A COMPARATIVE STUDY OF
EMISSIONS FROM COAL-FIRED POWER STATIONS
IN SOUTH AFRICA AND OTHER SELECTED COUNTRIES

by

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Gerlinde Isabelle Wilreker

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ABSTRACT

Worldwide, coal is one of the major sources of energy. In 1999 it was estimated that the global electricity generation from coal was about 36% of the total world electricity production (Knapp, 1999:11). With the combustion of coal for electricity generation however, negative environmental impacts occur. These are mainly caused by carbon dioxide, nitrous oxides, sulphur dioxide and particulate matter emissions. With an ever-growing global population, the need and demand for electricity is increasing. These needs and demands need to be addressed in an economically, socially and environmentally acceptable manner.

In this study the author examines, analyses and compares the emissions from coal-fired power stations in South Africa, Australia, Canada, Germany, India and the United States of America over a chosen period of time (1995-2001).

The results of the study indicate, that, within the comparative group, South Africa is not the greatest producer of emissions from coal-fired power stations. It is the fourth biggest emitter of CO₂. It has the highest SO₂ emissions, because of the low-grade coal burned in the power stations that have been specifically designed to burn this type of coal. It is the second biggest emitter of NOₓ, and the third biggest emitter of particulates.

Germany is the country that has shown the greatest progress in emissions reductions. This has been the result of restructuring and economic incentives.

Overall, South Africa can be ranked third, on par with Australia.
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LIST OF ABBREVIATIONS USED

CO$_2$: carbon dioxide
GtC: giga ton carbon
Gtoe: giga ton oil equivalent
GWh: gigawatt hour
kt: thousand tons
Mt: million tons
NO$_x$: nitrogen oxides
Pm: particulate matter
SO$_2$: sulphur dioxide
t/GWh: tons per gigawatt hour
CHAPTER 1. INTRODUCTION

1.1. INTRODUCTION

Over the last two centuries mankind has become increasingly dependent on coal, gas and oil as a source of energy. These fuels, when burned, release gases such as carbon dioxide (CO₂), nitrogen oxides (NOₓ) and sulphur oxides (SOₓ). Carbon dioxide and nitrous oxide (N₂O) are major greenhouse gases that enhance the earth’s natural greenhouse effect, leading to the phenomenon known as global warming.

Carbon dioxide is considered the most important greenhouse gas produced by human activities. Currently, developed countries are accountable for 60% of CO₂ emissions, and developing countries for the remaining 40% (Miller, 2000:501).

According to the Energy Information Administration (2003d), in 2001 the major carbon emitters in the world were:

- China (638.64 million metric tons),
- USA (561.13 million metric tons),
- India (162.05 million metric tons),
- Russia (130.36 million metric tons),
- Japan (91.04 million metric tons),
- South Africa (86.18 million metric tons),
- Germany (81.16 million metric tons),
- Australia (55.07 million metric tons), and
- Canada (42.22 million metric tons).

In these countries coal is mainly used for the generation of electricity.

Worldwide, coal is one of the major sources of energy. In 1999 it was estimated that the global electricity generation from coal was about 36% of the total world electricity production (Knapp, 1999:11).
In coal trade, 60% of the coal traded is steam coal, most of which is used for electricity generation (Knapp, 1999:12). This wide use of coal is due to the fact that steam coal is the cheapest and most abundant fuel for electricity production (Cameron, 2003), making it likely to remain a vital energy source for the future.

South Africa is one of the leading coal mining nations of the world, having produced 223,5 million tonnes of coal in 1999 (World Energy Council, 2003). Eskom, South Africa’s electric utility, accounts for over half of the country’s coal consumption. In 2001, 88% of the electricity produced was generated from coal (Eskom, 2002).

The worldwide amount of CO$_2$ emissions is expected to double by 2050. This will have an adverse effect on the global climate.

1.2. PROBLEM STATEMENT

In the past, studies have concentrated on carbon dioxide emissions. This is because it is the most important greenhouse gas linked to man’s economic activities. There have been fewer studies on the emissions of other gases (sulphur dioxide and nitrous oxides). The issue of these emissions has already been addressed in most of the developed countries. However, in developing countries, this issue has yet to be adequately addressed. These gases have a vast array of adverse effects on the environment (natural and physical) and this adversely affects the countries’ economies in the long run.

In many developed countries, some electricity is generated in nuclear power stations, which do not produce flue gases. In developing countries, however, this is most often not the case and energy production often relies on coal and oil. The national budget does not allow for the installation of clean coal technologies, because these technologies are expensive, and privately owned companies also often cannot afford to install them.
A number of questions that arise from the mentioned issues. These are:

- What is South Africa’s current status in terms of emissions?
- How have these emissions been changing over time?
- How do the emissions compare to other countries?

This paper investigates what the status of South Africa’s emissions from coal-fired power stations has been over a specific period of time, and how these emissions compare to those from other major coal consuming countries.

1.3. OBJECTIVES

The objectives of this study are to study and analyse carbon dioxide (CO₂), sulphur dioxide (SO₂), nitrous oxides (NOₓ), and particulate matter (Pm) emissions from coal-fired power stations in South Africa and other selected countries.

The countries whose emissions were examined and compared against South Africa’s were:

- Australia,
- Canada,
- Germany,
- India, and
- The United States of America,

The research investigates:

- South Africa’s historical trend in emissions from 1995 to 2001,
- Other countries’ historical trend in emissions from 1995 to 2001,
- The results are then compared to international emission standards.

This study shows how South Africa compares to the rest of the world in terms of emissions from its coal-fired power stations, and indicates how emissions have changed over the study period.

The structure and logic of the study is illustrated in Figure1.
Figure 1. Diagramatic framework for the study
CHAPTER 2. COAL

2.1. THE ORIGIN AND TYPES OF COAL

Coal is a fossil fuel that was formed from the buried remains of plants that existed during the Carboniferous period (345 million years ago). These plant remains were subjected to immense pressure and heat over millions of years, eventually forming coal.

Coal is comprised mainly of carbon, with some water, sulphur and other elements. The carbon, water and sulphur content varies within the different types of coal, depending on the age of the coal, as well as the pressure and heat it was subjected to during its formation. The older the coal, the higher its carbon content and the lower its water content. The carbon content can vary from 40 - 90%, water content from 0.2 - 1.2%, and sulphur content from 0.2 – 2.5% (Miller, 2000:377).

Figure 2.1. Stages in the formation of coal (Miller, 2000:377)
The stages in the formation of coal are peat, lignite, bituminous coal and anthracite.

**Peat** is not considered coal, as it is not fossilised but only decayed plant matter found in swamps and bogs. It has a very low calorific value and is used as a source of heat in some areas of the world (Miller, 2000:377).

