water (at full capacity). The water is abstracted from boreholes in Matsiloje and also from the North-South carrier (from Letsibogo dam). Water used in the power generation process is routinely polluted by scale formation. However, it is treated before being released to the environment.

Each of the four Morupule-B boilers (150MW each) has a 3 cylinder turbine with a re-heater system. The furnace of the boiler is lined with water tubes that absorb the heat, transferring it to the steam, which comes out at about 545°C and a pressure of around 124 Bar. At full load, the steam flow is about 500 tonnes per hour. The turbines run at about 3000 revolutions per minute driving a generator of electricity. The generator outputs about 15.75kV, which is stepped-up to 400kV (using an on-site transformer) to minimise losses during long-distance transmission.

Operating conditions at any power station will vary intermittently due to a myriad of factors. The above described conditions are therefore for 'normal' operations. For the Morupule-B power station, the randomness appears to be even more pronounced since the plant has never operated 'normally' even from the start. On Friday the 17th of April, 2015 at 11:30am, just a randomly sampled point in time, the power generation from Morupule-B was registered as follows:

Unit1: 151 MW

Unit 2: 77 MW

Unit 3: nil

Unit 4: 98 MW

This means that only one unit was operating at full capacity, two at partial capacity while the other one was totally off. This is due to various technical challenges that arise from time to time with different aspects of the power station.

4.2.1 COMPARISON OF PULVERISED COAL BOILERS TO CIRCULATING FLUIDISED BED BOILERS

Whereas the old Morupule-A power station used Pulverised Coal (PC) boilers, the Morupule-B power station uses Circulating Fluidised Bed (CFB) boilers. CFBC uses a fluidised bed, an apparatus that mixes coal and air with a sorbent such as limestone during the combustion process, to facilitate more effective chemical reactions and heat transfer (Zhu, 2013, p. 5). CFB boiler technology generally demonstrates better environmental and performance credentials, for instance, studies have established that emission for combustion of low quality coal did not exceed 250 ppm for SO_2 while combustion efficiencies were around of 98% (Belaid et al*.,* 2014, p. 72). In a CFB boiler, emissions of SOx and NOx are significantly reduced – even without the addition of expensive flue gas emissions control systems - because the lower combustion temperature (800–900°C, compared to 1300–1700°C for PC), results in much reduced NOx formation (Zhu, 2013, p. 5).

CFB boilers are more efficient to the extent that even coal of lower quality (discard coal) is now being burned profitably (Belaid et al., 2014, p. 75). Morupule-B's credentials would have been enhanced further if it had used super-critical pressure technology instead of sub-critical, which some scholars already regard as obsolete (see, for example Caldecott et al., 2015). The average subcritical coal-fired power station (SCPS) emits 75% more carbon pollution than an average advanced ultra-supercritical, with carbon-intensities exceeding 880kgCO_2/MWh (Caldecott *et al.,* 2015, p. 8).

4.2.2 AIR POLLUTION MONITORING AT MORUPULE

Under the Atmospheric Pollution Prevention Act of 1971, Botswana Power Corporation, the company managing the Morupule power stations, is required to observe stack plume characteristics three times a day. The plume can have different characteristics, which have a bearing on the efficiency or lack thereof of dilution of pollutants into the atmosphere. The characteristics are: coning, looping, fanning, fumigating and lofting.

Four URAS 14 Advanced Optima Analysers are used to monitor sulphur dioxide in each boiler. Ambient sulphur dioxide is measured using a Pulsed Fluorescence SO_2 Analyser (model 43C).

PM10 is measured using a FH62I-R sampler.

The measured emissions for the Morupule-B power station from April 2014 to March 2015 are depicted in Table 4.2.2 as follows:

MONTH	DUST (TONS)	SO_2(TONS)	NO_X(TONS)	O_2(TONS)
APRIL 2014	0.09	296.98	16.38	29,697.9
MAY 2014	20.53	676.45	76.33	68,599.1
JUNE 2014	18.36	677.32	78.38	74,119.1
JULY 2014	13.47	790.66	87.29	79,880.2
AUGUST 2014	7.32	699.11	106.73	72,706.4
SEPTEMBER 2014	14.81	498.88	61.24	52,486.7
OCTOBER 2014	12.32	167.54	19.89	26,431.3
NOVEMBER 2014	18.12	340.16	41.36	68,268
DECEMBER 2014	8.77	244.75	50.53	45,793.5
JANUARY 2015	22.53	87.25	17	52,475.2
FEBRUARY 2015	21.8	146.2	14.69	41,417.1
MARCH 2015	22.88	362.49	87.36	47,984.6
April 2014 to March 2015 total	**181**	**4,987.79**	**657.18**	**659,859.1**

Table 4.2.2 Exhaust gas components routinely measured from Morupule-B Power station smoke (Source: Morupule Power Station internal records).

However, it is worth mentioning that the power station has not been operating continuously in any of the months reviewed since it has always been experiencing random and intermittent breakdowns. It should also be noted that the power station does not measure carbon dioxide emissions since they are not regarded as a problem *per se*: CO_2 is just one of the normal products of 'healthy' combustion which is expected to be recycled by plants via the carbon cycle. On the other hand, oxygen is measured from the exhaust gases to monitor whether complete combustion is generally taking place, so it is some kind of a reverse indicator for other gases. This means that carbon dioxide has to be estimated using other variables, for example, amount of coal used and emission factors.

4.2.3 COAL QUALITY MEASUREMENTS AT MORUPULE

Coal from Morupule Colliery is transported along conveyors to the coal bunkers, from which it is fed to the mills to grind it to small particles of around 75µm. Coal destined for combustion is sampled every day between 10am and 11:30am. The sample is ground and completely air-dried before a proximate chemical analysis is undertaken on it. Two scientists are responsible for performing the daily analysis, which calculates;

- The inherent moisture
- The ash content
- The volatiles (gas impurities)
- The calorific value of the coal

The machine for calculating the calorific value is a SDACM 4000 supplied by Hunan Sundy Technology Development Company. Table 4.2.3a shows the results obtained from chemical analysis of coal sampled at the plant before combustion, while Table 4.2.3b shows the chemical composition of ash from the boilers.

Attribute	**9 April 2015**	**10 April 2015**	**11 April 2015**	**12 April 2015**	**13 April 2015**	**14 April 2015**	**Average**
Total Moisture (%)	6.44	4.63	7.21	6.27	7.29	8.38	6.70
Inherent Moisture (%)	3.58	4.68	4.66	3.53	4.09	3.99	4.09
Calorific Value (MJ/kg)	24.19	25.37	23.17	23.29	22.07	22.15	23.37
Ash Content (%)	22.72	21.66	22.39	22.58	24.56	24.26	23.03
Volatiles (%)	19.41	20.56	21.44	21.35	21.64	21.41	20.97

Table 4.2.3a: Typical proximate analysis results for coal used at Morupule-B Power Station (Source: Morupule Power Station).

Hardgrove Grindability Index indicates the ease for grinding: For coal it ranges from around 40 to around 90 (Tichánek, 2008, p. 27). The bigger the index, the easier the coal is to be grinded, which is a desirable trait when considering wear of equipment amount of energy / electricity needed to grind the coal (Tichánek, 2008, p. 29). In one of the chemical analyses performed on a sample of the coal, the Hardgrove index was calculated to be 64. Sixty-four is a good value since most coals tend to range between 47 and 60 (Tichánek, 2008, p. 30).

The Yancy, Gear and Price index is used for measuring abrasion on handling machinery (Keyla, 2013). Desired levels of abrasion for coal are set as below 200 (Keyla, 2013). For samples of Morupule coal, the index was found to be 141 mg on iron machinery (internal records at Morupule Power Station), so the coal is comfortably within desirable commercial limits in this attribute.

4.2.3.1 ASH ANALYSIS

The ash from a representative sample of coal burned at Morupule-B Power Station in April 2015 was reported to contain the following;

CHEMICAL	SYMBOL	PERCENTAGE
Silicon Dioxide	SiO_2	41.2
Aluminum Oxide	Al_2O_3	33.6
Calcium Oxide	CaO	6.45
Iron (III) Oxide	Fe_2O_3	5.08
Magnesium Oxide	MgO	3.0
Titanium Dioxide	TiO_2	2.31
Potassium Oxide	K_2O	0.44
Sodium Oxide	Na_2O	0.1
Phosphorus Pentoxide	P_2O_5	<0.05

Table 4.2.3b: Chemical composition of ash produced by Morupule-B Power Station (Source: Morupule-B Power Station chemistry technicians).

Ash is the inorganic residue of coal combustion products, composed of metal and non-metal oxides (Keyla, 2013). The ash is important because it serves as an indicator of how well the boiler functions and also the types of chemicals being produced. According to the technicians, the types of chemicals above are what is generally expected for a boiler that is functioning well. The ash is disposed into dumps or sold to cement makers (Botswana Power Corporation, 2012, p. 13).

4.3 GREENHOUSE GAS EMISSIONS FROM MORUPULE-B POWER STATION

The first research objective of this study was;

> **To quantify the total amount of greenhouse gas emissions from the Morupule-B power station in Botswana *("How much greenhouse gas emissions occur from Morupule-B and other coal-fired power generation projects in Botswana?")***

The GHG emissions were calculated from the quantities of coal used in each year using the default IPCC emission factor for $CO_2$from coal combustion for electricity generation in power stations (see chapter 3.3).

Table 4.3a shows the annual coal production and electricity utilisation statistics for Botswana from 2005 to 2015. Sources: (Statistics Botswana, 2015, p. 23; Department of Mines, 2009, p. 17; International Energy Agency, 2016; Statistics Botswana, 2016, pp. 3,5).

Table 4.3a: Botswana annual coal production and electricity utilisation, 2005-2015. (Sources: Statistics Botswana; Department of Mines and International Energy Agency.)

YEAR	TOTAL COAL PRODUCED (MILLIONTONNES)	COAL USED FOR ELECTRICITY GENERATON (MILLION TONNES)	ELECTRICITY GENERATION (GWh)	IMPORTED ELECTRICITY (GWh)	TOTAL ELECTRICITY USED IN BOTSWANA (GWh)	% OF ELECTRICITY GENERATED LOCALY
2005	0.986*	0.749¬	867	1,975	2,842	30.5
2006	0.962*	0.569¬	794	2,207	3,001	26.5
2007	0.828*	0.479¬	625	2,519	3,143	19.9
2008	0.909 *	0.472¬	587	2,728	3,315	17.7
2009	0.738*	0.421¬	444	2,793	3,237	13.7
2010	0.988¬	0.360¬	457	3,088	3,545	12.9
2011	0.788¬	0.296¬	303	3,169	3,472	8.7
2012	1.454`	0.169¬	703	3,000	3,703	19.0
2013	1.496`	0.515¬	1,681	1,821	3,502	48.0
2014			2,362	1,628	3,990	59.2
2015			2,446	1,528	3,974	61.6

(*Department of Mines 2009)
(`Statistics Botswana 2015)
(¬International Energy Agency, 2016)

The information from Table 4.3a was developed further to calculate the GHG emissions for each year using the default IPCC emission factor for CO_2 from coal combustion for electricity generation in power stations (see chapter 3.3). The assumption was that the emissions of the other GHG gases are much smaller in comparison to those for CO_2, and once the total is calculated, what emerges when rounding up the number is essentially the CO_2 figure. The GHG emissions were calculated using the quantity of coal, the emission factor and the average Calorific Value of Morupule coal. For example, for the year 2013; 515,000 tonnes of coal were used. The CO_2 emitted was calculated as follows:

Amount of coal per year X Calorific Value X Emission Factor = Amount of CO_2 per year

515,000 tons (coal) X 0.0237 TJ/ton X 96.1 tonnes of CO_2/TJ = 1,173,000 tons of CO_2 per year.

Table 4.3b shows the calculated values for the GHG emissions for electricity generated by coal-fired power stations in Botswana. It also depicts a scenario whereby all the electricity in a particular year had been produced locally (no imports at all but the same quantity of electricity used), from 2005 to 2015. Sources: (Statistics Botswana, 2015, p. 23), (International Energy Agency, 2016), (Statistics Botswana, 2016, pp. 3,5).

YEAR	POWER STATION	COAL USED (THOUSAND TONNES)	ELECTRICITY GENERATION (GWh)	AVERAGE POWER OUTPUT (MW)	% OF ELECTRICITY GENERATED LOCALY	GHG EMISSION FOR POWER GENERATED LOCALLY (MILLION TONNES)	GHG EMISSION FOR 100% LOCAL GENERATION SCENARIO (MILLION TONNES)
2005	MORUPULE-A	749¬	867	99	30.5	1.70	5.59
2006	MORUPULE-A	569¬	794	91	26.5	1.30	4.89
2007	MORUPULE-A	479¬	625	71	19.9	1.09	5.48
2008	MORUPULE-A	472¬	587	67	17.7	1.08	6.08
2009	MORUPULE-A	421¬	444	51	13.7	0.96	7.01
2010	MORUPULE-A	360¬	457	41	12.9	0.82	6.36
2011	MORUPULE-A	296¬	303	35	8.7	0.67	7.74
2012	MORUPULE-B	169¬	703	80	19.0	0.38	2.02
2013	MORUPULE-B	515¬	1,681	192	48.0	1.17	2.44
2014	MORUPULE-B	723	2,362	269	59.2	1.65	2.78
2015	MORUPULE-B	749	2,446	279	61.6	1.71	2.77

(¬International Energy Agency, 2016)

Table 4.3.b: Annual coal usage for electricity generation in Botswana (Sources: Statistics Botswana, 2015, p. 23; International Energy agency, 2016; Statistics Botswana, 2016, pp. 3,5)

Since there were no reference values for the years 2014 and 2015, the values for amounts of coal used were calculated from the value for the quantity electricity generated. The 2013 value was used as a baseline since for all the three years Morupule-B was the only plant in operation.