**Lignite**, also called brown coal, is the youngest type of coal. Because it is young it has a high moisture content and a low carbon content, and therefore it generates low heat in combustion. It also has a low sulphur content (Miller, 2000:377-78).

**Bituminous** coal has a lower moisture content and a higher carbon content than lignite. However it has a high sulphur content. This is the most widely used coal, as there exist vast reserves of it worldwide (Miller, 2000:377-78).

**Anthracite** is the most desirable of coals. This is due to the fact that it has a low sulphur and water content and a high carbon content. However, because it took such a long time to form, there are limited deposits of it in the world and this makes it a rather expensive commodity (Miller, 2000:377-78).

### 2.2. THE USES OF COAL

There are indications that coal has been in use in Europe since the Bronze Age (4000 years ago). Prior to the industrial revolution, coal use was limited. However, since the industrial revolution the use of coal has sharply increased. Since 1850, the use of coal has increased by nearly a 100-times (Kupchella & Hyland, 1993:116). The historical trends of coal change are illustrated in Table 2.1.

According to Miller (2000:378) coal provides 25% of the world’s commercial energy. It is used to generate 64% of the world’s electricity and is used in 75% of the world’s steel production.
Table 2.1. The historical trends in the production of coal since 1800
(WEC, 2001:43)

<table>
<thead>
<tr>
<th>Years</th>
<th>Million tons coal</th>
</tr>
</thead>
<tbody>
<tr>
<td>1800</td>
<td>&lt;12</td>
</tr>
<tr>
<td>1840</td>
<td>&lt;50</td>
</tr>
<tr>
<td>1850</td>
<td>81</td>
</tr>
<tr>
<td>1870</td>
<td>210</td>
</tr>
<tr>
<td>1889</td>
<td>500</td>
</tr>
<tr>
<td>1907</td>
<td>1100</td>
</tr>
<tr>
<td>1938</td>
<td>1582</td>
</tr>
<tr>
<td>1975</td>
<td>2429</td>
</tr>
<tr>
<td>1993</td>
<td>3466</td>
</tr>
</tbody>
</table>

Table 2.2. World Primary use of energy in 1998 and projected for 2050 (Gtoe)
(WEC, 2001:131)

<table>
<thead>
<tr>
<th></th>
<th>1998</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coal</td>
<td>2.22</td>
<td>3.1</td>
</tr>
<tr>
<td>Oil</td>
<td>3.39</td>
<td>3.8</td>
</tr>
<tr>
<td>Natural gas</td>
<td>2.02</td>
<td>2.5</td>
</tr>
<tr>
<td>Renewables</td>
<td>1.33</td>
<td>1.9</td>
</tr>
<tr>
<td>Nuclear</td>
<td>0.62</td>
<td>0.7</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>9.58</strong></td>
<td><strong>12.0</strong></td>
</tr>
</tbody>
</table>

Coal is still in extensive use, as a form of primary energy (Table 2.2.), and it will continue to be so for a long time. It is estimated that the ratio of coal reserves to the current annual production (referred to as the R/P ratio) now exceeds 280 years (WEC, 2001:161). Global coal reserves are estimated at 600 Gtoe (Table 2.3).
Table 2.3. Global fossil energy reserves and resources (Gtoe)
(WEC, 2001:161)

<table>
<thead>
<tr>
<th></th>
<th>Consumption (1850-2000)</th>
<th>Reserves</th>
<th>Resources</th>
<th>Resource base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Oil</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>123</td>
<td>140</td>
<td>123</td>
<td>263</td>
</tr>
<tr>
<td>Unconventional</td>
<td>-</td>
<td>193</td>
<td>332</td>
<td>523</td>
</tr>
<tr>
<td>Natural Gas</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional</td>
<td>61</td>
<td>142</td>
<td>280</td>
<td>422</td>
</tr>
<tr>
<td>Unconventional</td>
<td>-</td>
<td>192</td>
<td>258</td>
<td>450</td>
</tr>
<tr>
<td>Coal</td>
<td>148</td>
<td>600</td>
<td>2770</td>
<td>3370</td>
</tr>
</tbody>
</table>

2.3. THE ENVIRONMENTAL EFFECTS OF COAL COMBUSTION

In a typical coal-fired plant, coal is pulverised to a fine dust and then burned in a boiler at high temperatures. The high heat generated converts water to steam. This steam, under high pressure, spins the shaft of a turbine, which in turn rotates a generator to produce electricity. This electricity is then distributed via the national grid to customers.

When the coal is burned it releases a number of gases. These are carbon dioxide (CO₂), sulphur dioxide (SO₂) and nitrogen oxides (NOₓ). It also releases particulate matter (Pm) of different sizes. These emissions have serious environmental impacts.

2.3.1 Carbon dioxide

Carbon dioxide is one of the major greenhouse gases. According to Miller (2000:500) it represents 50 – 60% of the global greenhouse gases produced by man’s economic activities. The burning of fossil fuels in these activities is responsible for 70 – 75% of CO₂ production. The emission from fossil fuel
combustion rose from 6.5 gigaton in 1998 to 11.7 gigaton in 2001 (WEC, 2001:131). The increase is mainly in developing countries that rely heavily on coal as a source of primary energy.

Global warming is the result of an enhancement of the earth’s natural greenhouse effect. This leads to an increase in the average global temperature, which in turn leads to changes in the world’s climate. The hypothesised consequences of this are varied, but it is agreed that they will have a great impact on the environment, affecting it very negatively.

According to Miller (2000:101-105) and the IPCC (2002:101-105), the following main effects predicted include:

- Droughts in certain areas of the world where there were previously none, and increased rainfall and floods in other areas.

- An increase in atmospheric temperature will lead to the melting of ice in the Polar Regions. Melting of ice sheets, which are currently located on land such as Greenland and Antarctica, will result in an increase in the levels of oceans worldwide. Because the great majority of the world’s population lives in coastal areas, the result will be enforced relocation of many coastal settlements to higher grounds.

- The increased temperature will cause the climatic regions to shift northwards and southwards from the equator respectively. Agriculture will have to adapt, since areas, which are suitable for a particular agriculture today, will no longer be suitable in the same way. Fauna and flora will have to shift habitat in order to survive, but there might be nowhere for them to move to, thus resulting in a loss of biodiversity. Many tropical pests and diseases will become endemic to areas where they did not occur before, resulting in health and agricultural problems.
2.3.2 Sulphur dioxide

Sulphur dioxide is a colourless, acrid gas formed from the combustion of sulphur. It has numerous industrial uses including uses as refrigerant, disinfectant, preservative and bleach.