The average power output was calculated by dividing the electricity generated for the whole year (GWh) by the total number of hours in a year:

365.25 days / year X 24 hours / day = 8,766 hours per year

Average electricity generation = Total electricity generated per year (GWhour) / 8,766 hours per year

For example, in 2015:

Average electricity generation = 2,446 GW Hours ÷ 8,766 hours/year =0.279 GW = 279 MW

The column on the extreme right refers to calculations based on projecting a scenario whereby all the electricity used in Botswana was generated locally, the assumption being that it is all produced from coal using the same technology actually used during that same year. For the year 2013, if all the electricity used was generated locally using similar technology to Morupule-B (Phase 1); the total CO_2 emitted would have been:

Actual CO_2 emissions X 100% divided by actual percentage of electricity generated locally

1.17 Million tons X 100% divided by 48% = 2.44 Million tons of CO_2

From Table 4.3b, it is evident that despite producing much more electricity, Morupule-B has lower GHG emissions than Morupule-A. The difference can be seen by comparing emissions for the years Morupule-A was in operation (2005-2010) to 2012-2015, when it was now Morupule-B. This effect can be attributed to two factors: that during the period under review, Morupule-A was an aged plant, having started operating in 1983; secondly, Morupule-B benefited from improved technology (Whereas the old Morupule-A power station used Pulverised Coal (PC) boilers, the Morupule-B power station uses Circulating Fluidised Bed (CFB) boilers: (see chapter 4.2.1 for comparison of the two technologies).

4.3.1 CALCULATION OF GHG EMISSIONS FOR SCENARIO: MORUPULE-B (PHASE 1) OPERATING AT FULL CAPACITY (600MW)

According to senior technicians at the power station (information given during an interview with the researcher), each of the four Morupule-B units (boilers) uses between 60 and 70 tons of coal per hour when operating at full capacity (150 MW per unit), so on average 65 tons per unit coming to a total of around 260 tons per hour for all four units. However, we may estimate it to run at 75% capacity round the clock to factor in unit shutdowns for services and repairs. In that case, we may estimate that the plant, if working fine, would use196 tons of coal per hour.

195 tons/ hour X 24 hours/day X 365.25 days/ year = **1,709,370 tons per year**

This estimate agrees with that presented in World Bank initiated studies, which put the estimate at 1.7 million tons per annum (see Mott MacDonald (Pty) Ltd, 2014, p. 5).

The type of coal mined at Morupule is medium to low grade sub-bituminous (Grynberg, 2012, p. 12). Sub-bituminous coal has a default emission factor of 96,100 kg of carbon dioxide per TJ on a Net Calorific Basis (Source: IPCC, 2006, p.16). The Calorific Value for Morupule coal is 23.7 MJ/kg (from table 4.1), which converts to 0.0237 TJ/ton

1.7 million tons/ year X 0.0237 TJ/ton X 96.100 tons of CO_2/TJ = 3.9 Million tons of CO_2 per year

The estimate for methane, which has an emission factor of 1, is:

1.7 million tons/ year X 0.0237 TJ/ton X 1 kg of CH_4/TJ = 40.5 tons of CH_4 per year

The estimate for N_2O, which has an emission factor of 1.5, is:

1.7 million tons/ year X 0.0237 TJ/ton X 1.5 kg of N_2O /TJ = 60.8 tons of N_2O per year

4.3.1.1 CONVERSION OF GHGs TO CO_2 EQUIVALENTS

From Table3.2, the global warming potentials of the three gases above are:

Carbon dioxide: 1

Methane: 21

Nitrous oxide: 310

So, to convert all of them into CO_2 equivalents;

i. 40,500 kg of CH_4 X 21 kg of CO_2 equivalent / kg of CH_4= 851,000 kg CO_2 eq. per year

ii. 60,800 kg of N_2O X 310 kg of CO_2 equivalent / kg ofN_2O = 18,800,000 kg CO_2 eq. per year

iii. Total for all three greenhouse gases in CO_2 equivalent = 3,900,000,000 kg of CO_2 + 851,000 kg CO_2 eq. (from CH_4) + 18,800,000 kg CO_2 eq. (from N_2O) = 3,920,000,000 kg CO_2 equivalent per year,

Which is 3.9 million tonnes of CO_2 (equivalent) per annum.

4.3.1.2 GREENHOUSE GAS PROJECTIONS WITH PLANNED MORUPULE EXPANSIONS AND OTHER COAL PROJECTS INCLUDED

This section presents an overview of the gross output, projected annual coal usage and the projected GHG emissions of the existing, modified and planned coal-fired power stations in Botswana, going from the recent past to the near-future. Future projections are based on the respective enterprise plans of the various projects as released into public domain by their developers.

The projections for future undertakings are however not consistent: The developers often change the scales of their projects drastically due to changes in the investment climate, rival projects competing for a share of the same intended market, political inclinations in market countries, technology changes and changes in project ownership / management. In 2012 (Table 2.5a), Mmamabula's projection was for a 2,700MW project, but by 2014 (under new ownership) the projection had more than halved to 1,200MW (Table 4.3.1a). Similarly, in 2012, Mmamantswe's projection was for a 2,000MW plant, which has since been downgraded to 1,050MW. The projection for the sum of all of Morupule-B's stages was initially presented as 1,200MW, but the most recent literature only alludes to a total of 900MW.

One assumption entertained in the analysis is that the power stations will generally operate very close to their stated gross outputs. However, experiences from the Morupule-B (Phase 1) project show that a power station can operate intermittently, especially due to technical faults. The output and efficiency of a power station will also decline as it ages. Another assumption is that the power stations will use the combustion and emission control technology stated in their plans. This can however change drastically depending on the introduction of new technology and stricter regulations.

The Morupule-A power station (132MW) is currently (2016) closed for refurbishment. Morupule-B (Phase 1) has a capacity of 600MW. An expansion to Morupule-B by an additional 300MW (unit 5 and 6) is expected to be completed by 2020. Table 4.3.1a depicts the annual coal usage and GHG emissions of Botswana's planned coal-fired power stations (adapted from Mott MacDonald (Pty) Ltd, 2014, p. 6 with figures for Morupule-B Phase 1 re-oriented by the researcher to better represent how profuction has turned-out in reality).