When released from the stacks of coal-fired power stations and other coal-fired plants, it causes serious pollution. It reacts with water to form sulphuric acid, which later is deposited as acid rain. This corrodes limestone, metals and clothing. It also has negative effects on human health, as it affects the respiratory tracts. It reacts with enzymes, impairing their functioning, and lowers body fluid pH (Hoogervorst, 2000:84; Kupchella & Hyland, 1993:275; Miller, 2000:488).

2.3.3 Nitrogen oxides

During the combustion of coal, nitrous oxide (NO) is formed. This is a colourless gas which is toxic in high concentrations. When it is released into the atmosphere it reacts with ozone (O₃) to form nitrogen dioxide (NO₂). This reddish brown toxic gas is responsible for the colour of smog in cities.

Nitrogen dioxide affects the respiratory system, causes eye irritations and damages the lungs, heart and liver. Under solar radiation it breaks down into NO and O. The resulting oxygen atom reacts with oxygen molecules in the air to form ozone, a strong oxidant. (Ristinen & Kraushaar, 1999: 298-300).

Nitrogen oxides react with water vapour in the atmosphere to produce nitric acid (HNO₃), another form of acid rain. In the atmosphere it scatters and absorbs sunlight, affecting plant growth and productivity. It reduces visibility and enhances smog formation. It also soils clothing and covers buildings with soot, corrodes metals and degrades materials such as paint, masonry and electrical contacts (Ristinen & Kraushaar, 1999: 300).
2.3.4 Particulate matter

Hoogevorst (2000:69) defines particulates as “…particles of solid matter or droplets of liquid small or light enough to remain suspended in the atmosphere for short periods of time”. Solid particulates emitted from coal combustion include dust, soot, ash, lead, nitrate and sulphate salts. Liquid particulates include sulphuric acid, polychlorinated biphenyls (PCB) and dioxins.

Particulate matter smaller than 10 microns can be deposited in the lungs of mammals, interfering with their proper function. The particulates may be toxic and can cause bronchitis, emphysema, as well as lung cancer in humans.

2.4. CLEAN COAL TECHNOLOGIES

Pollution prevention requires the application of advanced technologies for coal combustion use. These technologies look promising in the short- and medium-term for power generation and co-generation of heat.

There exist numerous methods for reducing emissions from coal-fired stations. These methods take place at the pre-combustion, combustion and post-combustion stages of the process.

2.4.1 Pre-combustion

Pre-combustion techniques used are primarily coal cleaning or washing. Such techniques involve physical, chemical or biological cleaning. They improve the furnace quality of the coal and remove significant amounts of sulphur, ash and other contaminants from the coal. These technologies have a significant potential for lowering the costs of emissions reduction when used with other, lower cost advanced combustion or post-combustion technologies (Crowel, 1997).
2.4.2 Combustion

New combustion technologies can reduce emissions drastically. These technologies are characterised by “…high thermal efficiency, very low pollutant emissions, reduced CO₂ emissions, few solid waste problems and enhanced economics” (US-DoE, 1998:82). The US Department of Energy gives examples of five generic technological approaches:

- Fluidised bed combustion. This technology reduces most of the sulphur dioxide and sharply reduces nitrogen oxides (Miller, 2000:381). Coal and limestone are crushed into a fine powder, that when burnt forms a bubbling “liquid” in which the sulphur is trapped and becomes harmless slag (Durant, 1995:106). Not only are emissions reduced, but the coal is also burnt more efficiently and more cheaply than conventional methods, converting about 42% of the heat into electricity.

- Integrated gasification combined cycle. With this method coal is gasified and cleaned of particles, sulphur and nitrogen compounds. The gas is then combusted in a gas turbine generator to produce electricity. The residual heat is recovered in a heat recovery steam generator and the steam generated is used to produce additional electricity in a steam turbine generator (US-DoE, 1998:83-84). Although this method is far less polluting, it is expensive and consumes large quantities of water (Durant, 1995:106).

- Integrated gasification fuel cell. This system makes use of a coal gasifier with a gas cleanup system, a fuel cell to use the coal gas for electricity and heat generation, an inverter to convert direct current to alternating current, as well as a heat recovery system used to generate additional electricity (US-DoE, 1998:83).

- Coal fired diesel. This diesel-engine-driven electric generation system is fuelled with a coal-oil or coal-water slurry. Environmental control systems for SO₂, NOₓ and Pm removal treat the exhaust gases before they are released into the atmosphere (US-DoE, 1998:84).
• Slagging combustion. This is based on a cyclone combustor concept, where the coal is burned in a chamber outside of the furnace. The gases then pass into the boiler for heat exchange. Ash is kept out of the furnace and NO_x can be reduced by 70-80%. Injecting limestone reduces SO_2 emissions by 90% (US-DoE, 1998:84).

Nitrogen oxide formation can also be controlled. To control fuel-NO_x formation, the amount oxygen must be limited at the early stages of combustion. Limiting peak temperatures will also control thermal-NO_x formation (US-DoE, 1998:30).

2.4.3 Post-combustion
During the post-combustion process SO_2, NO_x and Pm can be removed through the use of catalysts and other methods. Particulate matters were the first to receive attention because of the visible nature of the pollutants, and the ease with which they could be controlled.

Various technologies exist that remove particulate matter from flue gases:
• Settling chambers (also known as gravitational collectors) treat flue gases and remove large particles (>50 microns).
• Cyclone or internal precipitators remove heavier particles than those in settling chambers. They can remove more than 99% of particles heavier than 50 microns, but are not efficient for particles smaller than 5 microns.
• Electrostatic precipitators are very successful at removing particulates as well as NO_x. Figure 2.2 illustrates the effectiveness of an electrostatic precipitator.
• Scrubbers use a liquid spray to remove aerosol and gaseous substances from emissions. They are efficient at removing SO_2. The more advanced scrubbers are designed to remove the sulphur in the form of an environmentally safe, solid powder, rather than a difficult to handle sludge which is created by other technologies (Crowel, 1997).
• Bag filters. These make use of fabric filters through which flue gases are forced. These bags remove dust and other particles. This is the only method that removes many of the more hazardous flue particles (Miller, 2000:493; Hupchella & Hyland, 1993:331). These are important at a number of Eskom stations.

Figure 2.2. Efficiency of electrostatic precipitator instalment at a steel-plant (Kupchella & Hyland, 1993:333)
Carbon dioxide that is emitted can be recaptured and stored (sequestrated) using existing technologies. It can be stored underground in depleted oil and natural gas fields, deep coal beds, deep saline aquifers and in the oceans. When stored in oil and natural gas fields, it can be used to enhance oil and natural gas recovery. In deep coal beds it can be used to assist coal bed methane recovery. An estimate of the sequestration potential of various reservoirs is tabulated in Table 2.4.