PROJECT NAME	OPERATING FROM:	GROSS OUTPUT (MW)	COAL BURNED ANNUALY (MTon)	GHG EMISSIONS (MTon CO_2)
Morupule-B (Phase 1: Unit 1)	2012	150	0.43	0.98
Morupule-B (Phase 1: Unit 2&3)	2015	300	0.85	1.95
Morupule-B (Phase 1: Unit 4)	2017	150	0.43	0.98
Morupule-A (refurbished)	2020	132	0.4	0.9
Morupule-B (Unit 5 & 6)	2020	300	0.9	2.1
Unnamed Greenfield	2020	300	1.2	2.7
Mmamabula	2024	1,200	4.3	9.8
Mmamantswe	2034	1,050	3.3	7.5
	TOTAL:	3,582	11.8	27

Table 4.3.1a: Specification details for existing and planned coal fired power stations (Source: Mott MacDonald (Pty) Ltd, 2014, p.6)

Table 4.3.1b depicts the annual total average electricity generation and GHG emissions of Botswana's existing and planned coal-fired power stations. The information for the years that have passed was adapted from Botswana Power Corporation electricity generation statistics. The assumption made is that all the generation was from coal fired power stations. In reality, some of the generation – even though comparatively much smaller – was realised from the two diesel generators at Matshelagabedi and Orapa which are used for peaking and standby purposes.

The information for the years from 2014 to 2018 were adapted by the researcher (from Mott MacDonald (Pty) Ltd, 2014, p. 6 and Statistics Botswana, 2015, p. 23) and re-oriented by the researcher to better represent how production has turned-out in reality, and how the repairs to the power station are reasonably expected to be undertaken over the years. The figures from 2019 onwards were obtained from Mott MacDonald (Pty) Ltd, 2014, p. 6. The assumptions for future power stations is that they will be undertaken at the scale announced, that the technology to be used will be what has already been announced, and that there will not be any other projects that will be introduced in the same period. The researcher has also added a column that provides commentary on the power stations operational / expected to be in a particular year and their respective situations / expected situations for most of that year.

YEAR	SITUATION	Total Average Electricity output (MW)	EMISSIONS (Million tons of CO2 per annum)
2005	Morupule A; Aged plant, lower efficiency	99	5.59
2006	Morupule A: Declining further each year.	91	4.89
2007	Morupule A: Declining further each year.	71	5.48
2008	Morupule A: Declining further each year.	67	6.08
2009	Morupule A: Declining further each year.	51	7.01
2010	Morupule A: Declining further each year.	41	6.36
2011	Morupule A: Finally shut down during the year.	35	7.74
2012	Morupule-B commences operating with one boiler during the year.	80	0.98
2013	Morupule-B: Second boiler comes on-board	192	0.98
2014	Morupule-B: Operating with all boilers but with frequent breakdowns.	269	0.98
2015	Morupule-B: Operating with all boilers but with frequent breakdowns.	279	2.93
2016	Morupule-B: Operating with all boilers but with frequent breakdowns.	354	3.9
2017	Morupule-B (Phase 1): Expected to be stabilising as repairs continue.	429	3.9
2018	Morupule-B (Phase 1): Expected to be stabilising as repairs continue.	429	3.9
2019	Morupule-B (Phase 1): Expected to have stabilised.	600	3.9
2020	Refurbished Morupule-A, Morupule-B (Unit 5 and 6) and a greenfield 300 MW power plant all expected to come on board.	1332	9.6
2024	Mmamabula Power Station (1,200 MW) expected to commence operating.	2532	19.4
2034	Mmamantswe Power Station (1,050 MW) expected to start operating.	3582	26.9

Table 4.3.1b: Projections of GHG emissions by Planned and existing power stations in Botswana (Sources: Mott MacDonald (Pty) Ltd, 2014, p. 6; Statistics Botswana, 2015, p. 23)

The information in table 4.3.1b was further displayed in Figure 4.3.1. The graph shows the expected trends for both CO_2 emissions and total installed electricity capacity up to 2036. A plot of the natural vegetation GHG absorption capacity of Botswana's vegetation was also included for purposes of comparing with the emissions from combustion of coal. However, the assumption used is that the GHG absorption capacity will remain at its year 2000 level in the entire period, although adverse climate change and land-cover changes are likely to result in its decline. Other sources of GHG emissions have not been factored in also.

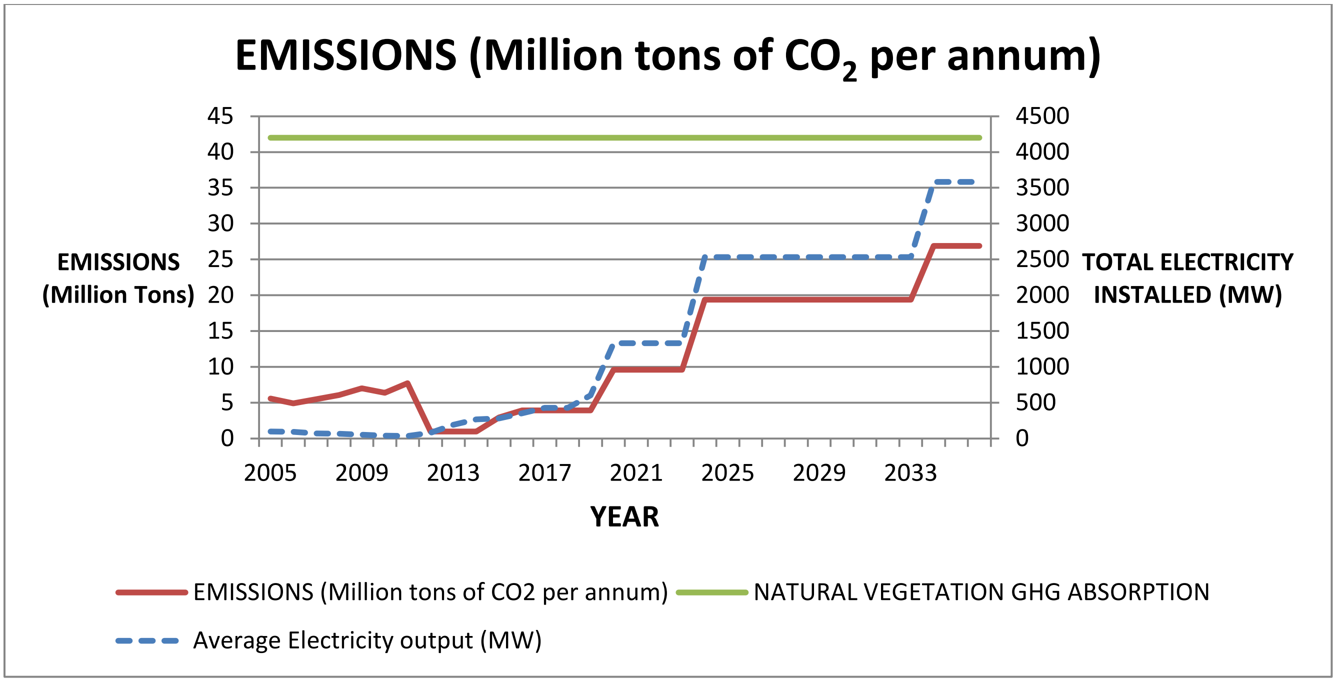


Figure 4.3.1: Total expected GHG emissions as planned coal-fired stations become operational.

From Table 4.3.1 and Figure 4.3.1, when the last among all the planned Morupule projects becomes operational in 2020, they will have a collective capacity of 1,032 MW and annual GHG emissions adding up to 6.9 Million tons of CO_2 per annum. When factoring-in the other planned power stations, BY 2034 the total capacity will be 3,582 MW - while emissions will reach 27 Million tons of CO_2 per annum.

4.4 IMPLICATIONS OF MORUPULE-B GREENHOUSE GAS EMISSIONS ON BOTSWANA'S COMMITMENTS TO INTERNATIONAL ENVIRONMENTAL CONVENTIONS

The second research objective of this study was;

> **To identify the implications of the GHG emissions on Botswana's commitments to international environmental conventions ("*Would the scale of emissions be significant enough to result in Botswana becoming a net emitter of greenhouse gases?"*).**

4.4.1 IMPLICATIONS ON BOTSWANA'S COMMITMENT TO THE UNFCCC

Botswana is a signatory to the United Nations Framework Convention on Climate Change (UNFCCC), promulgated in 1992. Botswana is further a signatory to all the accords subsequently agreed during Congresses of Parties (COP) to the UNFCCC, including the Kyoto Protocol of 1997 - which largely absolved developing countries from committing to reduce emissions (See UNFCCC, 1998; which mostly repeats allusions to "*All Annex 1 parties shall…*"). However, in December 2015, at COP 21 held in Paris, an agreement was reached that committed each party to play a role in limiting global warming (average temperatures) to not more than 2°C above pre-industrial averages (UNFCCC, 2016, p. 22) – see article 2.1(a).

Like many other parties, Botswana signed the Paris Agreement on the 22nd of April 2016 but, at the time of writing, was yet to ratify it. The Paris Agreement further expects implementation that reflects equity and the principle of common but differentiated responsibilities and respective capabilities, in the light of different national circumstances (UNFCCC, 2016, p. 22) – see article 1.2. Article 4.1 of the Paris Agreement (2015) of the UNFCCC:

> In order to achieve the long-term temperature goal set out in Article 2, Parties aim to reach global peaking of greenhouse gas emissions as soon as possible, recognizing that peaking will take longer for developing country Parties, and to undertake rapid reductions thereafter in accordance with best available science, so as to achieve a balance between anthropogenic emissions by sources and removals by sinks of greenhouse gases in the second half of this century, on the basis of equity, and in the context of sustainable development and efforts to eradicate poverty. (UNFCCC, 2016, p. 22)

From the paragraph above, it is clear that the intension of the Agreement is for Parties whose anthropogenic GHG emissions exceed their removal by GHG sinks to at least balance them within a reasonable timeframe, and for those whose GHG sinks exceed their emissions not to ever go beyond the balance, at most. Therefore, Botswana still has leeway to increase her emissions, for real and worthy needs, without even offending her obligations to the

UNFCCC. The Morupule-B (Phase 1) project will not on its own result in Botswana infringing on the UNFCCC.

4.4.2 IMPLICATIONS FOR BOTSWANA'S COMMITTMENT TO THE VIENNA CONVENTION FOR THE PROTECTION OF THE OZONE LAYER

Botswana is a signatory to the Vienna Convention for the Protection of the Ozone Layer (1985), including its subsidiary the Montreal Protocol on Substances that Deplete the Ozone Layer, having acceded in December 1991 (United Nations, 2016). The Vienna Convention governs the use and productions of substances such as Chlorofluorocarbons (CFCs), Hydrochlorofluorocarbons (HCFCs), Halons, Carbon tetrachloride, 1,1,1-Trichloroethane (Methyl chloroform), Hydrobromofluorocarbons, Methyl bromide, Bromochloromethane (UNEP, 2000, pp. 6-19).

None of the substances mentioned in the paragraph above is produced in any significant quantities by Morupule-B. There is thus no risk of offending the Vienna convention from the routine operations of the plant. However, such chemicals may be used for some of the industrial operations, therefore there still exists a risk of them escaping in large quantities in cases of spills, fires and other accidents.

4.4.3 IMPLICATIONS FOR THE SADC REGIONAL POLICY FRAMEWORK ON AIR POLLUTION

The Convention on Long-range Trans-boundary Air Pollution was the first international legally binding instrument to deal with problems of air pollution on a broad regional basis (UNECE, 2015). However, Botswana and other African countries are not signatories to this body: All of the signatories are European and North American countries (See United Nations, 2016). It would be important to have a similar treaty among countries in the SADC region on the monitoring of sulphur dioxide and related substances, a crucial issue for coal-burning neighbouring countries like Botswana and South Africa. Although still lacking specific targets, multilateral agreement on air quality continue to be signed among SADC countries. The Draft SADC Regional Policy Framework on Air Pollution (UNEP, 2016) is an envelope containing the efforts made thus far:

1. The 1998 Harare Resolution on the Prevention and Control of Regional Air Pollution in Southern Africa and its likely Trans-boundary Effects,

2. The 2003 Maputo Declaration on the Prevention and Control of Regional Air Pollution in Southern Africa and its likely Trans-boundary Effects.

3. Lusaka Agreement (2008) - Southern African Development Community (SADC) Regional Policy Framework on Air Pollution

These agreements just contain generic statements urging member states to 'do the right thing' without laying out any thresholds or red lines. As such, Botswana does not run the risk of violating the SADC regional policy on Air Pollution with any of the planned expansions to Morupule.

It is, however, critical to specifically address trans-boundary air pollution through bilateral agreements since there are considerable impacts (see, for example, the *Regional Environmental and Social Assessment of Coal-based Energy Projects along the Botswana and South African border* by Mott MacDonald (Pty) Ltd, 2014). For example, South Africa's net GHG emissions for the year 2000 were estimated at 442.5MtCO_2 (Mott MacDonald (Pty) Ltd, 2014, p. 15). Whilst projections show the total capacity of coal-fired power stations on the Botswana side close to the South African border to be around 1,332 MW by 2020, the projection for those on the South African side close to the Botswana border is 10,335 MW (see Mott MacDonald (Pty) Ltd, 2014, p. 8), including the behemoths Matimba (3,990 MW) and Medupe (4,800 MW).

4.5 POSSIBLE MITIGATION MEASURES AGAINST GREENHOUSE GAS EMISSIONS FROM MORUPULE-B COAL-FIRED POWER STATION

The third and final research objective of this study was;

> **To probe, discuss and suggest possible mitigation measures against GHG emissions from the coal fired power generation projects: ("What technological intervention options exist to mitigate the greenhouse gas emissions emanating from the combustion of coal?")**

Morupule-B already has a lot of features to mitigate pollution in general and greenhouse gas emissions in particular. It uses circulating fluidised bed boilers, a relatively new technology with the ability to achieve lower emission of pollutants. The main advantages of the fluidized bed combustion boilers are: reduced NOx, SOx due to relatively low combustion temperature and better efficiency (Ganesan & Lingappan, 2013). During the combustion phase, upward jets of air suspend the pulverised coal to ensure that it mixes with air turbulently for better heat transfer and optimality of chemical reactions.