Table 2.4. Conservative estimates of CO\textsubscript{2} storage potential in GtC
(WEC, 2001:163)

<p>| | |</p>
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Enhanced oil recovery</td>
<td>20</td>
</tr>
<tr>
<td>Depleted oil fields</td>
<td>40</td>
</tr>
<tr>
<td>Depleted gas fields</td>
<td>90</td>
</tr>
<tr>
<td>Aquifers (closed)</td>
<td>50</td>
</tr>
<tr>
<td>Horizontal open aquifers</td>
<td>2700</td>
</tr>
<tr>
<td>Ocean disposal</td>
<td>1200</td>
</tr>
<tr>
<td><strong>Total potential</strong></td>
<td><strong>4040</strong></td>
</tr>
</tbody>
</table>

2.5. SYNTHESIS

The current uses of coal and the effects that the emissions from the combustion of coal for electricity generation have on the environment have been examined in this chapter. Also examined were the numerous technologies existing during the pre-combustion, combustion and post-combustion processes that reduce NO\textsubscript{x}, SO\textsubscript{2} and Pm emissions.

The collection of emission data for countries selected for this study will be described in the following chapter.
CHAPTER 3. METHODOLOGY AND DATA

The collection and presentation of carbon dioxide (CO$_2$), nitrous oxide (NO$_x$), sulphur dioxide (SO$_2$) and particulate matter (Pm) emissions data for a set of chosen countries is the focus of this chapter. The methodology used to collect and manipulate the data will be explained first. This is followed by a discussion of data sources, and finally the data is presented.

3.1. METHODOLOGY

The purpose of this study is to do a comparative study on emissions from coal-fired power stations from various countries. The comparison looks at a time-line from 1995 to 2001.

The countries selected for this study, and the rationale for their selection, are:

- Australia. Coal is the main source of energy for the generation of electricity (Australian Greenhouse Office, 2001).
- Canada. 73% of the total greenhouse gas (GHG) emissions come from the combustion of fossil fuels, 80% of which are from coal-fired power stations (Environment Canada, 2004).
- Germany. Coal is the primary fuel in the energy sector (Energy Information Administration, 1995).
- India. Coal dominates the energy mix, contributing 70% of the total primary energy production (Teri, 2003).
- South Africa.
- United States of America. 20% of the world’s coal is found in the United States and its major use is for the production of electricity in power plants (Ristinen & Kraushaar, 1999:52). The United States are responsible for 23% of global CO$_2$ emissions, and energy related activities account for 86% of these emissions, through the burning of fossil fuels (Miller, 2000:501).
The emissions examined are:

- Carbon dioxide (CO$_2$),
- Nitrous oxides (NO$_x$),
- Sulphur dioxide (SO$_2$) and
- Particulate matter (Pm).

It was necessary to convert all data to a common unit since each country used different units of measurement. This made the comparison of emissions more effective. Carbon dioxide is measured in million tons (Mt), while sulphur dioxide, nitrous oxides and particulate matter are measured in thousand tons (kt).

The data for each country are compared against each other. Comparison and analysis are made easier by the use of graphs. This analysis indicates the magnitude of the emissions.

Energy demand and absolute emissions in each country differ, making meaningful comparisons unfeasible. Comparisons on a specific basis provide a solution and thus the emissions data were converted to ton per GWh (t/GWh). The results of this manipulation are then analysed to show how the emissions have changed over the study period.

### 3.2. DATA SOURCES

Data was acquired primarily in digital format from official Internet sites, as printed annual reports were not readily available in printed format. General data was gathered from official sites such as that of the World Energy Council, UN Stats and the International Energy Association. A list of the sources used for the individual countries is given in Table 3.1.

South Africa’s data were obtained from Eskom’s 2002 Annual Report (Eskom 2002). This was available in printed and digital format.
The data for the United States were extracted from various websites. The main source was from the website of the Energy Information Administration.

The data for Canada was obtained from the website of Environment Canada and from personal communication with Lorie Cummings (2004) from Environment Canada.

Germany’s data was acquired from the Umweltbundesamt (Federal Environmental Agency), as well as from Destatis (Federal Statistical Office).

Australia’s data was acquired from the Australian Greenhouse Office.

India does not have current estimates for fossil fuel consumption and pollutant emissions compiled by regulatory agencies. Therefore data was acquired from studies in this field. This in form of journal articles, which are published mainly in the Atmospheric Environment journal.

<table>
<thead>
<tr>
<th>Country</th>
<th>Data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Australia</strong></td>
<td>Australian Greenhouse Office</td>
</tr>
<tr>
<td><strong>Canada</strong></td>
<td>Environment Canada website</td>
</tr>
<tr>
<td></td>
<td>Personal communication with Lorie Cummings from Environment Canada</td>
</tr>
<tr>
<td><strong>Germany</strong></td>
<td>Umweltbundesamt (Federal Environmental Agency)</td>
</tr>
<tr>
<td></td>
<td>Destatis (Federal Statistical Office)</td>
</tr>
<tr>
<td><strong>India</strong></td>
<td>Journal articles, mainly from the Atmospheric Environment journal.</td>
</tr>
<tr>
<td><strong>South Africa</strong></td>
<td>Eskom’s 2002 Annual Report (Eskom 2002).</td>
</tr>
<tr>
<td><strong>United States of America</strong></td>
<td>Energy Information Administration</td>
</tr>
<tr>
<td><strong>Other sites</strong></td>
<td>World Energy Council, UN Stats and the International Energy Association.</td>
</tr>
</tbody>
</table>
3.3. RESULTS

The emissions data, both in absolute and specific units, as extracted from the primary source are presented in this section. For convenience the absolute values are presented together in the first section while the specific values are grouped together in the second section. Each table shows one particular emission, in which all the countries are compared against one another.

3.3.1. Absolute data

The following tables display the data that was collected for the different emissions for each country. The figures present a visual representation of the emission trends of emissions from 1995 through to 2001. The United States are not represented in the figures because the amount is so much greater than that of other countries.
Table 3.1. Carbon dioxide emissions (Mt)

<table>
<thead>
<tr>
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<td>111</td>
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<td>802</td>
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<td>722</td>
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Figure 3.1 Carbon dioxide emissions (Mt)
Table 3.2. Nitrous oxide emissions (kt)

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<td>274</td>
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<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
<td>n/a</td>
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<td>589</td>
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</table>

Figure 3.2. Nitrous oxide emissions (kt)
Table 3.3. Sulphur dioxide emissions (kt)

<table>
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Figure 3.3. Sulphur dioxide emissions (kt)
Table 3.4. Particulate matter (kt)

<table>
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Figure 3.4. Particulate matter (kt)
Table 3.5. Coal-fired electricity production (GWh)

<table>
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Figure 3.5. Coal-fired electricity production (GWh)
Table 3.6. Percentage absolute change in emissions between 1995 and 2001