Large external fans (with external heat exchangers) constantly supply an optimal amount of air for complete combustion. Air destined to the furnace goes through a pre-heater where it is heated to about 250 degrees first. Limestone (calcium carbonate) is also added and it removes up to about 95% of compounds of sulphur. After combustion, exhaust gases enter the convective pass at around 890°C. The gases are subsequently cooled to around 140°C, which is both an economic and environmental consideration (to re-use some of the waste heat and to avoid exhausting gases that are too hot into the atmosphere).

Morupule-B has a stack of 150m height and 3.65m diameter designed to emit gases at 130°C. Electrostatic precipitators are installed at the outlet for exhaust gases to trap fly-ash so as to minimise exhaust of suspended solids. Fly ash is stored in lagoons which however result in some contaminants seeping underground. To monitor these effects, there are sample boreholes. The fly ash can be used for bricks and cement (Botswana Power Corporation, 2012, p. 13).

There are some technological interventions that can be used to improve Morupule-B's environmental credentials, including:

1. *Carbon Capture and storage*
2. *Integrated Gasification Combined Cycle(IGCC)*
3. *Pure Oxygen Combustion*

4.5.1 CARBON CAPTURE AND STORAGE (CCS)

"End-of-pipe" technologies that would allow for the continued utilization of fossil fuel energy sources while significantly reducing carbon emissions are sometimes collectively termed "Carbon capture and storage" (CCS) (Anderson & Newell, 2003, p. 1). CCS is the removal of CO_2 directly from industrial or utility plants and subsequently storing it in secure reservoirs to enable the use of fossil fuels while reducing the emissions of CO_2 into the atmosphere, and thereby mitigating global climate change (Herzog & Golomb, 2004, p. 1).

The idea is that the CO_2 can be stored for a sufficiently long time such that if it gets re-released at a later time into the environment, this would be at a time when, due to technology advances, there would be much reduced emissions from other sources hence such a release would no longer be deemed detrimental (Herzog & Golomb, 2004, p. 1). The captured CO_2can also be directly used for various industrial and commercial processes, e.g. the production of urea, foam blowing, carbonated beverages, and dry ice production (Herzog & Golomb, 2004, p. 2).

Carbon Dioxide may be ''captured'' either before combustion or after combustion of hydrocarbon fuels. In the Integrated Gasification Combined-Cycle (IGCC) process, CO_2 is captured prior to combustion; coal is gasified to form a mixture of carbon monoxide (CO) and hydrogen (H_2) known as synthesis gas (syngas) (Anderson & Newell, 2003, p. 14). In IGCC without capture, syngas is combusted directly in gas turbines; whereas in IGCC with capture, syngas undergoes an additional reaction with steam in the presence of catalysts to form a mixture of H_2 and CO_2, and the H_2 is separated for use in a combined-cycle gas turbine, generating a pure stream of CO_2 that can be directly compressed and stored (Anderson & Newell, 2003).

Pre-combustion "capture"ofCO_2 entails partially combusting the fossil fuel with sub-stoichiometric (insufficient) amounts of oxygen (and usually some steam) at elevated pressures (typically 30 – 70 atmospheres) to give a 'synthesis gas' mixture of predominantly CO and H_2: Additional steam is then added and the mixture is passed through a series of catalyst beds for the 'water – gas' shift reaction to approach equilibrium: **$CO + H_2O \leftrightarrow 3\ CO_2 + H_2$** (Gibbins & Chalmers, 2008). The CO_2 is then captured, and the hydrogen gas is burnt as the fuel.

In post-combustion capture, wet scrubbing with aqueous amine solution is applied to remove most of the CO_2 from the combustion products just before they are vented to the atmosphere; a process that occurs at relatively low temperatures (order 50°C): The solvent is then regenerated for re-use by heating (to around 120°C), before being cooled and recycled continuously (Gibbins & Chalmers, 2008).

The storage method for captured CO_2 must satisfy several key criteria (Herzog & Golomb, 2004, p. 4):

(a) The storage period should be prolonged, preferably hundreds to thousands of years;

(b) The cost of storage, including the cost of transportation from the source to the storage site, should be minimized;

(c) The risk of accidents should be eliminated;

(d) The environmental impact should be minimal;

(e) The storage method should not violate any national or international laws and regulations.

Identified storage media include geologic sinks and the deep ocean. Geologic storage includes deep saline formations (sub-terranean and sub-seabed), depleted oil and gas reservoirs, enhanced oil recovery, and un-minable coal seams (Herzog & Golomb, 2004, p. 5). Deep ocean storage includes direct injection of liquid carbon dioxide into the water column to the ocean bottom to form a so-called “CO_2 lake” (Herzog & Golomb, 2004, p. 5).

The main element of CCS cost is the cost of capture (Gibbins & Chalmers, 2008). However, legal and regulatory frameworks for the transport (even transnational transit, considering a landlocked country like Botswana) and geological storage of CO_2, possibly offshore, would almost certainly require amending of relevant international treaties (Gibbins & Chalmers, 2008). Obviously, improvements in CCS technology will be incremental, since solutions will continuously be sought for problems as they surface. Nonetheless, plants operating with CO_2 capture will always have a higher cost of electricity generation than equivalent plants without capture.

Whereas CCS costs are very site-specific, indicative aquifer storage costs are in the region of US$10/t$CO_2$ (about P100 per ton) (Gibbins & Chalmers, 2008). Considering that Morupule-B produces an estimated 3.8 million tons of CO_2 yearly, this would translate to about 380 million pula per annum, which sadly does not even include transportation costs if the storage site is elsewhere. High standards would also need to be maintained for an extended period of time: seismic, resistivity, gravimetric monitoring and other imaging techniques to monitor the CO_2 underground (Gibbins & Chalmers, 2008); borehole logging and smart monitoring techniques to give early warning of seepage, operating semi-autonomously for decades (Gibbins & Chalmers, 2008). If just getting the Morupule-B plant to generate electricity continuously - using tried-and-tested technologies- is proving to be a challenge for Botswana Power Corporation, would they by any measure be ready to be entrusted with cutting edge emerging technologies at this stage?

4.5.2 PURE OXYGEN COMBUSTION

If fossil fuels were burnt in pure oxygen instead of air, (which contains approximately 78% nitrogen by volume), flue gas streams would have a much higher concentration of CO_2, thus reducing or eliminating the need for costly CO_2 capture and eliminating NO_X emissions (Anderson & Newell, 2003, p. 15). However, the Achilles’ heel to this technique is prohibitive production costs of oxygen in an air separation unit that make the capture costs higher than for other techniques (Anderson & Newell, 2003, p. 15).

CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS

5.0 INTRODUCTION

The purpose of this chapter is to summarise how the findings of the study have addressed the key research questions and to derive any useful implications of the findings, which would then be shared with other stakeholders, for example other researchers and policy makers.

5.1 CONCLUSIONS

Botswana is a large landmass that is not very industrialised and is relatively sparsely populated. Botswana had a population of 2,024,904 in 2011 (CSO, 2011) while the land area is 582,000 km^2 (AfDB/OECD, 2007). Even though much of the environment is classified as semi-arid, the country has very good credentials when it comes to preservation and conservation of biotic natural resources. Over 34% of the total land area is under protection in national parks, game reserves or wildlife management areas (ADB Regional Department – South Region A, 2009, p. 6). In the year 2000, greenhouse gas absorption by Botswana's woody biomass was estimated to be 42,941.0 Gg CO_2 equivalent (Masisi et al., 2011).

The Morupule-B power station is estimated to produce about 3.8 billion kg of CO_2 equivalent per annum. In the year 2000, greenhouse gas absorption by Botswana's woody biomass was estimated to 42.9 billion kg CO_2 equivalent (Masisi et al*.,* 2011). As such, the power station accounts for a mere 8.8% of what was the estimated biomass absorbing potential in the year 2000. However, the results on this aspect are inconclusive because available data on major sources of GHGs dates back to the year 2000, hence it is largely obsolete: In the intervening period between then and now there have been many developments, including mass importation of second-hand vehicles from Asia, new bitumen roads, expansion of urban settlements and changes in the climate, to name but a few. Another drawback is lack of comprehensive data on GHG absorption and emission by the soil resource in Botswana.

While the study has managed to provide an estimate of GHGs from Morupule-B, it has not conclusively managed to establish whether or not these emissions - when added to those from other sources- would combine to make Botswana a net emitter or not: This can only be done if there were other recent and valid sectoral studies to provide information on emissions from other sources and also on the capacity of different major carbon sinks like soils and biomass.

5.2 RECOMMENDATIONS

5.2.1 RECOMMENDATIONS FOR POLICY

The government of Botswana should consider adding more details and specifications to the Intended Nationally Determined Contributions (INDC) it has submitted to the UNFCCC: In its current format, it is a rather shallow document lacking specifics like how it intends to source the estimated USD18.4 billion to reduce GHGs by 15%. The government should also consider making it mandatory for electricity generation companies to comply with international energy management and environmental management standards. This is because the emissions produced in power generation are significant and they affect the wider public. Relevant standards for environmental management would include: environmental systems (ISO 14001:2015), international greenhouse gas (GHG) accounting and verification (ISO 14064:2006), environmental performance (ISO 14031:2013), life cycle analysis (ISO 14040 / 14044:2006). The relevant standard for energy management is ISO 50001:2011, which outlines specifications for establishing, implementing, maintaining and improving an energy management system (ISO, 2016).

Commendably, Morupule-B power station is already routinely implementing several environmental responsibility initiatives, including:

1. Coal destined for combustion is sampled every day. The sample is ground and completely air-dried before a proximate chemical analysis is undertaken on it.

2. The use of circulating fluidised bed boilers, a relatively new technology with the ability to achieve lower emission of pollutants. The main advantages of the fluidized bed combustion boilers are: reduced NOx, SOx due to relatively low combustion temperature and better efficiency (Ganesan & Lingappan, 2013).

3. After combustion, exhaust gases enter the convective pass at around 890°C. The gases are subsequently cooled to around 140°C, which is both an economic and environmental consideration (to re-use some of the waste heat and to avoid exhausting gases that are too hot into the atmosphere).

4. Four URAS 14 Advanced Optima Analysers are used to monitor sulphur dioxide in each boiler. Ambient sulphur dioxide is measured using a Pulsed Fluorescence SO_2 Analyser (model 43C). PM10 is measured using a FH62I-R sampler.

5. Electrostatic precipitators are installed at the outlet for exhaust gases to trap fly-ash so as to minimise exhaust of suspended solids.

6. Morupule-B has a stack of 150m height and 3.65m diameter designed to emit gases at 130°C.

7. Morupule power station observes stack plume characteristics three times a day. The plume can have different characteristics (coning, looping, fanning, fumigating and lofting), which have a bearing on the efficiency, or lack thereof, of dilution of

pollutants into the atmosphere. If the plume is seen to project an adverse risk, the plant may temporarily be shut down to await more favourable ambient conditions.

8. There are sample boreholes to monitor the possibility of contaminants seeping underground from fly ash stored in lagoons.

None of these measures can be said to be the panacea for the significant pollution associated with Morupule-B or any other fossil-fuel powered plant for that matter; however, each measure shows a genuine effort to at least be more environmentally responsible. Technology has presented other measures, collectively called Carbon Capture and Storage (CCS), which present a promise to drastically reduce the release of greenhouse gases into the atmosphere. Unfortunately, the costs associated with CCS are prohibitive: for example, storage only (excluding capture and possible transportation) is in the region of P100 per ton (Gibbins & Chalmers, 2008), which for Morupule-B would translate to about 380 million pula per annum. The storage also carries with it some risks and the need for very close technical monitoring for centuries thereafter. In any case, CCS is still an experimental technology, so it would be imprudent to bandy it about as a relevant solution at this stage.

Another option would be to totally give up on exploiting coal in favour of solar power. The solar resource potential of Botswana is approximated to be 3,200 sunshine hours on average per annum with levels of Direct Normal Irradiation averaging above 18 MW/m^2/annum (Kiravu et al., 2014). While a beautiful proposition in the utopian minds of conservationists, at this stage there is not a single county in the whole world that has achieved solar power as the majority sector in electricity generation. Even in the most developed photo-voltaic (PV) energy market, which is Europe, only 3% of the electricity mix is generated from PV systems (Karakaya & Sriwannawit, 2015): More specifically, in Germany, which is the country with the largest installation of PV, at over 24,000 MW of installed capacity (Karakaya et al., 2015), PV still accounts for only 4.5% of the total electricity supply (Kirsten, 2014).

It is worth conceding that, globally, the solar PV capacity has grown 167-fold within a 17 year period (from 0.6 GW in 1995 to 100 GW in 2012), which is still sobered by projections by the International Energy Agency that (notwithstanding this ‘’breakneck’’ pace) solar energy will still account for only 11 per cent of the global energy demand by 2050 (Kiravu et al., 2014). A myriad of challenges, both economic and technical, unfortunately bedevil the solar energy sector. The costs of solar energy production still exceed the costs of more conventional generation by a significant margin (Baker et al., 2013). A basic barrier to the development of solar energy technology lies in the high initial costs, including high installation costs with long payback times (Ohunakina et al., 2014).