<table>
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<tr>
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<th>NOₓ</th>
<th>SO₂</th>
<th>Pm</th>
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<td>+25</td>
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<td>India</td>
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<td></td>
<td>-9</td>
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<td>-0.66</td>
<td>+13</td>
<td></td>
</tr>
</tbody>
</table>

3.3.2. Specific data

The following tables present the specific data that was calculated for the different types of emissions for each country. The units for the specific data are given in t/GWh. The figures provide a visual representation of the trends of emissions from 1995 through to 2001.
Table 3.7. CO₂ emissions (t/GWh)

<table>
<thead>
<tr>
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Figure 3.6. CO₂ emissions (t/GWh)
### Table 3.8. NOx emissions (t/GWh)

<table>
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**Figure 3.7. NOx emissions (t/GWh)**
Table 3.9. SO$_2$ emissions (t/GWh)

<table>
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Figure 3.8. SO$_2$ emissions (t/GWh)
## Table 3.10. Particulate matter emissions (t/GWh)

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<th></th>
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</thead>
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<td>0.39</td>
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## Figure 3.9. Particulate matter emissions (t/GWh)
Table 3.11. Percentage specific change in emissions between 1995 and 2001

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<th>SO₂</th>
<th>Pm</th>
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3.4. SYNTHESIS

Data from various reliable websites was gathered for the different types of emissions from coal-fired power stations in selected countries. This data is presented in this chapter in terms of absolute data as well as manipulated specific (t/GWh) data.

The data outputs gathered and manipulated in this chapter, are analysed and interpreted in the next chapter.
CHAPTER 4. ANALYSIS AND INTERPRETATION

The data collected and presented in the previous chapter requires further analysis and interpretation to answer the question posed in the problem statement. This analysis is presented in this chapter. The countries, excluding South Africa, are presented in alphabetical order.

Absolute values are general values for the specific factors examined. Specific values look more specifically at the relation between two factors. In the case of this study, the factor against which emissions are compared is the amount of electricity generated.

As the absolute amount of coal burnt for electricity generation increases, so the absolute carbon dioxide emissions increase. Specific values, however, can either show an increase or decrease linked with the efficiency of the electricity generation method. A decrease implies an increased efficiency, as more electricity is generated with less coal. Decreases in nitrous oxides, sulphur dioxides and particulate matter indicate that clean coal technologies have been installed and/or that low ash and sulphur coals are being used to a greater extent.

In general, total electricity generation will have increased, as there is an ever-increasing demand for electricity from growing populations. There exist variations in the amount of electricity generated by different fuels as generators switch between fuels for supply, economic or environmental reasons. This accounts for the dips observed for some countries emissions. Electricity generated from specific fuels will vary according to the generating fuel mix used in each country.
4.1. AUSTRALIA

As illustrated in Figure 4.1., coal is Australia’s main fuel for electricity generation. Since 1971 there has been a gradual increase in electricity generated by coal. Between 1995 and 2001 there was a 29% increase in coal-generated electricity. This leads us to assume that the absolute values for CO₂ emissions will show an increase, which is indeed the case. Specific values depend on the efficiency of the combustion technologies utilised.

Hydroelectricity and gas-generated electricity have remained relatively constant in the past 20 years. Oil is a minor fuel and its use has also remained constant. Since the late 1980’s, data shows that there has been a slight increase in the use of combined renewable and waste-generated electricity.

4.1.1. Absolute values:
- Carbon dioxide emissions have increased by 27%.
- Nitrous oxide emissions decreased by 1%.
- Sulphur dioxide emissions increased by 13%.

4.1.2. Specific values:
- Carbon dioxide emissions per GWh decreased by 1%.
- Nitrous oxide emissions per GWh decreased by 23%.
- Sulphur dioxide emissions per GWh decreased by 7%.

Hard coal and lignite account for 80% of electricity generation. This coal is generally of high quality with high calorific value, moderate ash content and low sulphur and heavy metal content. The decrease of specific SO₂ emissions can be linked to this, and it can be assumed that clean coal technologies are also responsible for the drop in emissions.

Since 1975, coal combustion has been responsible for about 50% of Australia’s carbon emissions (EIA, 2002). With an increase in the use of coal, the ratio of coal
combustion for electricity generation has remained stable, which explains the continued increase in carbon dioxide emissions.

According to the Energy Information Administration (2002), Australia’s pollutant concentration meets the guidelines of the World Health Organisation (WHO), and is considered low by world standards.

4.2. CANADA

The main source of energy in Canada is hydroelectricity. Hydro and nuclear electricity generation has decreased since 1990, whereas fossil fuel generated electricity has increased to meet increasing demand (EC, 2004b). There was a 35% increase in electricity generated from coal between 1995 and 2001.

The emissions vary greatly in terms of absolute and specific values.

4.2.1. Absolute values:
- Carbon dioxide emissions between 1995 and 2001 have increased by 36%. This is due the increased use of coal as a source of fuel for electricity generation.
- Nitrous oxide emissions have increased by 28%.
- Sulphur dioxide emissions have decreased by 60%. Although more coal is being burnt, it is thought that it is either low in sulphur content or that clean coal technologies or both, might have been put into application.
- Particulate matter emissions have decreased by 11%. This could indicate low ash fuel and precipitator installations.

4.2.2. Specific values:
- Carbon dioxide emissions per GWh have decreased by 1%. This indicates improved efficiency in the combustion process.
- Nitrous oxide emissions per GWh have decreased by 5%.
- Sulphur dioxide emissions per GWh have decreased by 70%.
- Particulate matter emissions per GWh have decreased by 34%.

The decreased specific NOₓ, SO₂ and Pm emissions indicate increasing use of clean technologies and better grade coal.

4.3. GERMANY

Germany’s main source of fuel for electricity generation is coal. The increase in coal-generated electricity has been of 10% between 1995 and 2001. Coal, however, still generates over 50% of the country’s electricity (Umweltbundesamt, 2004d). Since the 1970’s there has been a rapid increase in the use of nuclear power for electricity generation. Hydroelectricity and gas generated electricity have remained relatively constant, with just a slight increase with gas-generated electricity. The use of oil for electricity generation has drastically decreased in the past 20 years. Recently, more renewable energy, especially in the form of geothermal, solar, wind and combined renewable and waste, is being used for electricity generation, albeit still in small quantities (Figure 4.3.).

Germany shows great initiative in the reduction of greenhouse gases and other emissions in its electricity generation sector. The collected and calculated data clearly illustrate this clearly.

4.3.1. Absolute values:

- Carbon dioxide emissions between 1995 and 2001 have decreased by 3%. The use of bituminous coal in the energy sector dropped by a quarter, but the use of lignite increased.
- Nitrous oxide emissions decreased by 17%.
- Sulphur dioxide emissions decreased by 74%.
- Particulate matter emissions decreased by 24%.
4.3.2. Specific values:

- Carbon dioxide emissions per GWh decreased by 10%.
- Nitrous oxide emissions per GWh decreased by 24%.
- Sulphur dioxide emissions per GWh decreased by 77%.
- Particulate matter emissions per GWh decreased by 31%.

Emissions have decreased because of regulations, incentive programs, better quality fuels and improved technologies. For example, the government reduced taxes on sulphur-free fuels and on natural gas (EIA, 2003b). Recent reductions were due to economic restructuring. Since 1995, Germany has closed down all of its obsolete coal power stations, especially in the former Eastern Germany. This has lead to the decrease of CO₂ emissions. Clean coal technologies have been installed which explains the drastic drop in NOₓ, SO₂ and Pm emissions.

4.4. INDIA

Over the last 30 years, annual electricity generation in India has risen from below 100 TWh to around 490 TWh (IEA, 2004). Coal is the main fuel for electricity generation and there has been a huge increase in the combustion thereof in order to provide enough electricity for its phenomenally rapid growing population. There has been a 60% increase in coal-generated electricity between 1995 and 2001. Hydroelectricity is the next biggest source of electricity. There has, however, only been a slight increase in hydro-generated electricity. Electricity from nuclear, gas and oil has remained small with only a slight increase indicated.

India’s current electricity generation capacity is seriously below the country’s demand. Although 80% of the population has access to electricity, power outages are common and supply is unreliable This puts a severe constraint on the country’s economic development (EIA, 2003c).
Carbon emissions from coal-fired power stations were derived from coal data obtained from the IEA and EIA databases. Accuracy of data and methodology has not been rigidly verified. It is an estimation based on different datasets. Errors can occur.

4.4.1. Absolute values:
- Carbon dioxide emissions between 1995 and 2001 have increased by 14%.
- Sulphur dioxide emissions have decreased by 9%.

4.4.2. Specific values:
- Carbon dioxide emissions per GWh have decreased by 43%.
- Sulphur dioxide emissions per GWh have decreased by 19%.

Indian coal in general has a high ash and sulphur content as well as a low calorific value. With 60% of power generation being coal-based, and the very high ash content of the coal (more than 40% in some cases), it is estimated that 80-100 million tons of fly ash are generated each year (TERI, 2002). As India does not have current estimates for fossil fuel consumption and pollutant emissions compiled by regulatory agencies, the data is highly speculative and based on estimates. It should follow rather that absolute SO\textsubscript{2} and particulate matter emissions have increased, as well as the specific values. Shekar Reddy and Venkataraman (2002:682) have assumed from their study that SO\textsubscript{2} emissions are uncontrolled.

The Central Pollution Control Board (2003) has issued the following national ambient air quality standards.

As India is a non-Annex I country under the United Nations Framework Convention on Climate Change, it is not obligated to reduce its carbon and greenhouse gas emissions (EIA, 2003c). The Indian government puts a high priority on the country’s economic development. The government prefers to create a higher electricity generating capacity which will result in a high rate of emissions, rather than installing low capacity systems which will produce lower emissions. This means that India’s emissions are projected to continue to rise in the coming decade.
Table 4.1. National Ambient Air Quality Standards

<table>
<thead>
<tr>
<th>Pollutants</th>
<th>Time-weighted average</th>
<th>Concentration in ambient air (µg/ m³)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Industrial areas</td>
</tr>
<tr>
<td>SO₂</td>
<td>Annual average</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>24 hour</td>
<td>120</td>
</tr>
<tr>
<td>NOₓ</td>
<td>Annual average</td>
<td>80</td>
</tr>
<tr>
<td></td>
<td>24 hour</td>
<td>120</td>
</tr>
<tr>
<td>PM₁₀</td>
<td>Annual average</td>
<td>120</td>
</tr>
<tr>
<td></td>
<td>24 hour</td>
<td>150</td>
</tr>
</tbody>
</table>

4.5. UNITED STATES OF AMERICA

Since 1971 (Figure 4.5.), the annual electricity output has risen from about 1 750 TWh to about 3 400 TWh (IEA, 2004). Coal has been, and still is, the main fuel used. Over the last 30 years, there has been a sharp increase in nuclear generated electricity, while hydroelectric power and gas-generated electricity have remained relatively constant. The use of oil as a fuel for electricity generation has decreased, and since 1988 geothermal and combined renewable and waste fuel have increasingly been used. There was a peak in electricity generation in 2000, which the data in Table 3.5. illustrates.

Changes in emissions varied greatly in term of absolute and specific values.

4.5.1 Absolute values:

- Carbon dioxide (CO₂) emissions between 1996 and 2001 increased by 2%. This was due to an 11% increase of electricity generation from 1995 to 2001.
- Sulphur dioxide (SO₂) emissions decreased by 17%. Sulphur dioxide decreases are due to the tightening of regulations. Reductions are to occur in two phases with larger (more than 100 megawatts) and higher emitting (more than 2.5 pounds per million Btu) plants making reductions first. Phase 1 in the reductions started in 1995, where 261 generating units at 110 plants were
issued tradable emissions allowances permitting SO₂ emissions to reach a fixed amount each year, generally less than the plant’s historical emissions. Most generators switched to lower sulphur bituminous coal, as only about 12 GW of capacity had been retrofitted with scrubbers by 1995 (EIA, 2003a).

- Nitrogen oxide (NOₓ) emissions decreased by 24%. Nitrogen oxide emissions are expected to drop further to 4.1 million tons by 2025 as the new regulations come into effect (EIA, 2003a).

4.5.2. Specific values:

- CO₂ emissions per GWh have decreased by 4%.
- NOₓ emissions per GWh have decreased by 28%.
- SO₂ emissions per GWh have decreased by 22%. According to the EIA (2003a) companies have recently announced plans to add scrubbers to 23 gigawatt of capacity to comply with State or Federal initiatives. Sulphur dioxide emissions are projected to decline from 10.6 million tons in 2001 to 8.9 million in 2025 as a result of the implementation of the plans.

4.6. SOUTH AFRICA

South Africa’s main fuel for electricity generation is coal. Other sources include nuclear and hydro (Figure 4.6.). Hydroelectricity generation has varied over time, depending on the availability of water. South Africa is considered a semi-arid country with limited water resources, which explains the small amount of hydroelectricity generated, compared to the other countries examined in this study. Nuclear generated electricity has remained constant. This is because South Africa has only one nuclear power station.

The data indicate a steady increase of electricity generated. There has been a 16% increase between 1995 and 2001. There was a dip in coal-generated electricity between 1998 and 2000. This was the result of an increased generation from hydroelectric and nuclear power stations.
4.6.1. Absolute values:

- Carbon dioxide emissions increased by 15%.
- Nitrous oxide emissions increased by 13%.
- Sulphur dioxide emissions increased by 25%.
- Particulate matter emissions decreased by 48%.