Taking all factors into consideration, Botswana still has room to expand exploitation of her coal reserves by building a few other coal-fired power stations and possibly becoming an electricity hub for Southern Africa before even upsetting the CO_2 emission-absorption balance. In the interest of good environmental stewardship and prudence, it would be desirable to implement best practices in emission control, including carbon capture and storage. However, Botswana’s level of technical sophistication and economic development is still too far behind to consistently keep pace with such demands; so the existing set of interventions at Morupule-B are appropriately metered. Solar energy should also be adopted alongside coal and be allowed to grow organically apace with global technological innovations as and when they occur. This is the correct perception of prudence.

Perhaps the best component of the multi-pronged mitigation strategy would be to proceed with developing coal-fired power station, using the best mitigation techniques available at a reasonable cost, but to supplement the mitigation efforts with ecological projects to enhance our carbon absorption potential. The ecological projects can be funded under the Clean Development Mechanism (CDM).

5.2.2 RECOMMENDATIONS FOR FURTHER RESEARCH

More research needs to be undertaken on issues related to GHG emissions, other pollutants associated with coal mining and combustion. More research also needs to be undertaken on estimating the carbon absorption potential of Botswana's vegetation and how it is likely to be affected by climate change and land use / land cover changes. Furthermore, research also needs to be carried out to quantify the GHG emission and absorption capacity of soil throughout Botswana. Research also needs to be undertaken on estimating the GHG emissions from Botswana that are exported to other countries and those from neighbouring countries that end up in Botswana.

Continuous and multi-faceted research also needs to be undertaken pertaining to keeping abreast of innovations relating to renewable energy, whose costs will hopefully decline to levels competitive with those of fossil fuels in the long run. More research also needs to be undertaken on how, in spite of climate change, Botswana can enhance, or at least maintain, her greenhouse gas absorption potential, which would entail setting-up relevant forestry projects. Research also needs to be undertaken on how Botswana can access the Clean Development Mechanism (CDM) and other global funding and enabling frameworks to maintain or even improve her physical environment.

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APPENDICES

RESEARCH ETHICS

The main ethical issues in the study on the expected environmental impacts of coal-fired electricity generation projects in Botswana are:

1. Objectivity: the research should stick to scientific truths and should not distort facts to favour or vilify the company undertaking the project. Likewise, it should not be tampered or sentimentalized in favour of any other stakeholder. The researcher should not smuggle any hidden agenda into the process.
2. Respect for property ownership and commercial interests: this research has concerned itself with a project that is basically a private investment vehicle. The proprietors may misconstrue the research effort to be an attack on their company and thus react in a hostile manner. However, their cooperation is required as they hold a wealth of information needed and permission to visit the site has to be sought from them. The researcher should endeavour to ensure that the company (and any other research participants and stakeholders, for that matter) are protected from undue intrusion, distress, indignity, physical discomfort, personal embarrassment, or psychological or other harm.
3. Reporting and dissemination of information pertaining to the research: the researcher should guard against divulging sensitive research data to third parties. As stated above, this research touches on matters of a private company which obviously has a reputation to protect and commercial goodwill to nurture. It is imperative therefore that the researcher endeavour to ensure that any reporting and dissemination are processed in a very responsible manner.
4. Respect for protocol and cultural practices: the researcher should be mindful of the fact that the people he is researching among have their own norms, cultural practices, religious beliefs, sensitivities and practices of etiquette. The researcher should appraise himself on such traditions prior to undertaking the research, so as to minimise chances of offending the locals and inadvertently placing the entire research in jeopardy.
5. Professionalism: the researcher needs to employ methods, tactics and practices that have been sanctioned academically, not just some riff-raff, half-baked sentiments from the figment of his imagination. The methodology and findings should be open for full discussion and peer review. The research can only have integrity if by and large it is reproducible even if conducted by someone else. For this particular study, even the preparatory aspects have been thoroughly winnowed by academic supervisors and grilled by peers. The study is undertaken under the auspices of a full academic department, hence it has no chance of escaping scrutiny. Any questionable research practices shall surely be brought to task. Any aspects of Research Misconduct Research such as Fabrication, Falsification, or Plagiarism (FFP) as well as data manipulation should not even stand a chance. The researcher should further know that even if such shenanigans were to somehow see the light of day, they would still be likely to be exposed at an even more inconvenient later date.

6. The researchers should endeavour to ensure that decisions about participation in research are made from an informed position: As alluded-to in the consent form annexed to this document, the researcher needs to be ethically upright in requesting information from research participants. Information should not be obtained by coercion, misrepresentation, false promises, financial manipulation or subterfuge. The researcher should not prey on the simplicity of participants, who for this particular study are likely to be mostly elderly rural folks, some possibly without any formal education. The researcher should respect the intelligence of all subjects of his study.

RESEARCH PERMIT

TELEPHONE: 3647900
TELEGRAMS: MEWT
TELEX:
TELEFAX: 3908076

MINISTRY OF ENVIRONMENT,
WILDLIFE AND TOURISM
PRIVATE BAG BO 199
GABORONE
BOTSWANA

REPUBLIC OF BOTSWANA

REFERENCE: EWT 8/36/4 XXIX (36)

ALL CORRESPONDENCE MUST BE ADDRESSED TO THE PERMANENT SECRETARY

5th February 2015

Mr Montwedi Mozila
Department of Environmental Science
Faculty of Science
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Private Bag 0022
Gaborone

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APPLICATION FOR A RESEARCH PERMIT: COAL DEMAND FOR POWER GENERATION IN BOTSWANA: GREENHOUSE GAS EMISSION IMPLICATIONS": EWT 8/36/4 XXIX (27)

We are pleased to inform you that you are granted permission to conduct a research entitled: **"coal demand for power generation in Botswana: greenhouse gas emission implications".**

The research will be conducted at **Palapye and Morupule.**

This permit is valid for a period effective from the **1st March 2015 to 30th August 2015.**

This permit is granted subject to the following conditions:

1. Signing and submission of an Agreement between Government of Botswana and Independent Researchers.
2. Progress should be reported periodically to the **Department of Environmental Affairs.**
3. The permit does not give authority to enter premises, private establishments or protected areas. Permission for such entry should be negotiated with those concerned.
4. You conduct the study according to particulars furnished in the approved application taking into account the above conditions.

5. Failure to comply with any of the above conditions will result in the immediate cancellation of this permit.

6. The research team comprises of **Professor R Chanda, Dr M. Lenkopane, Mr D. Lesolle and**.

7. The applicant should ensure that the Government of Botswana is duly acknowledged.

8. Copies of videos/publications produced as a result of this project are directly deposited with the Office of the President, National Assembly, Ministry of Environment, Wildlife and Tourism, Department of Wildlife and National Parks, Gaborone Botswana Tourism Organization, National Archives, National Library Service, and the University of Botswana Library.

Thank you.

Yours faithfully

G. Tapeng
FOR/PERMANENT SECRETARY

cc: Director, Department of Environmental Affairs
District Commissioner, Palapye