4.6.2. Specific values:

- Carbon dioxide emissions per GWh dropped by 0.4%.
- Nitrous oxide emissions per GWh increased by 1.8%.
- Sulphur dioxide emissions per GWh increased by 13%.
- Particulate matter emissions per GWh decreased by 55%. These emissions have decreased due to the retrofitting of units with fabric filter bags at the Hendrina Power Station, the installation of sulphur trioxide flue gas conditioning on all six units at the Lethabo Power Station and enhanced management attention at Matla Power Station (Eskom 2003). All modern Eskom power stations are fitted with electrostatic precipitators to minimise particulate emissions.

South Africa’s power stations have been designed to burn low-grade coal (Eskom, 2003). This explains the high SO₂ and particulate emissions. There has been no decreases in NOₓ and SO₂ emissions because most power stations are over 20 years old and have not been equipped with clean coal technologies.
Figure 4.1. The evolution of electricity generation by fuel for Australia from 1971 to 2001 (IEA, 2004)
Figure 4.2. The evolution of electricity generation by fuel for Canada from 1971 to 2001 (IEA, 2004)
Figure 4.3. The evolution of electricity generation by fuel for Germany from 1971 to 2001 (IEA, 2004)
Figure 4.4. The evolution of electricity generation by fuel for India from 1971 to 2001 (IEA, 2004)
Figure 4.5. The evolution of electricity generation by fuel for the United States from 1971 to 2001 (IEA, 2004)
Figure 4.6. The evolution of electricity generation by fuel for South Africa from 1971 to 2001 (IEA, 2004)
4.7. COUNTRY COMPARISONS

The final question posed in the problem statement, mainly how South Africa compares to other selected countries, can now be addressed. As noted previously, the most meaningful comparison needs to be done on a specific basis. The calculations were made and were presented in and are now analysed. Some additional factors need to be considered to facilitate as broad understudy as possible.

The countries studied are tabulated (Table 4.2.) in descending order based on the absolute value of electricity generated from coal-fired power stations. Additional data on the geographic area and the human population of the countries is included.

**Table 4.2. National data of selected countries (Bateman & Egan, 2002:12, 27, 199, 311, 411).**

<table>
<thead>
<tr>
<th>Country</th>
<th>Electricity generated in 2001 (TWh)</th>
<th>Area (km²)</th>
<th>Population size (2001 est.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>United States</td>
<td>1709</td>
<td>9 166 600</td>
<td>278 058 881</td>
</tr>
<tr>
<td>South Africa</td>
<td>152</td>
<td>1 225 815</td>
<td>43 586 097</td>
</tr>
<tr>
<td>India</td>
<td>299</td>
<td>3 287 263</td>
<td>1 029 991 145</td>
</tr>
<tr>
<td>Germany</td>
<td>256</td>
<td>356 954</td>
<td>83 029 536</td>
</tr>
<tr>
<td>Canada</td>
<td>82</td>
<td>9 976 140</td>
<td>31 592 805</td>
</tr>
<tr>
<td>Australia</td>
<td>131</td>
<td>7 682 300</td>
<td>19 357 594</td>
</tr>
</tbody>
</table>

The area of each country and the population must be taken into consideration when interpreting the data. The electricity consumption of a country depends of standard of living and lifestyle of the human population. This means that some countries, with a small population might demand and use more electricity. An example is the United States (see Table 4.2.). Under normal circumstances, a country with a small population should generate less electricity than a country with a bigger population. With the exception of the United States and India, the other countries produce
electricity in relation to the size of their population. The countries with the greatest population will need to generate more electricity in order to meet demand.

The ranking of the countries according to emissions in 2001 is presented in Table 4.3., while the situation in each country is discussed below:

- **Australia**: Australia is intermediate in terms of emissions. The SO$_2$ emissions are low because of the low-sulphur coal utilised. Data on particulate emission is not available, but it is most probably low, because of the good coal grade. Because overall emissions are relatively low, one can assume that there are measures in place to reduce particulate matter emissions.

- **Canada**: Canada has high CO$_2$ and particulate matter emissions. Its CO$_2$ emissions are high for the amount of electricity generated. Low SO$_2$ emissions are due to the low-sulphur coal being used.

- **Germany**: In terms of NO$_x$, SO$_2$ and particulate matter emission, Germany is the country that emits the least and significant reductions were noted between 1995 and 2001. The reductions are due to economic restructuring and the use of cleaner fuels, especially in former- Eastern Germany. In terms of CO$_2$, Germany is the highest emitter, but that is linked to the great amount of electricity generated.

- **India**: India’s data is of poor quality and not readily accessible, so most data are only estimates from previous studies. The analysis as presented here must thus be evaluated with caution. More accurate data could indicate a different reality. India’s SO$_2$, NO$_x$ and particulate emissions fall into the assumptions of Shekar Reddy and Venkataraman (2002:682): that they are elevated because they are uncontrolled and because the coal utilized has a high ash and sulphur content.

- **South Africa**: South Africa has high SO$_2$ emissions because of high sulphur coal used with no desulphurisation technologies installed. It also has the second highest NO$_x$ emissions. It has low particulate matter emissions and CO$_2$ emissions, indicating that measures are in place for the removal of particulate matter, and that the power stations are quite efficient in electricity generation.
- **United States**: The United States is the second biggest CO₂ and SO₂ emitter, but has low NOₓ emissions.

**Table 4.3. Ranking of countries according to specific emissions in 2001.**

<table>
<thead>
<tr>
<th>Carbon dioxide / GWh</th>
<th>Nitrous oxide / GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. India</td>
<td>1. Canada</td>
</tr>
<tr>
<td>2. Canada and Germany</td>
<td>2. South Africa and (presumed)</td>
</tr>
<tr>
<td>3. United States</td>
<td>India</td>
</tr>
<tr>
<td>4. Australia</td>
<td>3. Australia</td>
</tr>
<tr>
<td>5. South Africa</td>
<td>4. United States</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sulphur dioxide / GWh</th>
<th>Particulate matter / GWh</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. South Africa</td>
<td>1. India (presumed)</td>
</tr>
<tr>
<td>2. United States</td>
<td>2. Canada</td>
</tr>
<tr>
<td>3. India (presumed)</td>
<td>3. South Africa</td>
</tr>
<tr>
<td>4. Australia</td>
<td>4. Germany</td>
</tr>
<tr>
<td>5. Canada</td>
<td></td>
</tr>
<tr>
<td>6. Germany</td>
<td></td>
</tr>
</tbody>
</table>

The changes in specific emissions, with countries ranked from highest to lowest reductions over the period from 1995 to 2001, are tabulated in Table 4.4.

Overall, Germany is the country that has made the most progress in terms of reducing emissions. It is followed by the United States, then Canada. Australia and South Africa are more or less on par with reducing their emissions. India has made the least improvements, with the least percentage in reductions.
### Table 4.4. Ranking of countries according to percentage change of specific emissions between 1995 and 2001.

<table>
<thead>
<tr>
<th>Carbon dioxide (t/ GWh)</th>
<th>Nitrous oxide (t/ GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>India 40% decrease</td>
<td>United States 28% decrease</td>
</tr>
<tr>
<td>Germany 10% decrease</td>
<td>Germany 24% decrease</td>
</tr>
<tr>
<td>United States 4% decrease</td>
<td>Australia 23% decrease</td>
</tr>
<tr>
<td>Australia 1% decrease</td>
<td>Canada 5% decrease</td>
</tr>
<tr>
<td>South Africa 0.4% decrease</td>
<td>South Africa 1.8% decrease</td>
</tr>
<tr>
<td>Canada 0.7% increase</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Sulphur dioxide (t/ GWh)</th>
<th>Particulate matter (t/ GWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Germany 77% decrease</td>
<td>South Africa 55% decrease</td>
</tr>
<tr>
<td>Canada 70% decrease</td>
<td>Canada 34% decrease</td>
</tr>
<tr>
<td>United States 22% decrease</td>
<td>Germany 31% decrease</td>
</tr>
<tr>
<td>India (estimated) 19% decrease</td>
<td></td>
</tr>
<tr>
<td>South Africa 8% decrease</td>
<td></td>
</tr>
<tr>
<td>Australia 7% decrease</td>
<td></td>
</tr>
</tbody>
</table>

#### 4.8. SYNTHESIS

Data for the selected countries of this study were analysed and interpreted in this chapter. From the data one can see that South Africa is not the greatest emitter of emissions from coal-fired power stations, and that there has been a reduction in emissions between 1995 and 2001.
CHAPTER 5. CONCLUSION

The purpose of this study was to analyse South Africa’s trends in carbon dioxide (CO$_2$), nitrous oxide (NO$_x$), sulphur dioxide (SO$_2$) and particulate matter (Pm) emissions from coal-fired power stations over the period 1995 to 2001. These trends were then to be compared to those of other countries. The aim was to determine how South Africa compares with other large coal-using countries.

5.1. Limitations

For this study the major challenge was the availability of the required reliable data. Data was often incomplete or was not available at all. For India, for example, there are no current estimates of fossil fuel consumption and emissions compiled by Indian regulatory agencies (Shekar Reddy & Venkataraman, 2002:678). This means that for India, some of the figures represent estimates and interpretations, and must be considered accordingly.

Another limiting factor was that the study was done on only six countries. Although it gives a good comparison for those countries, additional countries would lead to a more in depth understanding of the problem.

The study was based on an analysis of published data. The accuracy of this data could not be certified. Any errors or inaccuracies in the same data will affect the results calculated in this study.

5.2. Further studies

This study has examined one certain aspect of coal-fired power stations. Further studies in this field are desirable. For example, other aspects that could be examined are water consumption, the amount of coal used and the amount of ash generated. These aspects could be compared specifically against the amount of electricity
generated, Gross Domestic Product and other efficiency indicators. The economic and environmental efficiency of power stations could be examined in more detail.

In this study only six countries were examined. In order to gain a clearer understanding of South Africa’s position internationally, additional countries will need to be investigated. China is the second biggest electricity generating country in the world and should be included. Russia and Japan, as well as the countries of Eastern Europe, all of which are highly reliant on coal-generated electricity, need to be studied.

5.3. Conclusion

The study focused on emissions of carbon dioxide, sulphur dioxide, nitrogen oxides and particulate matter from coal-fired power plants in six countries. The study examined the data over a time period from 1995 to 2001. Despite limitations to the study, the examination of emissions data from coal-fired power stations presents an interesting picture of how several countries are approaching the issue.

With the exception of Germany, no other countries have displayed a consistent improvement in emissions reductions for all emissions studied. The reason for such progress in Germany can be directly attributed to the policy of closing old stations in the former East Germany. As most of the higher polluting stations have now been closed, it is likely that continued improvement opportunities will be severely limited.

The study for South African emissions showed that there was a concerted effort to reduce particulate emissions over the study period. According to Eskom (2002:70) the Chief Air Control Officer (CAPCO) of the Department of Environmental Affairs and Tourism (DEAT) regulates the emission of particulates. Registration certificates allow a certain quantity of particulates that may be emitted. The permitted allowance is of 120.50 thousand tons. From the data collected one can see that during the chosen timeframe, the emissions were well below the allowance. Eskom considers the reduction of emissions important and “…is committed to reducing overall particles to an average 0.28kg/MWh sent out by the end of 2003, as part of a five year strategy initiated in 1998” (Eskom, 2002:70).
However, the reduction of other emissions was very small. Here seems to be very little opportunity to reduce carbon emissions given the high reliance on coal, and the limited options for using alternatives in any meaningful quantities, in the short to medium term. A concerted effort to reduce sulphur emissions is a possibility, although the cost and efficiency penalties of doing so needs to be recognized.

5.4. Recommendations

The South African government is aiming to provide each house with electricity. Because of the country’s growing population, it will become necessary to generate more electricity in order to meet the population’s needs. However, South Africa’s excess peaking capacity is projected to run out in 2007 and to be depleted by 2010. In order to avoid potential outages, the South African government has said that new capacity had to be built as early as 2008 (Phasiwe, 2004).

South Africa’s power stations are in general very old. Of the 14 stations, the oldest is 40 years old, four are more than 30 years old, four between 20 and 29 years old, four between 10 and 19 years old, and one is 8 years old (Eskom, 2002). Few of the stations have clean coal technology installations.

Eskom has embarked on a R12bn plan to bring back to service the coal-fired power stations that had been mothballed in the 1980’s. This might mean that new technologies will be installed that will ensure a reduction of emissions and an increased efficiency. The total restructuring of the electricity-generation industry is estimated at R100bn (Phasiwe, 2004).

With an expanding world population, the demand for electricity is ever increasing. This demand will have to be met, at least in the near future, with coal-fired power plants. Because of the negative impacts which coal-fired power plants have on the environment, clean coal technologies have to be developed. These technologies must be environmentally sustainable and economically viable.
This study has examined the emissions from coal-fired power stations for six countries that rely heavily on coal as a source of fuel for electricity generation. This should enable these countries to see their status of technology and their status of environmental concern relative to other electricity producing countries. It will provide relevant data to guide the decision-making agents in formulating electricity producing policy framework, which is socially, economically and environmentally defendable in the international arena.
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